Electromagnetism: The basic concepts

- Electric charge is conserved. This is one of the fundamental symmetries of nature (just like mass conservation).

- Charge is quantized as a multiple of the electron or proton charge:

⊕ proton charge $e = 1.602 \times 10^{-19}$ coulombs

⊖ electron charge $-e = -1.602 \times 10^{-19}$ coulombs

- The rate of flow of electric charge is called **electric current** and is measured in **Amperes**.

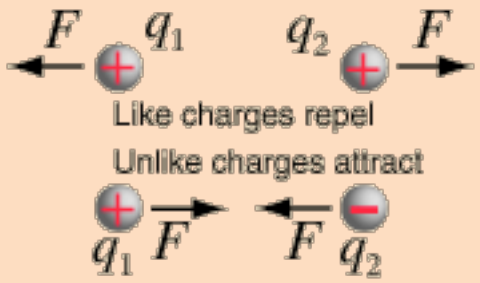
- **All charges observed in nature are multiples of these fundamental charges**. Although the standard model of the **proton** depicts it as being made up of fractionally charged particles called **quarks**, those fractional charges are not observed in isolation but always in combinations which produce +/- the electron charge.

- An isolated single charge can be called an **electric monopole.**

Coulomb's Law

- Formulated by Charles-Augustin de Coulomb (1736 – 1806)
- **Like charges repel, unlike charges attract.**

- The **electric force** acting on a **point charge** q_1 as a result of the presence of a second point charge q_2 is given by Coulomb's Law:



$$F = \frac{kq_1q_2}{r^2} = \frac{q_1q_2}{4\pi\varepsilon_0 r^2}$$ *Coulomb's Law*

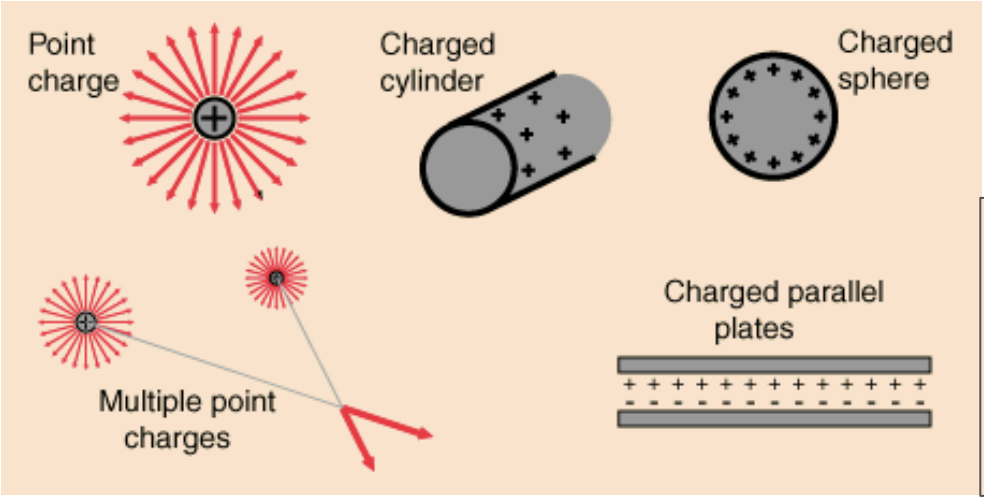
where ε_0 = **permittivity** of free space

- Coulomb's law describes a force of infinite range which obeys the inverse square law, and is of the same form as gravitation in Newtonian physics.

$$k = \frac{1}{4\pi\varepsilon_0} \approx 9x10^9 N \cdot m^2/C^2 = \text{Coulomb's constant}$$

Electric field

- **Electric field is defined as the electric force per unit charge**. The direction of the field is the direction of the force it would exert on a positive test charge. The electric field is radially outward from a positive charge and radially in toward a negative point charge.



Electric field in N/C or volts/m.

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

$\vec{F}$: electric force in Newtons

q: charge in Coulombs

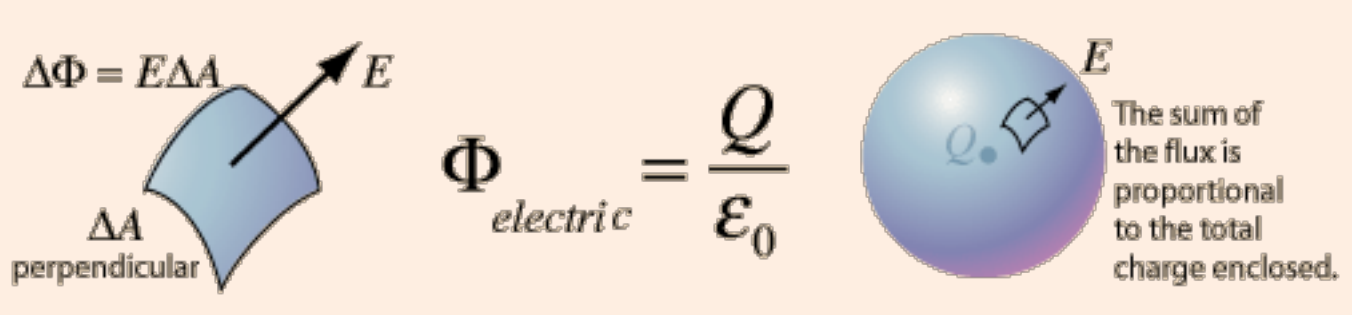
- **Since the measured electric field can depend on your reference frame, a more general definition comes from the Lorentz force law:** The electromagnetic force on a test charge at a given point and time is a certain function of its charge *q* and velocity **v**, which can be parameterised by exactly two vectors **E** and **B**, in the functional form:

$$\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$$

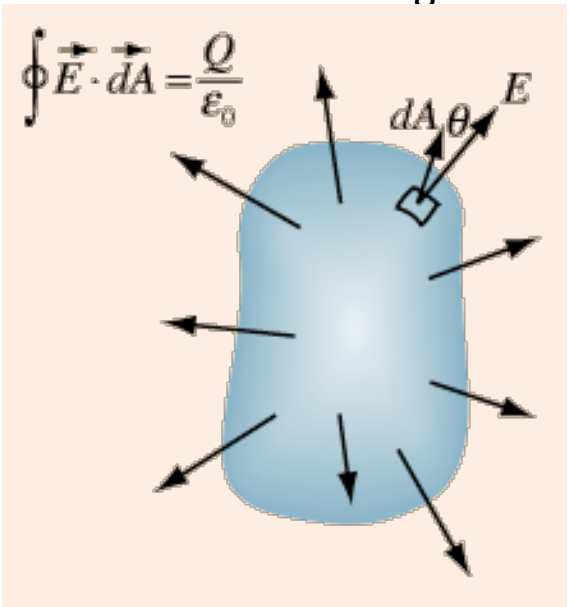
- **E is the electric field**
- **B is the magnetic field**

Gauss's Law

- Formulated by Carl Friedrich Gauss (1777 –1855)
- **The total of the electric flux out of a closed surface is equal to the charge enclosed divided by the permittivity.**



- The electric flux through an area is defined as the electric field multiplied by the area of the surface projected in a plane perpendicular to the field. Gauss's Law is a general law applying to any closed surface.



  - A more formal statement is the **integral form**: The **area integral** of the **electric field over any closed surface** is equal to the **net charge** enclosed in the surface divided by the permittivity of space.

  - Gauss' law is a form of one of **Maxwell's equations**.