Electrical charge
Property of an object, electric force

units: C (coulombs)
Q or q

Matter is made up of charged particles:
electrons and nuclei (protons and neutrons)

Electron is elementary particle with charge \(-e = -1.604 \times 10^{-19} \text{ C}\)
Charge of composite object is sum of charges
Charge of nucleus is \(+Ze\) (\(Z=\text{number of protons, charge } +e\))

Charge of atom is exactly zero
Charge conservation

Simple charge conservation
Cut an object into two pieces
Put two objects together
(count up the electrons and nuclear charges)

In high energy physics
particles are created and destroyed
but **total charge does not change**
What is the direction of the net force on the middle particle, if the particles on the x axis are equidistant from the origin?
Four particles with identical charges $q$ are arranged as shown below. In which of the three arrangements is the magnitude of the net electric force on the central charge LARGEST?

(a)  

(b)  

(c)
Can there be an electric force between a charged object and a neutral object?
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Object can have charged regions and still have net charge $= 0$
Can there be an electric force between a charged object and a neutral object?

Object can have charged regions and still have net charge = 0
Simple example where net force is not zero
All materials are made of nuclei and electrons

Insulators (wood, plastic, glass)

electrons have to stay close to their home nuclei – charges move only about an interatomic spacing

Conductors: (metal, tap water, the human body)

Some fraction of the electrons are free to move anywhere in the material
External charge induces rearrangement of charges in an object.
Can there be an electric force between a charged object and a neutral object?

Induced charge rearrangement leads to a net force
What is the direction of the force for a negative external charge?

- $-q$

(A) towards the external charge  
(B) away from the external charge  
(C) the force is zero  
(D) cannot determine without more information
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Charged particle $Q$
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\[ \mathbf{F} = q_1 \left( \frac{kQ}{r^2} \right) \hat{r} \]

\[ \vec{r} = \text{vector from } Q \text{ to } q_1 \]

\[ \hat{r} = \frac{\vec{r}}{|\vec{r}|} \]
Charged particle $Q$

\[
\vec{F} = q_2 \left( \frac{kQ}{r^2} \right) \hat{r}
\]
Repeat for any value $q$ of the charge of the 2\textsuperscript{nd} particle
Repeat for any position $\vec{r}$

$$\vec{F} = q \left( kQ / r^2 \right) \hat{r}$$

Electric field $\vec{E}(\vec{r}) = \left( kQ / r^2 \right) \hat{r}$ (vector field, units are N/C)

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

More than just a computational convenience

A charged particle produces an electric field, modifying the space around it.

The electric field produced by a system of two or more charges is the vector sum of the electric field produced by each particle.
Iclicker: The figure shows four systems in which charges are arranged on a line. In which system is the magnitude of the electric field at the central point GREATEST?
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Electric field lines point in the direction of $\mathbf{E}$ at any point.

Spacing of lines decreases as magnitude of $\mathbf{E}$ increases.

$q > 0$

$q < 0$
Definition of **dipole**

Electric field of the dipole?
Electric field at points on the x-axis
Electric field at points on the x-axis
Electric field at points on the y-axis
Continuous charge distributions

Surface charge density $\sigma$: charge/area (C/m$^2$)
EXAMPLE: uniform spherical shell $Q$, $R$
$\sigma = Q/(4\pi R^2)$

Line charge density $\lambda$: charge/length (C/m)
Volume density $\rho$: charge/volume (C/m$^3$)
Force exerted by a uniform shell

on a particle outside the shell

A uniform spherical shell of matter attracts a particle that is outside the shell as if all the shell’s mass were concentrated at its center.

A shell of uniform charge attracts or repels a charged particle that is outside the shell as if all the shell’s charge were concentrated at its center.

on a particle inside the shell

A uniform shell of matter exerts no net gravitational force on a particle located inside it.

If a charged particle is located inside a shell of uniform charge, there is no net electrostatic force on the particle from the shell.
Electric field of a uniform spherical shell with $Q < 0$
Continuous charge distributions

Surface charge density $\sigma$: charge/area (C/m$^2$)
EXAMPLE: uniform spherical shell $Q$, $R$
\[ \sigma = \frac{Q}{(4\pi R^2)} \]

Line charge density $\lambda$: charge/length (C/m)
EXAMPLE: uniform straight wire $Q$, $L$
\[ \lambda = \frac{Q}{L} \]

Volume density $\rho$: charge/volume (C/m$^3$)
Thin wire of length $L$ has total charge $Q$ distributed uniformly. Find $E$ at any point $x>L$.

Define a linear charge density: $\lambda = Q/L$

$$dE = k \lambda \, ds / (x-s)^2$$
integrate from $s=0$ to $s=L$

$$E = k \lambda \, L / (x(x-L))$$
for $x \gg L$, looks like point charge $Q$