SCIENCE

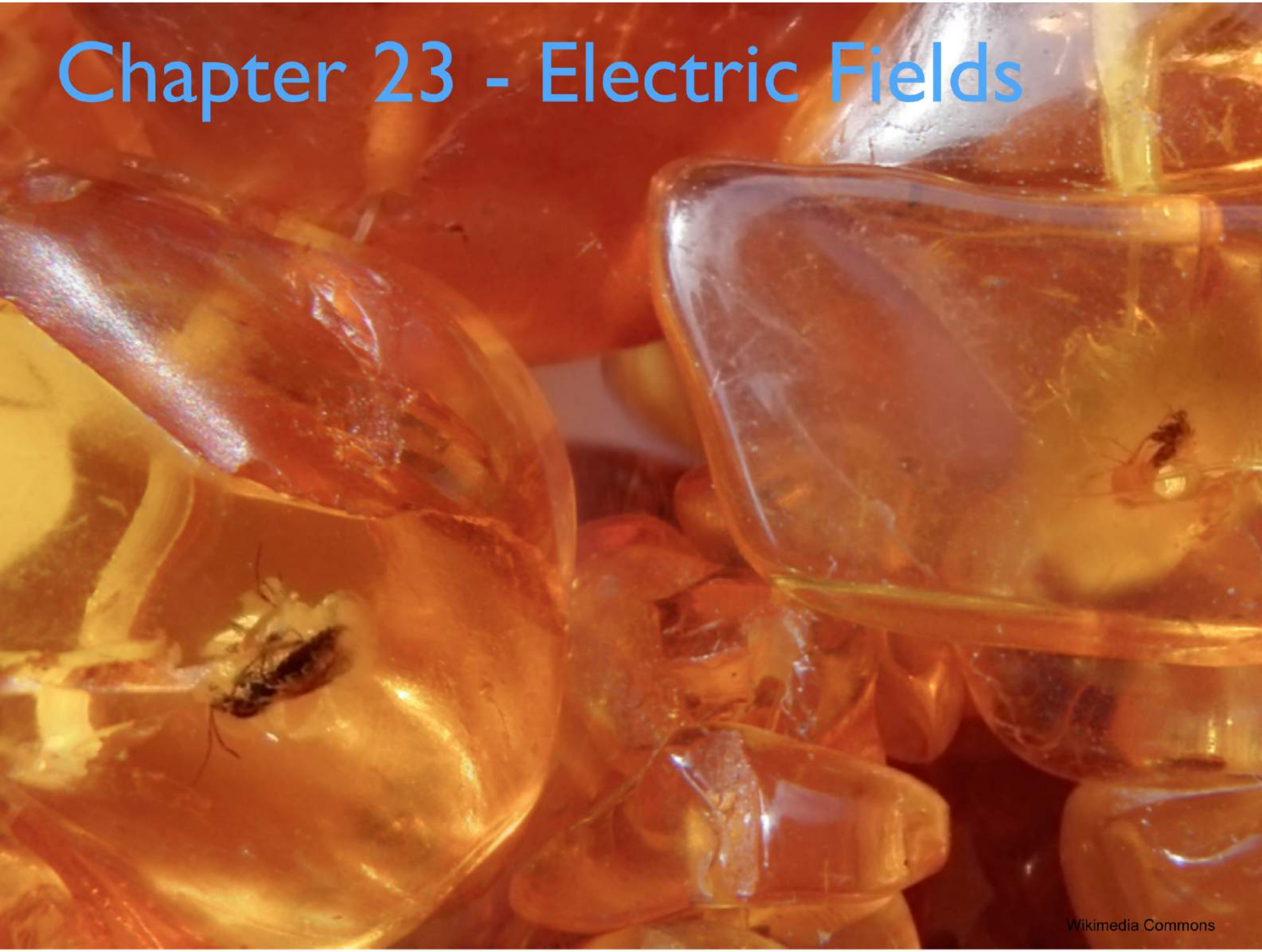
JUL 9 2014, 4:50 PM ET

Shocking! Geckos Use Static Electricity to Stick to Walls

https://www.youtube.com/watch?v=uEYcY7WfDTY

https://www.youtube.com/watch?v=Y-OxbBu1sKU

Chapter 23 - Electric Fields



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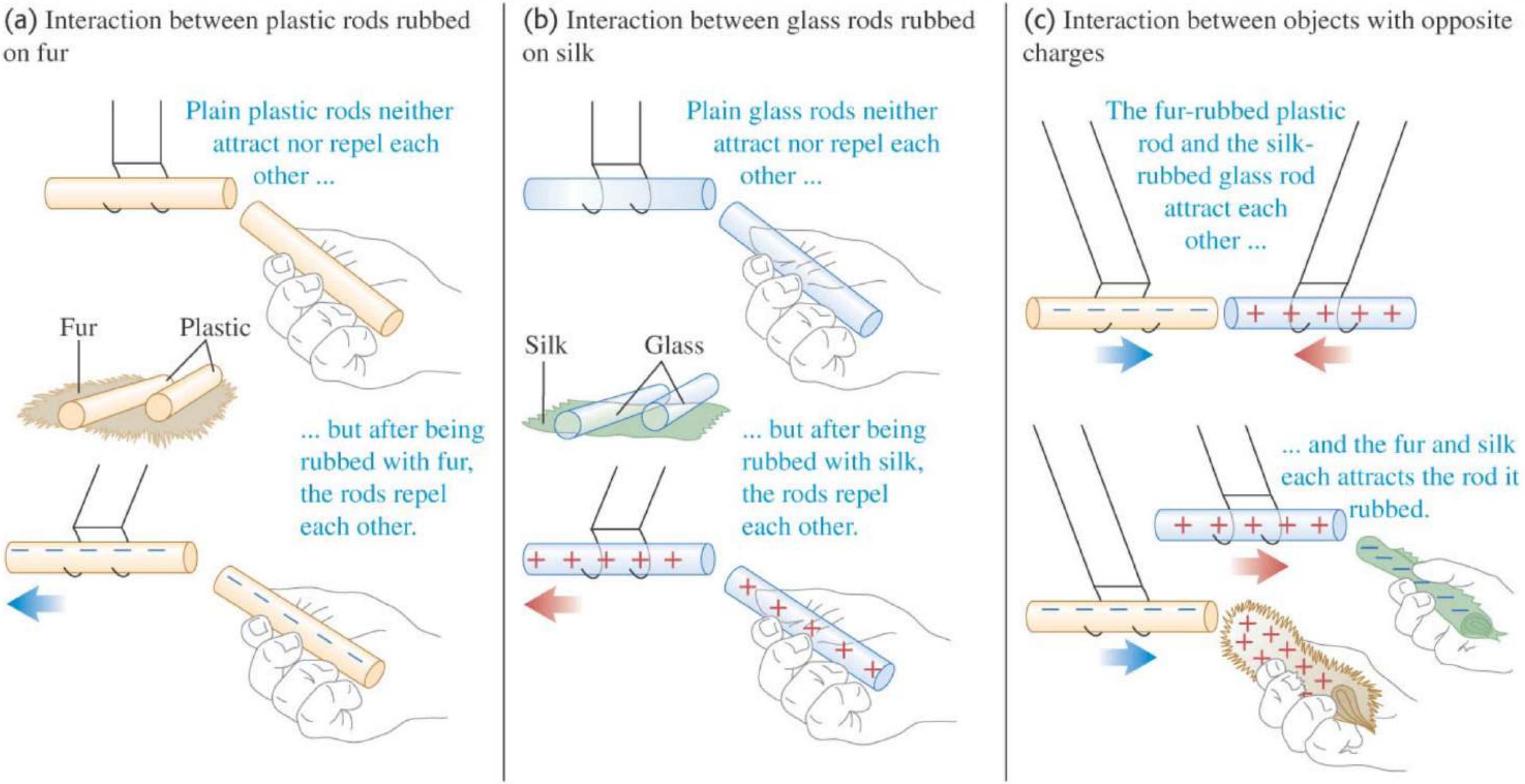
Electric charge

- 600 B.C.: Amber rubbed with wool will attract other objects. The word electric comes from the Greek work elektron, which means amber.
- Two positive or two negative charges repel each other. A positive charge and a negative charge attract each other.



(a) Interaction between plastic rods rubbed on fur

(b) Interaction between glass rods rubbed on silk

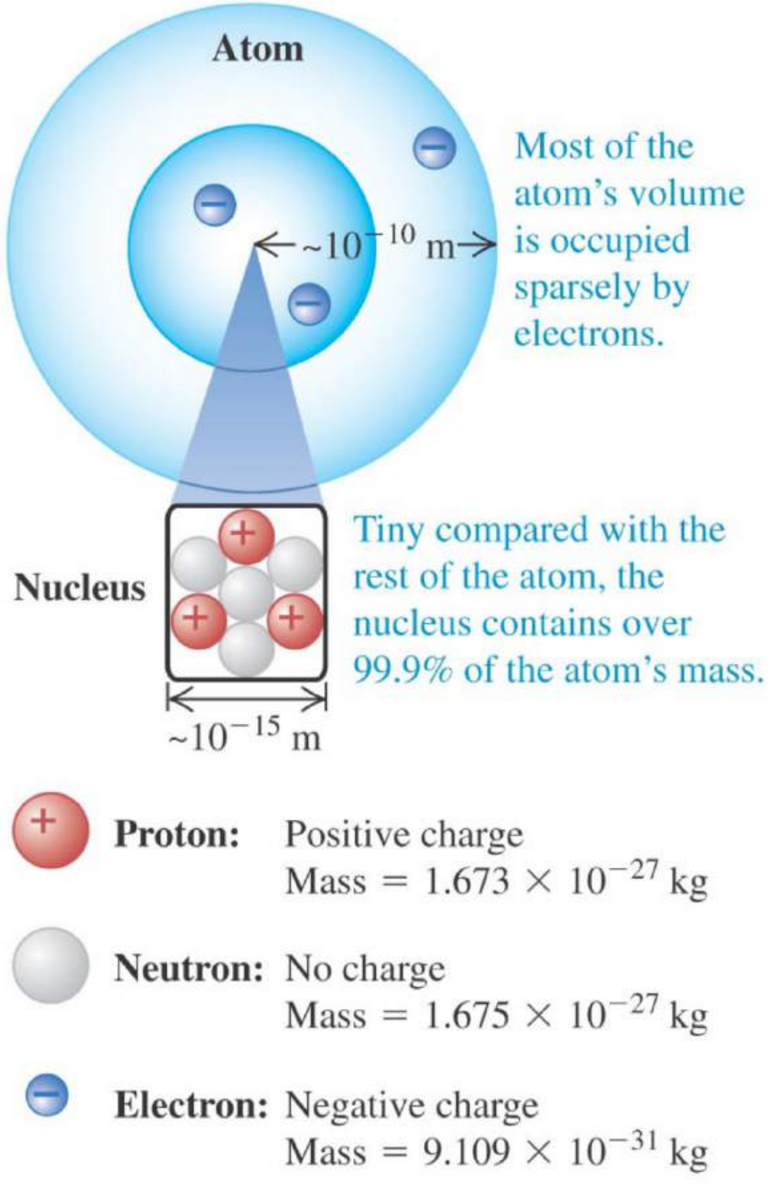
(c) Interaction between objects with opposite charges

Goals for Chapter 23

- To study electric charge and charge conservation
- To see how objects become charged
- To calculate the electric force between objects using Coulomb's law
- To learn the distinction between electric force and electric field
- To calculate the electric field due to many charges
- To visualize and interpret electric fields
- To calculate the properties of electric dipoles

Electric charge and the structure of matter

- The particles of the atom are the negative *electron*, the positive *proton*, and the uncharged *neutron*.
- Protons and neutrons make up the tiny dense nucleus which is surrounded by electrons.
- The electric attraction between protons and electrons holds the atom together. The nucleus is held together by the strong nuclear force.
- Protons and electrons have charges with equal magnitude.
- Protons and neutrons are made of charged particles: quarks, which have charges of $\pm\frac{1}{3}e$ and $\pm\frac{2}{3}e$



Most of the atom's volume is occupied sparsely by electrons.

Tiny compared with the rest of the atom, the nucleus contains over 99.9% of the atom's mass.

Proton: Positive charge
Mass = 1.673×10^{-27} kg

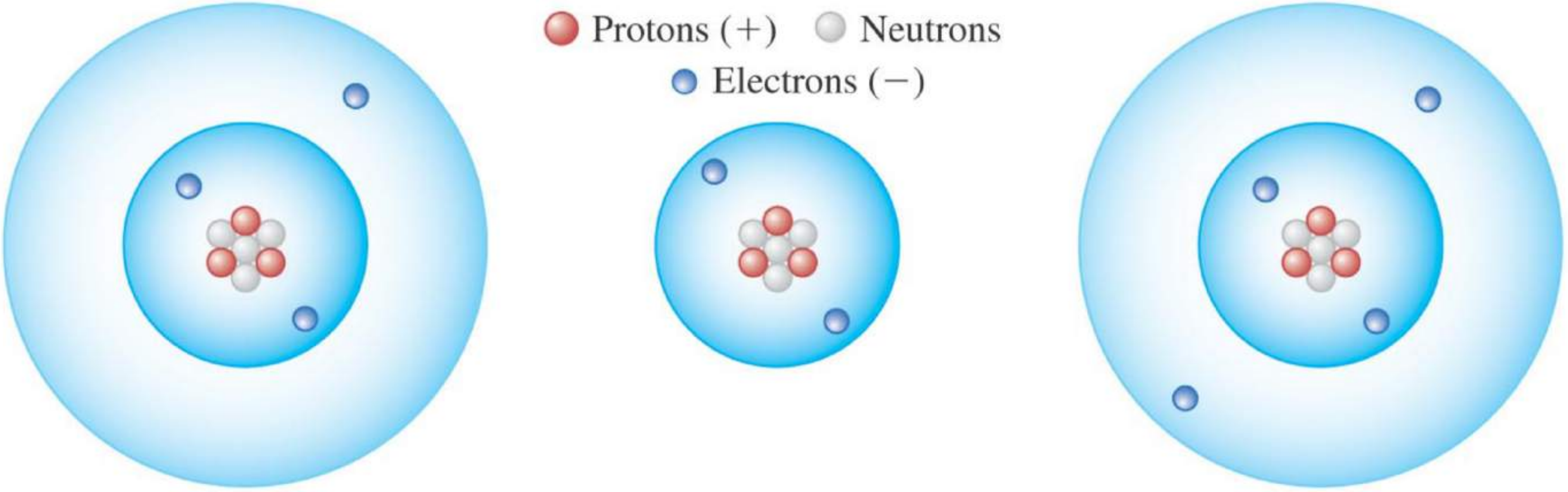
Neutron: No charge
Mass = 1.675×10^{-27} kg

Electron: Negative charge
Mass = 9.109×10^{-31} kg

The charges of the electron and proton are equal in magnitude.

Atoms and ions

- A neutral atom has the same number of protons as electrons.
- A *positive ion* is an atom with one or more electrons removed. A *negative ion* has gained one or more electrons.



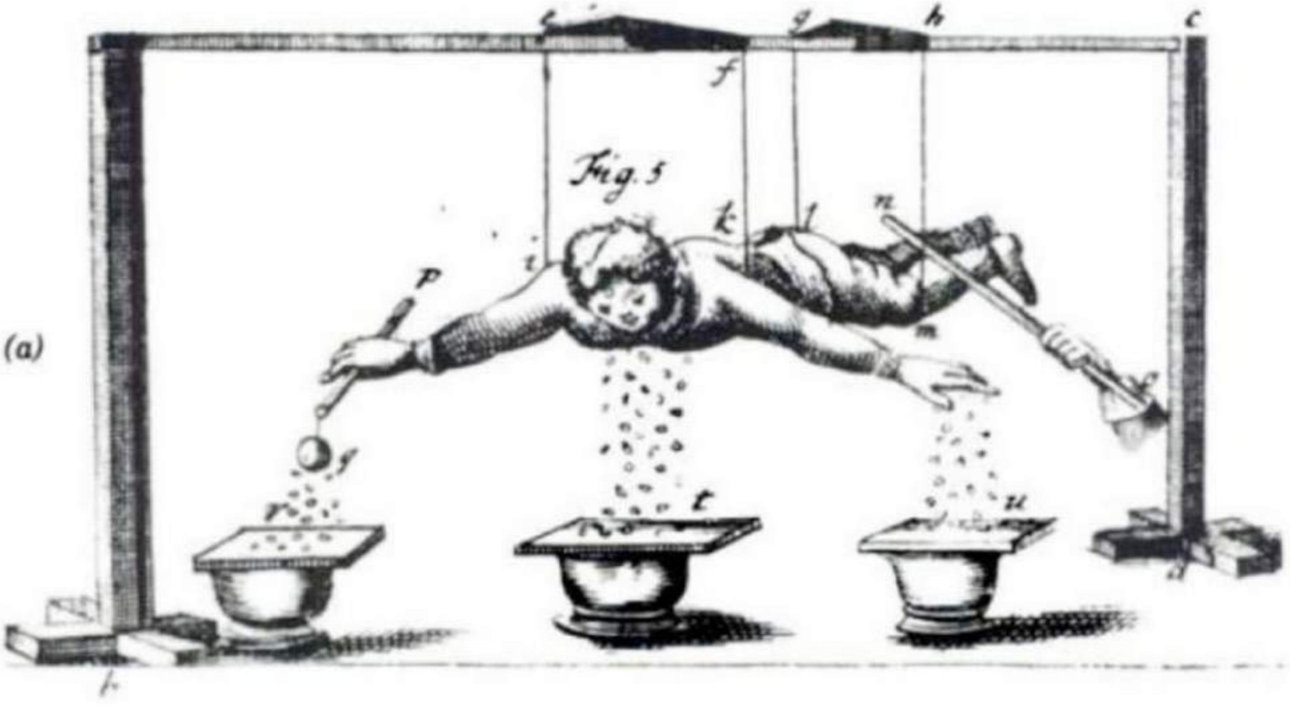
(a) **Neutral lithium atom (Li):**	(b) **Positive lithium ion (Li^+):**	(c) **Negative lithium ion (Li^-):**
3 protons (3+)	3 protons (3+)	3 protons (3+)
4 neutrons	4 neutrons	4 neutrons
3 electrons (3−)	2 electrons (2−)	4 electrons (4−)
Electrons equal protons: Zero net charge	Fewer electrons than protons: Positive net charge	More electrons than protons: Negative net charge

Conservation of charge

- The proton and electron have the same magnitude charge.
- The magnitude of charge of the electron or proton is a natural unit of charge. All observable charge is *quantized* in this unit.
- The universal *principle of charge conservation* states that the algebraic sum of all the electric charges in any closed system is constant.
- When we talk about the charge of a body, we mean the *net* charge. This is an extremely small fraction of the total charge in a body.

Electric Charge

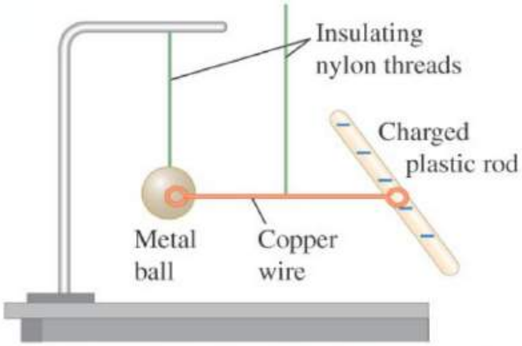
- We now learn about positive and negative change in grade school, but for centuries the reason for these mysterious electrostatic forces were elusive.
- In the 1600's, science had yet to turn serious attention to this phenomena. In the UK, it was primarily used for parlour tricks by street performer-types called "electricians".
- One such elaborate trick was made by Stephen Gray (1666-1736):



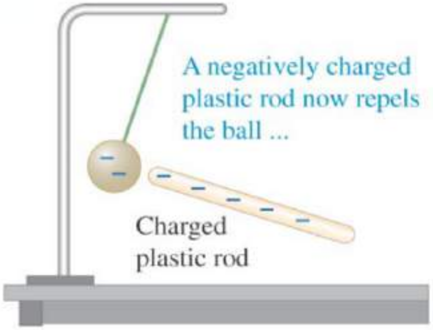
http://hipstwiki.wikifoundry.com/page/Stephen+Gray+-+Electrical+Conduction+on+the+wrong+track

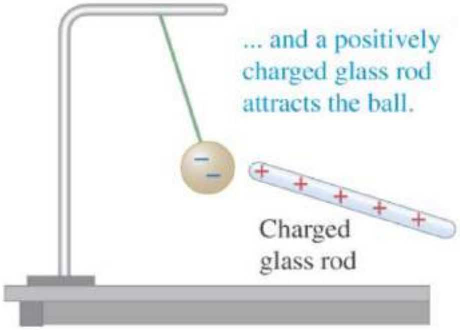
Conductors and Insulators

- Stephen Gray had begun the first systematic experiments with electrical conduction - the ability to move charge. He reasoned that silk from which the boy hung could not be charged.
- A conductor permits the easy movement of charge through it. An insulator does not.
- Most metals are good conductors, while most nonmetals are insulators.
- Despite this progress by Gray, there were still no signs that this could be a useful phenomena because charge could not be stored. Also, the reasons behind the observed phenomena were still not understood.

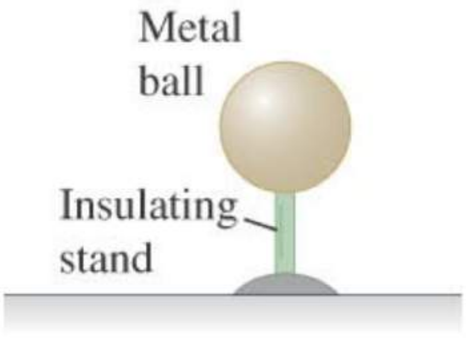


The wire conducts charge from the negatively charged plastic rod to the metal ball.

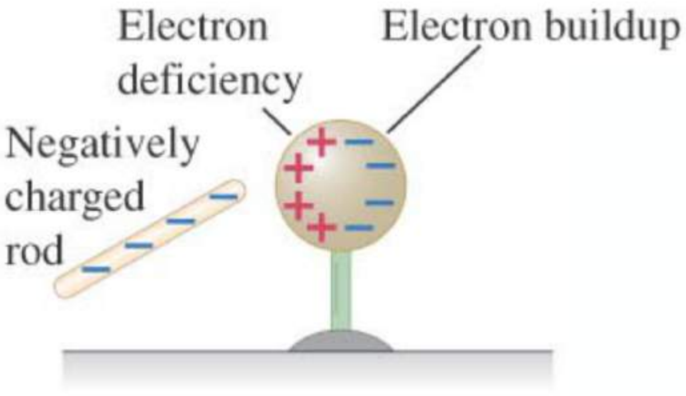

A negatively charged plastic rod now repels the ball ...


... and a positively charged glass rod attracts the ball.

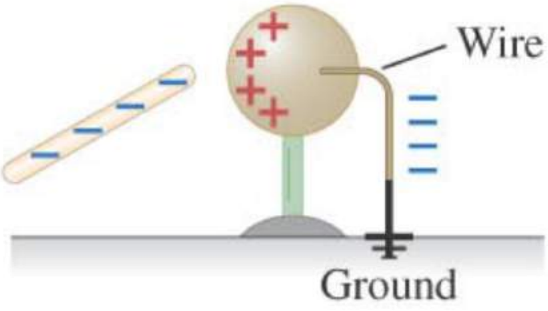
Charging by Induction



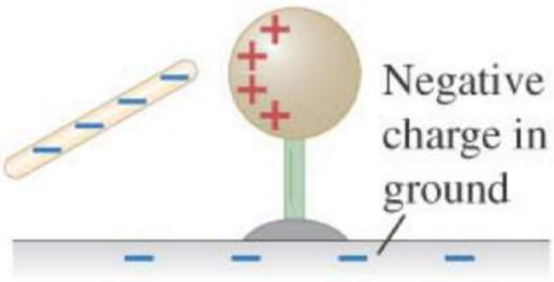
(a) Uncharged metal ball



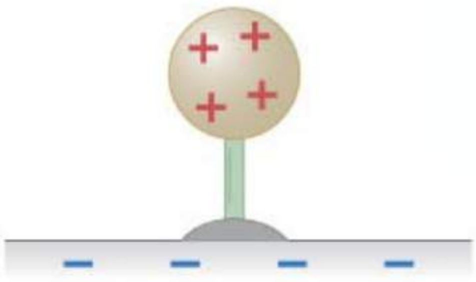
(b) Negative charge on rod repels electrons, creating zones of negative and positive **induced charge**.



(c) Wire lets electron buildup (induced negative charge) flow into ground.



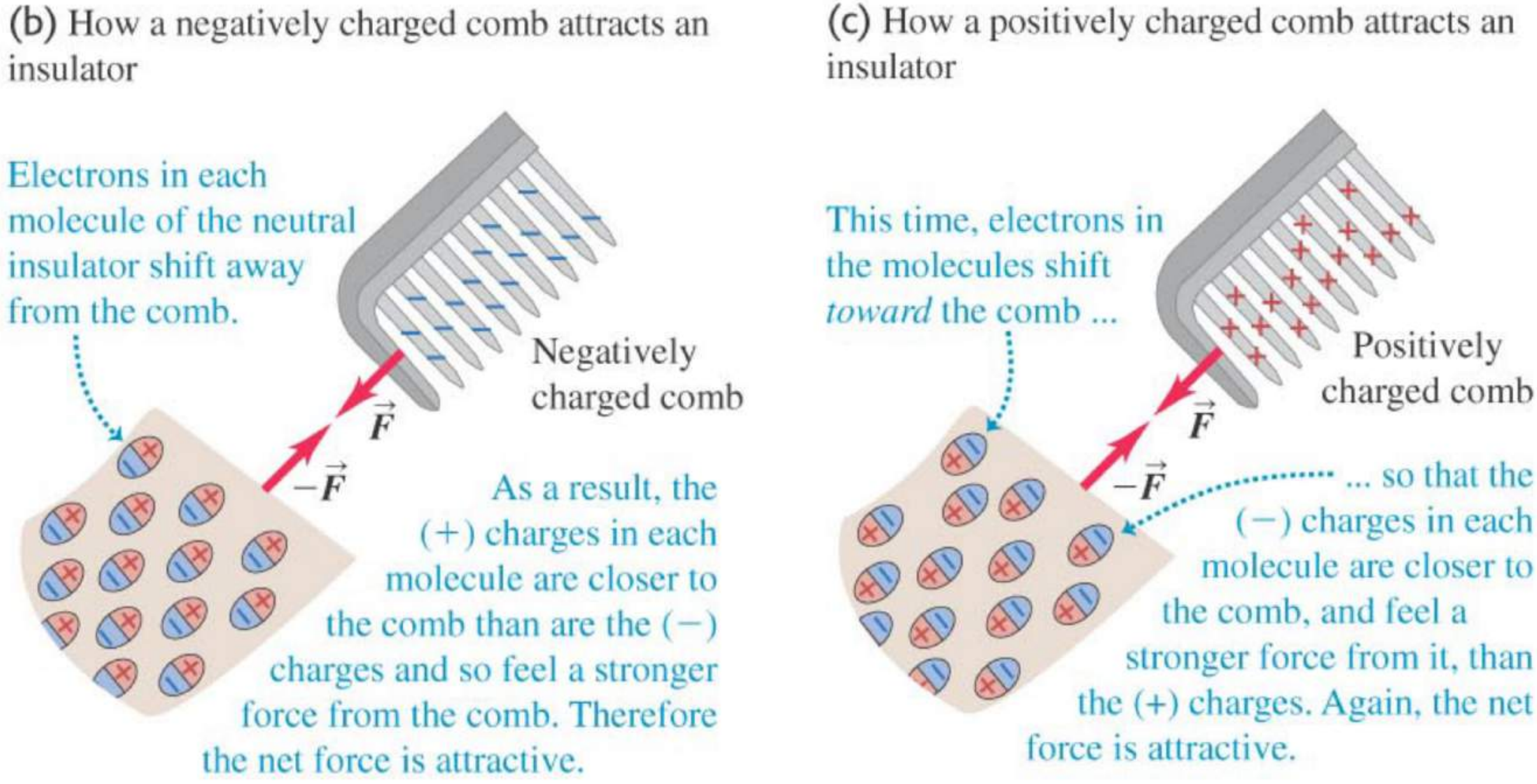
(d) Wire removed; ball now has only an electron-deficient region of positive charge.



(e) Rod removed; electrons rearrange themselves, ball has overall electron deficiency (net positive charge).

Electric forces on uncharged objects

- The charge within an insulator can shift slightly. As a result, two neutral objects can exert electric forces on each other, as shown below.



(b) How a negatively charged comb attracts an insulator

Electrons in each molecule of the neutral insulator shift away from the comb.

As a result, the (+) charges in each molecule are closer to the comb than are the (−) charges and so feel a stronger force from the comb. Therefore the net force is attractive.

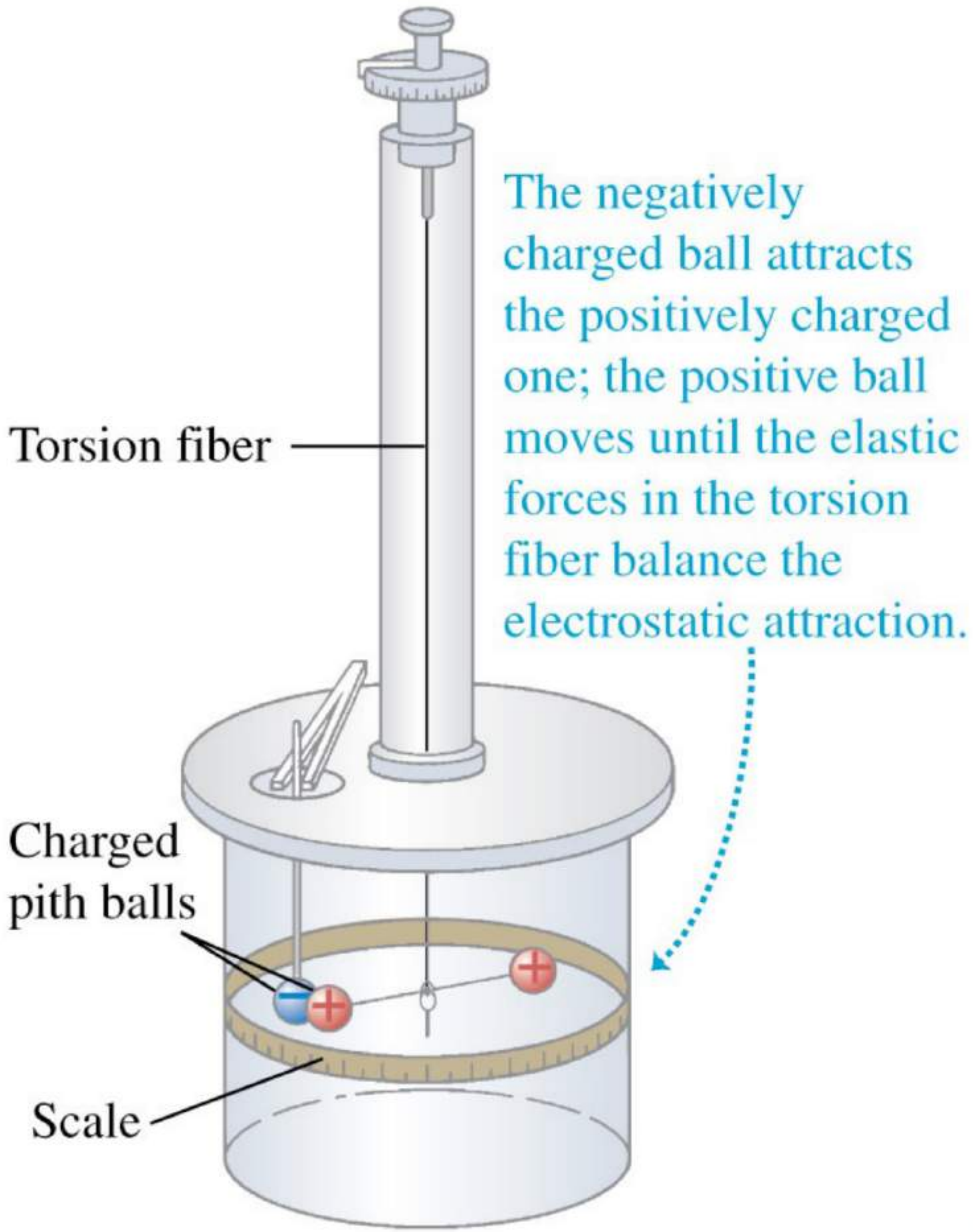
(c) How a positively charged comb attracts an insulator

This time, electrons in the molecules shift *toward* the comb ...

... so that the (−) charges in each molecule are closer to the comb, and feel a stronger force from it, than the (+) charges. Again, the net force is attractive.

Charles Coulomb and the Torsion Balance

Measuring the electric force between point charges



The negatively charged ball attracts the positively charged one; the positive ball moves until the elastic forces in the torsion fiber balance the electrostatic attraction.

Coulomb's observations :

1. For point charges (very small charged bodies), the electric force is proportional to $\frac{1}{r^2}$ $r \gg r_{bodies}$ (for point charges)

2. The electric force between 2 point charges depends on the quantity of charge on each body.

$\rightarrow$ the forces exerted on each other are proportional to the product of 2 charges.

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

COULOMB'S LAW

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

SI unit for charge is the Coulomb C

$$k = 8.988 \times 10^{9} \ N \cdot m^2/C^2$$

$$= \frac{1}{4\pi \epsilon_0}$$

↑ permittivity of free space

$$\epsilon_0 = 8.854 \times 10^{-12} \ C^2/N \cdot m^2$$

Interesting! → $k = (10^{-7} \ N \cdot s^2/C^2)\, c^2$

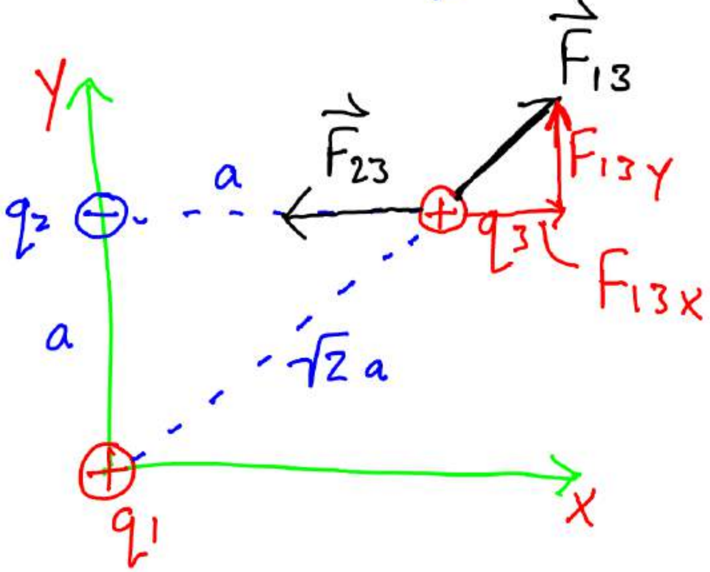
↑ speed of light

Most fundamental unit of charge is that of a proton or electron

$$e = 1.602 \times 10^{-19} \ C$$

What if there are 3 or more charges?

EXAMPLE: What is the force on q_3, given $q_1 = q_3 = 5.0\,\mu C$, $q_2 = -2.0\,\mu C$, and $a = 0.10\,m$?



$$F_{23} = k\frac{|q_2||q_3|}{a^2} = \frac{(9.0\times10^{9}\,N\cdot m^2/C^2)(2.0\times10^{-6}\,C)(5.0\times10^{-6}\,C)}{(0.10\,m)^2}$$

$$= 9.0\,N$$

$$F_{13} = k\frac{|q_1||q_3|}{(\sqrt{2}\,a)^2} = \frac{(9.0\times10^{9}\,N\cdot m^2/C^2)(5.0\times10^{-6}\,C)(5.0\times10^{-6}\,C)}{(\sqrt{2}\,(0.10\,m))^2}$$

$$= 11.0\,N$$

$$F_{13x} = (\cos 45°)(F_{13}) = 7.9\ \text{N}$$

$$F_{13y} = (\sin 45°)(F_{13}) = 7.9\ \text{N}$$

$$\vec{F}_{3x} = \vec{F}_{23} + \vec{F}_{13x}$$

$$= (9.0\ \text{N})(-\hat{i}) + (7.9\ \text{N})(\hat{i})$$

$$= (-1.1\ \text{N})\,\hat{i}$$

$$\vec{F}_{3y} = \vec{F}_{13y} = (7.9\ \text{N})\ \hat{j}$$

$$\underline{\vec{F}_{3} = (-1.1\,\hat{i} + 7.9\,\hat{j})\ \text{N}}$$

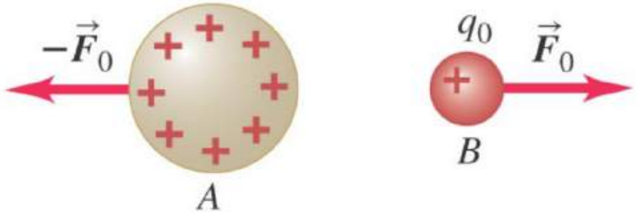
Electric field

- A gravitational field at a point in space is equal to the gravitational force acting on a test mass divided by the test mass:

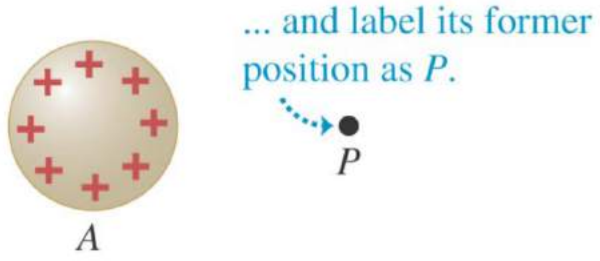
$$\vec{g} = \vec{F}/m_0$$

- Analogous to mass and gravity, a charged body produces an *electric field* in the space around it.
- We use a small *test charge* q_0 to find out if an electric field is present.
- If so, the field is said to exist regardless of whether or not a test charge is located at that point.

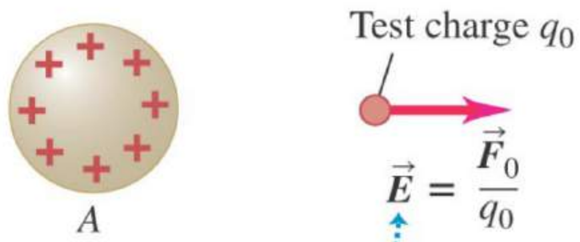
(a) *A* and *B* exert electric forces on each other.



(b) Remove body *B* ...


... and label its former position as *P*.

(c) Body *A* sets up an electric field $\vec{E}$ at point *P*.



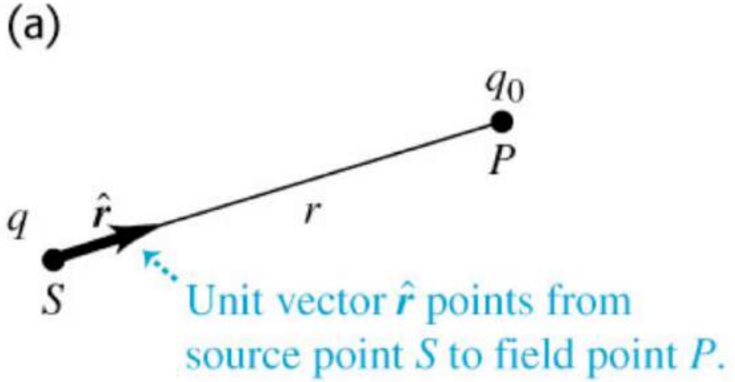
$$\vec{E} = \frac{\vec{F}_0}{q_0}$$

$\vec{E}$ is the force per unit charge exerted by *A* on a test charge at *P*.

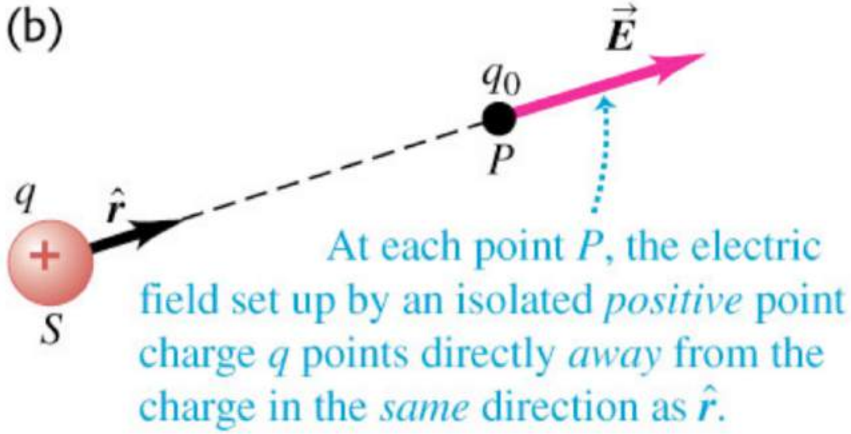
Definition of the electric field

- An electric field, or force per unit charge, is useful because it does not depend on the charge of the body on which the electric force is exerted.

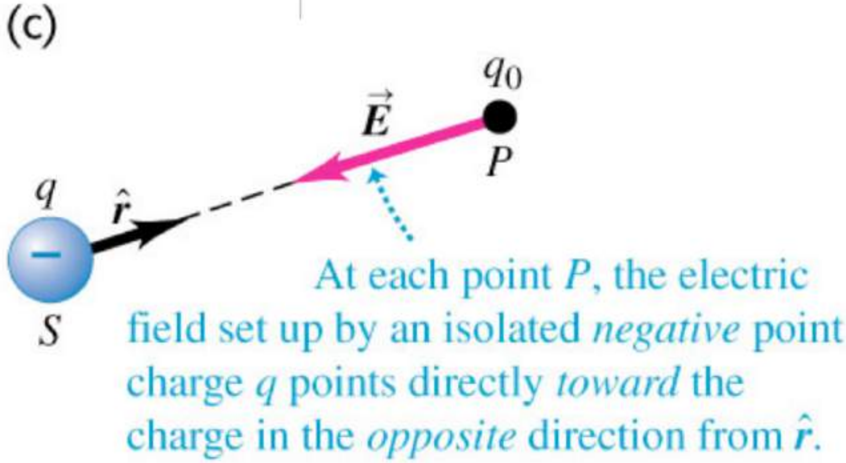
$$\vec{E} = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}\hat{r}$$



Unit vector $\hat{r}$ points from source point S to field point P.



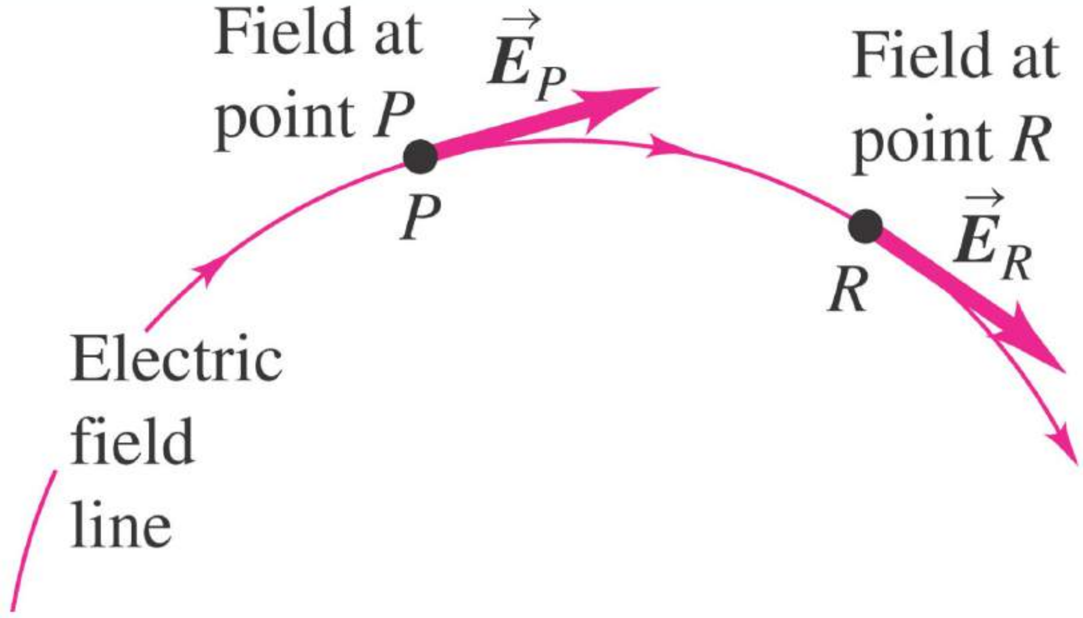
At each point P, the electric field set up by an isolated *positive* point charge q points directly *away* from the charge in the *same* direction as $\hat{r}$.



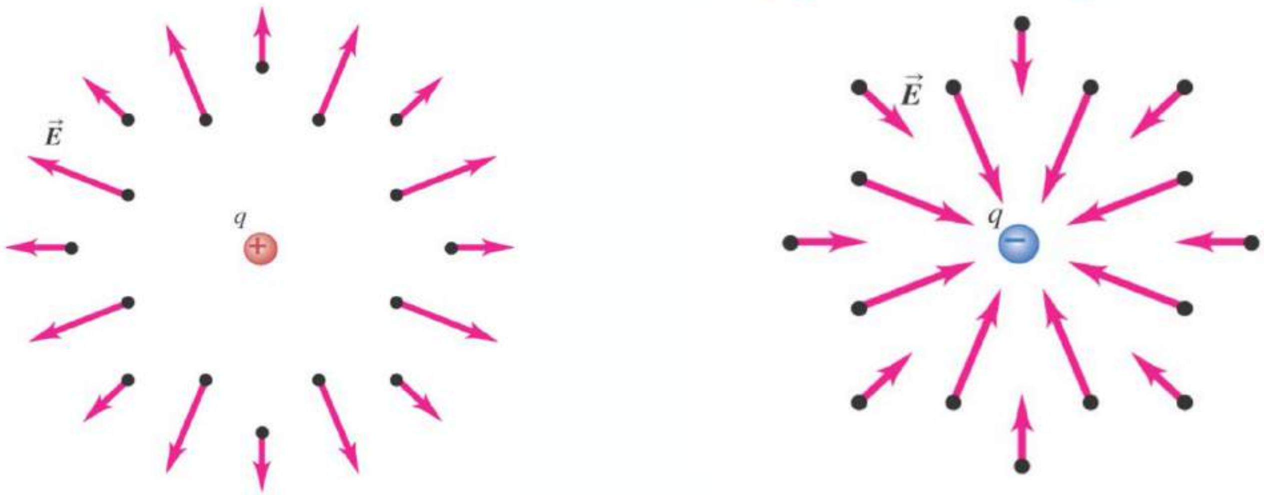
At each point P, the electric field set up by an isolated *negative* point charge q points directly *toward* the charge in the *opposite* direction from $\hat{r}$.

Electric field lines

- An *electric field line* is an imaginary line or curve whose tangent at any point is the direction of the electric field vector at that point.

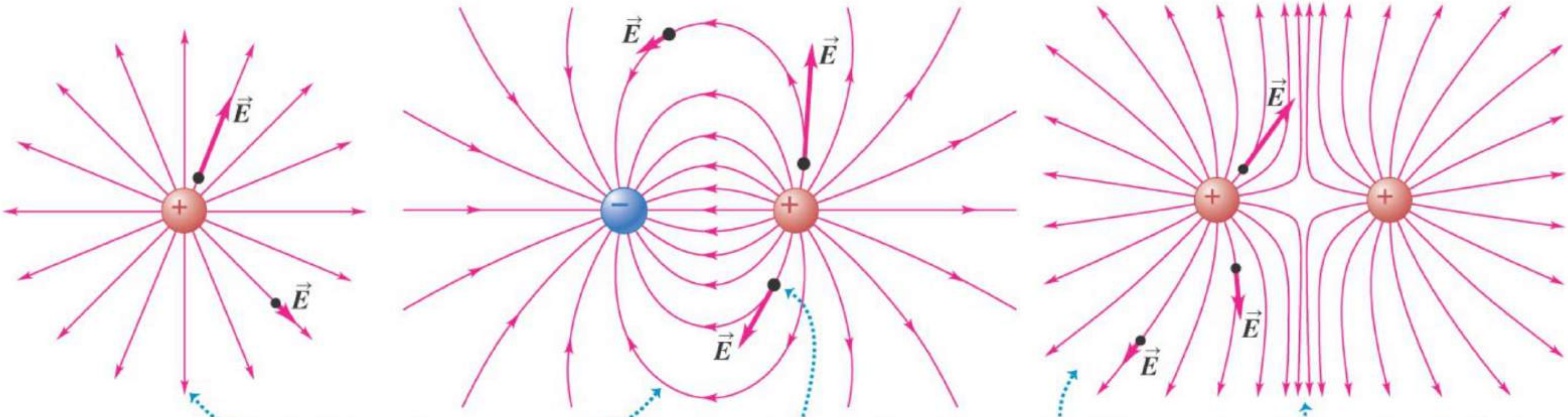


Electric field of a point charge and field lines



(a) The field produced by a positive point charge points *away from* the charge.

(b) The field produced by a negative point charge points *toward* the charge.



(a) A single positive charge

(b) Two equal and opposite charges (a dipole)

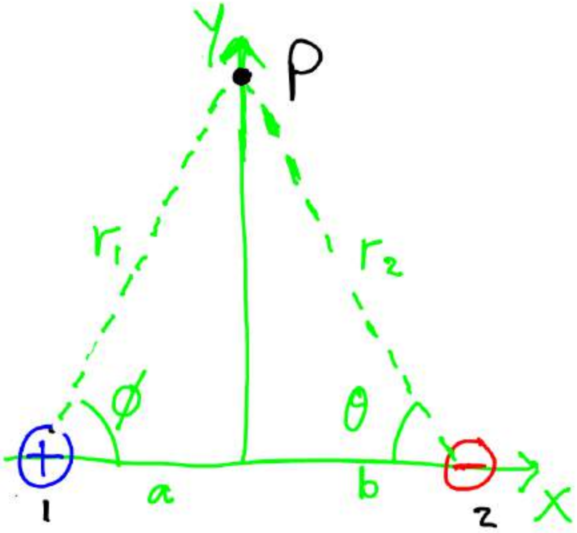
(c) Two equal positive charges

Field lines always point *away from* (+) charges and *toward* (−) charges.

At each point in space, the electric field vector is *tangent* to the field line passing through that point.

Field lines are close together where the field is strong, farther apart where it is weaker.

EXAMPLE: What is the electric field at P?



$$E_1 = \frac{k|q_1|}{r_1^2} = \frac{k|q_1|}{a^2+y^2}$$

$$E_2 = \frac{k|q_2|}{r_2^2} = \frac{k|q_2|}{b^2+y^2}$$

$$\vec{E}_1 = \frac{k|q_1|}{a^2+y^2}\cos\phi\,\hat{i} + \frac{k|q_1|}{a^2+y^2}\sin\phi\,\hat{j}$$

$$\vec{E}_2 = \frac{k|q_2|}{b^2+y^2}\cos\theta\,\hat{i} - k|q_2|\sin\theta\,\hat{j}$$

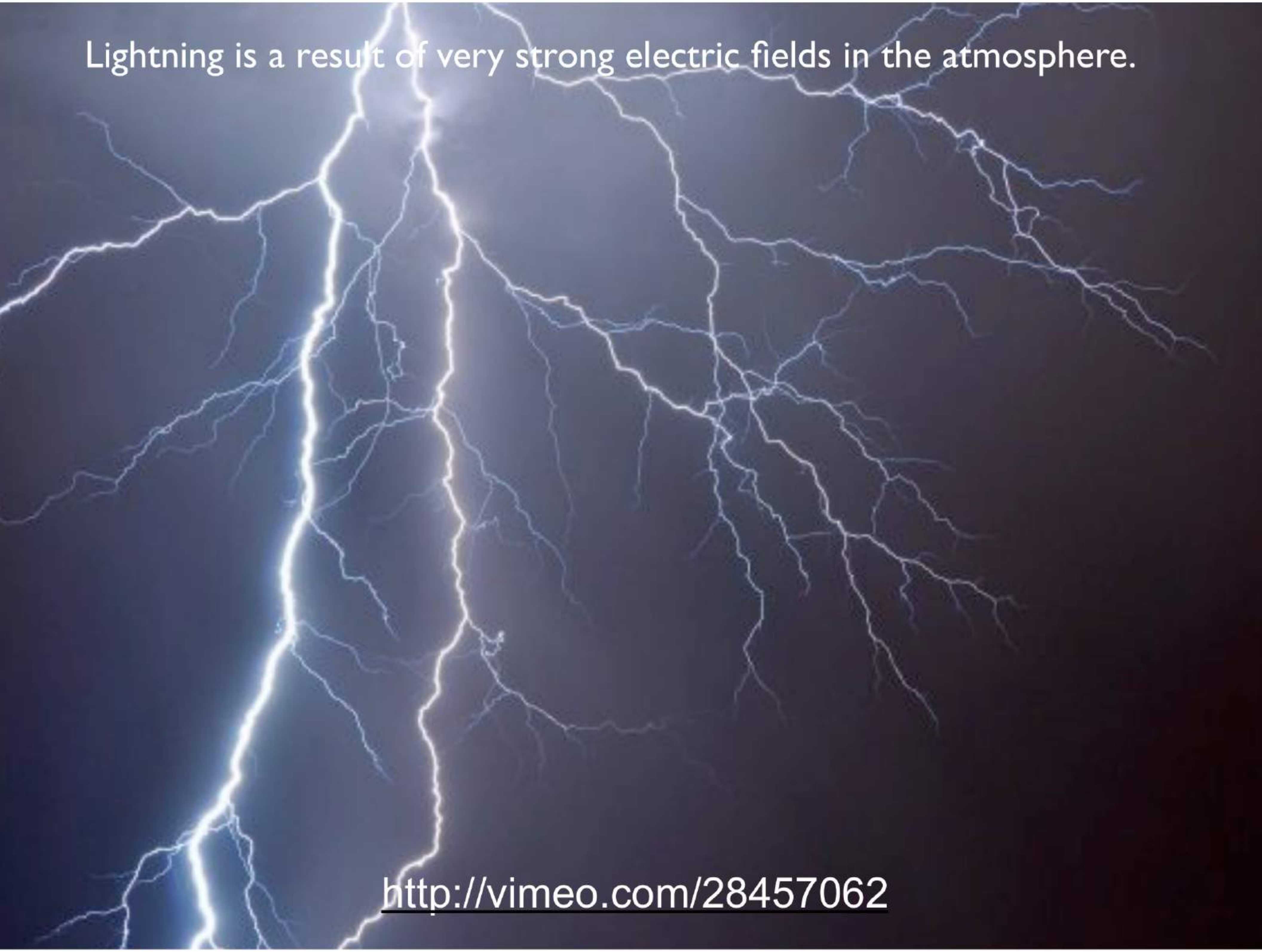
$$E_x = E_{1x} + E_{2x}$$

$$= \frac{k\,|q_1|\cos\phi}{a^2 + y^2} + \frac{k\,|q_2|\cos\theta}{b^2 + y^2}$$

$$E_y = E_{1y} + E_{2y}$$

$$= \frac{k\,|q_1|\sin\phi}{a^2 + y^2} - \frac{k\,|q_2|\sin\theta}{b^2 + y^2}$$

$$\underline{\vec{E}_p = E_x\,\hat{i} + E_y\,\hat{j}}$$



Lightning is a result of very strong electric fields in the atmosphere.

http://vimeo.com/28457062