Electricity

Ildikó László, PhD

Dept. Programming Languages and Compilers
Eötvös Loránd University, Budapest, Hungary

Financed from the financial support ELTE won from the Higher Education Restructuring Fund of the Hungarian Government

Electric charge and its conservation

- - electricity:
  comes from the Greek word "elektron"
  which means "amber";
- - if one rubs an amber rod with a piece of cloth,
  the amber attracts small pieces of leaves or dust;
- - the same is true for a plastic ruler etc.;
- - this is called static electricity;
  - an object becomes "charged" due to a rubig
  process;
- - it is said to possess electric charge;

Electric charge and its conservation

- - electricity:
  comes from the Greek word "elektron"
  which means "amber";
- - if one rubs an amber rod with a piece of cloth,
  the amber attracts small pieces of leaves or dust;
- - the same is true for a plastic ruler etc.;
- - this is called static electricity;
  - an object becomes "charged" due to a rubig process;
- - it is said to possess electric charge;

Electric charge and its conservation

- - electricity:
  comes from the Greek word "elektron"
  which means "amber";
- - if one rubs an amber rod with a piece of cloth,
  the amber attracts small pieces of leaves or dust;
- - the same is true for a plastic ruler etc.;
- - this is called static electricity;
  - an object becomes "charged" due to a rubig process;
- - it is said to possess electric charge;

Electric charge and its conservation

- - electricity:
  comes from the Greek word "elektron"
  which means "amber";
- - if one rubs an amber rod with a piece of cloth,
  the amber attracts small pieces of leaves or dust;
- - the same is true for a plastic ruler etc.;
- - this is called static electricity;
  - an object becomes "charged" due to a rubig
  process;
- - it is said to possess electric charge;

Electric charge and its conservation

- - electricity:
  comes from the Greek word "elektron"
  which means "amber";
- - if one rubs an amber rod with a piece of cloth,
  the amber attracts small pieces of leaves or dust;
- - the same is true for a plastic ruler etc.;
- - this is called static electricity;
  - an object becomes "charged" due to a rubig
  process;
- - it is said to possess electric charge;

Electric charge and its conservation

- - if one rubs two rulers
  - or two glass rods
  - and tries to bring them close,
- - the same kind of rubbed materials
  will repel each- other;
- - two different (the glass and the ruler for ex.)
  - will attract each-other;
- - Benjamin Franklin (1706-1790) argued that
- - there has to be two type of charges
  - which are called positive and negative;

Electric charge and its conservation

- - if one rubs two rulers
  - or two glass rods
  - and tries to bring them close,
- - the same kind of rubbed materials
  will repel each- other;
- - two different (the glass and the ruler for ex.)
  - will attract each-other;
- - Benjamin Franklin (1706-1790) argued that
- - there has to be two type of charges
  - which are called positive and negative;

Electric charge and its conservation

- - if one rubs two rulers
  - or two glass rods
  - and tries to bring them close,
- - the same kind of rubbed materials
  will repel each- other;
- - two different (the glass and the ruler for ex.)
  - will attract each-other;
- - Benjamin Franklin (1706-1790) argued that
- - there has to be two type of charges
  - which are called positive and negative;

Electric charge and its conservation

- - if one rubs two rulers
  - or two glass rods
  - and tries to bring them close,
- - the same kind of rubbed materials
  will repel each- other;
- - two different (the glass and the ruler for ex.)
  - will attract each-other;
- - Benjamin Franklin (1706-1790) argued that
- - there has to be two type of charges
  - which are called positive and negative;

Electric charge and its conservation

- - if one rubs two rulers
  - or two glass rods
  - and tries to bring them close,
- - the same kind of rubbed materials
  will repel each- other;
- - two different (the glass and the ruler for ex.)
  - will attract each-other;
- - Benjamin Franklin (1706-1790) argued that
- - there has to be two type of charges
  - which are called positive and negative;

Electric charge and its conservation

- - during any such process,
  - the net change in the amount of charge is zero;
- - the law of conservation of electric charge says that:
- - *the net amount of electric charge produced in any process is zero;*
- - the atom has a heavy positively charged nucleus
  - surrounded by one or more negatively charged electrons;
- - in the normal state the positive and negative charges within the atom are equal, and the atom is electrically neutral;

Electric charge and its conservation

- - during any such process,
  - the net change in the amount of charge is zero;
- - the law of conservation of electric charge says that:
- *- the net amount of electric charge produced in any process is zero;*
- - the atom has a heavy positively charged nucleus
  - surrounded by one or more negatively charged electrons;
- - in the normal state the
  positive and negative charges within the atom
  are equal, and the atom is electrically neutral;

Electric charge and its conservation

- - during any such process,
  - the net change in the amount of charge is zero;
- - the law of conservation of electric charge says that:
- - *the net amount of electric charge produced in any process is zero;*
- - the atom has a heavy positively charged nucleus
  - surrounded by one or more negatively charged electrons;
- - in the normal state the
  positive and negative charges within the atom
  are equal, and the atom is electrically neutral;

Electric charge and its conservation

- - during any such process,
  - the net change in the amount of charge is zero;
- - the law of conservation of electric charge says that:
- - *the net amount of electric charge produced in any process is zero;*
- - the atom has a heavy positively charged nucleus
  - surrounded by one or more negatively charged electrons;
- - in the normal state the positive and negative charges within the atom are equal, and the atom is electrically neutral;

Electric charge and its conservation

- - during any such process,
  - the net change in the amount of charge is zero;
- - the law of conservation of electric charge says that:
- - *the net amount of electric charge produced in any process is zero;*
- - the atom has a heavy positively charged nucleus
  - surrounded by one or more negatively charged electrons;
- - in the normal state the
  positive and negative charges within the atom
  are equal, and the atom is electrically neutral;

Electric charge and its conservation

- - an atom may lose or may gain one or more electrons;
- - than becomes positively or negatively charged;
- - when objects are charged by rubbing, they hold their charge only for a limited time;
- - or they are neutralized by charged ions in the air,
- - or they can leak off onto water molecules in the air;

Electric charge and its conservation

- - an atom may lose or may gain one or more electrons;
- - than becomes positively or negatively charged;
- - when objects are charged by rubbing, they hold their charge only for a limited time;
- - or they are neutralized by charged ions in the air,
- - or they can leak off onto water molecules in the air;

Electric charge and its conservation

- - an atom may lose or may gain one or more electrons;
- - than becomes positively or negatively charged;
- - when objects are charged by rubbing, they hold their charge only for a limited time;
- - or they are neutralized by charged ions in the air,
- - or they can leak off onto water molecules in the air;

Electric charge and its conservation

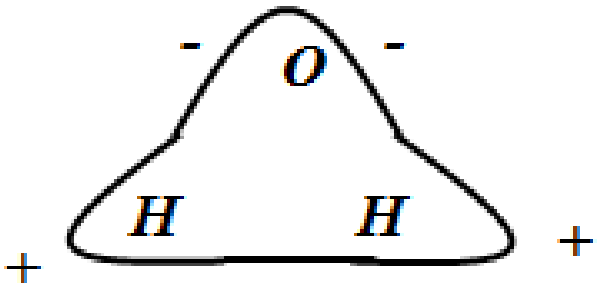
- - an atom may lose or may gain one or more electrons;
- - than becomes positively or negatively charged;
- - when objects are charged by rubbing, they hold their charge only for a limited time;
- - or they are neutralized by charged ions in the air,
- - or they can leak off onto water molecules in the air;

Electric charge and its conservation

- - an atom may lose or may gain one or more electrons;
- - than becomes positively or negatively charged;
- - when objects are charged by rubbing, they hold their charge only for a limited time;
- - or they are neutralized by charged ions in the air,
- - or they can leak off onto water molecules in the air;

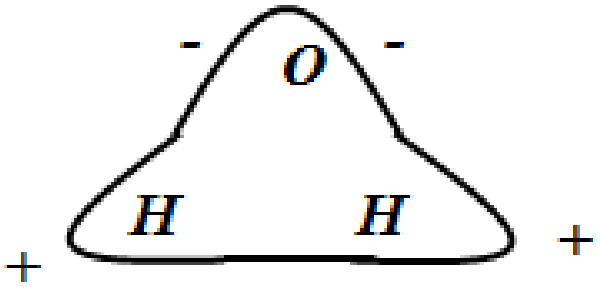
Electric charge and its conservation

- - the water molecules are polar;
- - that is, even though they are neutral, their charge is not distributed uniformly;
- - so electrons can be attracted by the positive end of water molecules;



Electric charge and its conservation

- - the water molecules are polar;
- - that is, even though they are neutral, their charge is not distributed uniformly;
- - so electrons can be attracted by the positive end of water molecules;



Electric charge and its conservation

- - metals, are good conductors;
- - if a positively charged metal
  is brought close to a neutral one:
- - then the electrons in the neutral one
  will move toward the positively charged one;
- - this leaves a positive charge at the opposite end;
- - this charge is said to be induced at the two ends of the metal;

Electric charge and its conservation

- - metals, are good conductors;
- - if a positively charged metal
  is brought close to a neutral one:
- - then the electrons in the neutral one
  will move toward the positively charged one;
- - this leaves a positive charge at the opposite end;
- - this charge is said to be induced at the two ends of the metal;

Electric charge and its conservation

- - metals, are good conductors;
- - if a positively charged metal
  is brought close to a neutral one:
- - then the electrons in the neutral one
  will move toward the positively charged one;
- - this leaves a positive charge at the opposite end;
- - this charge is said to be induced at the two ends of the metal;

Electric charge and its conservation

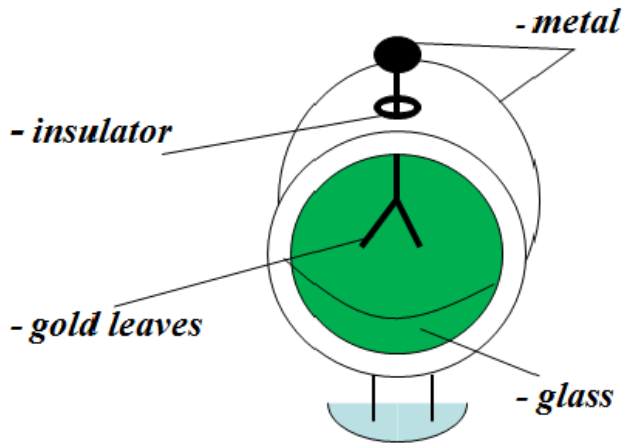
- - metals, are good conductors;
- - if a positively charged metal
  is brought close to a neutral one:
- - then the electrons in the neutral one
  will move toward the positively charged one;
- - this leaves a positive charge at the opposite end;
- - this charge is said to be induced at the two ends of the metal;

Electric charge and its conservation

- - metals, are good conductors;
- - if a positively charged metal
  is brought close to a neutral one:
- - then the electrons in the neutral one
  will move toward the positively charged one;
- - this leaves a positive charge at the opposite end;
- - this charge is said to be induced at the two ends of the metal;

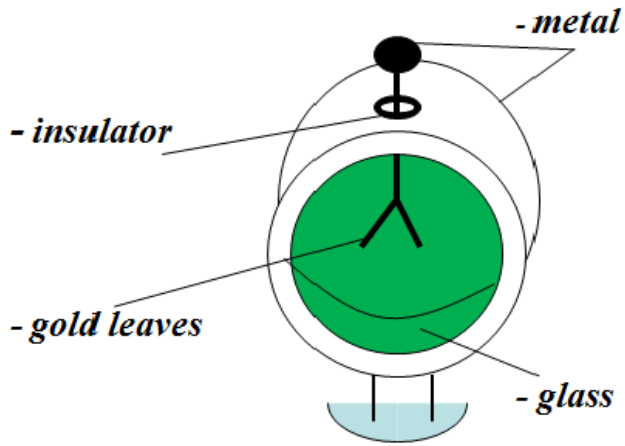
Electric charge and its conservation

- - another way to induce a net charge on a metal is:
- - to connect it with a conducting wire to the ground; (it is said to be grounded or earthed;)
- - an electroscope, is a device that can be used for detecting charge;
- - if a charged object is brought close to the knob - a separation of charge is induced, and



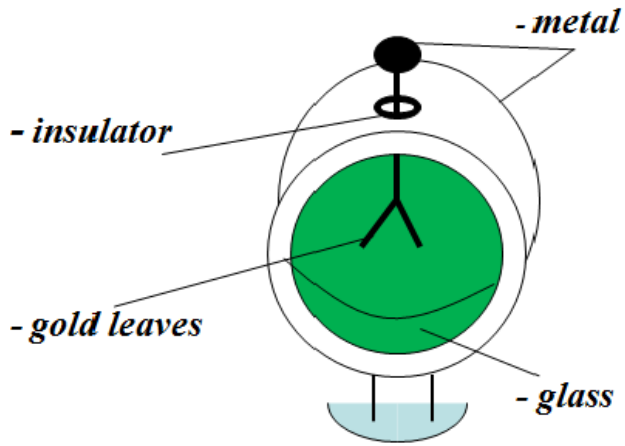
Electric charge and its conservation

- - another way to induce a net charge on a metal is:
- - to connect it with a conducting wire to the ground; (it is said to be grounded or earthed;)
- - an electroscope, is a device that can be used for detecting charge;
- - if a charged object is brought close to the knob - a separation of charge is induced, and



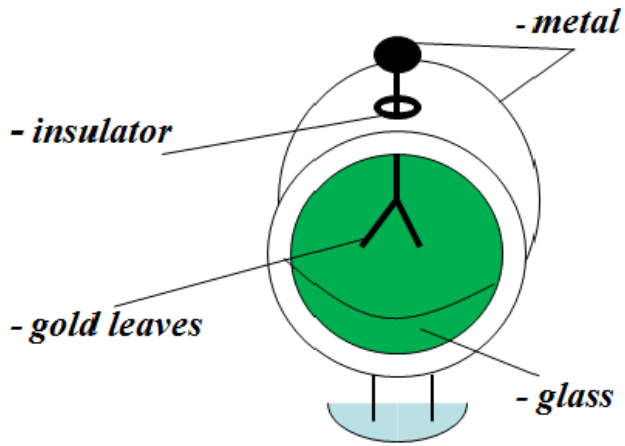
Electric charge and its conservation

- - another way to induce a net charge on a metal is:
- - to connect it with a conducting wire to the ground; (it is said to be grounded or earthed;)
- - an electroscope, is a device that can be used for detecting charge;
- - if a charged object is brought close to the knob - a separation of charge is induced, and



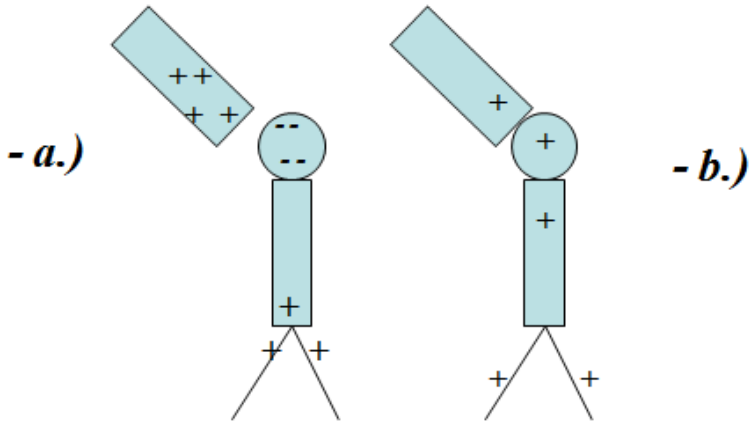
Electric charge and its conservation

- - another way to induce a net charge on a metal is:
- - to connect it with a conducting wire to the ground; (it is said to be grounded or earthed;)
- - an electroscope, is a device that can be used for detecting charge;
- - if a charged object is brought close to the knob
  - a separation of charge is induced, and



Electric charge and its conservation

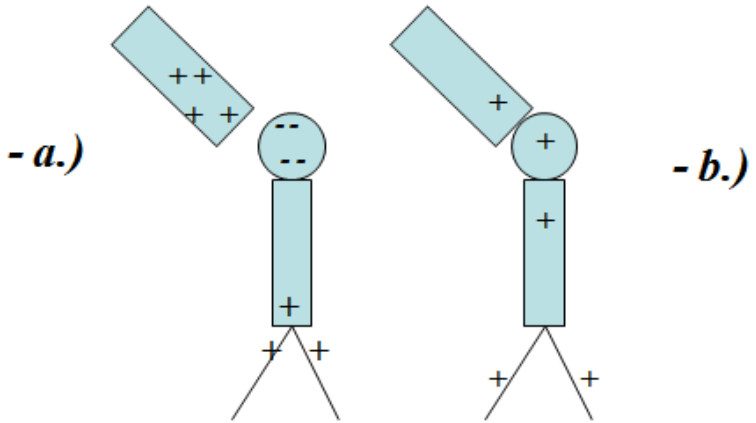
- - the two leaves become charged and repel each-other: - a.)
- - if the knob is charged by conduction,
  - the hole apparatus becomes charged: - b.)



- - important:
  - you cannot tell in this way the sign of the charge;

Electric charge and its conservation

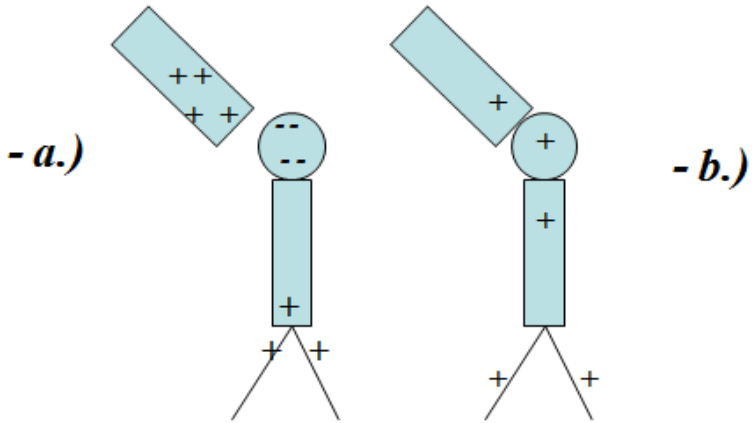
- - the two leaves become charged and repel each-other: - a.)
- - if the knob is charged by conduction,
  - the hole apparatus becomes charged: - b.)



- - important:
  - you cannot tell in this way the sign of the charge;

Electric charge and its conservation

- - the two leaves become charged and repel each-other: - a.)
- - if the knob is charged by conduction,
  - the hole apparatus becomes charged: - b.)



- - important:
  - you cannot tell in this way the sign of the charge;

Coulomb's law

- - Charles Coulomb (1736-1806) - the French physicist
- - reasoned that:
- - if a charged conducting sphere is placed in contact with an identical uncharged one
- - the charge on the first would then be shared equally by the two of them;

Coulomb's law

- - Charles Coulomb (1736-1806) - the French physicist
- - reasoned that:
- - if a charged conducting sphere is placed in contact with an identical uncharged one
- - the charge on the first would then be shared equally by the two of them;

Coulomb's law

- - Charles Coulomb (1736-1806) - the French physicist
- - reasoned that:
- - if a charged conducting sphere is placed in contact with an identical uncharged one
- - the charge on the first would then be shared equally by the two of them;

Coulomb's law

- - Charles Coulomb (1736-1806) - the French physicist
- - reasoned that:
- - if a charged conducting sphere is placed in contact with an identical uncharged one
- - the charge on the first would then be shared equally by the two of them;

Coulomb's law

- - Coulomb's law:

$$\vec{F} = k\frac{q_1 q_2}{r^2}\frac{\vec{r}}{r} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\frac{\vec{r}}{r}; \qquad (1)$$

- - where k is a proportionality constant;
  - in SI has the value:
  $k = 8.988\ 10^9\ Nxm^2/C^2$;

Coulomb's law

- - Coulomb's law:

$$\vec{F} = k\frac{q_1 q_2}{r^2}\frac{\vec{r}}{r} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\frac{\vec{r}}{r}; \qquad (1)$$

- - where k is a proportionality constant;
  - in SI has the value:
  $k = 8.988\ 10^9\ Nxm^2/C^2$;

The Electric Field

- - according to Michael Faraday (1791-1867)
  - an electric field extends outward from every charge and permeates all space;
- - when a second charge is placed near the first one,
  - it feels a force because of the electric field;
- - this field is interacting directly with the second charge,
  - which is placed in the field of the first one;

$$\vec{E} = \frac{\vec{F}}{q}; \tag{2}$$

The Electric Field

- - according to Michael Faraday (1791-1867)
  - an electric field extends outward from every charge and permeates all space;
- - when a second charge is placed near the first one,
  - it feels a force because of the electric field;
- - this field is interacting directly with the second charge,
  - which is placed in the field of the first one;

$$\vec{E} = \frac{\vec{F}}{q}; \tag{2}$$

The Electric Field

- - according to Michael Faraday (1791-1867)
  - an electric field extends outward from every charge and permeates all space;
- - when a second charge is placed near the first one,
  - it feels a force because of the electric field;
- - this field is interacting directly with the second charge,
  - which is placed in the field of the first one;

$$\vec{E} = \frac{\vec{F}}{q}; \tag{2}$$

The Electric Field

- - the direction of the electric field is defined as:
  - the direction of the force on a positive test charge at that point;
- - E does not depend on the magnitude of the test charge q;
  - that is, E describes only the effect of the charges creating the electric field at that point;
  - $\vec{E}$ is a vector field;

The Electric Field

- - the direction of the electric field is defined as:
  - the direction of the force on a positive test charge at that point;
- - E does not depend on the magnitude of the test charge q;
  - that is, E describes only the effect of the charges creating the electric field at that point;
  - $\vec{E}$ is a vector field;

The Electric Field

- - the electric field of a charge Q, at a given point in space at a distance $\vec{r}$ is:

$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}\frac{\vec{r}}{r}; \tag{3}$$

- - if the field is due to more than one charge,
  - then the total field is the vector sum of the field of each of the charges:

$$\vec{E} = \vec{E}_1 + \vec{E}_2 + \ \ldots\ + \vec{E}_n = \sum_{i=1}^{n} \vec{E}_i; \tag{4}$$

The Electric Field

- - the electric field of a charge Q, at a given point in space at a distance $\vec{r}$ is:

$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}\frac{\vec{r}}{r}; \tag{3}$$

- - if the field is due to more than one charge,
  - then the total field is the vector sum of the field of each of the charges:

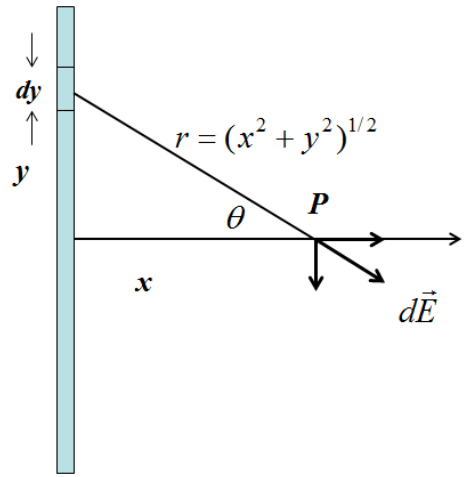
$$\vec{E} = \vec{E_1} + \vec{E_2} + \ \ldots \ + \vec{E_n} = \sum_{i=1}^{n} \vec{E_i}; \tag{4}$$

The Electric Field

- - the validity of this superposition principle derives from experiment, and
  - no exceptions have ever been observed;
- - the electric field of an infinitesimal charge dq at a distance r is:

$$dE = \frac{1}{4\pi\varepsilon_0}\frac{dq}{r^2}; \tag{5}$$

- - another example:
  - a very long wire, of uniformly distributed charges;

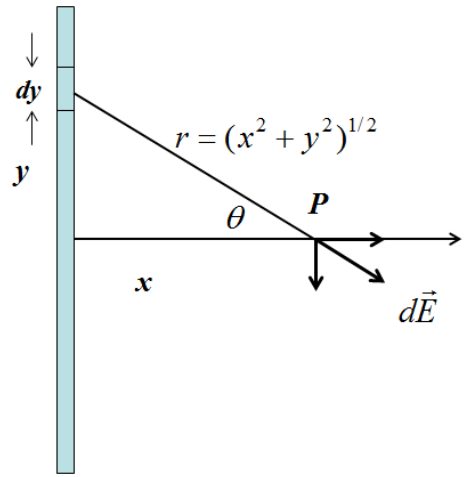


The Electric Field

- - the validity of this superposition principle derives from experiment, and
  - no exceptions have ever been observed;
- - the electric field of an infinitesimal charge dq at a distance r is:

$$dE = \frac{1}{4\pi\varepsilon_0}\frac{dq}{r^2}; \tag{5}$$

- - another example:
  - a very long wire, of uniformly distributed charges;

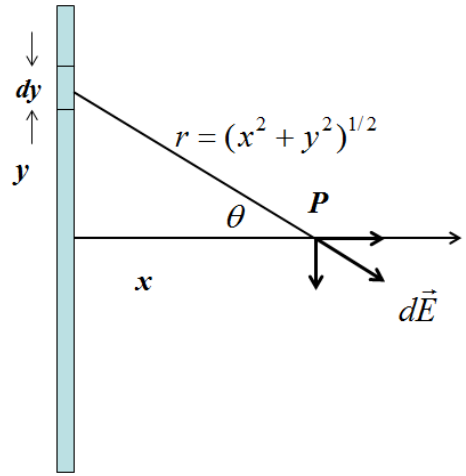


The Electric Field

- - the validity of this superposition principle derives from experiment, and
  - no exceptions have ever been observed;
- - the electric field of an infinitesimal charge dq at a distance r is:

$$dE = \frac{1}{4\pi\varepsilon_0}\frac{dq}{r^2}; \tag{5}$$

- - another example:
  - a very long wire, of uniformly distributed charges;



The Electric Field

- - the magnitude of the electric field at any point P at a distance x from a very long wire of uniformly distributed charges is:

$$dE = \frac{1}{4\pi\varepsilon_0}\frac{edy}{(x^2+y^2)} = \tag{6}$$

$$= \frac{e}{4\pi\varepsilon_0}\frac{1}{x}\int_{-\pi/2}^{\pi/2} cos\theta d\theta = \frac{1}{2\pi\varepsilon_0}\frac{e}{x};$$

Electric Fields and Conductors

- - the electric field inside a good conductor is zero;
- - any net charge on a good conductor distributes itself on the outer surface;
- - the electric field is always perpendicular to the surface of the conductor;
- - if there were a component of $\vec{E}$ parallel to the surface

Electric Fields and Conductors

- - the electric field inside a good conductor is zero;
- - any net charge on a good conductor distributes itself on the outer surface;
- - the electric field is always perpendicular to the surface of the conductor;
- - if there were a component of $\vec{E}$ parallel to the surface

Electric Fields and Conductors

- - the electric field inside a good conductor is zero;
- - any net charge on a good conductor distributes itself on the outer surface;
- - the electric field is always perpendicular to the surface of the conductor;
- - if there were a component of $\vec{E}$ parallel to the surface

Electric Fields and Conductors

- - the electric field inside a good conductor is zero;
- - any net charge on a good conductor distributes itself on the outer surface;
- - the electric field is always perpendicular to the surface of the conductor;
- - if there were a component of $\vec{E}$ parallel to the surface

Conductors and Electric Dipoles

- - electrons at the surface would move along the surface
- - until they reached positions, where no force was exerted on them;
- - two equal charges of opposite signs are referred to as
- - *electric dipole;*

Conductors and Electric Dipoles

- - electrons at the surface would move along the surface
- - until they reached positions, where no force was exerted on them;
- - two equal charges of opposite signs are referred to as
- - *electric dipole;*

Conductors and Electric Dipoles

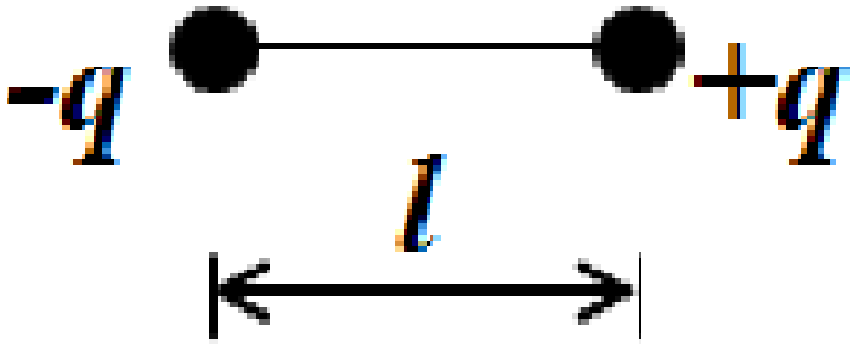
- - electrons at the surface would move along the surface
- - until they reached positions, where no force was exerted on them;
- - two equal charges of opposite signs are referred to as
- *- electric dipole;*

Conductors and Electric Dipoles

- - electrons at the surface would move along the surface
- - until they reached positions, where no force was exerted on them;
- - two equal charges of opposite signs are referred to as
- - *electric dipole;*

Conductors and Electric Dipoles

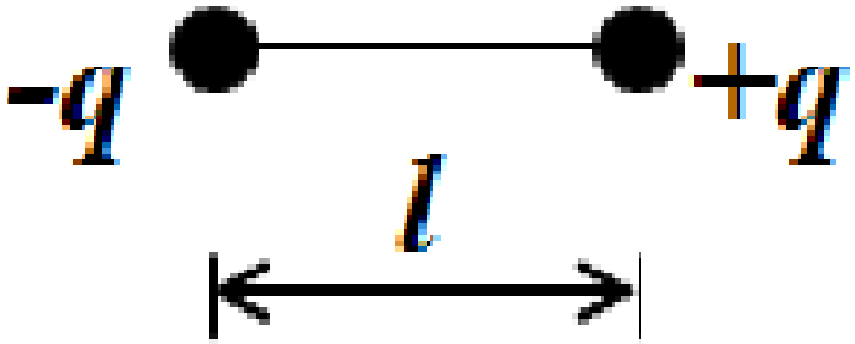
- - many molecules have a dipole moment: $\vec{p} = q\vec{l}$;



- - that points from the negative to the positive charge;
- - if a dipole is placed in a uniform electric field
- - then the force acting on the positive charge

Conductors and Electric Dipoles

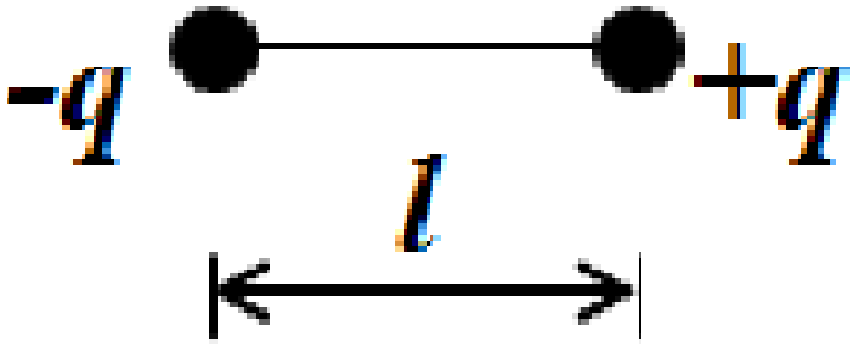
- - many molecules have a dipole moment: $\vec{p} = q\vec{l}$;



- - that points from the negative to the positive charge;
- - if a dipole is placed in a uniform electric field
- - then the force acting on the positive charge

Conductors and Electric Dipoles

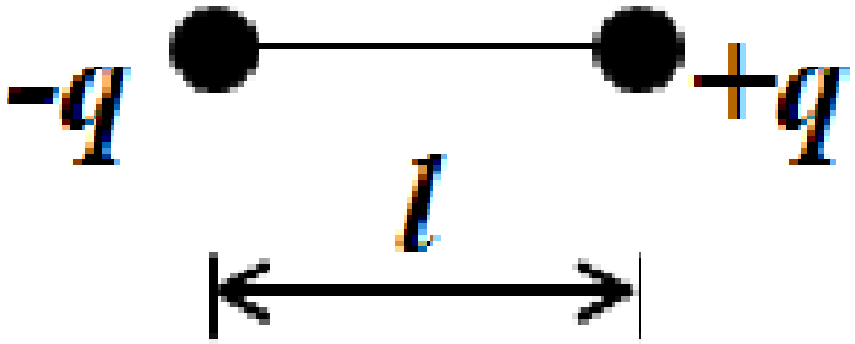
- - many molecules have a dipole moment: $\vec{p} = q\vec{l}$;



- - that points from the negative to the positive charge;
- - if a dipole is placed in a uniform electric field
- - then the force acting on the positive charge

Conductors and Electric Dipoles

- - many molecules have a dipole moment: $\vec{p} = q\vec{l}$;



- - that points from the negative to the positive charge;
- - if a dipole is placed in a uniform electric field
- - then the force acting on the positive charge

Electric Dipoles -

- - will be opposite to the force which is exerted on the negative charge;
- - as a result, a torque will be exerted on the dipole
- - which tries to turn the dipole p so that $\vec{p}$ is parallel to $\vec{E}$;

Electric Dipoles -

- - will be opposite to the force which is exerted on the negative charge;
- - as a result, a torque will be exerted on the dipole
- - which tries to turn the dipole p so that $\vec{p}$ is parallel to $\vec{E}$;

Electric Dipoles -

- - will be opposite to the force which is exerted on the negative charge;
- - as a result, a torque will be exerted on the dipole
- - which tries to turn the dipole p so that $\vec{p}$ is parallel to $\vec{E}$;