PHYS 1444 – Section 003
Lecture #2

Wednesday, Aug. 31, 2005
Dr. Jaehoon Yu

- Coulomb's Law
- The Electric Field
- Field Lines
- Electric Fields and Conductors
- Motion of a Charged Particle in an Electric Field
- Electric Dipoles
- CH22: Gauss' Law

Announcements

- Next Monday, Sept. 5, is a Labor day.
  – No class
  – Homework due has been changed to noon, Tuesday, Sept. 6, to reflect this.
- Your five extra credit points for e-mail subscription is till midnight tonight.   Please take a full advantage of the opportunity.
  – Nine of you have subscribed so far. Thank you!!!
- All of you have registered in the homework system.
  – I am TOTALLY impresssed!!! GOOOOOOOD Job!!
  – Two of the registered, though, forgot to submit the homework. I will extend the free 100% credit on HW#1 till midnight tonight, unless you don't want me to….

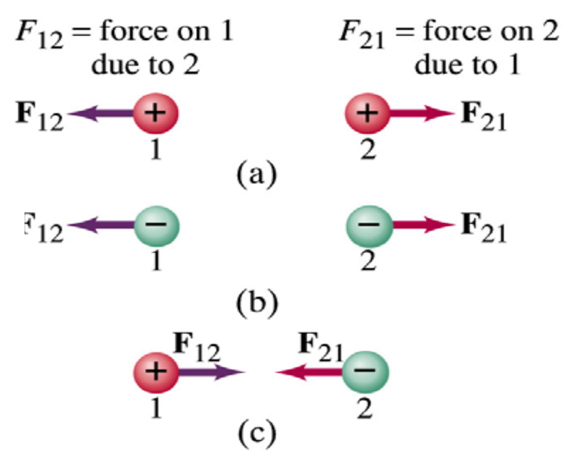
Coulomb's Law

- Charges exert force to each other. What factors affect the magnitude of this force?
  - Any guesses?
- Charles Coulomb figured this out in 1780's.
- Coulomb found that the electrical force is
  - Proportional to the multiplication of the two charges
    - If one of the charges doubles the force doubles.
    - If both the charges double, the force quadruples.
  - Inversely proportional to the square of the distances between them.
  - Electric charge is a fundamental property of matter, just like mass.
- How would you put the above into a formula?

Coulomb's Law – The Formula

$$F \propto \frac{Q_1 \times Q_2}{r^2} \quad \xrightarrow{\text{Formula}} \quad F = k\frac{Q_1 Q_2}{r^2}$$

- Is Coulomb force a scalar quantity or a vector quantity? Unit?
  - A vector quantity. Newtons
- Direction of electric (Coulomb) force is always along the line joining the two objects.
  - If the two charges are the same: forces are directed away from each other.
  - If the two charges are opposite: forces are directed toward to each other.
- Coulomb force is precise to 1 part in 10^{16}.
- Unit of charge is called Coulomb, C, in SI.
- The value of the proportionality constant, k, in SI unit is $k = 8.988 \times 10^9 \ \mathrm{N \cdot m^2}/C^2$
- Thus, 1C is the charge that gives F~9x10^{9}N of force when placed 1m apart from each other.



Electric Force and Gravitational Force

$$F = k\frac{Q_1 Q_2}{r^2} \Longleftrightarrow F = G\frac{M_1 M_2}{r^2}$$

Extremely Similar

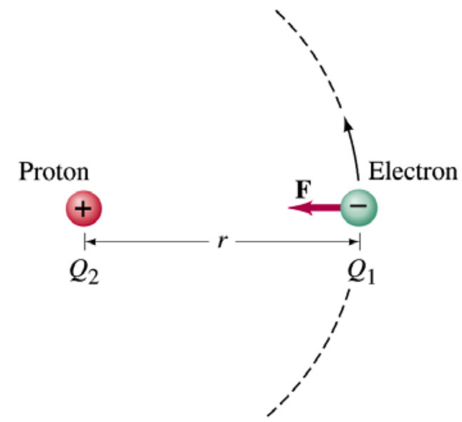
- Does the electric force look similar to another force? What is it?
  - Gravitational Force
- What are the sources of the forces?
  - Electric Force: Charges, fundamental properties of matter
  - Gravitational Force: Masses, fundamental properties of matter
- What else is similar?
  - Inversely proportional to the square of the distance between the sources of the force ➔ What is this kind law called?
    - Inverse Square Law
- What is the difference?
  - Gravitational force is always attractive.
  - Electric force depends on the type of the two charges.

The Elementary Charge and Permittivity

- Elementary charge, the smallest charge, is that of an electron: $e = 1.602 \times 10^{-19} C$
  - Since electron is a negatively charged particle, its charge is $-e$.
- Object cannot gain or lose fraction of an electron.
  - Electric charge is quantized.
    - It changes always in integer multiples of e.
- The proportionality constant k is often written in terms of another constant, ε_0, the permittivity of free space. They are related $k = 1/4\pi\varepsilon_0$ and $\varepsilon_0 = 1/4\pi k = 8.85 \times 10^{-12}\, C^2/N \cdot m^2$.
- Thus the electric force can be written: $F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r^2}$
- Note that this force is for "point" charges at rest.

Example 21 – 1

- **Electric force on electron by proton.** Determine the magnitude of the electric force on the electron of a hydrogen atom exerted by the single proton (Q_2=+e) that is its nucleus. Assume the electron "orbits" the proton at its average distance of r=0.53x10^{-10}m.



Using Coulomb's law $$F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r^2} = k\frac{Q_1Q_2}{r^2}$$

Each charge is $Q_1 = -e = -1.602\times10^{-19}C$ and $Q_2 = +e = 1.602\times10^{-19}C$

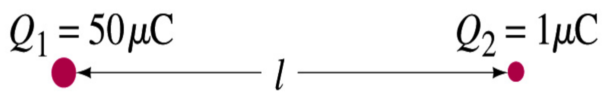
So the magnitude of the force is

$$F = \left|k\frac{Q_1Q_2}{r^2}\right| = 9.0\times10^9\ N\cdot m^2/C^2\frac{\left(1.6\times10^{-19}C\right)\left(1.6\times10^{-19}C\right)}{\left(0.53\times10^{-10}m\right)^2}$$
$$= 8.2\times10^{-8}\,N$$

Which direction? Toward each other…

Example 21 – 2

- **Which charge exerts greater force?** Two positive point charges, Q_1=50μC and Q_2=1μC, are separated by a distance L. Which is larger in magnitude, the force that Q_1 exerts on Q_2 or the force that Q_2 exerts on Q_1?



What is the force that Q_1 exerts on Q_2?

$$F_{12} = k\frac{Q_1 Q_2}{L^2}$$

What is the force that Q_2 exerts on Q_1?

$$F_{21} = k\frac{Q_2 Q_1}{L^2}$$

Therefore the magnitudes of the two forces are identical!!

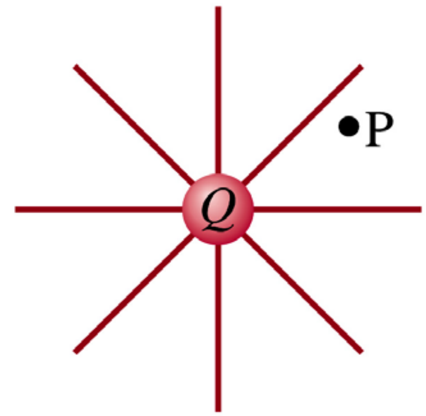
Well then what is different? The direction.

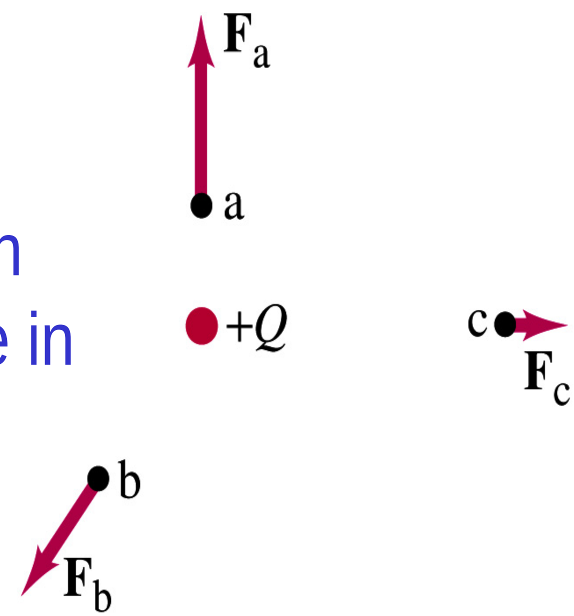
Which direction? Opposite to each other!

What is this law? Newton's third law, the law of action and reaction!!

The Electric Field

- Both gravitational and electric forces act over a distance without touching objects → What kind of forces are these?
  - Field forces
- Michael Faraday developed an idea of field.
  - Faraday argued that the electric field extends outward from every charge and permeates through all of space.
- Field by a charge or a group of charges can be inspected by placing a small test charge in the vicinity and measuring the force on it.





The Electric Field

- The electric field at any point in space is defined as the force exerted on a tiny positive test charge divide by the test charge
  - Electric force per unit charge

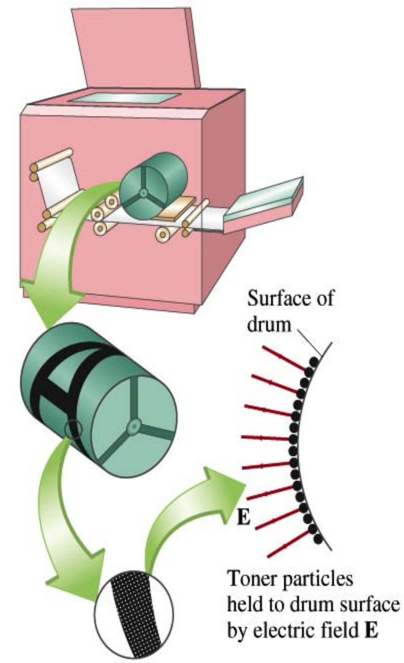
$$\vec{E} = \frac{\vec{F}}{q}$$

- What kind of quantity is the electric field?
  - Vector quantity. Why?
- What is the unit of the electric field?
  - N/C
- The magnitude of the electric field at a distance r from a single point charge Q is

$$E = \frac{F}{q} = \frac{kQq/r^2}{q} = \frac{kQ}{r^2} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$$

Example 21 – 5

- **Electrostatic copier**. An electrostatic copier works by selectively arranging positive charges (in a pattern to be copied) on the surface of a nonconducting drum, then gently sprinkling negatively charged dry toner (ink) onto the drum. The toner particles temporarily stick to the pattern on the drum and are later transferred to paper and "melted" to produce the copy. Suppose each toner particle has a mass of 9.0×10^{-16}kg and carries the average of 20 extra electrons to provide an electric charge. Assuming that the electric force on a toner particle must exceed twice its weight in order to ensure sufficient attraction, compute the required electric field strength near the surface of the drum.



The electric force must be the same as twice the gravitational force on the toner particle.

So we can write $F_e = qE = 2F_g = 2mg$

So the magnitude of the electric field is

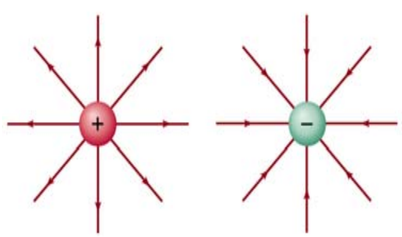
$$E = \frac{2mg}{q} = \frac{2 \cdot \left(9.0 \times 10^{-16} kg\right) \cdot \left(9.8 \, m/s^2\right)}{20\left(1.6 \times 10^{-19} C\right)} = 5.5 \times 10^3 \, N/C.$$

Direction of the Electric Field

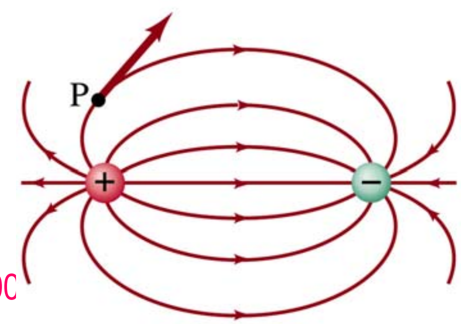
- If there are more than one charge, the individual fields due to each charge are added vectorially to obtain the total field at any point. $$\vec{E}_{Tot} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \vec{E}_4 + ...$$
- This superposition principle of electric field has been verified by experiments.
- If given the electric field E at a given point in space, we can calculate the force F on any charge q, F=qE.
  - What happens to the direction of the force and the field depending on the sign of the charge q?
  - The two are in the same directions if q>0
  - The two are in opposite directions if q<0

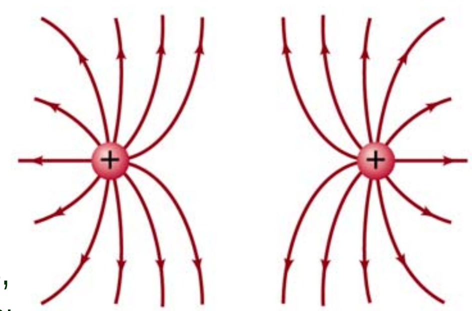
Field Lines

- The electric field is a vector quantity. Thus, its magnitude can be expressed in the length of the vector and the arrowhead pointing to the direction.
- Since the field permeates through the entire space, drawing vector arrows is not a good way of expressing the field.
- Electric field lines are drawn to indicate the direction of the force due to the given field on a positive test charge.
  - Number of lines crossing unit area perpendicular to E is proportional to the magnitude of the electric field.
  - The closer the lines are together, the stronger the electric field in that region.
  - Start on positive charges and end on negative charges.



(a) (b)

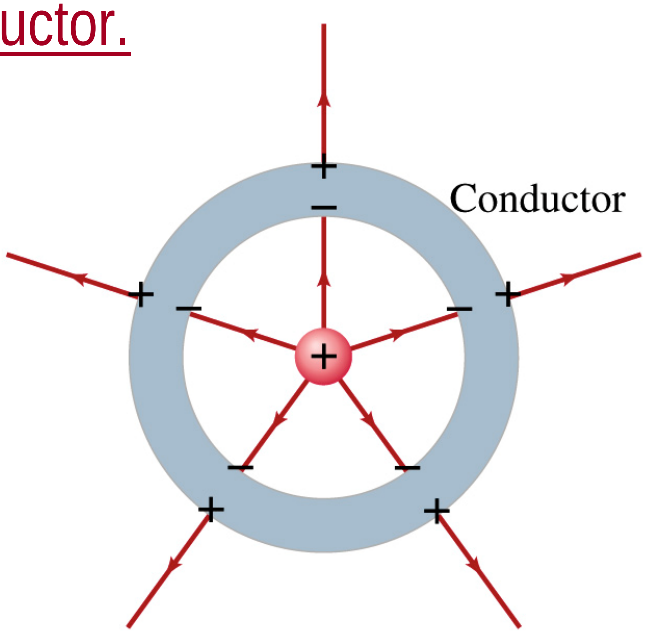




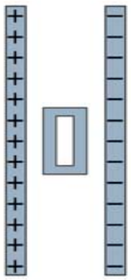
Earth's G-field lines

Electric Fields and Conductors

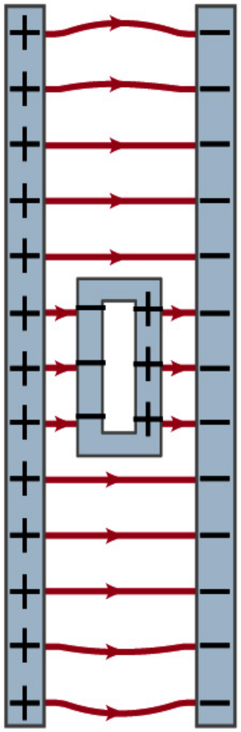
- The electric field in a conductor is ZERO in the static situation. (If the charge is at rest.) Why?
  - If there were an electric field within a conductor, there would be force on its free electrons.
  - The electrons will move until they reached positions where the electric field become zero.
  - Electric field can exist inside a non-conductor.
- Consequences of the above
  - Any net charge on a conductor distributes itself on the surface.
  - Although no field exists inside a conductor, the fields can exist outside the conductor due to induced charges on either surface
  - The electric field is always perpendicular to the surface outside of a conductor.



Example 21-13



- **Shielding, and safety in a storm.** A hollow metal box is placed between two parallel charged plates. What is the field like in the box?
- If the metal box were solid
  - The free electrons in the box would redistribute themselves along the surface so that the field lines would not penetrate into the meta.



- The free electrons do the same in hollow metal boxes just as well as it did in a solid metal box.
- Thus a conducting box is an effective device for shielding. ➔ Faraday cage
- So what do you think will happen if you were inside a car when the car was struck by a lightening?