PHYS 1441 – Section 001
Lecture #3

Wednesday, June 10, 2020

Dr. Jaehoon Yu

- Chapter 21
  - The Electric Field & Field Lines
  - Electric Fields and Conductors
  - Motion of a Charged Particle in an Electric Field
  - Electric Dipoles
- Chapter 22
  - Electric Flux

Today's homework is homework #2, due 11pm, Monday, June15!!

Announcements

- 44/48 of you have registered in the homework system.
  - 35/44 submitted the homework!
  - You MUST submit your answer to obtain 100% credit!
- Virtual Physics Clinic: (M: 9am – 1pm, TuWTh: 9am – 5pm) https://teams.microsoft.com/l/channel/19%3ae5b118c00e8d4baa8c0b2b4be09bbcd5%40thread.tacv2/General?groupId=a272a438-e2fd-42e7-8c18-1a8166647940&tenantId=5cdc5b43-d7be-4caa-8173-729e3b0a62d9
- Term Exam 1
  - In class, coming Monday, June 15: DO NOT MISS THE EXAM!
  - CH21.1 to what we learn on tomorrow, Thursday, June 11 + Appendices A1 – A8
  - BYOF: You may bring a one 8.5x11.5 sheet (front and back) of **handwritten** formulae and values of constants for the exam
  - No derivations, word definitions or setups or solutions of any problems!
  - No additional formulae or values of constants will be provided!
  - Must send me the photos of front and back of the formula sheet, including the blank, no later than 10am Monday morning
    - Once submitted, you cannot change, unless I ask you to delete some part of the sheet!

Reminder: Extra Credit Special Project #1

- Compare the Coulomb force to the Gravitational force in the following cases by expressing Coulomb force (F_C) in terms of the gravitational force (F_G)
  - Between the two protons separated by 1m
  - Between the two protons separated by an arbitrary distance R
  - Between the two electrons separated by 1m
  - Between the two electrons separated by an arbitrary distance R
- Five points each, totaling 20 points
- BE SURE to show all the details of your own work, including all formulae, proper references to them and explanations
- Must be handwritten and submit all pages in a single PDF file
  - File name must be: SP1-First-Last-summer20.pdf
- Due at the beginning of the class Monday, June 15

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. The unit is Newtons (N)!
- The direction of electric (Coulomb) force is always along the straight line joining the two objects.
  - If the two charges are the same: forces are directed away from each other.
  - If the two charges are the opposite: forces are directed toward 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 **$F \sim 9\times10^9$N** of force when placed 1m apart from each other.

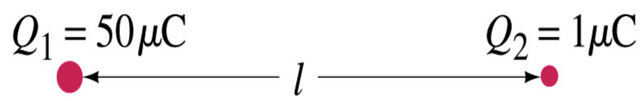
The Elementary Charge and Permittivity

- The elementary charge, the smallest unit 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.
    - Charge of an object changes always in an integer multiples of e.
    - What kind of quantity is the electric charge? **Scalar!!**
- 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 also be written as: $F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r^2}$
- Note that this force is for "point" charges at rest.

***Mirriam-Webster, Permittivity: The ability of a material to store electric potential energy under the influence of an electric field**

Example 21 – 1

- **Which charge exerts a 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!!

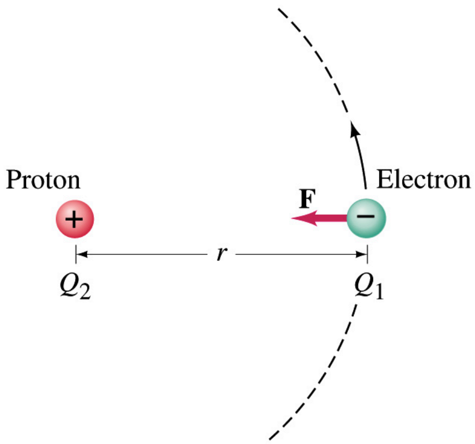
Well then what is different? The direction.

Which direction? Opposite to each other!

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

Example on the Coulomb Force

- **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. What is the orbital speed of the electron (m_e=9.12x10^{-31}kg)?



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 $Q_2 = +e = 1.602\times10^{-19}C$

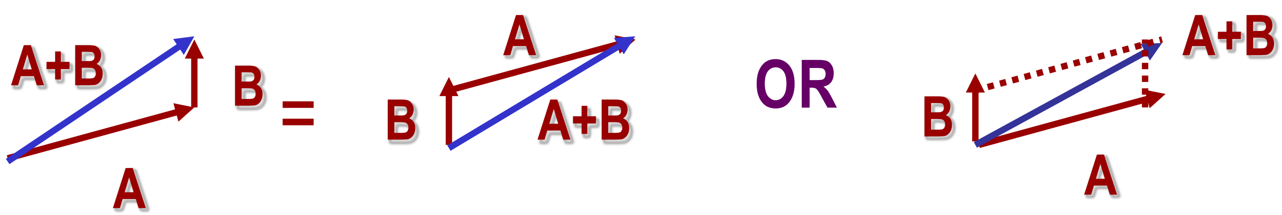
So the magnitude of the force is

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

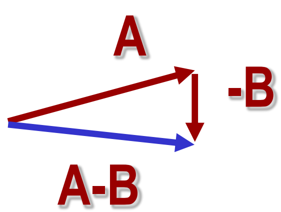
Which direction? Toward each other… Orbital speed of the election?

Vector Additions and Subtractions

- Addition:
  - Triangular Method: One can add vectors by connecting the head of one vector to the tail of the other (head-to-tail)
  - Parallelogram method: Connect the tails of the two vectors and extend
  - Addition is commutative: Changing order of operation does not affect the results **A+B=B+A**, **A+B+C+D+E=E+C+A+B+D**



- Subtraction:
  - The same as adding a negative vector: **A** - **B** = **A** + (-**B**)



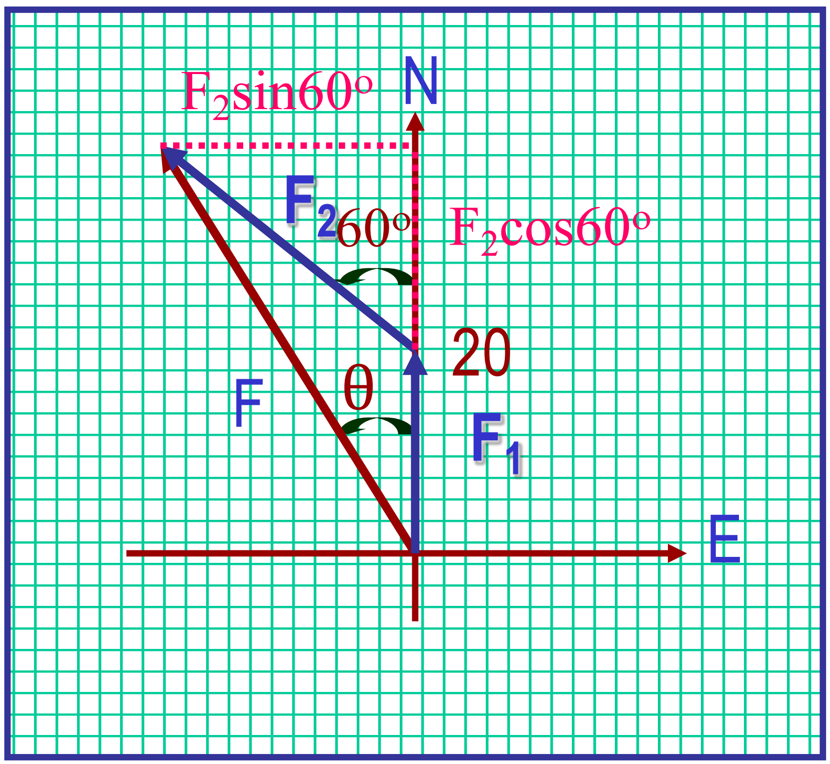
Since subtraction is equivalent to adding a negative vector, subtraction is also commutative!!!

- Multiplication by a scalar is increasing the magnitude **A**, **B**=2**A**

$$|\mathcal{B}| = 2|\mathcal{A}|$$

Example for Vector Addition

A force of 20.0N applies to north while another force of 35.0N applies in the direction 60.0° west of north. Find the magnitude and direction of resultant force.



$$F = \sqrt{\left(F_1 + F_2\cos 60^\circ\right)^2 + \left(F_2\sin 60^\circ\right)^2}$$

$$= \sqrt{F_1^2 + F_2^2\left(\cos^2 60^\circ + \sin^2 60^\circ\right) + 2F_1F_2\cos 60^\circ}$$

$$= \sqrt{F_1^2 + F_2^2 + 2F_1F_2\cos 60^\circ}$$

$$= \sqrt{(20.0)^2 + (35.0)^2 + 2\times 20.0\times 35.0\cos 60}$$

$$= \sqrt{2325} = 48.2(N)$$

$$\theta = \tan^{-1}\frac{\left|\vec{F}_2\right|\sin 60^\circ}{\left|\vec{F}_1\right| + \left|\vec{F}_2\right|\cos 60^\circ}$$

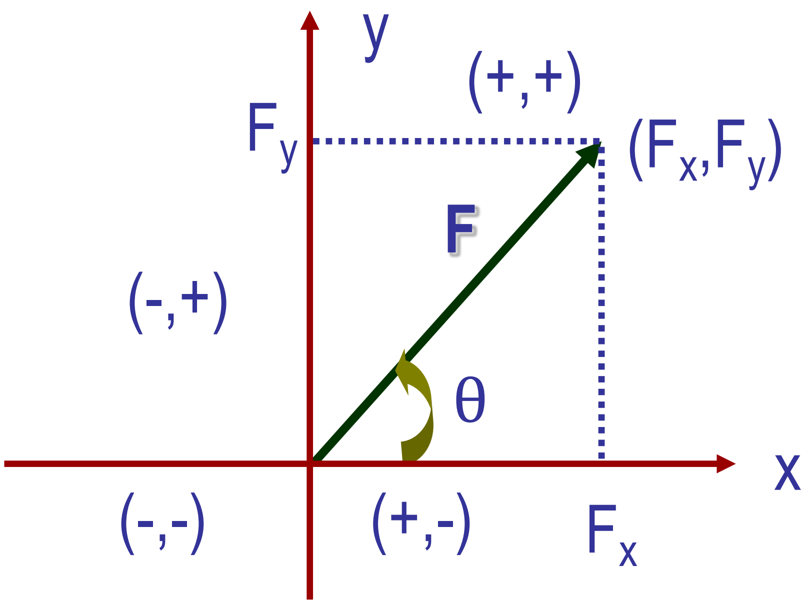
$$= \tan^{-1}\frac{35.0\sin 60}{20.0 + 35.0\cos 60}$$

$$= \tan^{-1}\frac{30.3}{37.5} = 38.9^\circ \text{ to W wrt N}$$

Find other ways to solve this problem…

Components and Unit Vectors

Coordinate systems are useful in expressing vectors in their components



$$F_x = \left|\vec{F}\right| \cos\theta$$

$$F_y = \left|\vec{F}\right| \sin\theta$$

} Components

$$\left|\vec{F}\right| = \sqrt{F_x^2 + F_y^2}$$

} Magnitude

$$\left|\vec{F}\right| = \sqrt{\left(\left|\vec{F}\right|\cos\theta\right)^2 + \left(\left|\vec{F}\right|\sin\theta\right)^2}$$

$$= \sqrt{\left|\vec{F}\right|^2 \left(\cos^2\theta + \sin^2\theta\right)} \quad = \left|\vec{F}\right|$$

Unit Vectors

- A unit vector is the vector that indicates only the directions of the components
- <u>**Dimensionless**</u>
- <u>**Magnitudes are exactly 1**</u>
- Unit vectors are usually expressed in **i, j, k** or $\vec{i}, \vec{j}, \vec{k}$ (←preferred method in this class!)

So the vector **F** can be re-written as

$$\vec{F} = F_x \vec{i} + F_y \vec{j} = \left|\vec{F}\right| \cos\theta \vec{i} + \left|\vec{F}\right| \sin\theta \vec{j}$$

Examples of Vector Operations

Find the resultant force which is the sum of **F1**=(2.0**i**+2.0**j**)N and **F2** =(2.0**i**-4.0**j**)N.

$$\vec{F}_3 = \vec{F}_1 + \vec{F}_2 = \left(2.0\vec{i} + 2.0\vec{j}\right) + \left(2.0\vec{i} - 4.0\vec{j}\right)$$
$$= \left(2.0+2.0\right)\vec{i} + \left(2.0-4.0\right)\vec{j} = 4.0\vec{i} - 2.0\vec{j}\left(N\right)$$

$$\left|\vec{F}_3\right| = \sqrt{\left(4.0\right)^2 + \left(-2.0\right)^2}$$
$$= \sqrt{16+4.0} = \sqrt{20} = 4.5(N)$$

$$\theta = \tan^{-1}\frac{F_{3y}}{F_{3x}} = \tan^{-1}\frac{-2.0}{4.0} = -27^\circ$$

Find the resultant force of the sum of three forces: $\mathbf{F_1}$=(15**i**+30**j** +12**k**)N, $\mathbf{F_2}$=(23**i**+14**j** -5.0**k**)N, and $\mathbf{F_3}$=(-13**i**+15**j**)N.

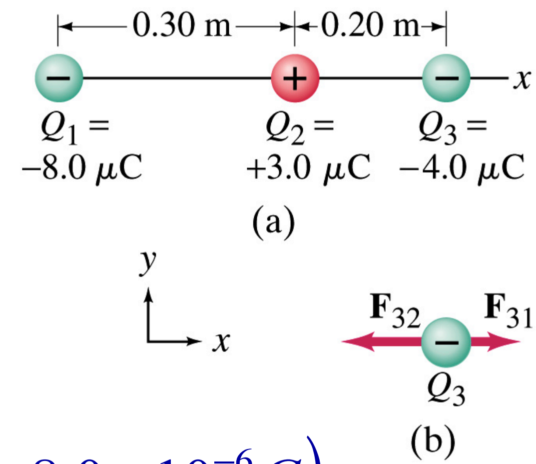
$$\vec{F} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 = \left(15\vec{i} + 30\vec{j} + 12\vec{k}\right) + \left(23\vec{i} + 14\vec{j} - 5.0\vec{k}\right) + \left(-13\vec{i} + 15\vec{j}\right)$$
$$= \left(15+23-13\right)\vec{i} + \left(30+14+15\right)\vec{j} + \left(12-5.0\right)\vec{k} = 25\vec{i} + 59\vec{j} + 7.0\vec{k}(N)$$

Magnitude

$$\left|\vec{D}\right| = \sqrt{\left(25\right)^2 + \left(59\right)^2 + \left(7.0\right)^2} = 65(N)$$

Example 21.2

- **Three charges on a line.** Three charged particles are arranged in a line as shown in the figure. Calculate the net electrostatic force on particle 3 (the -4μC on the right) due to other two charges.



What is the force that Q_1 exerts on Q_3?

$$F_{13x} = k\frac{Q_1 Q_3}{L^2} = \frac{\left(9.0\times10^9\ N\cdot m^2/C^2\right)\left(-4.0\times10^{-6}C\right)\left(-8.0\times10^{-6}C\right)}{\left(0.5m\right)^2} = 1.2N$$

What is the force that Q_2 exerts on Q_3?

$$F_{23x} = k\frac{Q_2 Q_3}{L^2} = \frac{\left(9.0\times10^9\ N\cdot m^2/C^2\right)\left(-4.0\times10^{-6}C\right)\left(3.0\times10^{-6}C\right)}{\left(0.2m\right)^2} = -2.7N$$

Using the vector sum of the two forces

$$F_x = F_{13x} + F_{23x} = 1.2 + \left(-2.7\right) = -1.5\left(N\right) \qquad F_y = 0\left(N\right)$$

$$\vec{F} = -1.5\vec{i}\ (N)$$