PHYS 1441 – Section 002
Lecture #4

Wednesday, Sept. 9, 2020

Dr. Jaehoon Yu

- CH21
  - Coulomb's Law
  - Vector Refresh
  - The Electric Field & Field Lines
  - Electric Fields and Conductors

Today's homework is homework #3, due 11pm, Friday, Sept. 18!!

Announcements

- Virtual physics clinic on MS Teams
  - Monday: 9am-2:30; 4pm-5pm
  - Tuesday: 9am-5pm
  - Wednesday: 9am-1pm; 4pm-5pm
  - Thursday: 9am-3:30pm; 4:30-5pm
  - Friday: 9am-5pm
  - Direct link: https://teams.microsoft.com/l/channel/19%3ae5b118c00e8d4baa8c0b2b4be09bbcd5%40thread.tacv2/General?groupId=a272a438-e2fd-42e7-8c18-1a8166647940&tenantId=5cdc5b43-d7be-4caa-8173-729e3b0a62d9
- 1st term exam in class Wed., Sept. 23 ➔ Mark your calendar
  - Will cover CH21.1 through what we learn on Mon. Sept. 21 + A1 – A9
  - BYOF
- Special project submission changed to CANVAS uploads
- Quiz 1 results
  - Class average: 56.7/70
    - Equivalent to 81/100
  - Stop score: 70/70

SP#2 – Angels & Demons

- Compute the total possible energy released from an annihilation of x-grams of anti-matter and the same quantity of matter, where x is the last two digits of your SS# or DL#. (20 points)
  - Use the famous Einstein's formula for mass-energy equivalence
- Compute the power output of this annihilation when the energy is released in x ns, where x is again the first two digits of your SS# or DL#. (10 points)
- Compute how many cups of gasoline (8MJ) this energy corresponds to. (5 points)
- Compute how many months of world electricity usage (3.6GJ/mo) this energy corresponds to. (5 points)
- Due by the beginning of the class, 1pm, Wednesday, Sept. 23
  - Must be **HANDWRITTEN**
  - All pages must be in one PDF file with the name SP2-LastName-FirstName-fall20.pdf uploaded to CANVAS.

SP#3 – Civic Duty I: Voter Registration

- Voter registration in Texas ends on Monday, Oct. 5, 2020
  - Registration can be done: https://www.votetexas.gov/register/index.html
  - Check your registration: https://teamrv-mvp.sos.texas.gov/MVP/mvp.do
- For those who are legal to take part in the election
  - Your own registration to vote: 10 points
    - Include the screen shot your own voter registration check
  - You can have up to 3 more people who are not registered to register: 5 points each
    - Must include before and after the registration screen shots of the same person next to each other to show these are newly registered
- For those who are not legal to take part in the election
  - You can have up to 5 people who are not registered to register: 5 points each
    - Must include before and after the registration screen shots of the same person next to each other to show these are newly registered
- Deadline: 1pm Wednesday, Oct. 7, 2020
- Put all screen shots in one pdf file following the naming convention – SP3-LastName-FirstName-Fall20.pdf and upload to the CANVAS assignment

SP#3 – Civic Duty I: Voter Registration – 2

Voter Information

Name: JAEHOON YU
[redacted]
Gender: MALE
Valid From: 01/01/2020
Effective Date of Registration: 05/20/2004
Voter Status: ACTIVE
County: TARRANT
Precinct: 2266
VUID: 1050748339

Change your Address

Upcoming Elections (Select Election for available polling information)

11/03/2020--2020 NOVEMBER 3RD GENERAL ELECTION

***Eligibility is determined by Effective Date of Registration (Must be on or before Election Day)

Coulomb's Law – The Formula

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

- Is Coulomb force a scalar quantity or a vector quantity? Unit? (polls 1&2)
  - A vector quantity. The unit is Newtons (N)!
- The direction of electric (Coulomb) force is always along the straight line joining the two objects. (poll 7)
  - 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 the 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

$$F = k\frac{Q_1 Q_2}{r^2} \quad \text{Extremely Similar} \quad F = G\frac{M_1 M_2}{r^2}$$

- Does the electric force look similar to another force? What is it? (poll 4)
  - **Gravitational Force**
- What are the sources of the forces?
  - Electric Force: Electric 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? (poll 6)
  - Gravitational force is always attractive.
  - Electric force depends on the signs of the two charges. (must pay good attention to the signs due to the sign of the charge and the vector force directions!!)

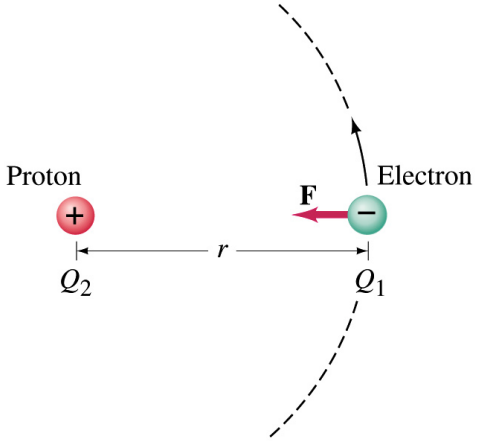
The Elementary Charge and Permittivity

- 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? (poll 2) **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 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 $$F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r^2} = k\frac{Q_1 Q_2}{r^2}$$

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

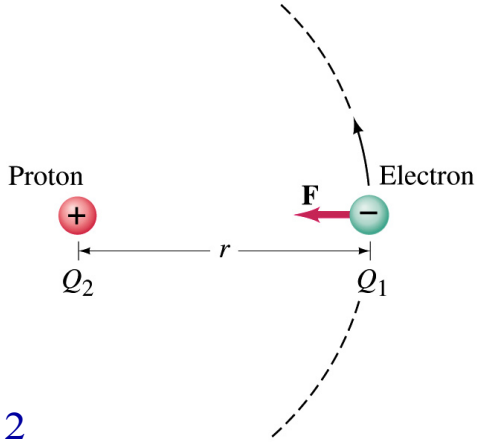
So the magnitude of the force is

$$F = \left|k\frac{Q_1 Q_2}{r^2}\right| = 9.0\times10^{9}\ N\cdot m^2/C^2\ \frac{\left(1.6\times10^{-19}\,C\right)\left(1.6\times10^{-19}\,C\right)}{\left(0.53\times10^{-10}\,m\right)^2}$$
$$= 8.2\times10^{-8}\,N$$

Which direction? (poll 7) Toward each other… What is the orbital speed of the election?

Example on the Coulomb Force, cnt'd

- **Orbital Speed of the electron in a hydrogen atom?**
  Assume the electron "orbits" the proton at its average distance of $r=0.53\times10^{-10}$m. What is the orbital speed of the electron ($m_e=9.12\times10^{-31}$kg)?



Coulomb force acts as the centripetal force!!

$$F=\frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r^2}=k\frac{Q_1Q_2}{r^2} \qquad F_c=m\frac{v^2}{r}=m_e\frac{v_e^2}{r_H}$$

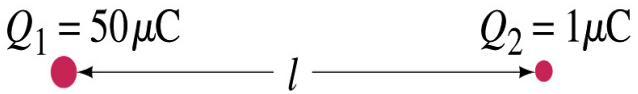
So the set up is $F_C=F_c \Rightarrow \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r_H^2}=m_e\frac{v_e^2}{r_H}$

Solve the equation for v_e

$$v_e=\sqrt{\frac{1}{4\pi\varepsilon_0}\frac{e^2}{m_e r_H}}=e\sqrt{\frac{1}{4\pi\varepsilon_0}\frac{1}{m_e r_H}}=2.18\times10^6\left(m/s\right)=7.3\times10^3 c$$

Example 21 – 1

- **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!!

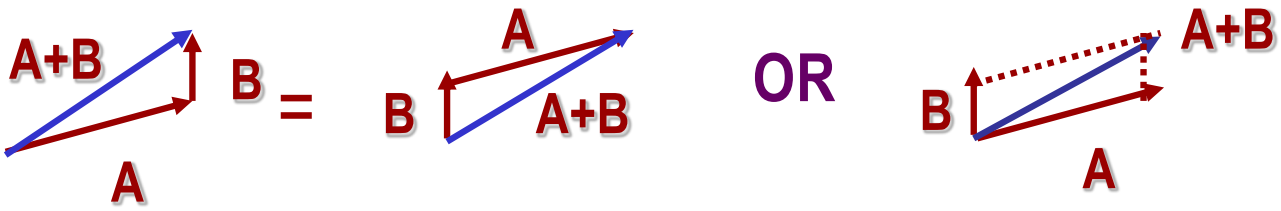
Well then what is different? The direction.

Which direction? Opposite to each other!

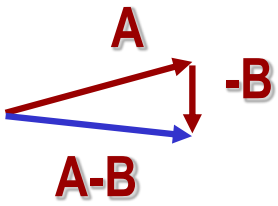
What is this law? Newton's third law, the law of action and reaction!!

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**)



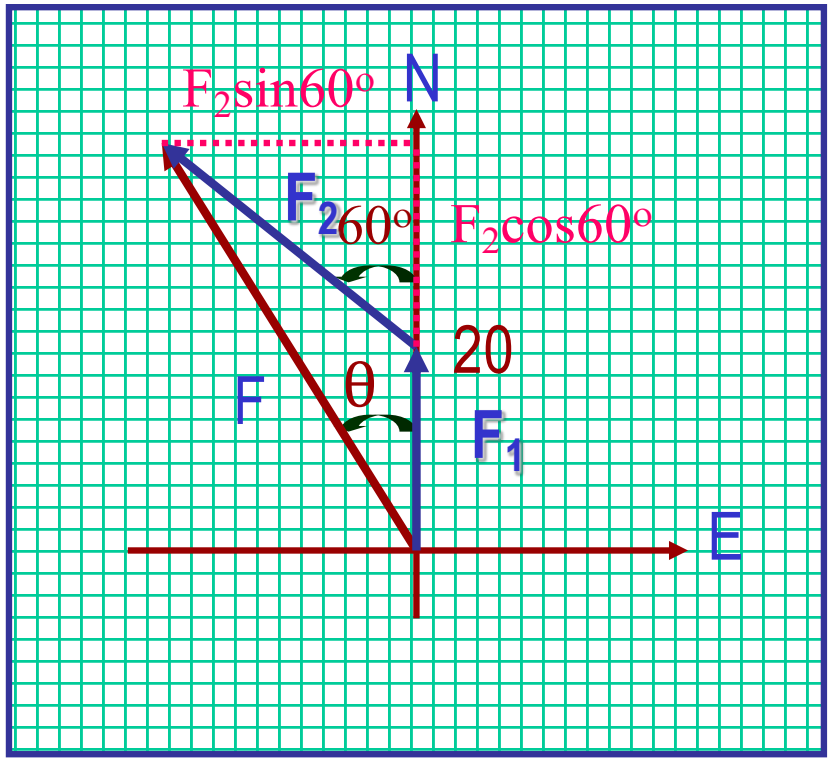
Since subtraction is equivalent to adding a negative vector, subtraction is also commutative!!!

- 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 60.0º West of North. Find the magnitude and direction of resultant force.



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

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

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

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

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

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

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

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

Find other ways to solve this problem…