PHYS 1441 – Section 002
Lecture #5

Monday, Sept. 14, 2020
Dr. Jaehoon Yu

- CH21
  - Vector component refresh
  - The Electric Field
  - The Directions of The Electric Field and the Electric Force
  - Electric Fields and Conductors
  - Motion of a Charged Particle in an Electric Field

Announcements

- 1st term exam in class Wed., Sept. 23
  - DO NOT MISS THE EXAM! You will get an F!
  - Come to class by 12:40pm, roll call will start at that time
  - CH21.1 to what we've learned on next Monday, Sept. 21 + Appendices A1 – A9, the math refresher
  - 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, figures, pictures, setups or solutions of any problems!
  - No additional formulae or values of constants will be provided!
  - Must send me the photos of both front & back of the formula sheet, including the blank, in a single file by 11:00am, Sept. 23
    - File name must be FS-E1-LastName-FirstName-fall20.pdf
  - Once submitted, no changes allowed

Reminder: 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.

Reminder: 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

Texas Secretary of State

AM I REGISTERED?

TEXAS ELECTIONET ADMINISTRATION SYSTEM

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

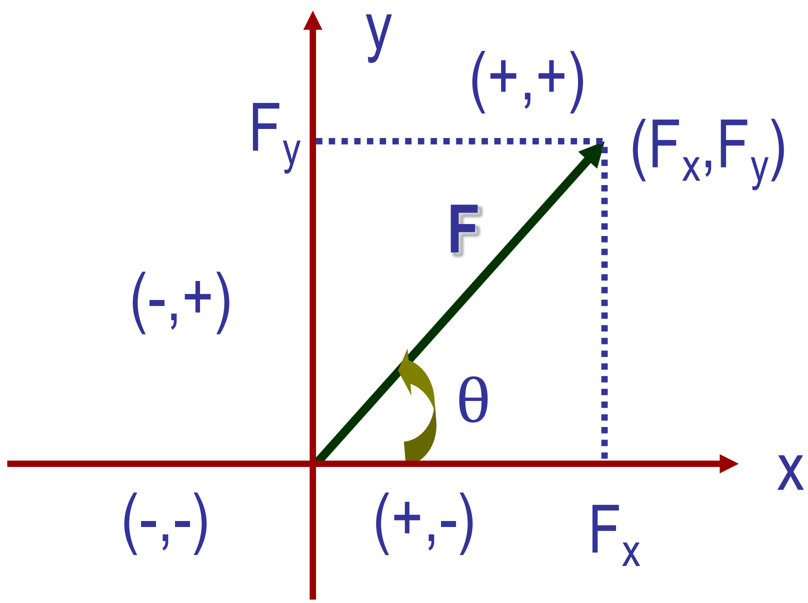
Upcoming Elections (Select Election for available polling information)

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

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

Components and Unit Vectors

Coordinate systems are useful in expressing vectors in their components



$$\left.\begin{array}{l} \boxed{F_x = \left|\vec{F}\right| \cos\theta} \\ \boxed{F_y = \left|\vec{F}\right| \sin\theta} \end{array}\right\} \text{Components}$$

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

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

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

Unit Vectors

- A unit vector is the vector that indicates only the directions of the components
- **Dimensionless**
- **Magnitudes are exactly 1**
- 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 $$\left|\vec{D}\right| = \sqrt{\left(25\right)^2 + \left(59\right)^2 + \left(7.0\right)^2} = 65(N)$$

Coulomb Force, The Formula

$$F = k\frac{Q_1 Q_2}{r^2}$$

$$k = 8.988\times10^{9}\ \mathrm{N\cdot m^2}/C^2$$

$$k = 1/4\pi\varepsilon_0$$

$$\varepsilon_0 = 1/4\pi k = 8.85\times10^{-12}\ C^2/N\cdot m^2$$

$$e = 1.602\times10^{-19}\ C$$ **Unit charge**

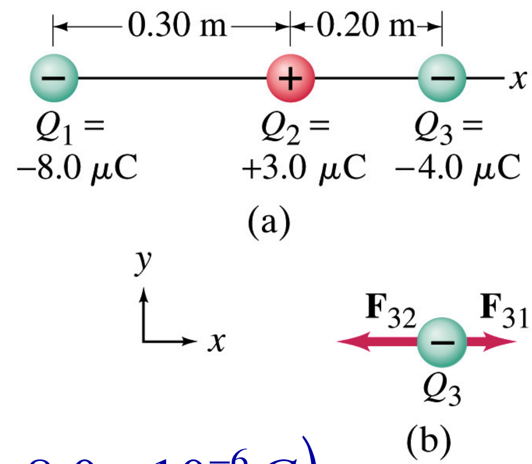
How to solve electric F problems?

Typical problem: Find out the net force on a subject charge at the given position by some source charges

1. Compute the magnitude of the force by each source charge on the subject charge at the given position using Coulomb force formula
2. Compute the components of the force by the pair of the charges, taking into account the signs of the two charges – subject and source
3. Repeat 1 and 2 for all pairs of each of the source charges to the subject charge
4. Add all values on each component – x, y and z, etc
5. Express F vector using the component and the unit vector

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?

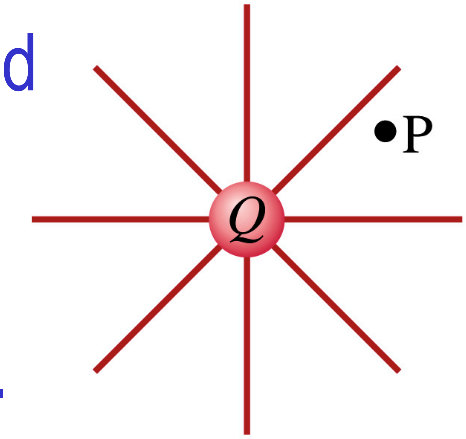
$$F_{23x} = k\frac{Q_2 Q_3}{L^2} = \frac{\left(9.0\times10^9\ N\cdot m^2/C^2\right)\left(-4.0\times10^{-6}C\right)\left(3.0\times10^{-6}C\right)}{\left(0.2m\right)^2} = -2.7N$$

Using the vector sum of the two forces

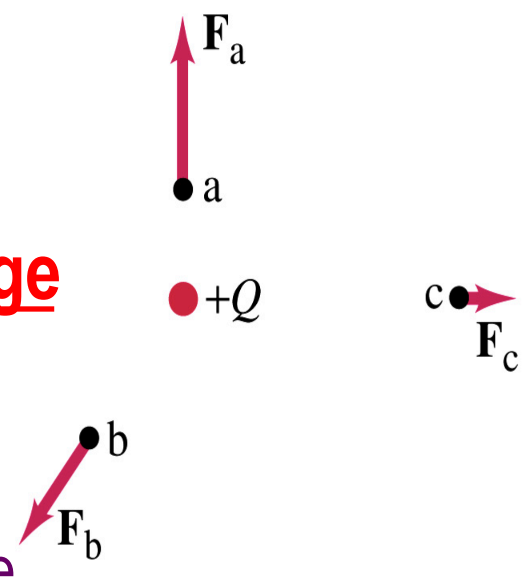
$$F_x = F_{13x} + F_{23x} = 1.2 + \left(-2.7\right) = -1.5\left(N\right) \qquad F_y = 0\left(N\right)$$

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

The Electric Field

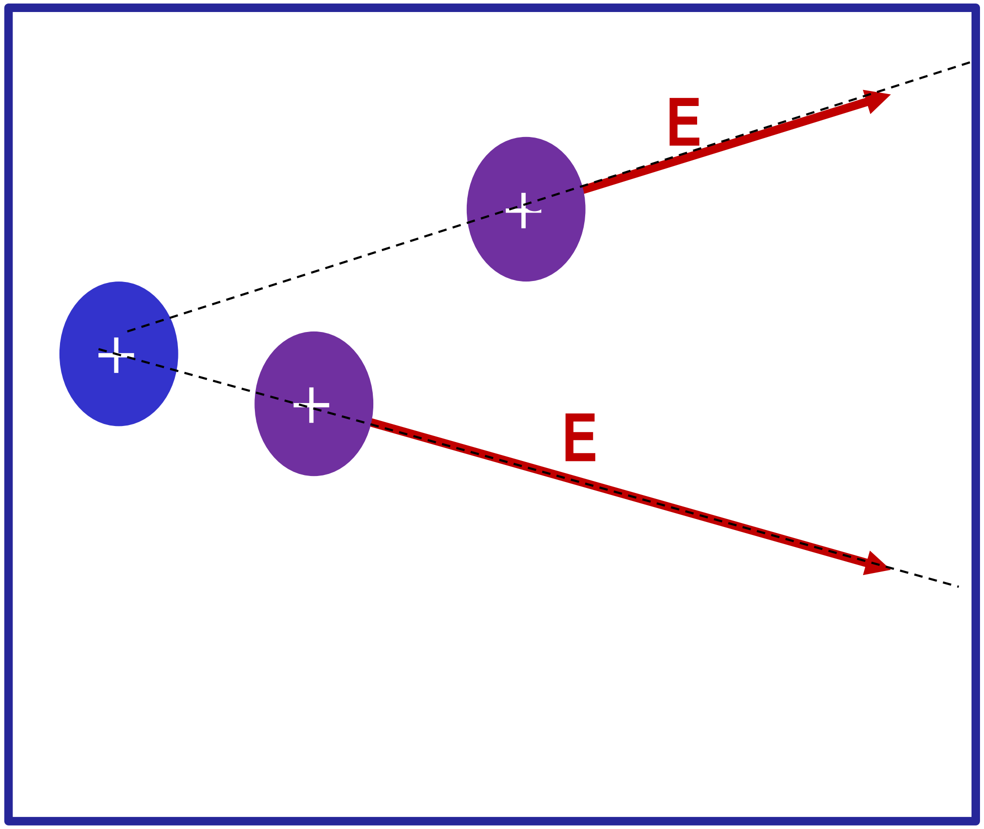


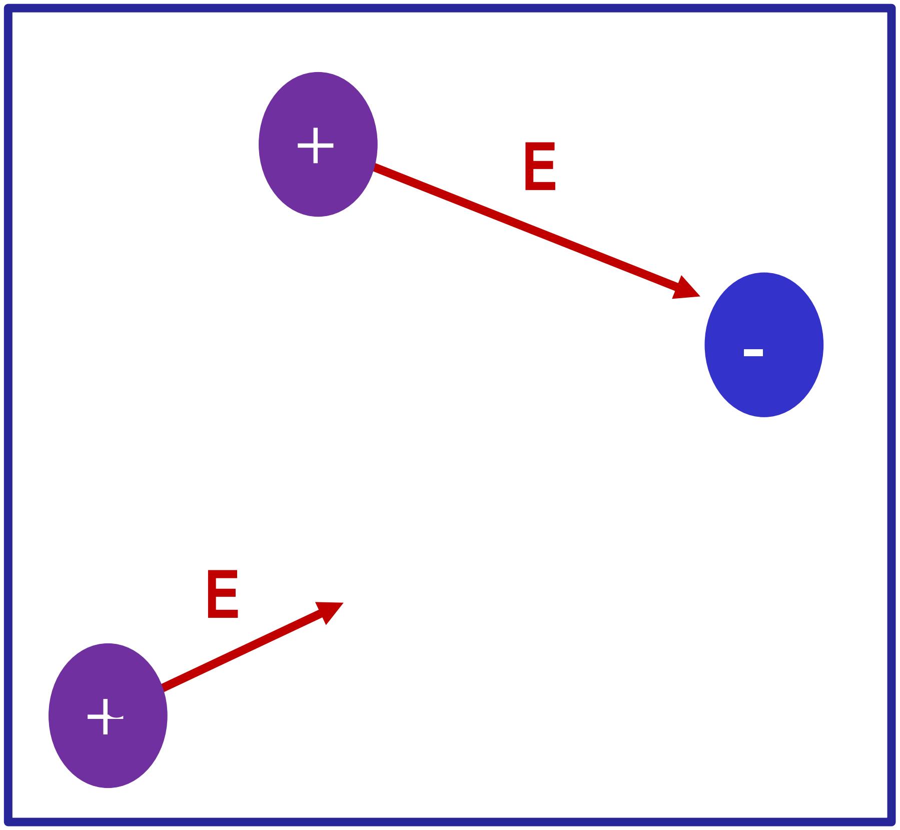
- Both gravitational and electric forces act over distance without contacting objects ➔ What kind of forces are these?
  - Field forces
- Michael Faraday developed the idea of the field.
  - Faraday (1791 – 1867) argued that the electric field extends outward/inward from every charge and permeates through all of space



- Field by a charge or a group of charges can be inspected by placing a small **positive test charge** in the vicinity and measuring the force on it.
  - You imagine what would happen to the test charge!
  - E due to a charge is independent of the other charge

What are the directions of the field?





Direction of the field depends only on the sign of the source charge

The Electric Field

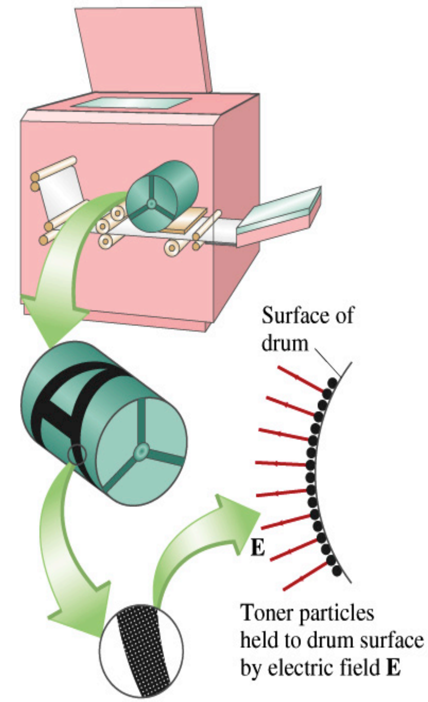
- The electric field at any point in space is defined as the force exerted on a tiny positive test charge divide by magnitude of the test charge
  - Electric force per unit charge

$$\vec{E} = \frac{\vec{F}}{q} \quad \text{or } \vec{F} = q\vec{E}$$

- What kind of quantity is the electric field? (poll 2)
  - Vector quantity. Why?
- What is the unit of the electric field? (poll 3)
  - N/C
- What is the magnitude of the electric field at a distance r from a single point charge Q (source)?

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

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 non-conducting 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 $9.0\text{x}10^{-16}$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 $F_e = qE = 2F_g = 2mg$

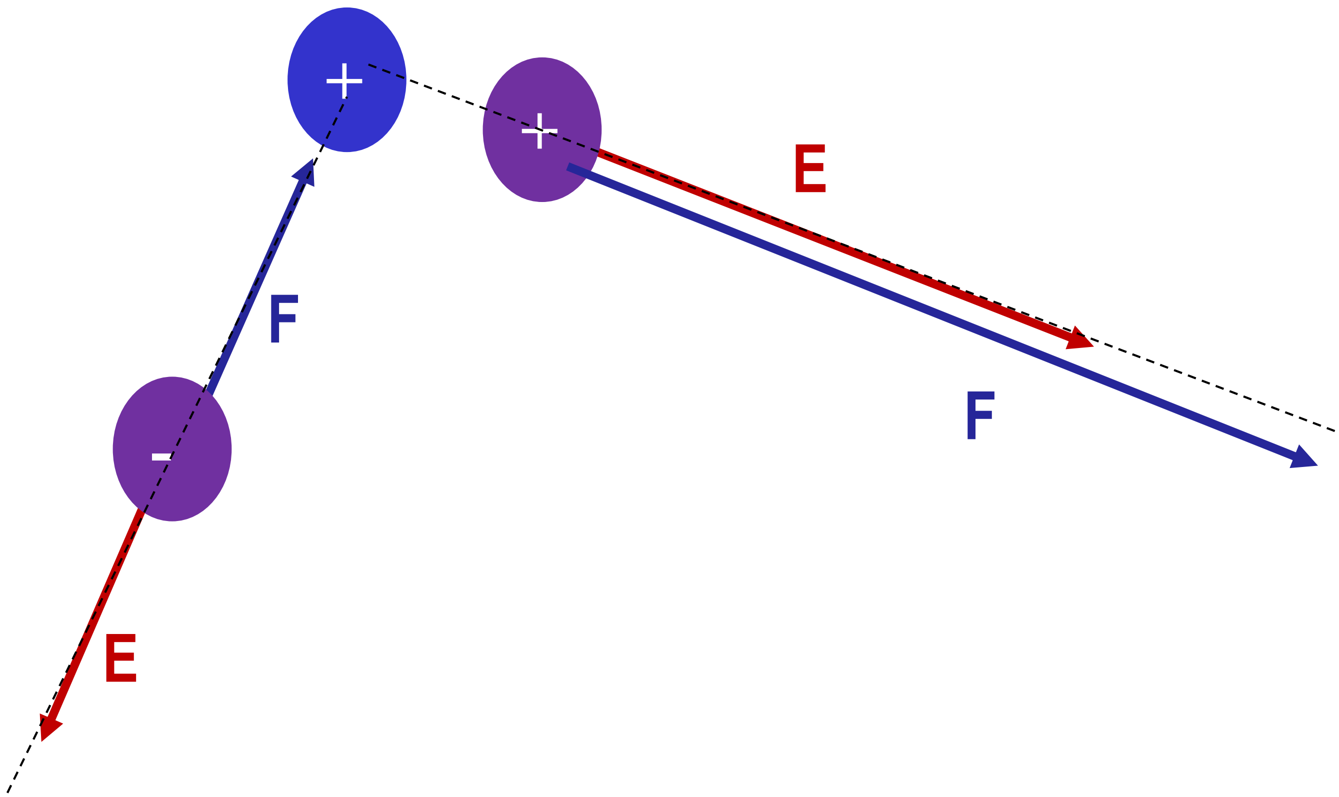
Thus, the magnitude of the electric field is

$$E = \frac{2mg}{q} = \frac{2\cdot\left(9.0\times10^{-16}\,kg\right)\cdot\left(9.8\,m/s^2\right)}{20\left(1.6\times10^{-19}\,C\right)} = 5.5\times10^{3}\,N/C.$$

Direction of the Electric Field

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

What are the directions of the field vs F?



Direction of the field depends only on the sign of the source charge

Direction of the force depends on both the signs of the source and subject charge

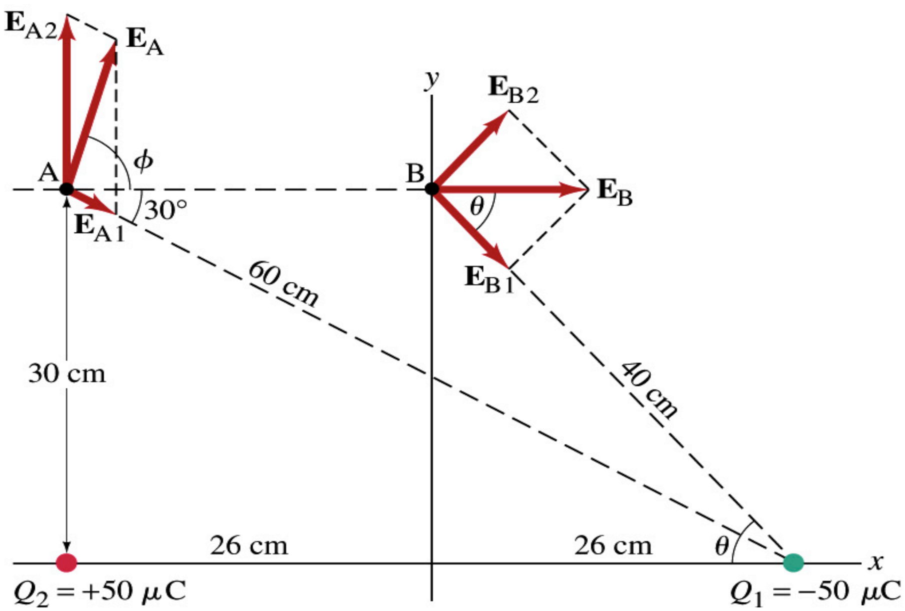
How to solve electric F and E problems?

Typical problem: Find out the field by some charges at the given position and the net force on a charge at the position by these charges.

1. Compute the magnitude of the field by each charge at the position
2. Compute the components of the field by the charge, taking into account the sign of the charge
3. Repeat 1 and 2 for all charges that affects the field at the position
4. Add all values on each component – x, y and z, etc
5. Express E field vector using the component and the unit vector
6. The net electric force on a subject charge q at the position is then simply using the formula $\vec{F} = q\vec{E}$, taking into account the sign of the subject charge for the direction

Example 21 – 8

- **E above two point charges**: Calculate the total electric field (a) at point A and (b) at point B in the figure on the right due to both the charges Q_1 and Q_2.



How do we solve this problem?

First, compute the magnitude of fields at each point due to each of the two charges.

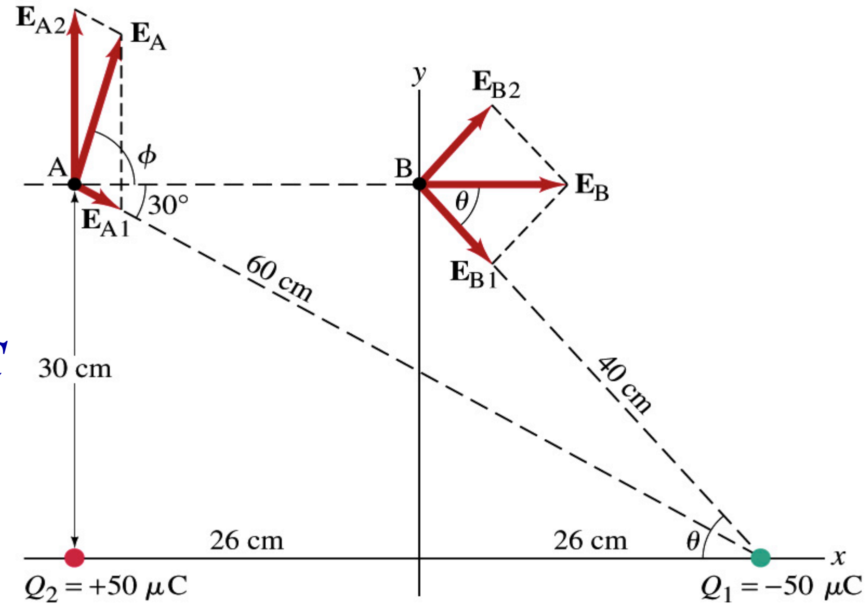
Then add them at each point vectorially!

First, the electric field at point A by Q_1 and then Q_2.

$$\left|E_{A1}\right| = k\frac{Q_1}{r_{A1}^2} = \frac{\left(9.0\times10^9\ N\cdot m^2/C^2\right)\cdot\left(50\times10^{-6}C\right)}{\left(0.60m\right)^2} = 1.25\times10^6\ N/C$$

$$\left|E_{A2}\right| = k\frac{Q_2}{r_{A2}} = \frac{\left(9.0\times10^9\ N\cdot m^2/C^2\right)\cdot\left(50\times10^{-6}C\right)}{\left(0.30m\right)^2} = 5.0\times10^6\ N/C$$

Example 21 – 8, cnt'd



Now the components of the electric field vectors by the two charges at point A.

$$E_{Ax} = E_{A1} \cos 30 = 1.1 \times 10^6\ N/C$$

$$E_{Ay} = E_{A2} - E_{A1} \sin 30 = 4.4 \times 10^6\ N/C$$

So the electric field at point A is

$$\vec{E}_A = E_{Ax}\vec{i} + E_{Ay}\vec{j} = \left(1.1\vec{i} + 4.4\vec{j}\right) \times 10^6\ N/C$$

The magnitude of the electric field at point A is

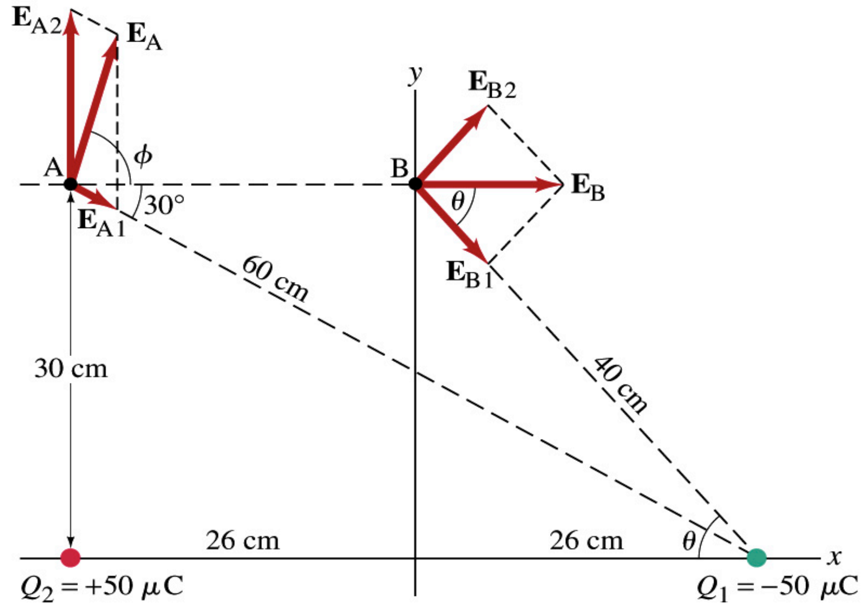
$$\left|E_A\right| = \sqrt{E_{Ax}^2 + E_{Ay}^2} = \sqrt{(1.1)^2 + (4.4)^2} \times 10^6\ N/C = 4.5 \times 10^6\ N/C$$

Now onto the electric field at point B

Example 21 – 8, cnt'd

Electric field at point B is easier due to symmetry!

Since the magnitude of the charges are the same and the distance to point B from the two charges are the same, the magnitude of the electric field by the two charges at point B are the same!!



$$\left|E_{B1}\right| = k\frac{Q_1}{r_{B1}^2} = \left|E_{B2}\right| = k\frac{Q_2}{r_{B2}^2} =$$

$$= \frac{\left(9.0\times10^9\ N\cdot m^2/C^2\right)\cdot\left(50\times10^{-6}\ C\right)}{\left(0.40m\right)^2} = 2.8\times10^6\ N/C$$

Now the components! First, the y-component! $E_{By} = E_{B2}\sin\theta - E_{B1}\sin\theta = 0$

Now, the x-component! $\cos\theta = 0.26/0.40 = 0.65$

$$E_{Bx} = 2E_{B1}\cos\theta = 2\cdot2.8\times10^6\cdot0.65 = 3.6\times10^6\ N/C$$

So the electric field at point B is $\vec{E}_B = E_{Bx}\vec{i} + E_{By}\vec{j} = \left(3.6\vec{i} + 0\vec{j}\right)\times10^6\ N/C = 3.6\times10^6\vec{i}\ N/C$

The magnitude of the electric field at point B $\left|E_B\right| = E_{Bx} = 2E_{B1}\cos\theta = 2\cdot2.8\times10^6\cdot0.65 = 3.6\times10^6\ N/C$