Electricity and Magnetism

- Physics 259 – L02
- Lecture 3

Section 21.1

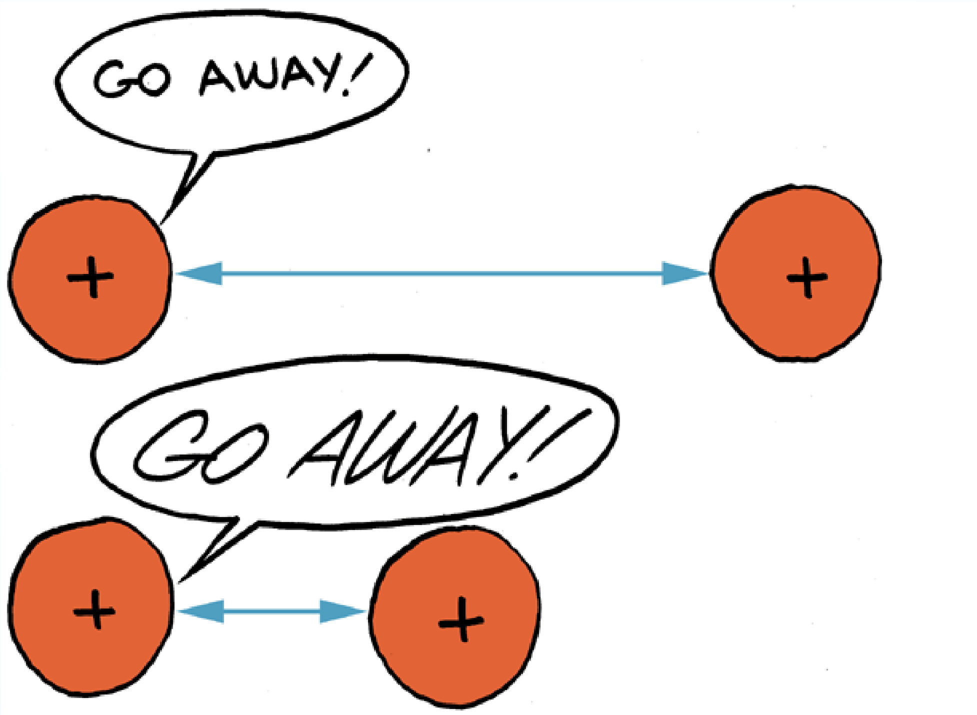
What we know

- There are positive and negative charges
- Like charges repel each other
- Opposite charges attract each other
- The force between charged objects varies with distance
- The force between charged objects depends on the amount of charge

HOW CAN WE QUANTIFY THIS?

Coulomb's Law

- Electric field decreases with distance



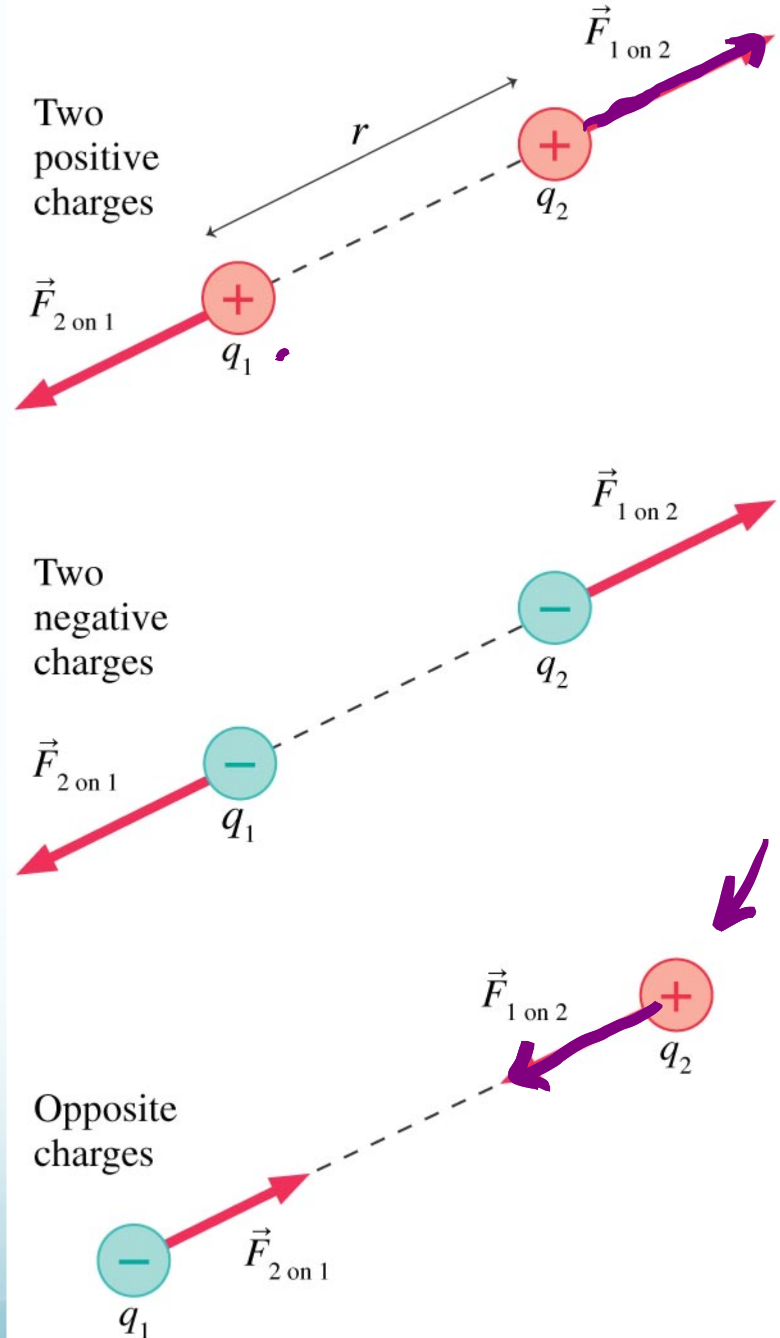
- The force that describes this behavior is known as **Coulomb's law**

Coulomb's Law

Describes the forces that charged **particles** exert on each other:

point charges

The forces always act along the line joining the charges.



Two Ways of Writing Coulomb's Law

$$\boxed{F_{1\,on\,2} = F_{2\,on\,1} = K\frac{|q_1||q_2|}{r^2}}$$

K = electrostatic constant

$$\underline{K} = 8.99\times10^{9}\,\frac{N\cdot m^2}{C^2}$$

$\vec{F}$ vector

$|\vec{F}|$ scalar

$$\boxed{F_{1\,on\,2} = F_{2\,on\,1} = \frac{1}{\underline{4\pi\varepsilon_0}}\frac{|q_1||q_2|}{r^2}}$$

ε_0 = permittivity of free space

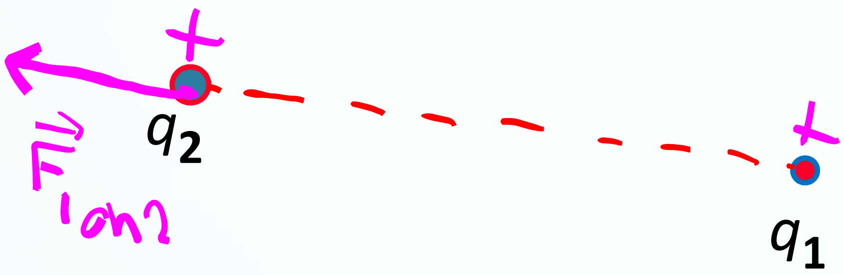
$$\varepsilon_0 = \frac{1}{4\pi K} = 8.85\times10^{12}\,\frac{C^2}{N\cdot m^2}$$

$K = \frac{1}{4\pi\varepsilon_0}$

Coulomb's Law

How to compute the magnitude and direction properly?

$\vec{F}$ has both magnitude and direction



$$\left|\vec{F}_{21}\right| = K \frac{|q_1||q_2|}{r_{21}^2}$$

constant

1) Find the distance between the charges.

2) Draw a line passing through the two charges.

3) The force on q_1 due to q_2 has its tail at location 1 and points either towards q_2 or away from q_2.

4) Pick the direction according to basic rule of charges:

Like charges repel, Opposite charges attract

SI unit of charge: the **coulomb** (C)

Fundamental charge:

the smallest possible amount of free charge

= charge of one proton: $\boxed{e = 1.60 \times 10^{-19}\ C}$

Then 1 C is approximately **6.25 x 10^{18} protons**.

1 C is **BIG!!**

$$\boxed{\begin{array}{l} 1\ \mu C = 1\ \text{microcoulomb} = 10^{-6}\ C \\ 1\ nC = 1\ \text{nanocoulomb} = 10^{-9}\ C \end{array}}$$

1 Coulomb is a great deal of charge

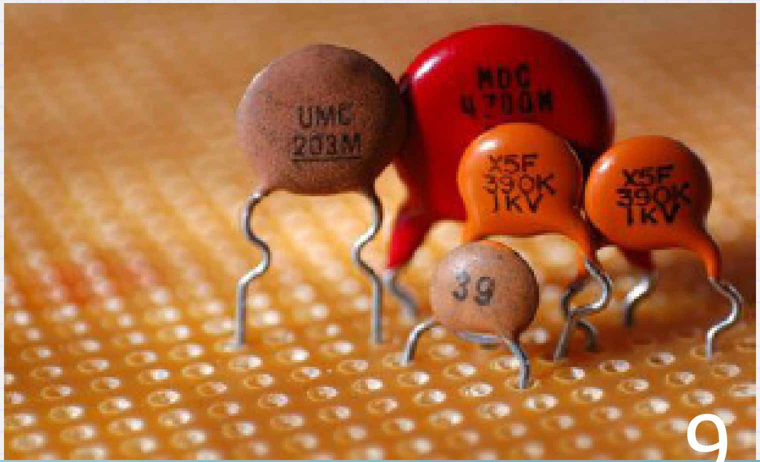
An average bolt of lightning

charge = 5 Coulombs
current = 50,000 Amperes
power = 500,000,000 Joules

so all the electrons in a copper penny have a total charge equivalent to 30,000 lightning bolts.

A single electron has 1.6E-19 Coulombs of charge.

Capacitors in circuits typically hold charges on the order of 10E-9 to 10E-3 Coulombs.



All materials contain very large numbers of charges, but they are usually in nearly perfect balance ($N_+ = N_-$).

Scalars *vs.* Vectors

A **scalar** is any physical quantity that can be described by a single number.

- The temperature in the room is 20°C.

$m_1 = 2\,kg$
$m_2 = 1\,kg$ $\Rightarrow$ $m_T = m_1 + m_2 = 3\,kg$

A **vector** is a physical quantity that has both a magnitude and a direction.

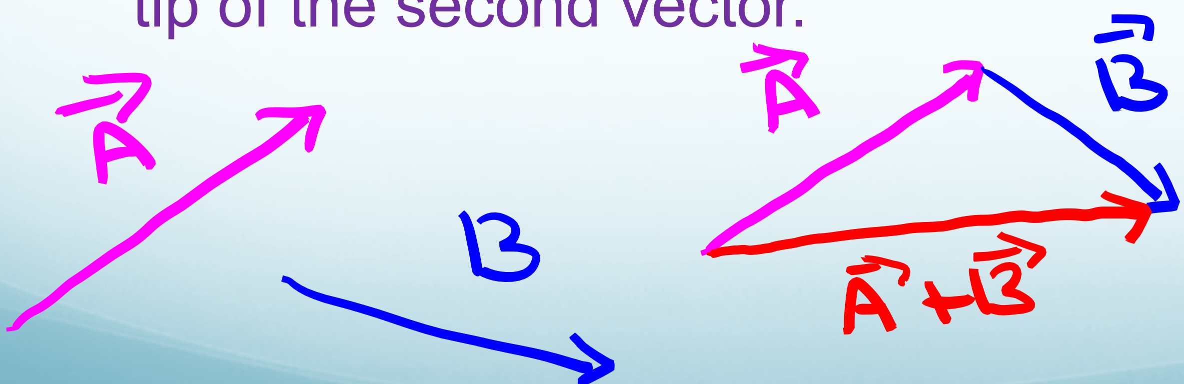
- Edmonton is 300 km north of Calgary.

Vector Addition

Adding vectors requires taking not only their magnitudes into account, but also their directions.

To find the sum of two vectors:

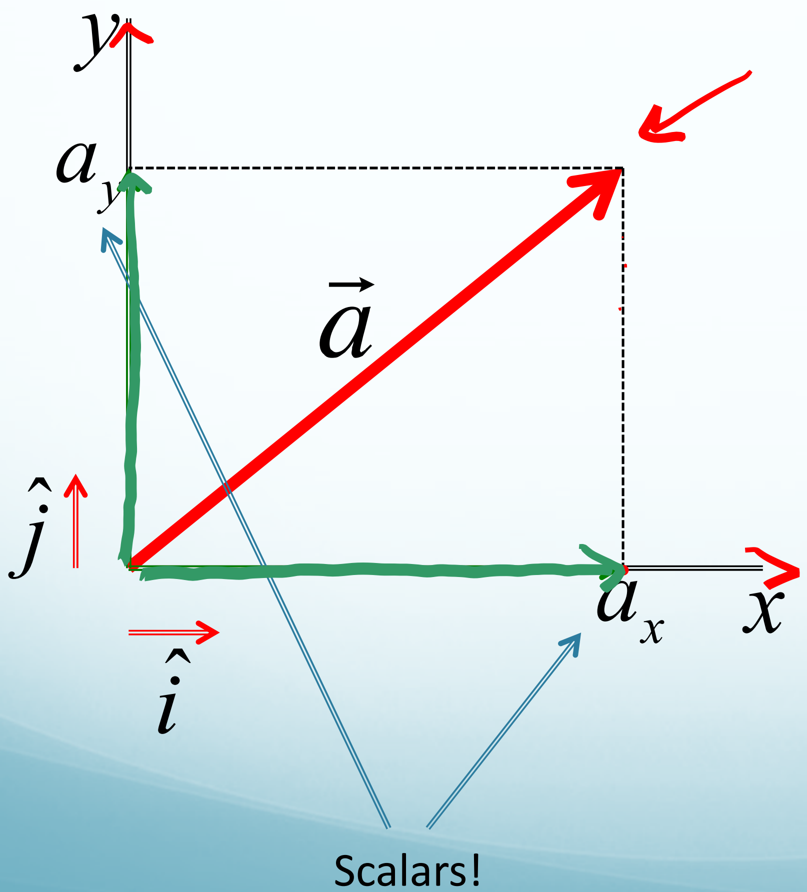
- Draw the first vector.
- Draw the second vector with the tail starting where the tip of the first vector ended.
- Draw a final vector from the tail of the first vector to the tip of the second vector.



$$\vec{C} = \vec{A} + \vec{B}$$

Vector Components

Scalars are usually easier to use than vectors. So let's replace our vectors with scalar quantities called vector components.

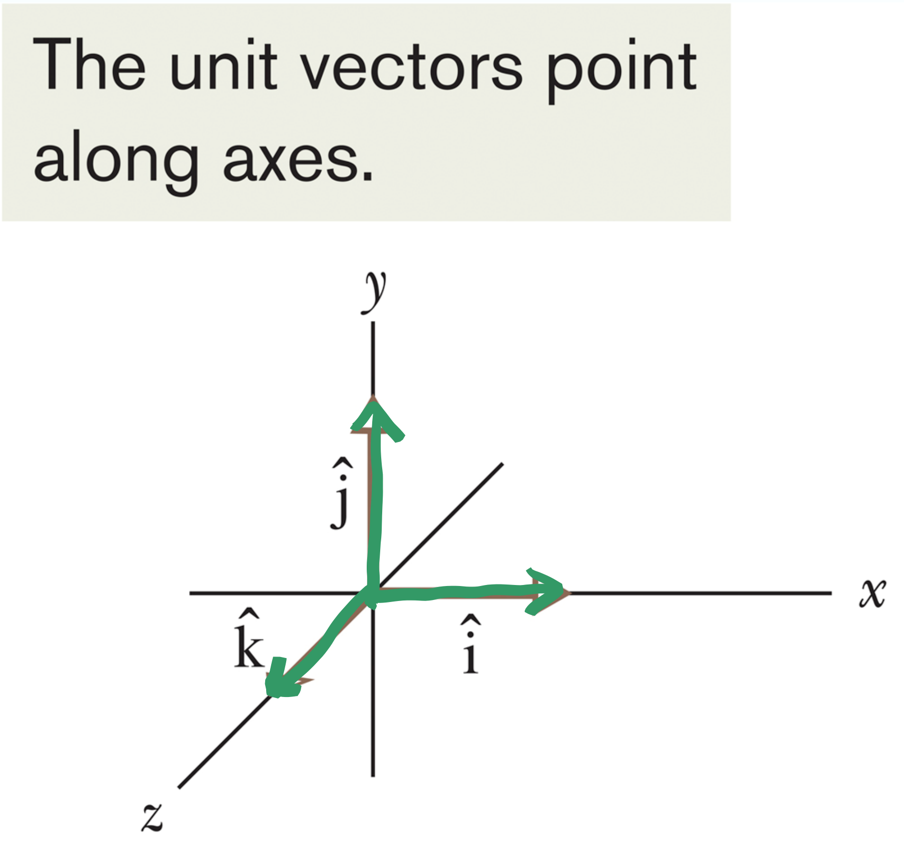


$$\vec{a} = a_x \hat{i} + a_y \hat{j}$$

$$|\vec{a}| = \sqrt{a_x^2 + a_y^2}$$

magnitude is always positive

Unit vectors



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Unit → No unit

Size → 1

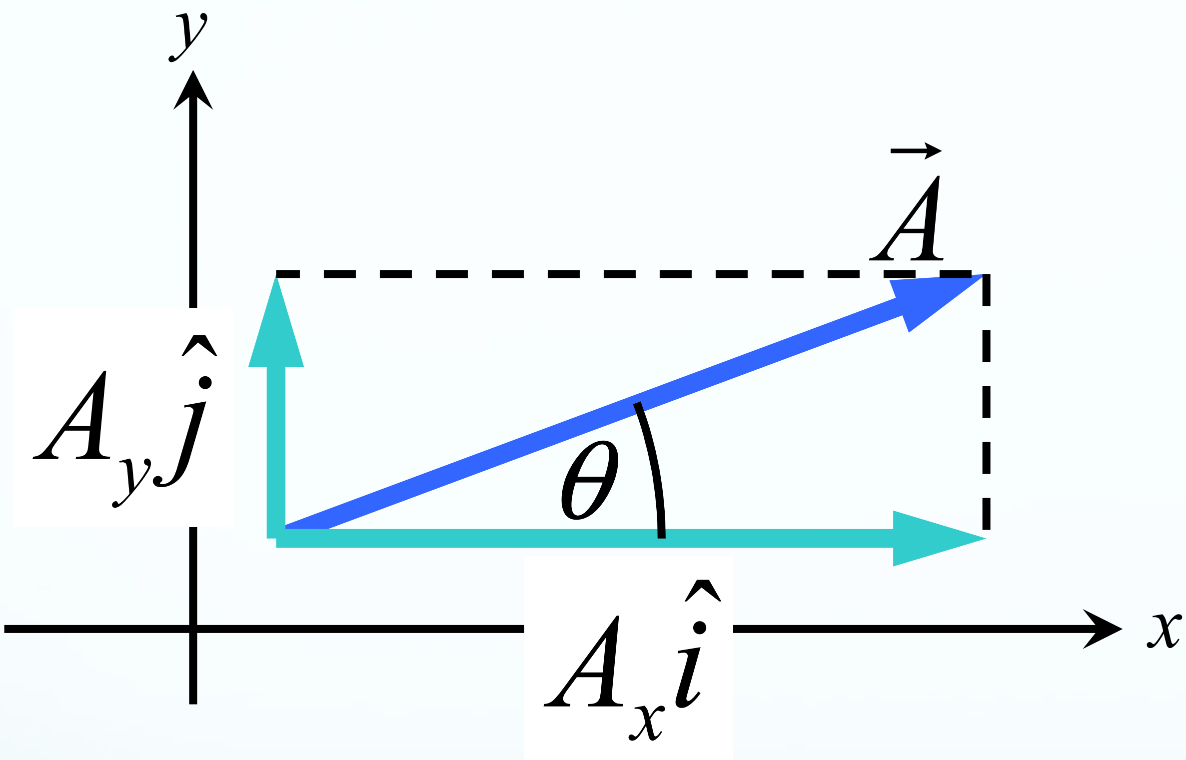
Direction → has direction

$|\hat{i}| = 1$

$|\hat{j}| = 1$

$|\hat{k}| = 1$

Finding Components of Vectors

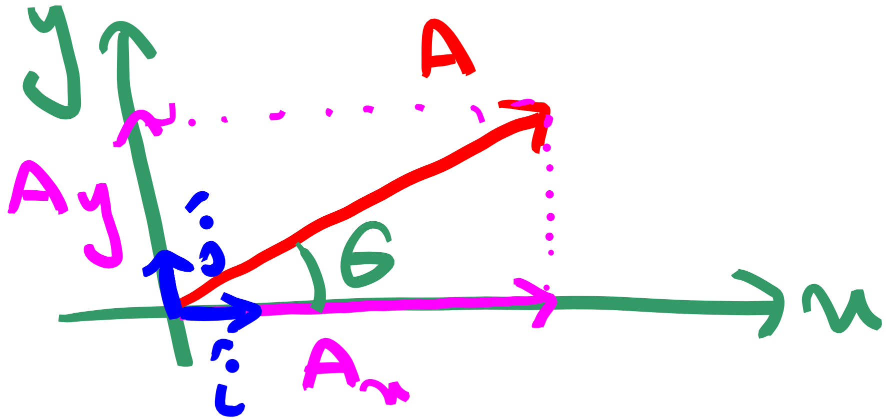


$$A_x = A\cos\theta$$

$$A_y = A\sin\theta$$

$$A^2 = A_x^2 + A_y^2$$

$$\theta = \tan^{-1}\left|\frac{A_y}{A_x}\right|$$



$$\vec{A} = A_x \hat{i} + A_y \hat{j}$$

$$\left.\begin{matrix} A_x \\ A_y \end{matrix}\right\} \rightarrow \text{Scalar}$$

$$|\vec{A}| = \sqrt{A_x^2 + A_y^2} = A$$

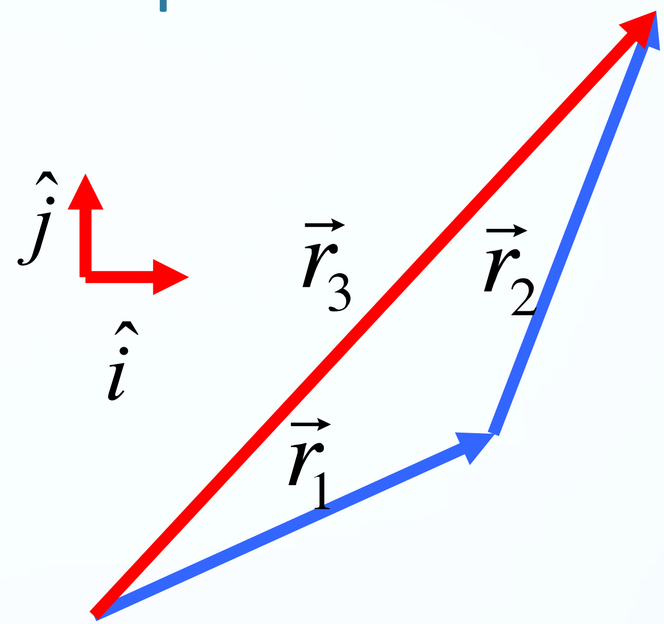
$$A_x = A\cos\theta$$

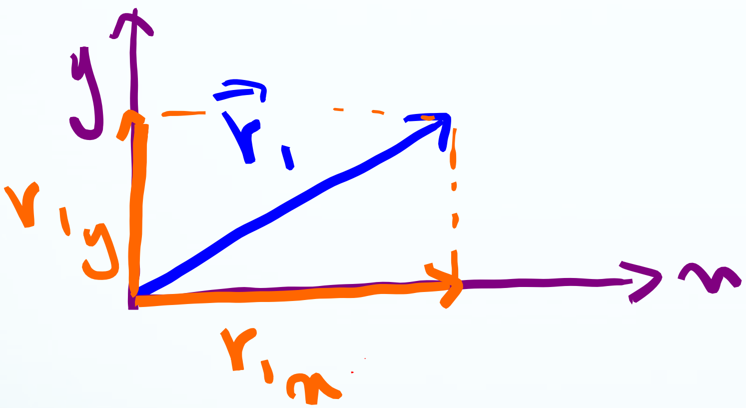
$$A_y = A\sin\theta$$

$$\vec{A} = A_x \hat{i} + A_y \hat{j} = \overbrace{A\cos\theta}^{\text{Scalar}}\,\hat{i} + \overbrace{A\sin\theta}^{\text{Scalar}}\,\hat{j}$$

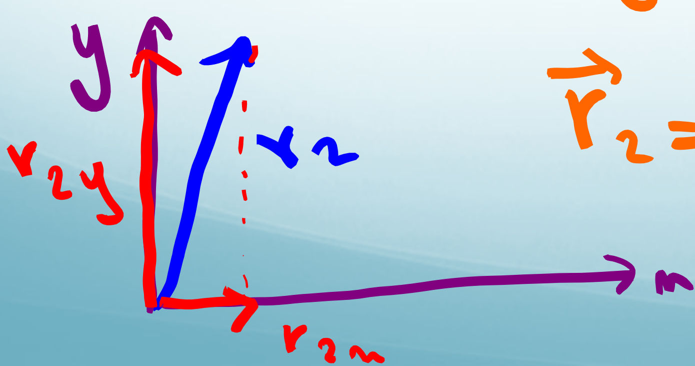
Vector Addition using Components

$$\boxed{\vec{r}_3 = \vec{r}_1 + \vec{r}_2}$$





$$\vec{r}_1 = r_{1x}\,\hat{i} + r_{1y}\,\hat{j}$$

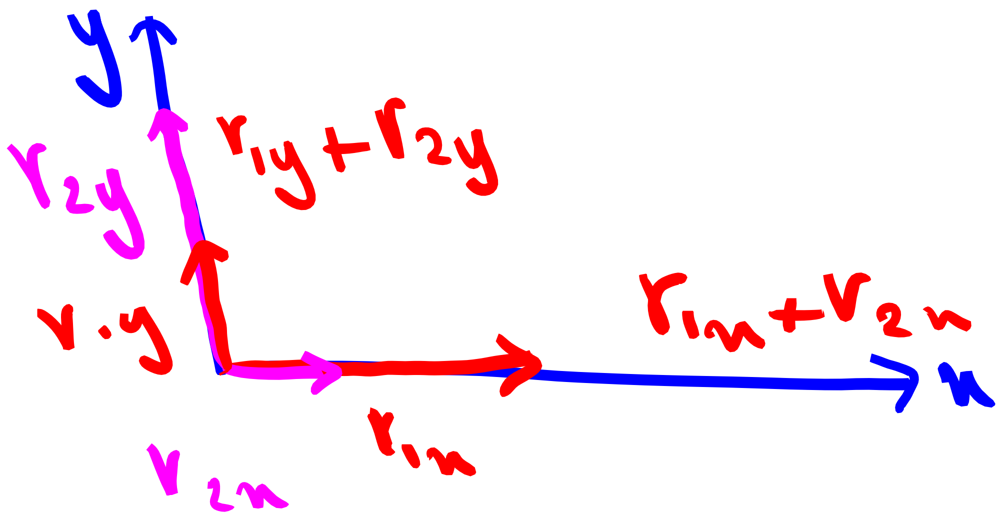


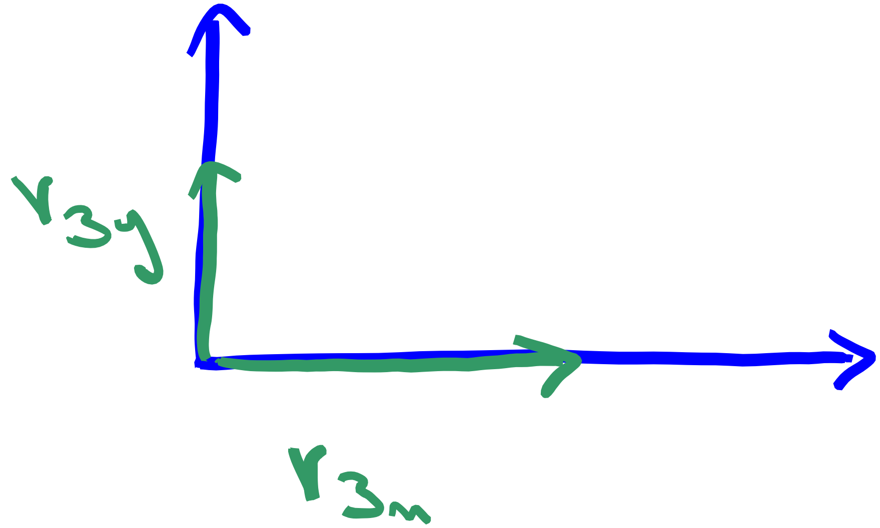
$$\vec{r}_2 = r_{2x}\,\hat{i} + r_{2y}\,\hat{j}$$

$$\vec{r}_3 = \vec{r}_1 + \vec{r}_2$$

$$= (r_{1x}\hat{i} + r_{1y}\hat{j}) + (r_{2x}\hat{i} + r_{2y}\hat{j})$$

$$= (r_{1x} + r_{2x})\hat{i} + (r_{1y} + r_{2y})\hat{j} \leftarrow$$





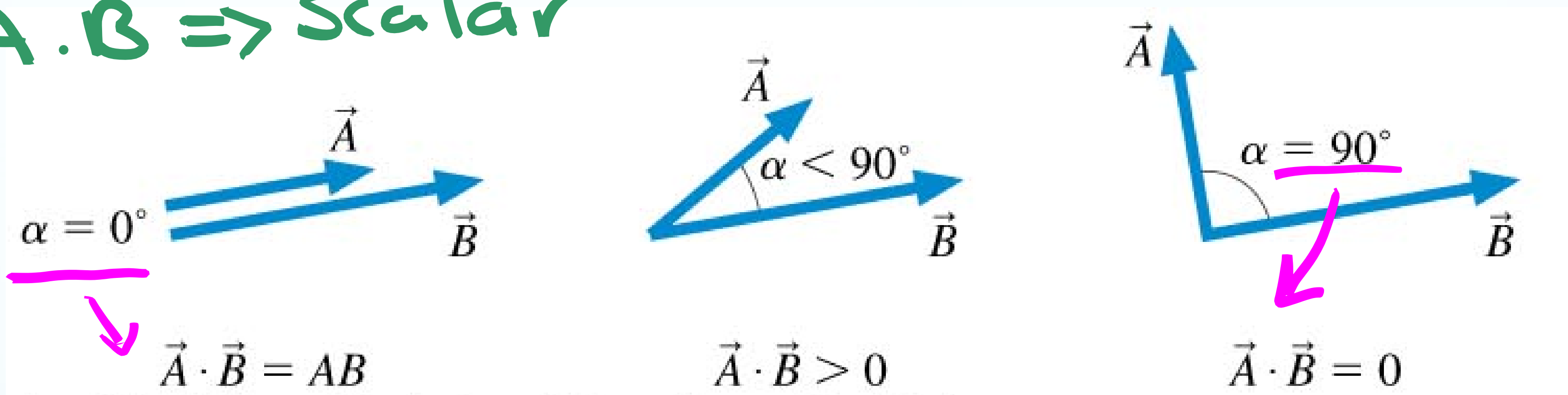
$$\vec{r}_3 = r_{3x}\,\hat{i} + r_{3y}\,\hat{j}$$

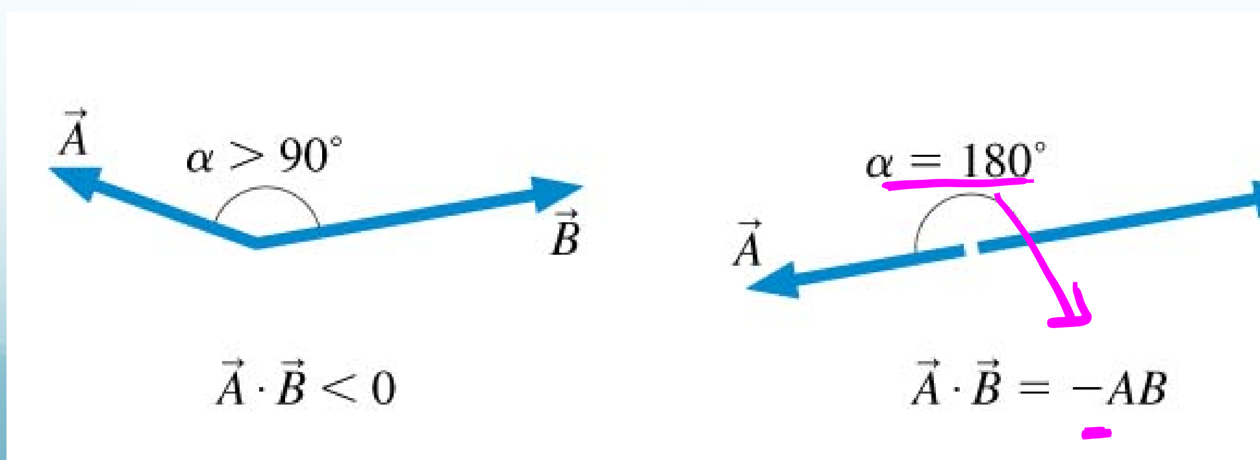
$$\rightarrow |\vec{r}| = \sqrt{r_{3x}^2 + r_{3y}^2}$$

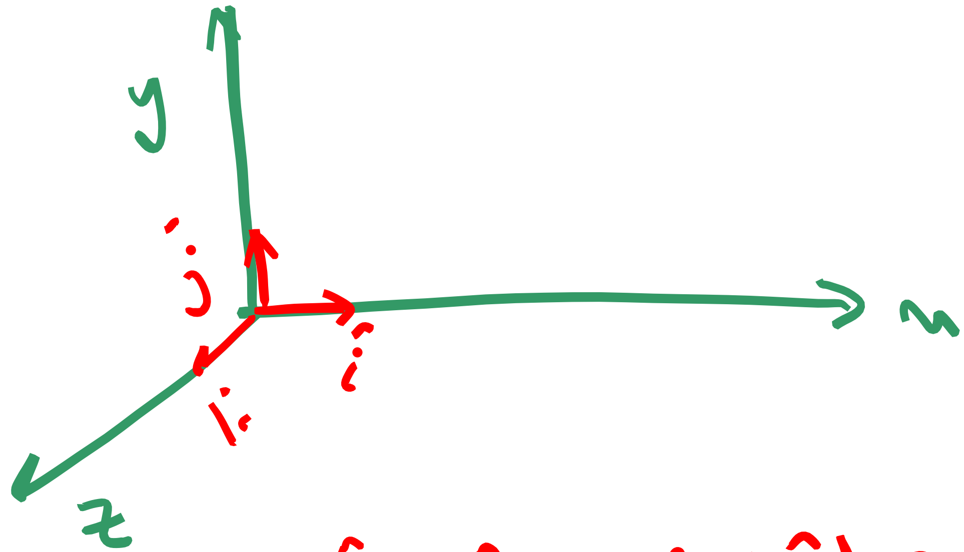
Dot Product of Two Vectors

Scalar $\leftarrow$ $\vec{A}\cdot\vec{B} = AB\cos\alpha$

$\vec{A}.\vec{B} \Rightarrow$ Scalar







$$\hat{i}\cdot\hat{i} = |\hat{i}||\hat{i}|\underbrace{\cos(0)}_{1} = 1$$

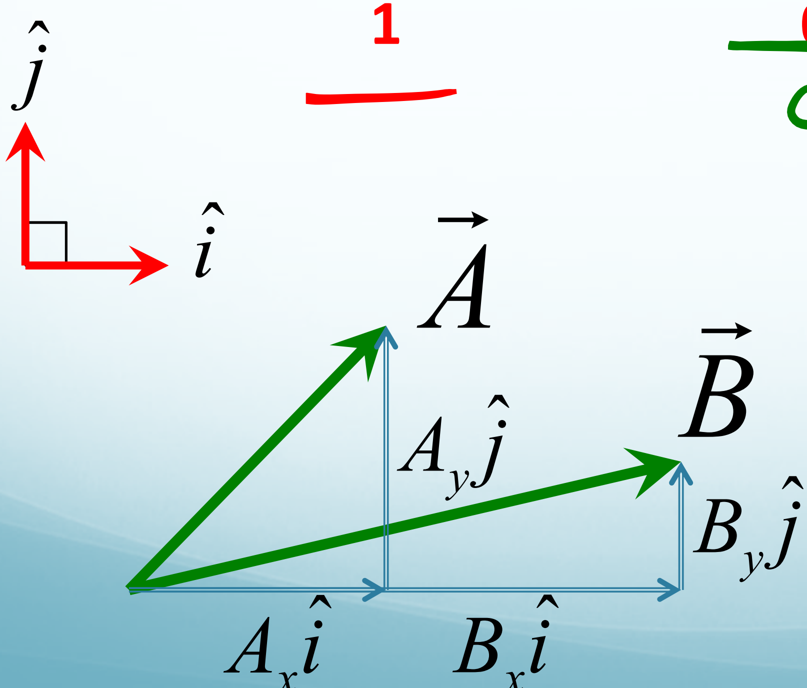
$$\hat{i}\cdot\hat{j} = |\hat{i}||\hat{j}|\underbrace{\cos(90)}_{0} = 0$$

Dot Product of Two Vectors

$$\vec{A}\cdot\vec{B} = \left(A_x\hat{i}+A_y\hat{j}\right)\cdot\left(B_x\hat{i}+B_y\hat{j}\right)$$

$$= A_xB_x\underbrace{\hat{i}\cdot\hat{i}}_{1} + A_xB_y\underbrace{\hat{i}\cdot\hat{j}}_{0} + A_yB_x\underbrace{\hat{j}\cdot\hat{i}}_{0} + A_yB_y\underbrace{\hat{j}\cdot\hat{j}}_{1}$$

0

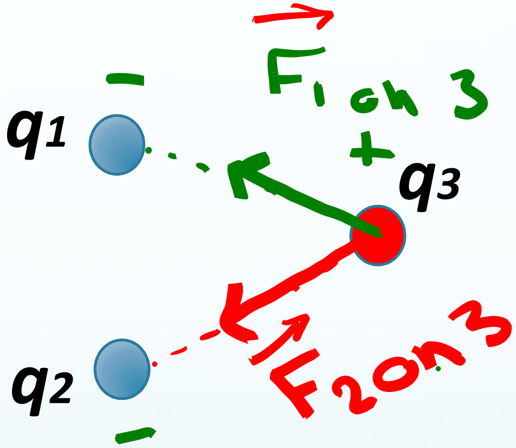


$$\boxed{\vec{A}\cdot\vec{B} = A_xB_x + A_yB_y}$$

Superposition Principle

The total force on q_3 is the vector sum of the individual forces:

$$\vec{F}_{on\,3} = \vec{F}_{1\,on\,3} + \vec{F}_{2\,on\,3}$$



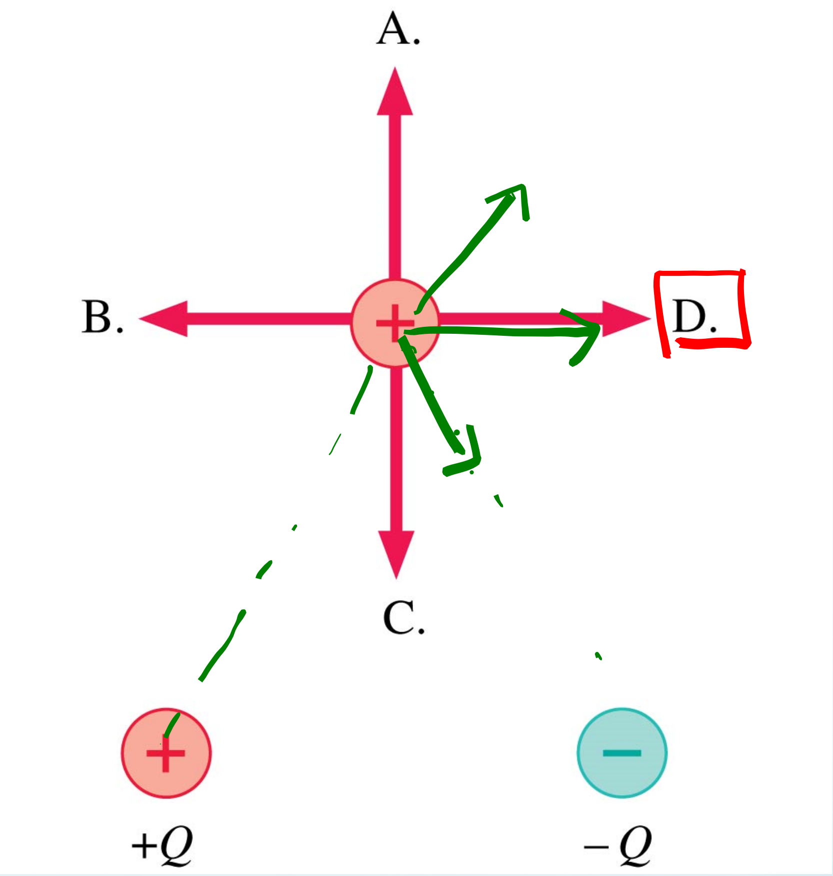
QuickCheck 25.10

TOPHAT QUESTION

Which is the direction of the net force on the charge at the top?

92% correct

thank you



E. None of these.

This section we talked about:

Chapter 21.1

See you on Friday

20