Electricity and Magnetism
Coulomb's Law

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De Anza College

Jan 10, 2018

Last time

- introduced charge
- conductors
- insulators
- induced charge

Warm Up

Do both balloons A and B have a charge?

(A) yes

(B) no, neither is charged

(C) at least 1 is charged.

Warm Up

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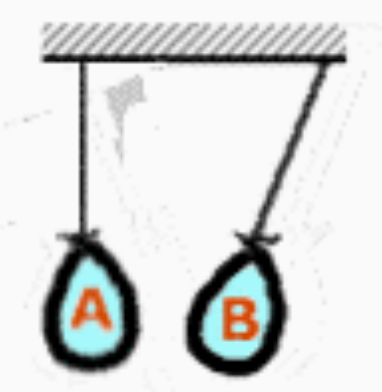
Warm Up

Does this happen?



(A) yes

(B) no

Warm Up

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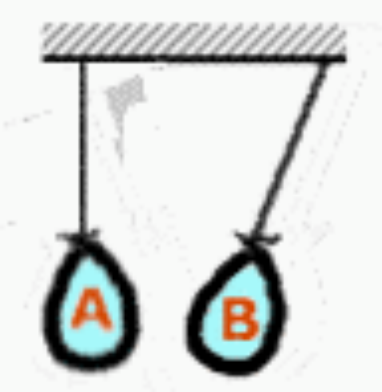


(A) yes

(B) no $\leftarrow$ consider Newton's 3rd law

Overview

- Force from a point charge
- Quantization of charge
- Charge conservation

Electrostatic Forces

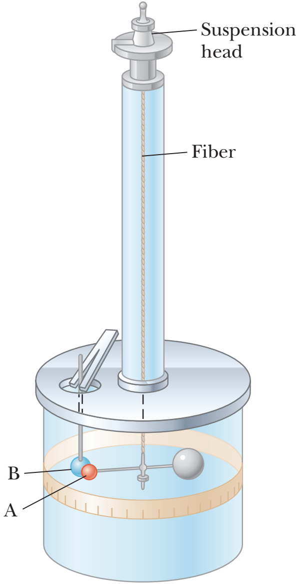
For a pair of point-particles with charges q_1 and q_2, the magnitude of the force on each particle is given by **Coulomb's Law**:

$$F_{1,2} = \frac{k_e \, q_1 q_2}{r^2}$$

k_e is the electrostatic constant and r is the distance between the two charged particles.

$k_e = \frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \text{ N m}^2/\text{C}^2$

How Coulomb's Law was found: Torsion Balance



[1]Figure from Serway & Jewett, Physics for Scientists and Engineers, 9th ed.

Electrostatic Forces: Coulomb's Law

$$F_{1,2} = \frac{k_e \, q_1 q_2}{r^2}$$

Remember however, forces are vectors. The vector version of the law is:

$$\mathbf{F}_{1\to 2} = \frac{k_e \, q_1 q_2}{r^2} \, \hat{\mathbf{r}}_{1\to 2}$$

where $\mathbf{F}_{1\to 2}$ is the force that particle 1 exerts on particle 2, and $\hat{\mathbf{r}}_{1\to 2}$ is a unit vector pointing from particle 1 to particle 2.

Coulomb's Law

Coulomb's Law:

$$\mathbf{F}_{1\to 2} = \frac{k\, q_1 q_2}{r^2}\,\hat{\mathbf{r}}_{1\to 2}$$

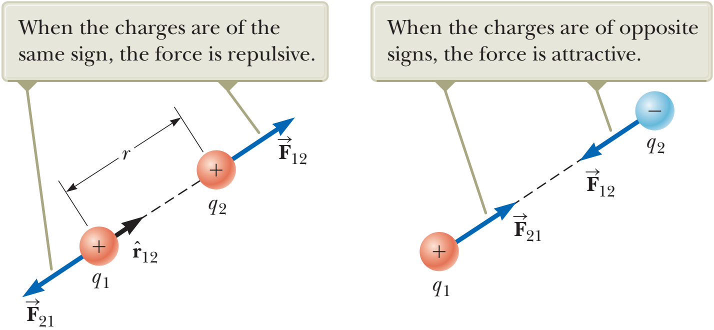
Does this look a bit familiar?

Similar to this?

$$\mathbf{F}_{1\to 2} = -\frac{G\, m_1 m_2}{r^2}\,\hat{\mathbf{r}}_{1\to 2}$$

Coulomb's Law

$$\mathbf{F}_{1\to 2} = \frac{k\, q_1 q_2}{r^2}\, \hat{\mathbf{r}}_{1\to 2}$$



[1]Figure from Serway & Jewett, Physics for Scientists and Engineers, 9th ed.

Electrostatic Constant

The electrostatic constant is:

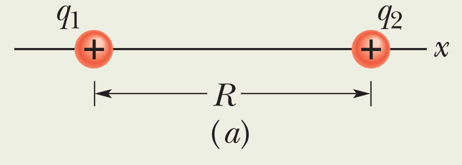
$$k = \frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$$

ϵ_0 is called the **permittivity constant** or the **electrical permittivity of free space**.

$\epsilon_0 = 8.85 \times 10^{-12}$ C^2 N^{-1} m^{-2}

Example

The diagram a shows two positively charged particles fixed in place on the x axis.The charges are $q_1 = 1.60 \times 10^{-19}$ C and $q_2 = 3.20 \times 10^{-19}$ C, and the particle separation is $R = 0.0200$ m. What are the magnitude and direction of the electrostatic force $\mathbf{F}_{2\rightarrow 1}$ from particle 2 on particle 1?



$k = 8.99 \times 10^9$ N m^2 C^{-2} or $\epsilon_0 = 8.85 \times 10^{-12}$ C^2 N^{-1} m^{-2}

[1]Question from Halliday, Resnick, Walker, 9th ed

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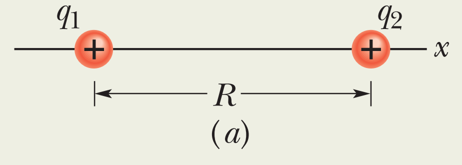


Answer: $\mathbf{F}_{2\to1} = -1.15 \times 10^{-24}\ \hat{\mathbf{i}}$ N

[1]Question from Halliday, Resnick, Walker, 9th ed

Force from many charges

Forces from many charges add up to give a net force

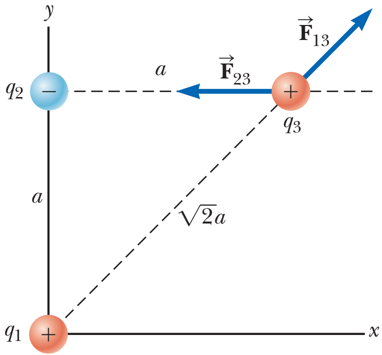
This is (very grandly) called the "principle of superposition".

The net force on particle 1 from particles 2, 3, ... n is:

$$\mathbf{F}_{\text{net},1} = \mathbf{F}_{2\rightarrow 1} + \mathbf{F}_{3\rightarrow 1} + \ldots + \mathbf{F}_{n\rightarrow 1}$$

Example

Consider three point charges located at the corners of a right triangle as shown, where $q_1 = q_3 = 5.00\ \mu\text{C}$, $q_2 = -2.00\ \mu\text{C}$, and $a = 0.100$ m. Find the resultant force exerted on q_3.



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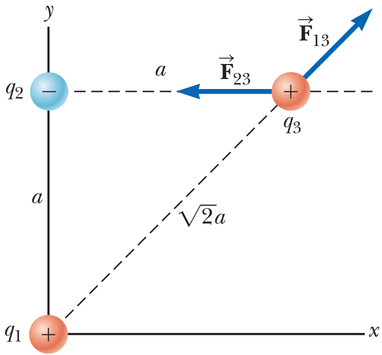


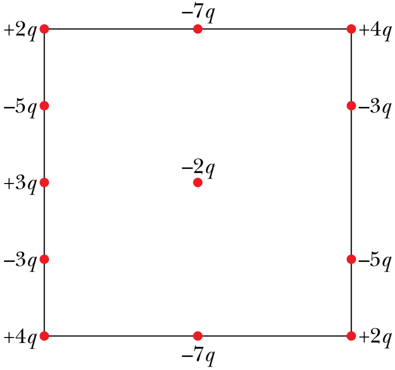
Answer: $\mathbf{F}_{\text{net},3} = (-1.04\ \mathbf{i} + 7.94\ \mathbf{j})$ N

[1]Figure from Serway & Jewett, pg 696, Ex 2.

Question

pg 574, #10, HRW

10 In Fig. 21-20, a central particle of charge $-2q$ is surrounded by a square array of charged particles, separated by either distance d or $d/2$ along the perimeter of the square. What are the magnitude and direction of the net electrostatic force on the central particle due to the other particles? (*Hint:* Consideration of symmetry can greatly reduce the amount of work required here.)



Forces at a Fundamental Level

Often people think about two kinds of forces: contact forces and field forces (*ie.* forces that act at a distance).

In mechanics problems, all forces except gravity are from direct contact.

Gravity is a field force.

The electric and magnetic forces are also field forces.

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In mechanics problems, all forces except gravity are from direct contact.

Gravity is a field force.

The electric and magnetic forces are also field forces.

And actually, at a fundamental level, *all* forces that we know of are field forces.

Forces at a Fundamental Level

Contact forces are a result of electrostatic repulsion at very small scales.

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Fundamental forces:

Force	$\sim$ Rel. strength	Range (m)	Attract/Repel	Carrier
Gravitational	10^{-38}	∞	attractive	graviton
Electromagnetic	10^{-2}	∞	attr. & rep.	photon
Weak Nuclear	10^{-13}	$< 10^{-18}$	attr. & rep.	W^+, W^-, Z^0
Strong Nuclear	1	$< 10^{-15}$	attr. & rep.	gluons

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Gravity is actually quite a weak force, but it is the only one that (typically) matters on large scales - charges cancel out!

Fields

field (physics)

A field is any kind of physical quantity that has values specified at every point in space and time.

Vector Fields

In EM we have vector fields. The electrostatic force is mediated by a vector field.

vector field (physics)

any kind of physical quantity that has values specified *as vectors* at every point in space and time.

vector field (math, 3 dimensions)

A vector field is a vector-valued function $\mathbf{F}$ that takes a point (x, y, z) and maps it to a vector $\mathbf{F}(x, y, z)$.

Fields

Fields were first introduced as a calculation tool.

A force-field can be used to identify the force a particular particle will feel at a certain point in space and time without needing a detailed description of the other objects in its environment that it will interact with.

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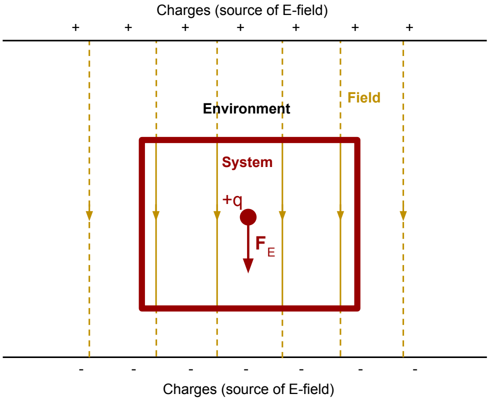
Fields

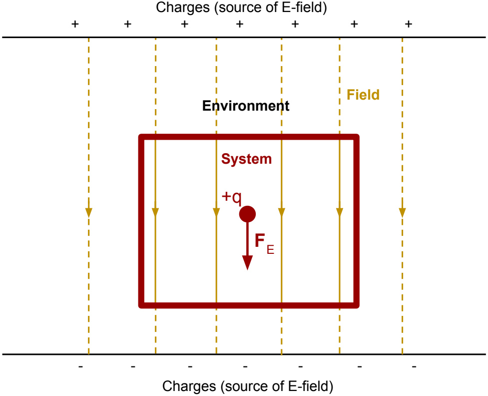
Imagine a charge q_0. We want to know the force it would feel if we put it at a specific location.

The electric field **E** at that point will tell us that!

$$\mathbf{F} = q_0 \mathbf{E}$$



Fields

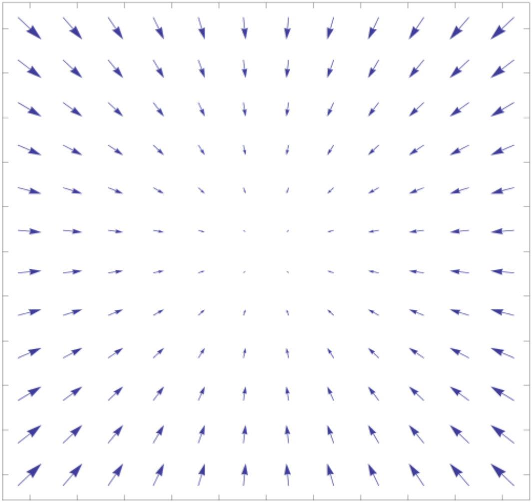


The source of the field could be another charge or charges, but we do not need a description of the sources of the field to describe what their effect is on our particle. All we need to know is the field!

(This is also true for gravity. We do not need the mass of the Earth to know something's weight.)

Vector Fields

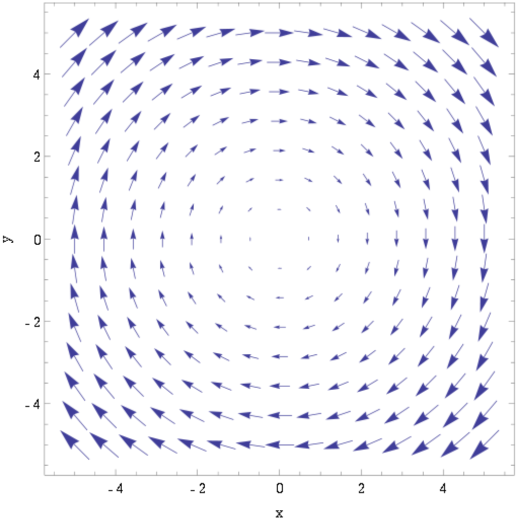
2 - dimensional examples



Irrotational (curl-free) field.

Vector Fields

2 - dimensional examples



Solenoidal (divergence-free) field.

Summary

- Force from a point charge
- Force from many charges
- vector fields

Quiz Friday, start of class.

Homework

- Collected homework 1, posted online, due on Monday, Jan 22.

Serway & Jewett:

- Read Ch 23
- Ch 23, onward from page 716. Conceptual Qs: 5; Section Qs: 11, 13