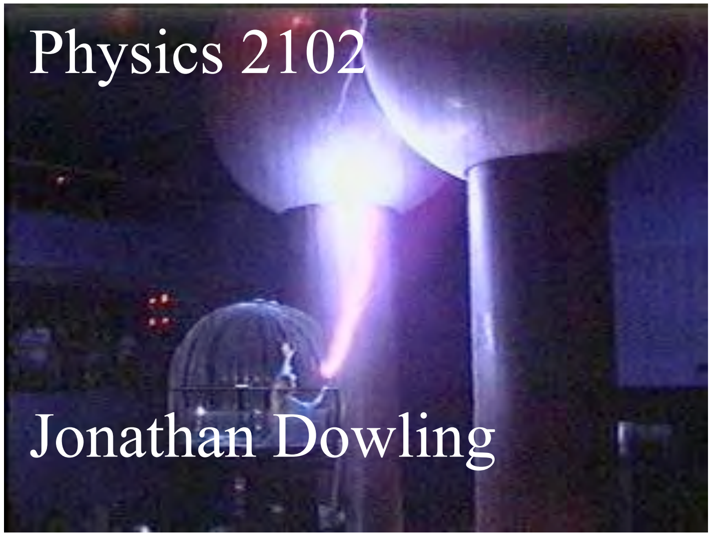

Physics 2102
Lecture 1
Electric Charge

Version: 1/17/07

Charles-Augustin
de Coulomb
(1736-1806)

Who Am I?

Prof. Jonathan P. Dowling

1994–98: Research Physicist, US Army Aviation & Missile Command
1998–2004: Principal Scientist, NASA Jet Propulsion Laboratory
2004–Present: Director, Hearne Institute for Theoretical Physics, LSU

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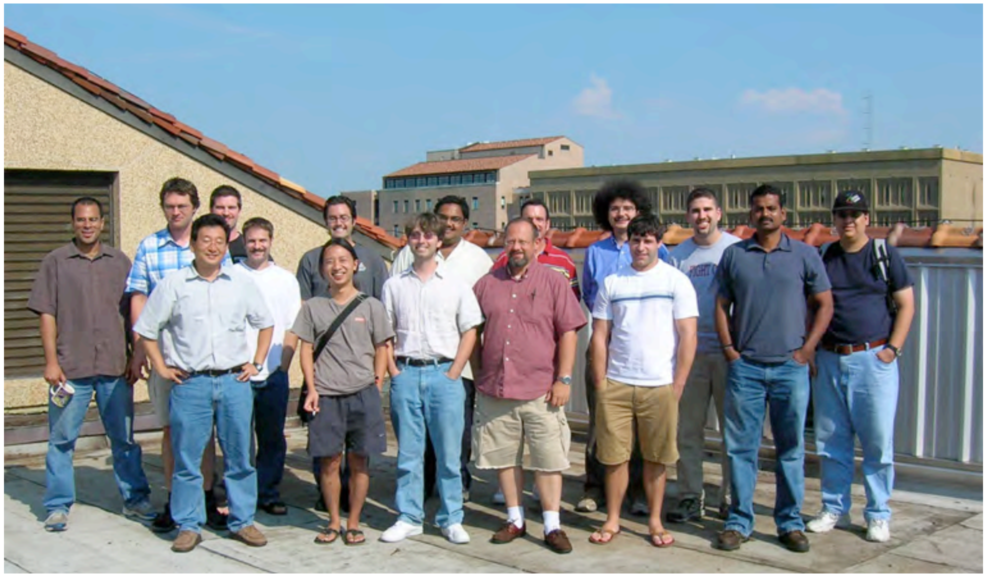
My Research:
Quantum Optics
Quantum Computing
Photonic Crystals

Hearne Institute for Theoretical Physics
Quantum Sciences & Technologies Group



Course Details

• **Class Website**:
http://www.phys.lsu.edu/classes/spring2007/phys2102/
Syllabus, schedule, grade policy, …

• **Lectures** will be posted in this sections' website:
http://phys.lsu.edu/~jdowling/phys21024/

• **Text:**
Fundamentals of Physics, Halliday, Resnick, and Walker, 7th edition.
We will cover chapters 21-36 in this class.

• **Exams:**
Three midterms: 08 FEB, 08 MAR, 12 APR
Final Exam (cumulative): 10 MAY

• **Quizzes:**
Nearly every class.

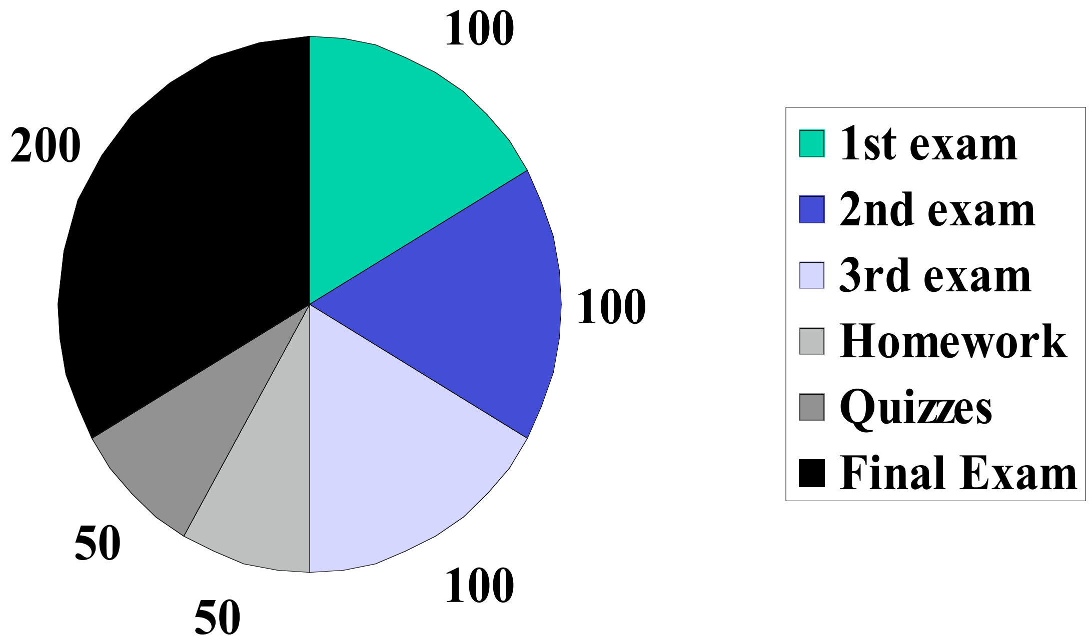
Course details: Homework

Web-based system: Web Assign
To register:
- Go to **http://www.webassign.net/student.html**
- On the left frame, "student login"
    - *Username*: lsuemail
    - *Institution*: lsu
    - *Password*: your SSN
- Choose "credit card registration" ($8.50)

There will be one assignment per week due 2:00AM Tuesdays.

The first assignment will be posted later today.

Course details: Grading



A	B	C	D	F
>88%	88–76%	76–60%	60–50%	<50%

What are we going to learn?
A road map

- **Electric *charge***
  ➔ Electric *force* on other electric charges
  ➔ Electric *field*, and electric *potential*
- **Moving electric charges : current**
- **Electronic circuit components: batteries, resistors, capacitors**
- **Electric currents ➔ Magnetic field**
  ➔ Magnetic force on moving charges
- **Time-varying magnetic field ➔ Electric Field**
- **More circuit components: inductors, AC circuits.**
- **Maxwell's equations ➔ Electromagnetic waves ➔ light waves**
- **Geometrical Optics (light rays).**
- **Physical optics (light waves): interference, diffraction.**

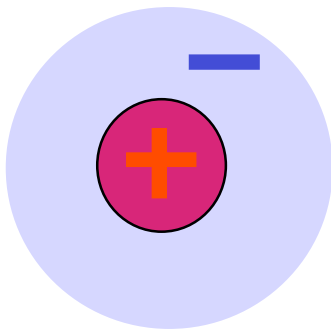
Let's get started!
Electric charges

- **Two types of charges: positive/negative**
- **Like charges repel**
- **Opposite charges attract**

Atomic structure :

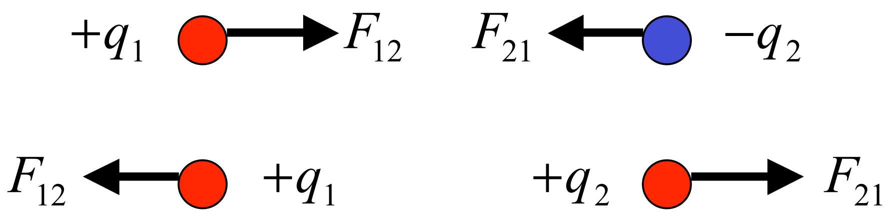
- **negative electron cloud**
- **nucleus of positive protons, uncharged neutrons**

[[Why doesn't the nucleus fly apart??
Why doesn't the atom collapse??]]



Charles-Augustin de Coulomb (1736-1806)

Force between pairs of point charges: Coulomb's law

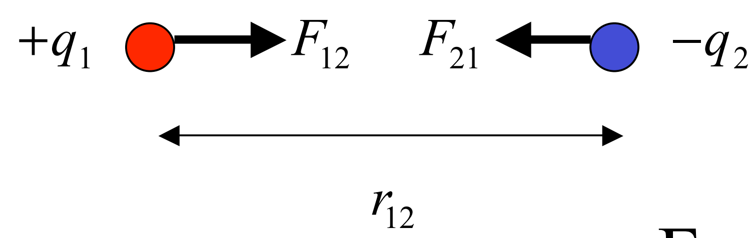


or

Coulomb's law -- the force between point charges:

- Lies along the line connecting the charges.
- Is proportional to the magnitude of each charge.
- Is inversely proportional to the distance squared.
- Note that Newton's third law says $|F_{12}| = |F_{21}|$!!

Coulomb's law



$$|F_{12}| = \frac{k\ |q_1||q_2|}{r_{12}^2}$$

For charges in a VACUUM

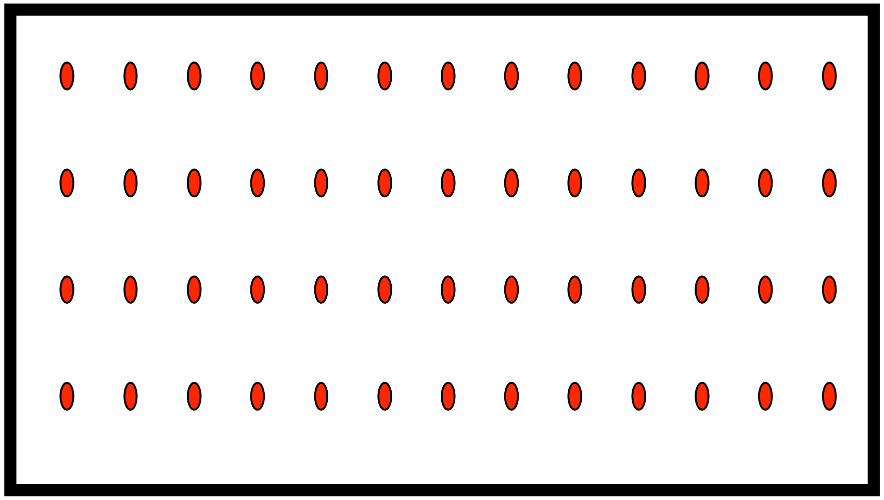
$$\mathrm{k} = 8.99\times10^{9}\ \frac{N\,m^2}{C^2}$$

Often, we write *k* as:

$$k = \frac{1}{4\pi\varepsilon_0} \text{ with } \varepsilon_0 = 8.85\times10^{-12}\ \frac{C^2}{N\,m^2}$$

Electric charges in solids

- In macroscopic solids, nuclei often arrange themselves into a stiff regular pattern called a “lattice”.
- Electrons move around this lattice. Depending on how they move the solid can be classified by its “electrical properties” as an insulator or a conductor.

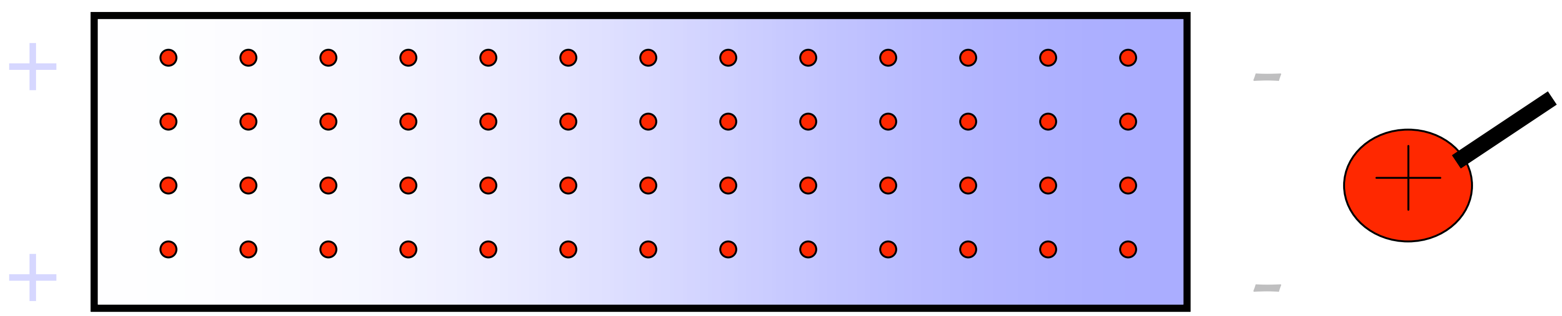


Charges in solids

- In a conductor, electrons move around freely, forming a "sea" of electrons. This is why metals conduct electricity.
- Charges can be "induced" (moved around) in conductors.

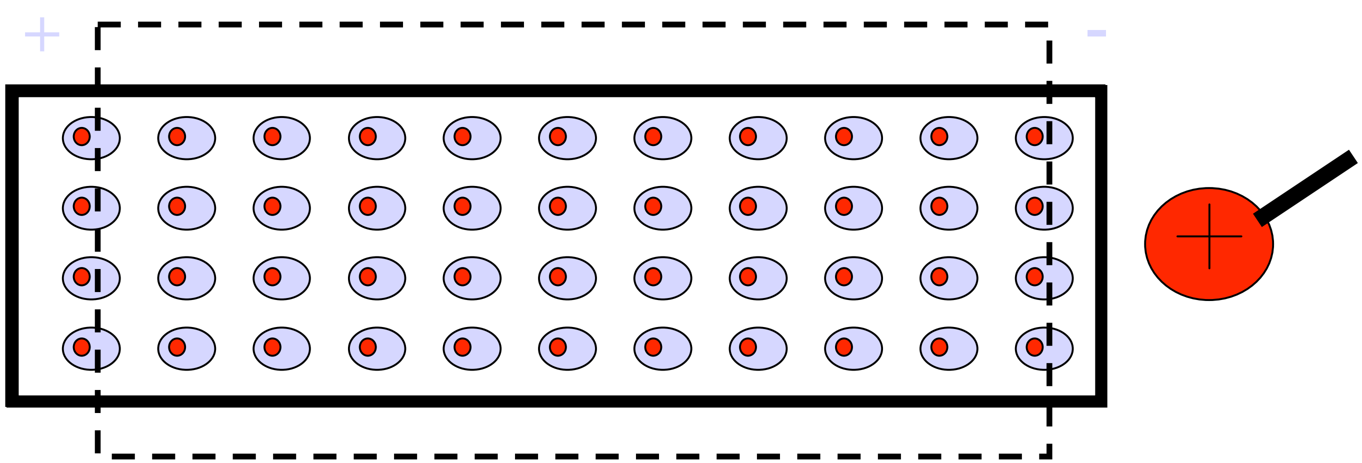
Blue background = mobile electrons

Red circles = static positive charge (nuclei)



Insulating solids

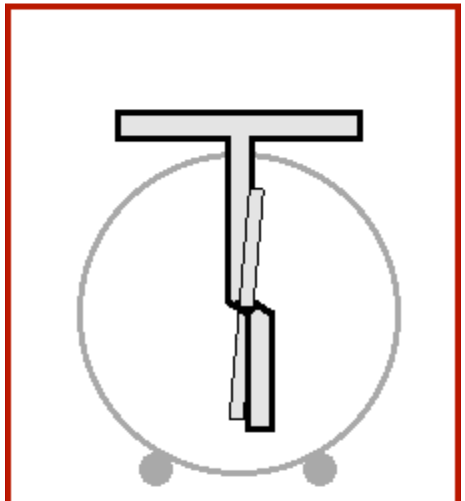
- In an insulator, each electron cloud is tightly bound to the protons in a nucleus. Wood, glass, rubber.
- Note that the electrons are not free to move throughout the lattice, but the electron cloud can "distort" locally.



How to charge an object

- An object can be given some “excess” charge: giving electrons to it (we give it negative charge) or taking electrons away (we “give” it positive charge).
- How do we do charge an object? Usually, moving charges from one surface to another by adhesion (helped by friction), or by contact with other charged objects.
- If a conductor, the whole electron sea redistributes itself.
- If an insulator, the electrons stay where they are put.

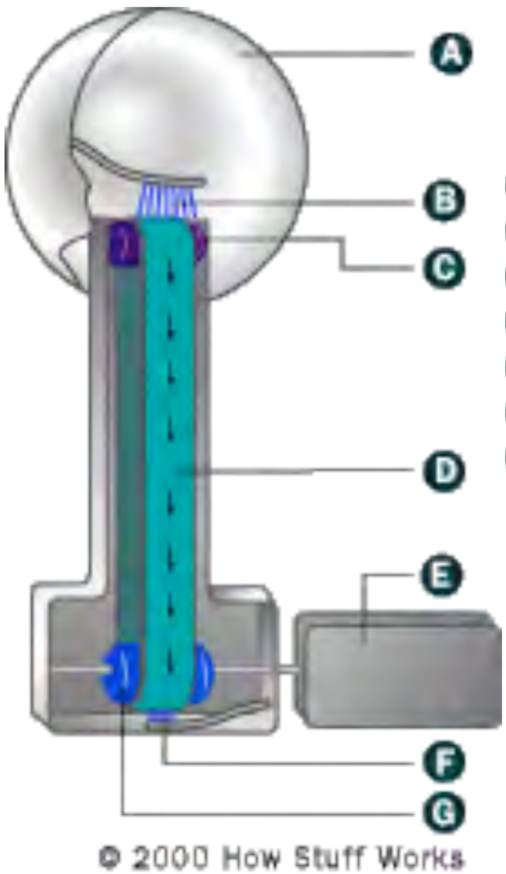
Electroscope



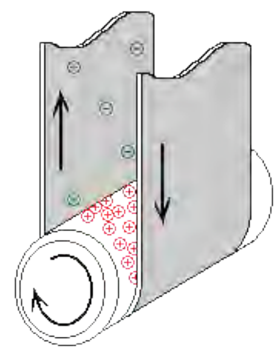
The electroscope is neutral as evidenced by the needle in a relaxed position.

http://www.physicsclassroom.com/mmedia/estatics/esn.html

Van der Graaf generator



- A Output terminal — An aluminum or steel sphere
- B Upper brush — A piece of fine metal wire
- C Upper roller — A piece of nylon
- D Belt — A piece of surgical tubing
- E Motor
- F Lower brush
- G Lower roller — A piece of nylon covered with silicon tape



http://science.howstuffworks.com/vdg2.htm

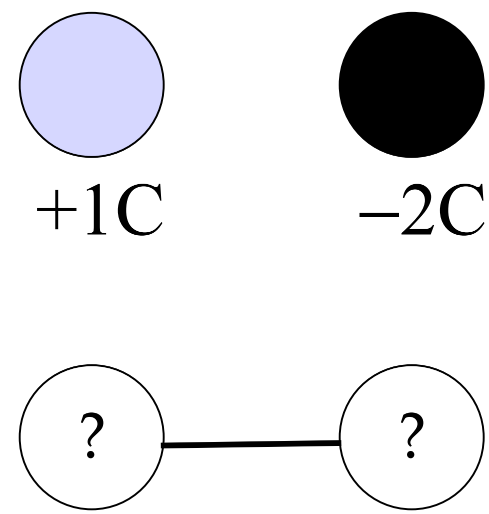
http://www.amasci.com/emotor/vdg.html

Conservation of Charge

Total amount of charge in an isolated system is fixed ("conserved")

Example: 2 identical metal spheres have charges +1C and –2C.

You connect these together with a metal wire; what is the final charge distribution?



Quantization of Charge

- Charge is always found in **INTEGER** multiples of the charge on an electron/proton ([[*why*?]])
- Unit of charge: Coulomb (C) in SI units
- Electron charge = $-e$ = -1.6×10^{-19} Coulombs
- Proton charge = $+e$ = $+1.6 \times 10^{-19}$ Coulombs
- One cannot ISOLATE FRACTIONAL CHARGE (e.g. -0.8×10^{-19} C, $+1.9 \times 10^{-19}$ C, etc.) [[but what about quarks…?]]
- Unit of current: Ampere = Coulomb/second

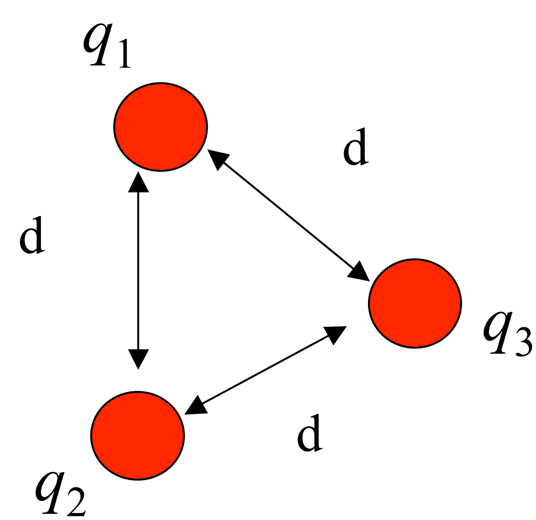
Superposition

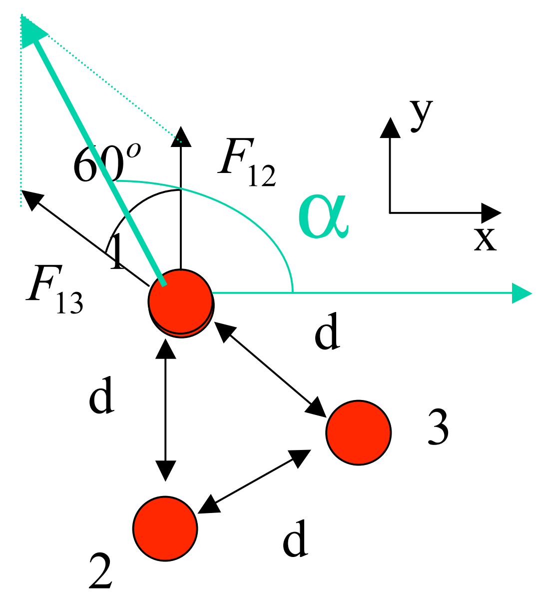
- **Question**: How do we figure out the force on a point charge due to many other point charges?
- **Answer**: consider one pair at a time, calculate the force (a vector!) in each case using Coulomb's Law and finally add all the vectors! ("superposition")
- Useful to look out for SYMMETRY to simplify calculations!

Example

$q_1 = q_2 = q_3 = 20\ \mu C$

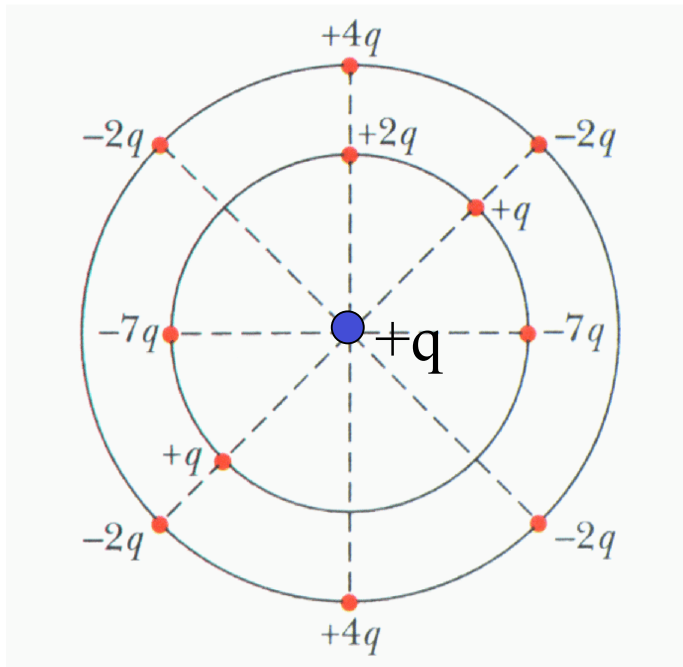
- Three equal charges form an equilateral triangle of side 1.5 m as shown
- Compute the force on q_1
- What is the force on the other charges?





Solution: Set up a coordinate system, compute vector sum of F_{12} and F_{13}

Another example with symmetry



Charge +q placed at center

What is the force on central particle?

Summary

- **Electric charges** come with two signs: **positive and negative**.

- Like charges repel, opposite charges attract, with a magnitude calculated from **Coulomb's law**: $F=kq_1q_2/r^2$

- **Atoms** have a positive nucleus and a negative "cloud".

- Electron clouds can combine and flow freely in **conductors**; are stuck to the nucleus in **insulators**.

- We can **charge objects** by transferring charge, or by induction.

- Electrical charge is **conserved**, and **quantized**.