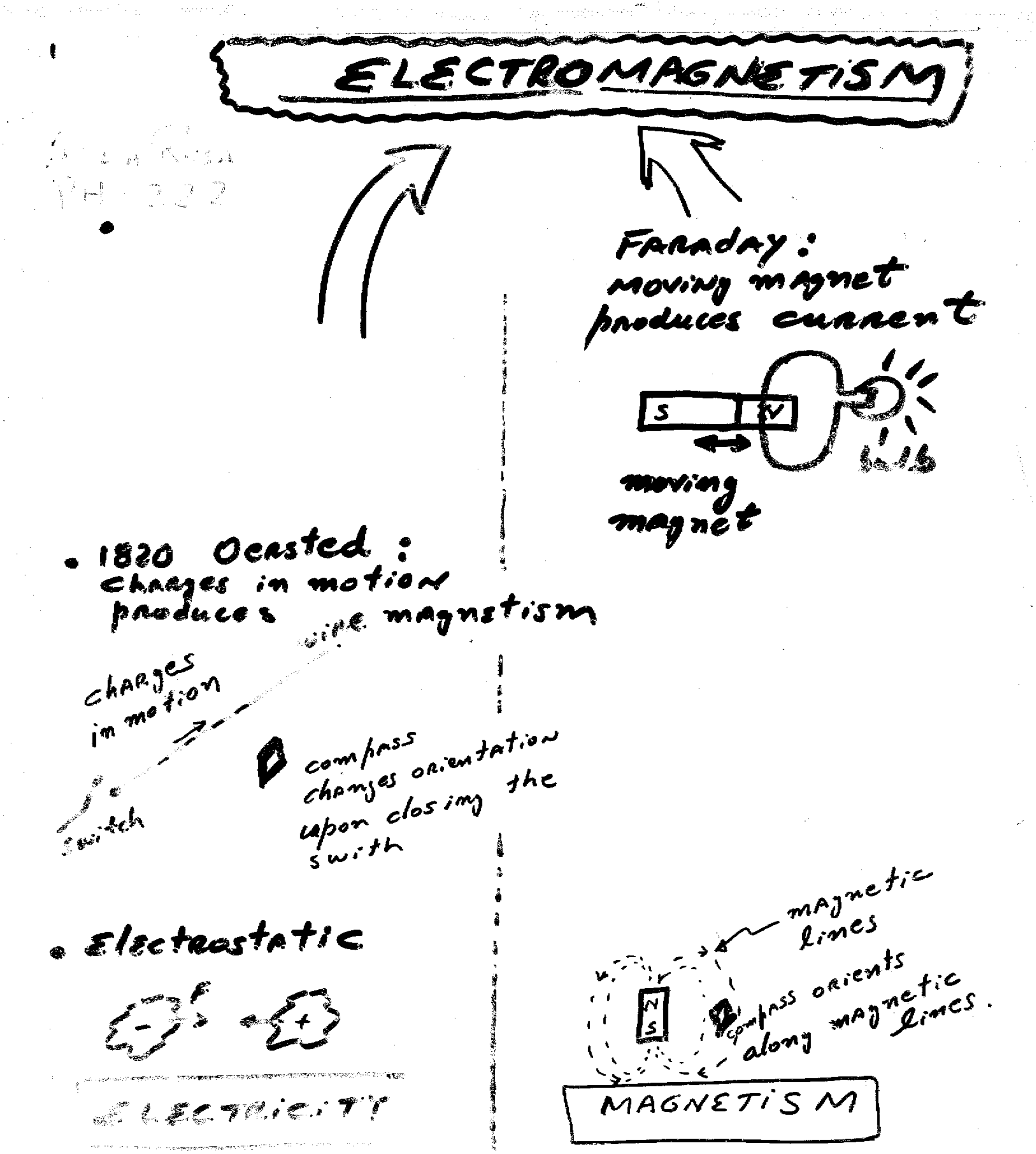

ELECTROMAGNETISM
FARADAY:
moving magnet
produces current
S
N
bulb
moving
magnet
1820 Oersted:
charges in motion
produces magnetism
wire
charges
in motion
switch
compass
changes orientation
upon closing the
swith
Electrostatic
F
-
+
ELECTRICITY
magnetic
lines
N
S
compass orients
along magnetic
lines.
MAGNETISM

ELECTROMAGNETISM

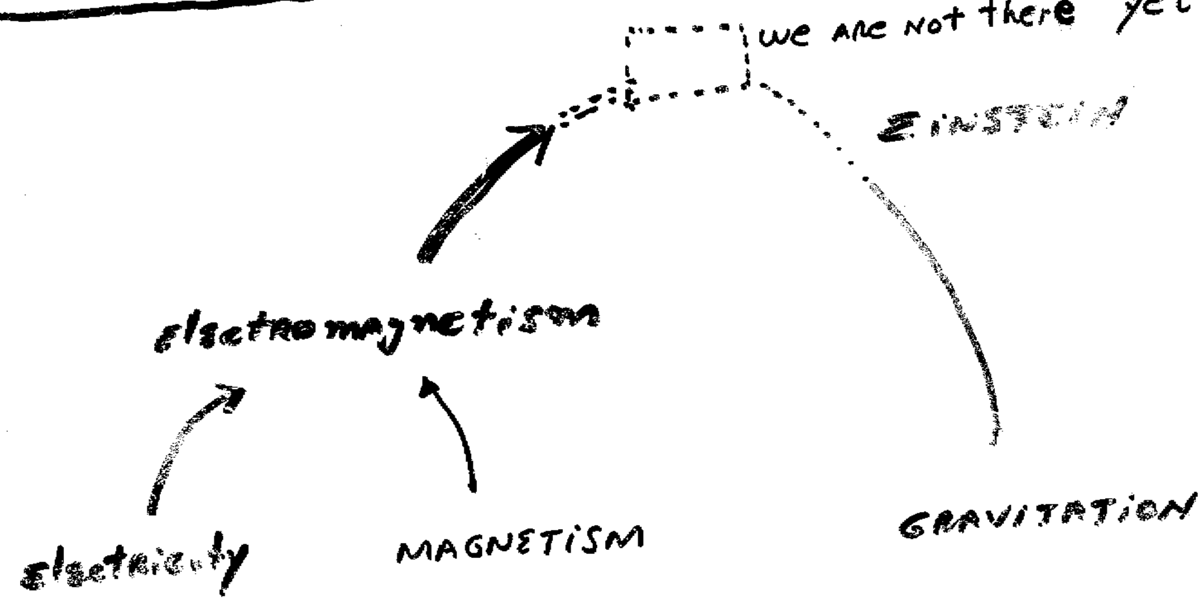
MAXWELL EQUATIONS

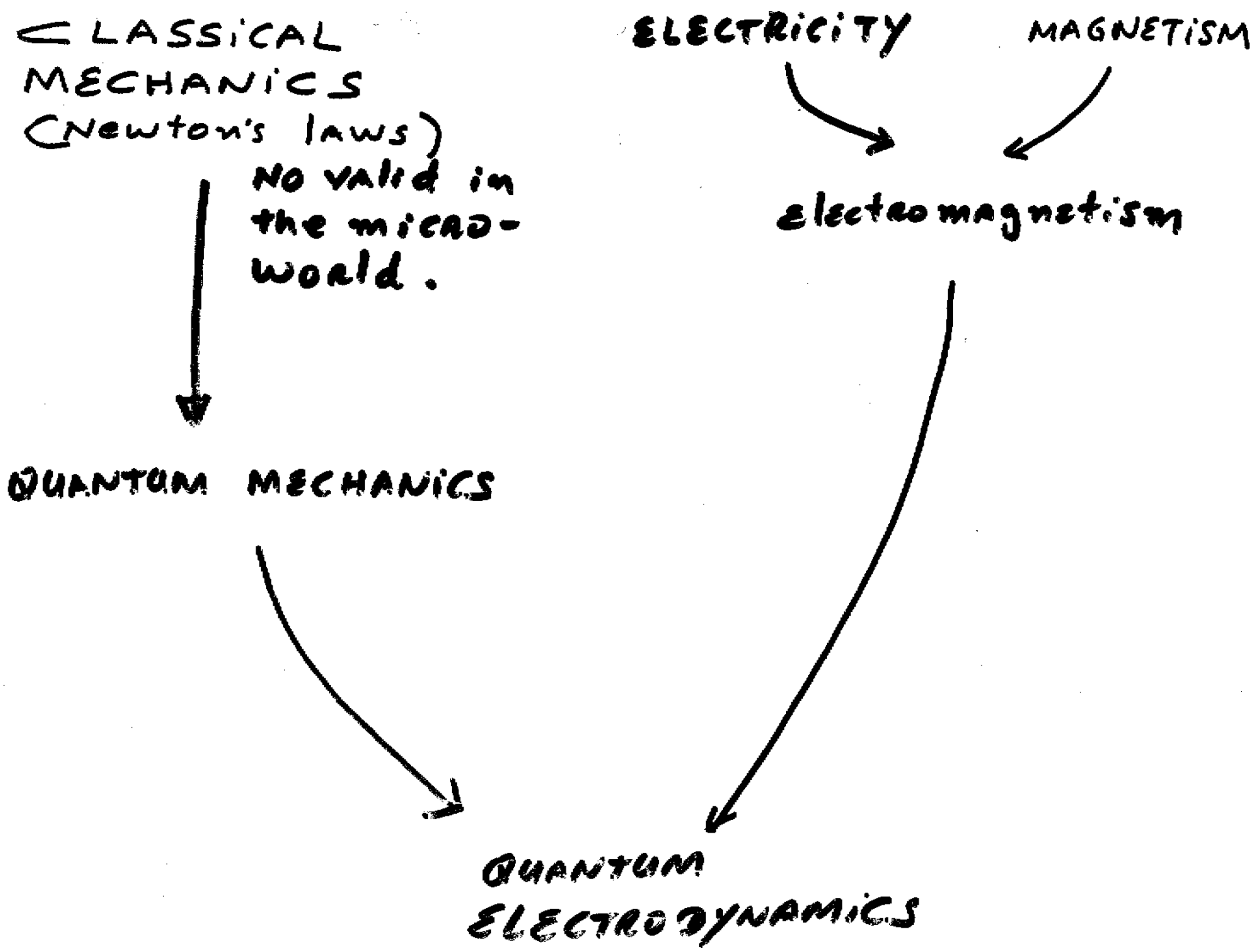
$$\bar{E} = \bar{E}\left(\bar{B}, \frac{d\bar{B}}{dt}\right)$$

$$\bar{B} = \bar{B}\left(\bar{E}, \frac{d\bar{E}}{dt}\right)$$

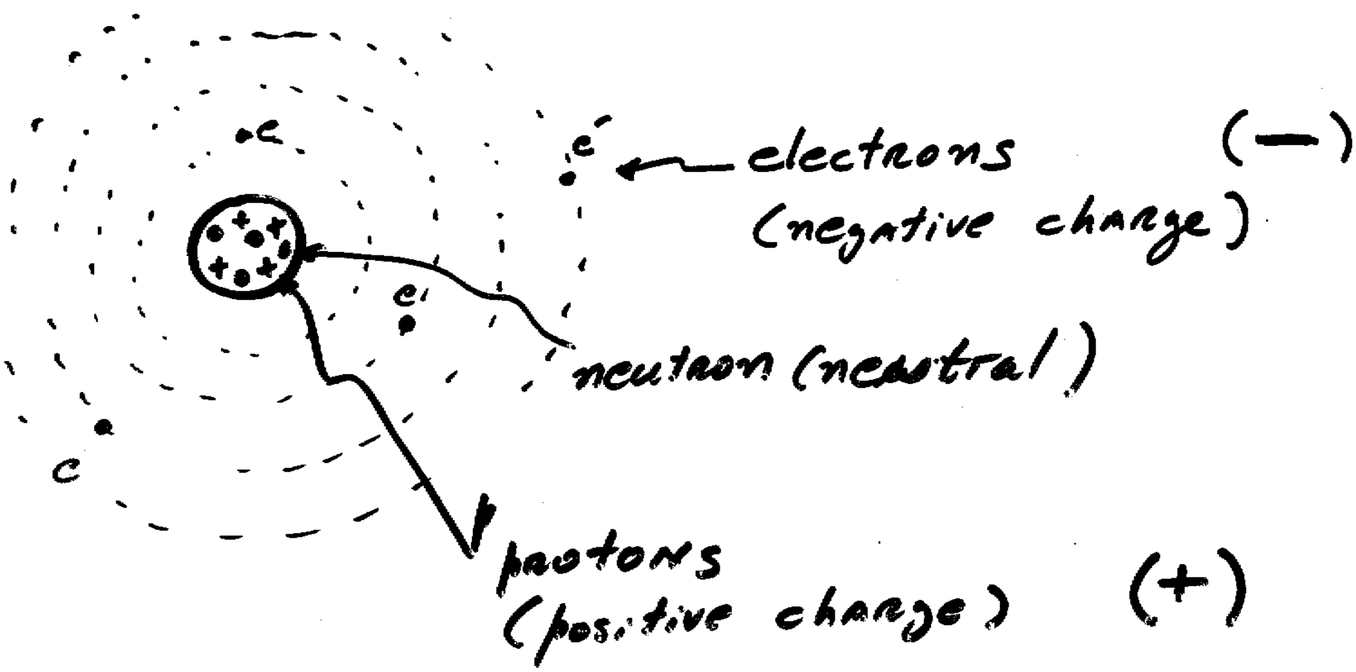
Theoretical foundation

MAXWELL equations PREDICTS that light is an electromagnetic WAVE




CLASSICAL MECHANICS (Newton's laws)
No valid in the micro-world.
QUANTUM MECHANICS
ELECTRICITY
MAGNETISM
electromagnetism
QUANTUM ELECTRODYNAMICS

ELECTRIC CHARGE

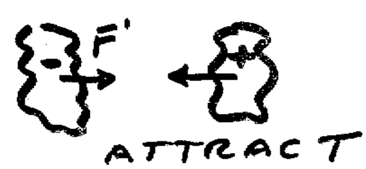


Typically: ATOMS ARE ELECTRICALLY neutral

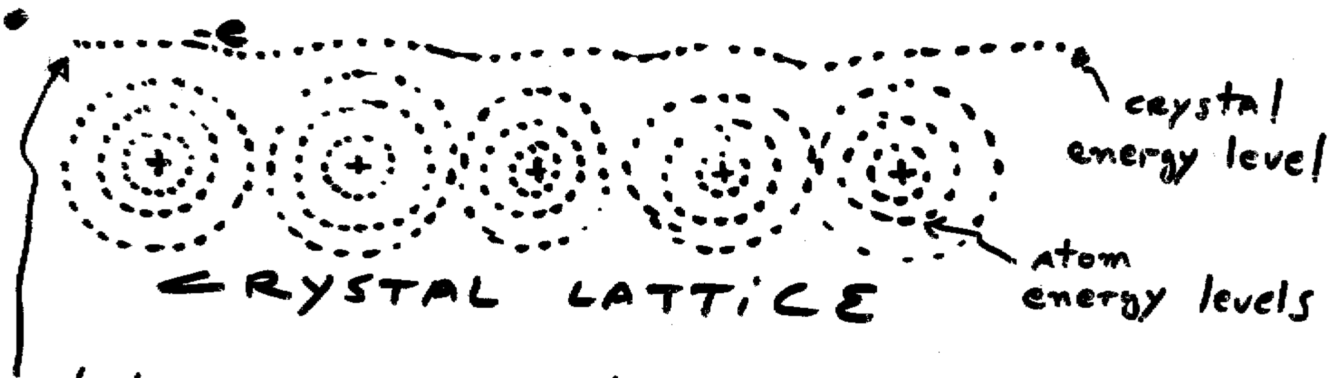
$$\#e = \#p$$

- Charges of the SAME sign REPEAL each other

- Charges of OPPOSITE sign ATTRACT each other



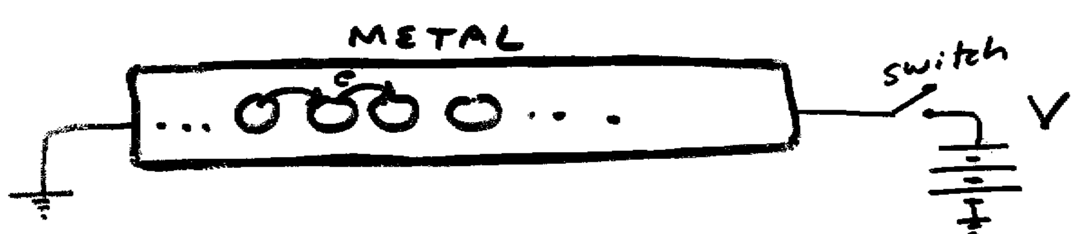
CONDUCTORS (contain "free electrons")



- electrons in the crystal energy level are "FREE" to wander across the metal
- In short, we may say:

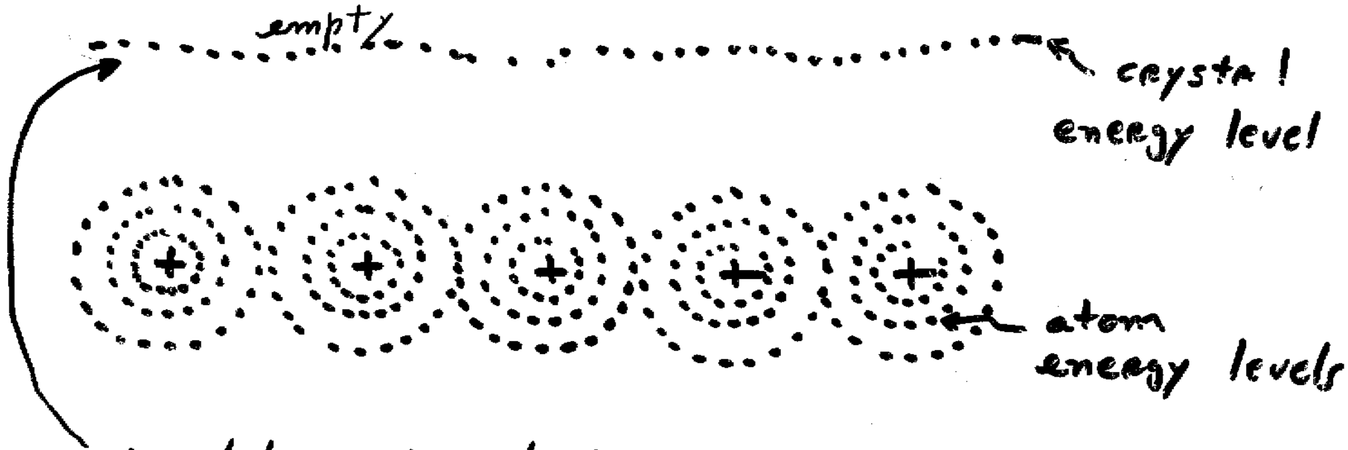
CONDUCTOR is a neutral structure with electrons free to move across the whole crystal.

- Another classical view



Q: How fast electrons jump from atom to atom? 10^{-6} m/s, 10 m/s, 10^{6} m/s ?

INSULATORS (do not have free electrons)

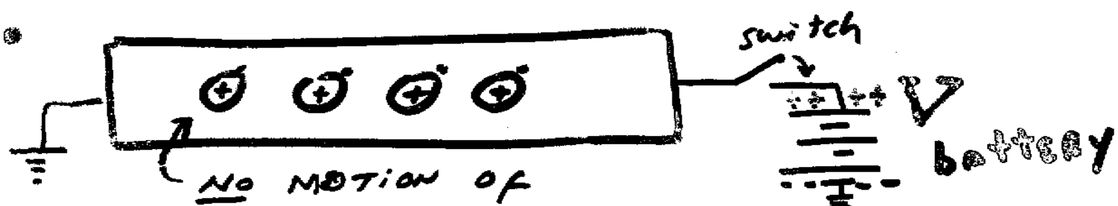


insulators do not have free electrons in the crystal energy level

- We can say:

INSULATOR

No free electrons available



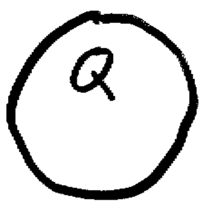
At most changes redistribute inside each atom

positive changes position to the left side

negative changes position them selves to the right side

(For really high voltage V, we may destroy the material)

- **CHARGE IS QUANTIZED**



Charge Q

$$Q = Ne$$

$$N = \pm 1, \pm 2, \pm 3, \ldots$$

$$e = 1.6 \times 10^{-19} \text{ coulomb}$$

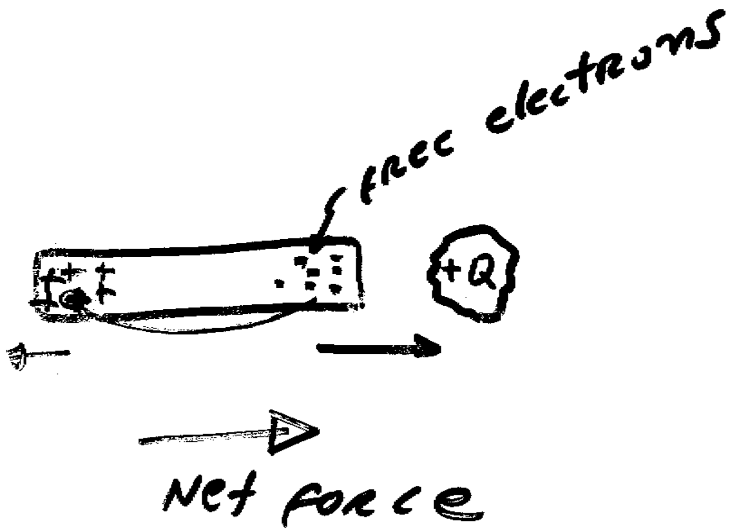
e is the smallest charge that has been detected.

(It has never been detected changes like 0.25e nor any fraction of e

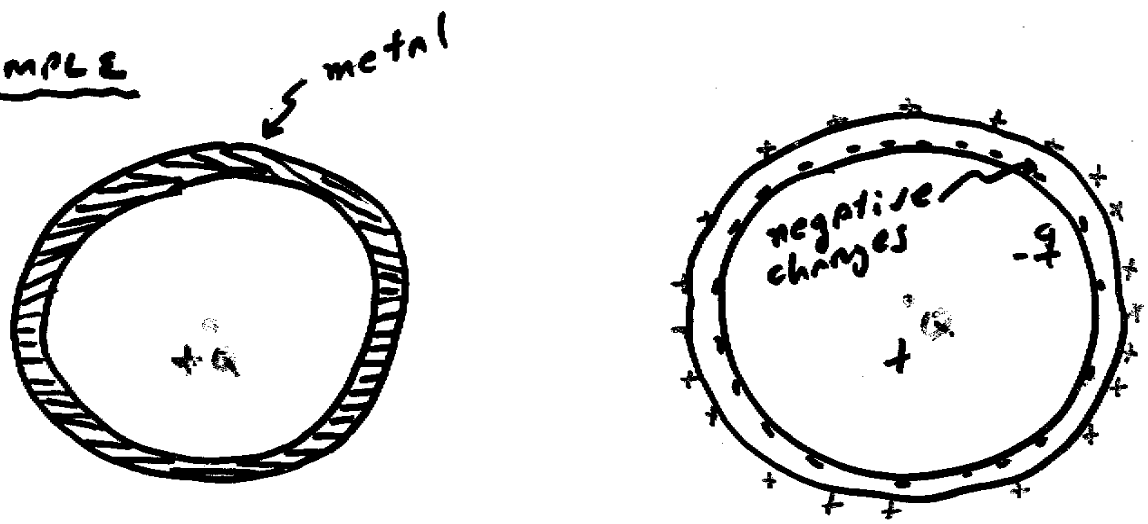
detected charge $Q = 0.37\,e$ ← WRONG!)

Phenomenom of INDUCED CHARGE

Example



EXAMPLE

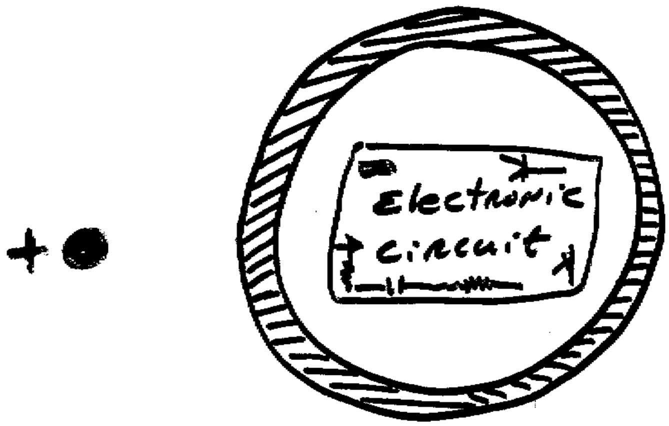


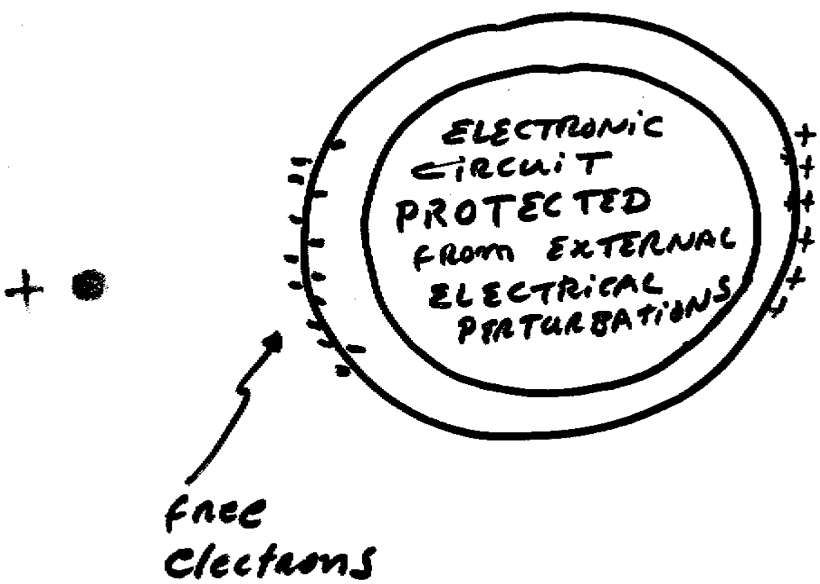
- CHARGE IS CONSERVED

$$\underbrace{Q}_{\text{before}} = \underbrace{q_1 + q_2}_{\text{after}}$$

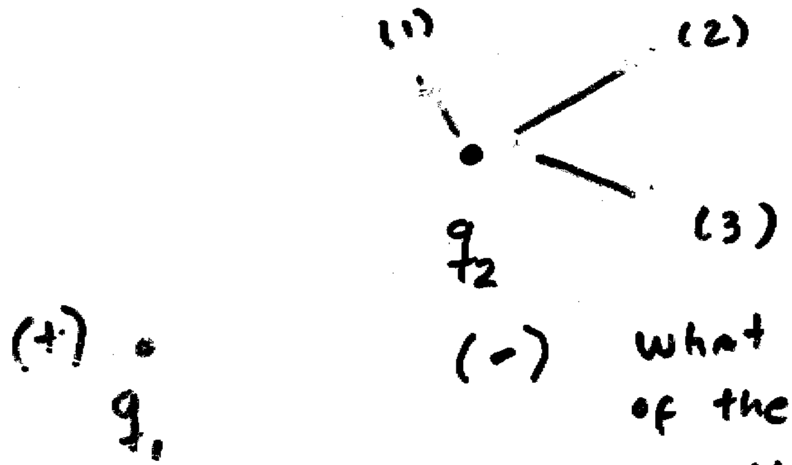
- SAMPLE PROBLEM 22-3, TEXTBOOK p. 513

" EXAMPLE


Electronic
circuit

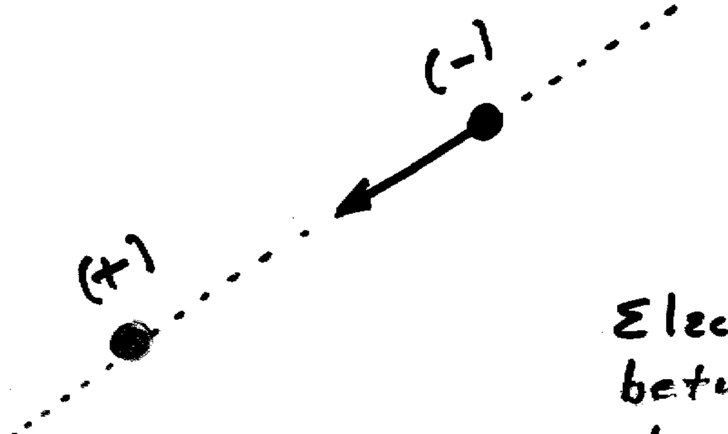

ELECTRONIC
CIRCUIT
PROTECTED
FROM EXTERNAL
ELECTRICAL
PERTURBATIONS
free
electrons

COULOMB'S LAW



What is the direction of the force acting on the charge q_2?

ANSWER:



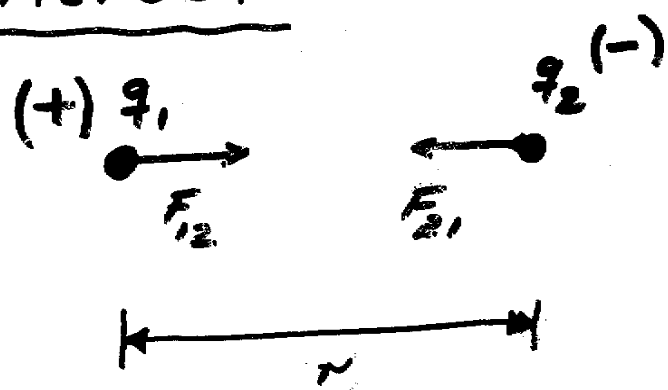
Electrical force between two charges acts along the line that passes through the charges

13 Reading homework: - induction (page 508, textbook)
- semiconductors
- superconductors

QUANTITATIVE ASPECT

- We know

$$\vec{F}_{12} = -\vec{F}_{21}$$



what is new is the following

r: distance between the particles 1 and 2

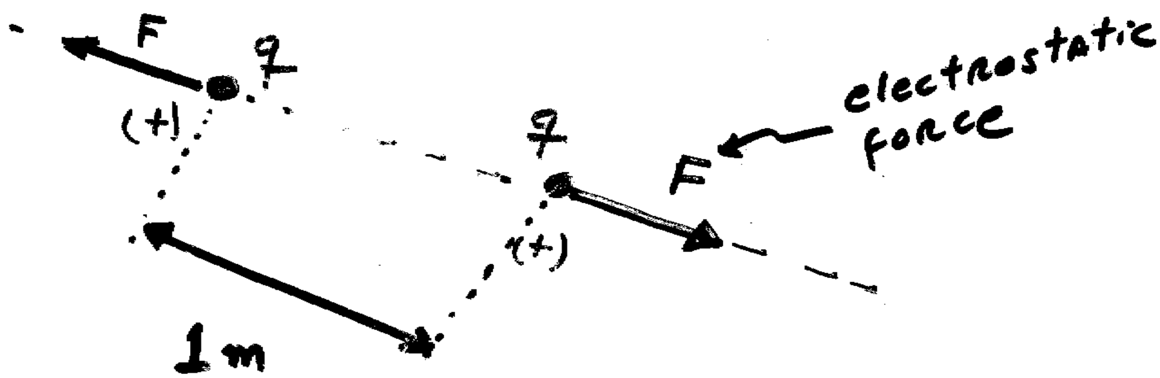
$$|\vec{F}_{12}| = \underbrace{\frac{1}{4\pi\epsilon_0}}_{K} \frac{|q_1||q_2|}{r^2} \quad \text{Coulomb's law}$$

where $\frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \; N \cdot m^2/C^2 = K$

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

Definition of the unit charge: THE COULOMB

If the distance between two punctual charges is 1 meter,



and $F = 9 \times 10^9$ Newtons

then

$q = ?$

15

• When $q_1 = q_2 = 1$ coulomb and they are apart $r = 1$ meter, the electrostatic force they exert each other is 9×10^9 Newtons

definition of the unit charge:
the coulomb (C)

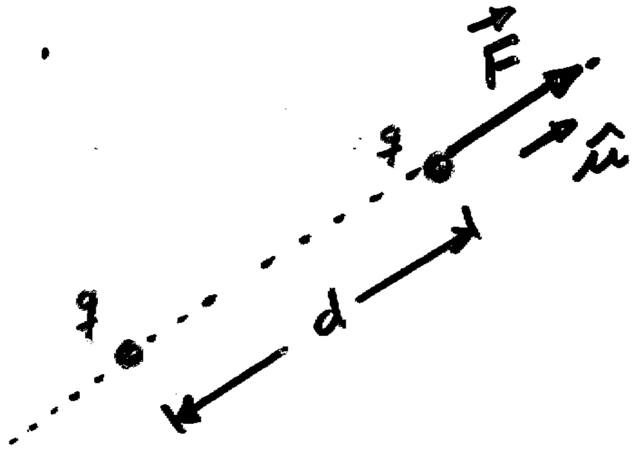
16

FORCE is a VECTOR

- Remember: the electrostatic force is a VECTOR !

  So, we must provide magnitude and orientation

17



$\vec{F}$ = magnitude & orientation

$F \equiv |\vec{F}|$

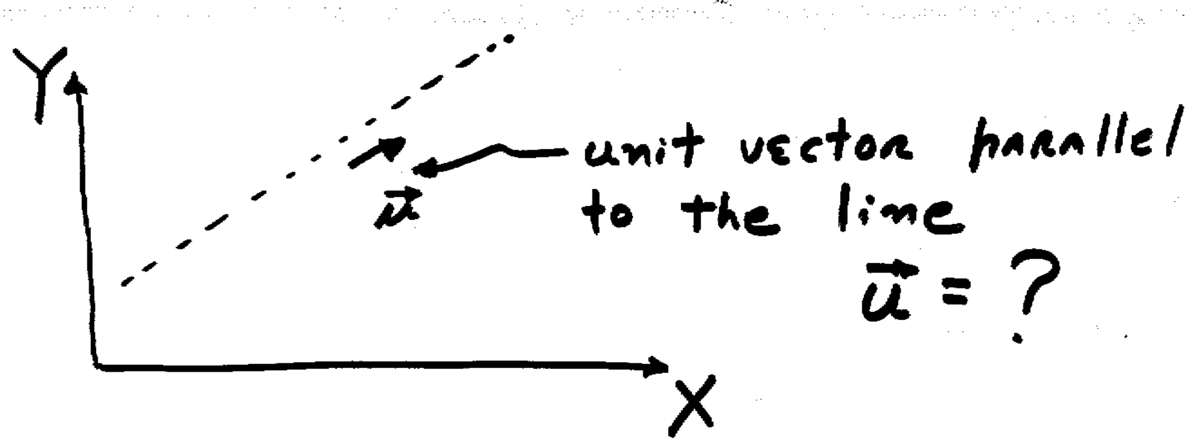
= $F \; \vec{u}$

$\vec{u}$ ← unit vector

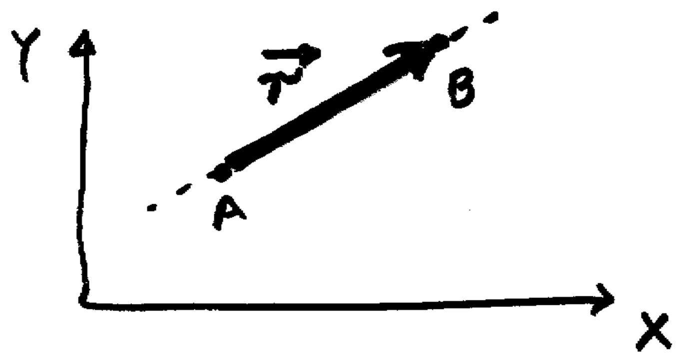
F ← $9 \times 10^9 \dfrac{q^2}{d^2}$

We know how to evaluate the magnitude
but
how to figure out the unit vector?

18



① Pick up any two points **A** and **B** along the line

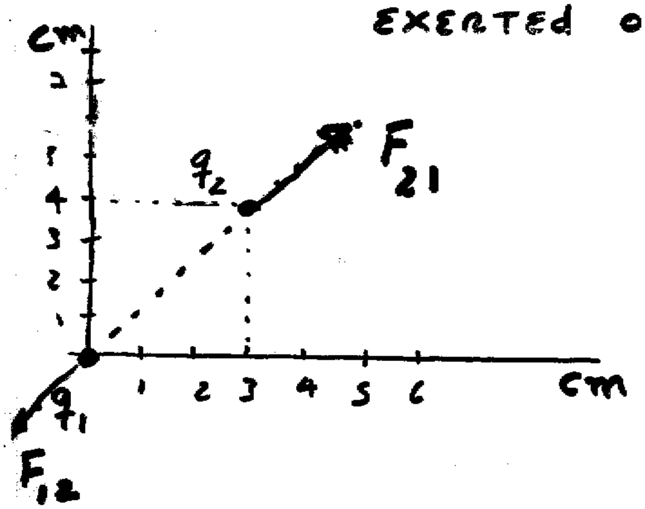


② Define the vector $\vec{r}$

Evaluate the magnitude of $\vec{r}$: $r = |\vec{r}|$

③ The vector $\dfrac{\vec{r}}{|\vec{r}|}$ will be a unit vector along the specified line. $\vec{u} = \dfrac{\vec{r}}{|\vec{r}|}$

[19] **Exercise** Find the electrostatic force exerted on charge q_2 due to the charge q_1.



$q_1 = 10\,\mu C$

$q_2 = 5\,\mu C$

SOLUTION

a) Magnitude of the force

$$F = |\vec{F}| = \frac{1}{4\pi\epsilon_0}\frac{q_1 \cdot q_2}{r^2} = 9\times 10^9 \frac{N\,m^2}{c^2}\;\frac{50\times 10^{-12}\,c^2}{(5\,cm)^2}$$

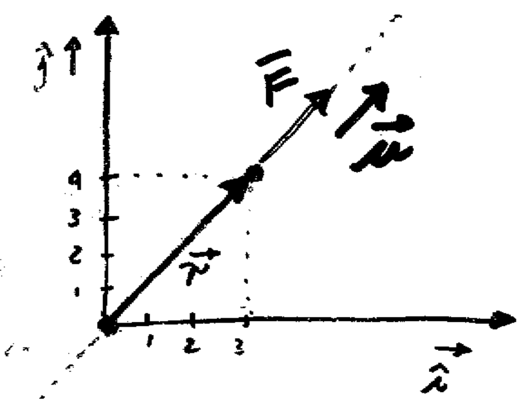
(10^{-2} m)

F = 180 N

$\vec{F} = 180\,\vec{u}$ Newtons

b) Orientation of the force

strategy ⟶ let's find the proper UNIT VECTOR



$\vec{r} = 3\hat{i} + 4\hat{j}$ cm

$|\vec{r}| = \sqrt{3^2 + 4^2} = 5$ cm

unit vector $\vec{u} = \frac{\vec{r}}{|\vec{r}|} = \frac{3}{5}\hat{i} + \frac{4}{5}\hat{j}$

20

the answer to the problem is:

$$\vec{F} = F\,\vec{u} = 180\,\underset{\smile}{N}\,\vec{u} \qquad (1)$$

F ↑ magnitude; $\vec{u}$ ↑ unit vector

Equally acceptable is the following answer:

$$\vec{F} = 180N \cdot \left(\frac{3}{5}\hat{i} + \frac{4}{5}\hat{j}\right)$$

$$= 108\hat{i} + 144\hat{j} \qquad (2)$$

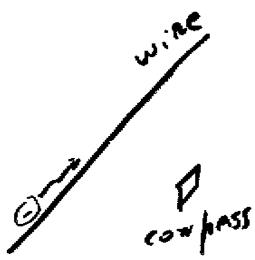
Newtons Newtons

<u>EXERCISE</u> Just for the sake of verifying we are doing things all right, FIND the magnitude of the vector force $\vec{F}$ given by expression (2)

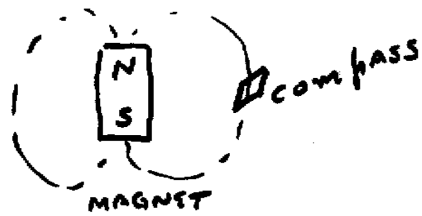
Review

ELECTROSTATIC

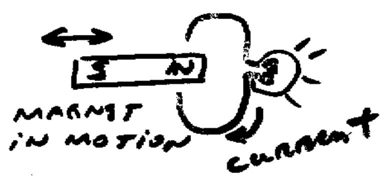
Charges in motion produces magnetism



MAGNETISM



MAGNETS in motion produces electric current

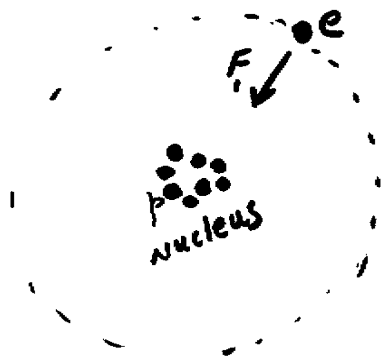


Electricity and MAGNETIC phenomena are governed by the same physical laws

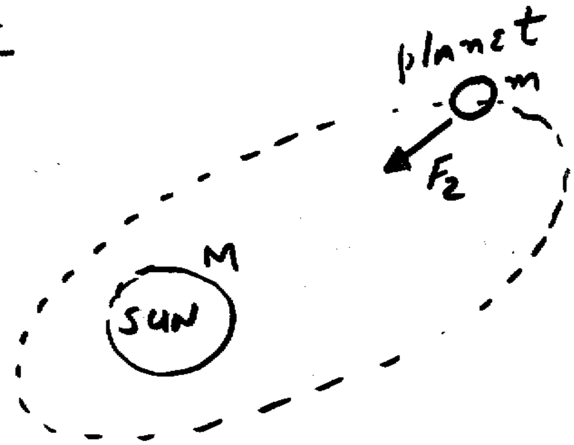
ELECTROMAGNETISM

THE 4 FORCES IN NATURE

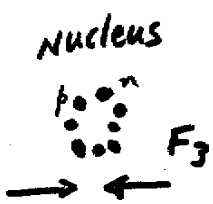
p • +
e • −
n • zero charge



electromagnetic force ①



gravitational force ②



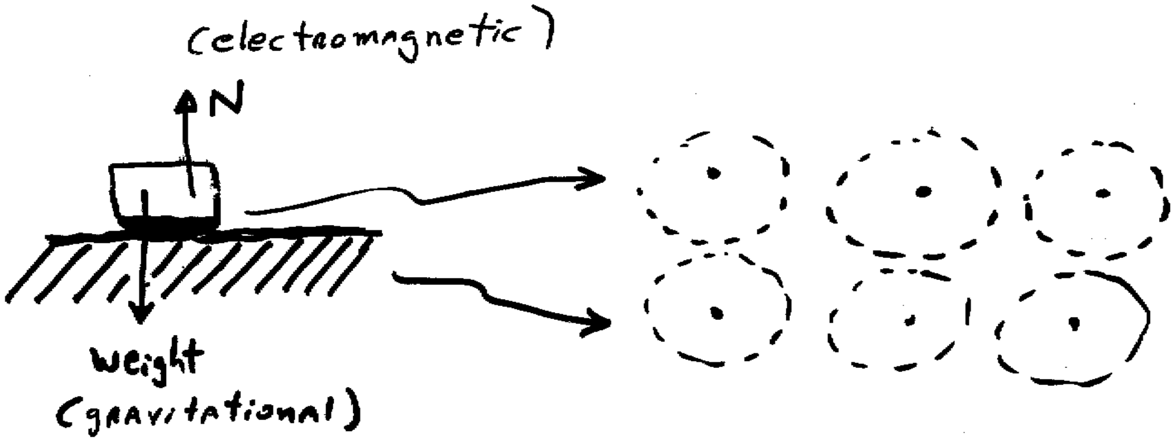
strong force ③

(keep nucleons together
stronger than electromag force
shorter range than ")

$n \rightarrow p + e^- + \bar{\nu}_e$

WEAK FORCE ④

NORMAL FORCE



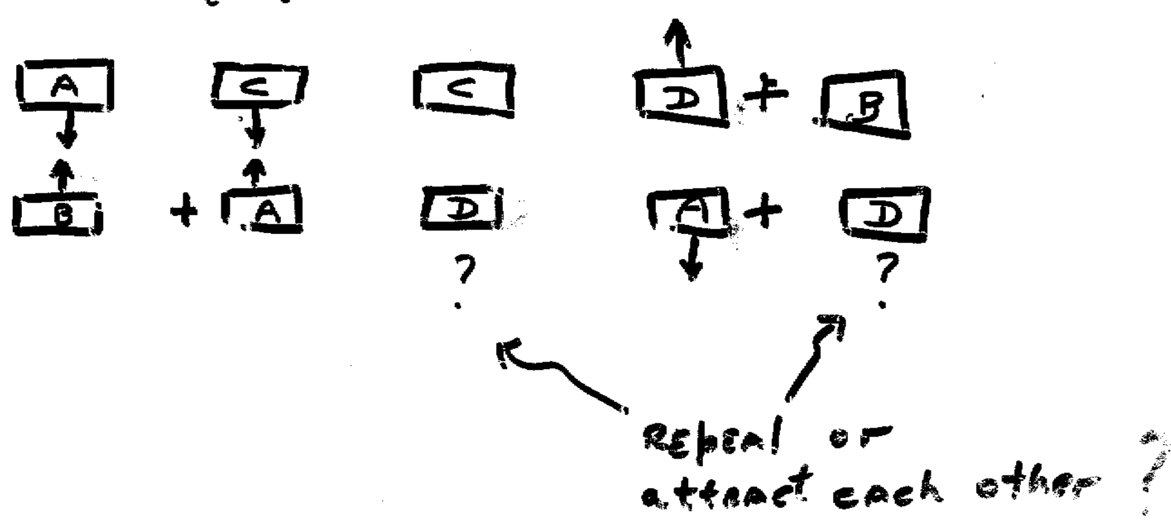
Reading assignment

- sample problem 22-4 page 515
- sample problem 22-3 page 513

Suggested practice problems
Chapter 22: 2E, 8P, 15P, 23E

* Applications
- Electrostatic paint spraying
- Powder coating
- Non impact ink-jet printing
- Photo copying

EXERCISE (page 508 textbook)



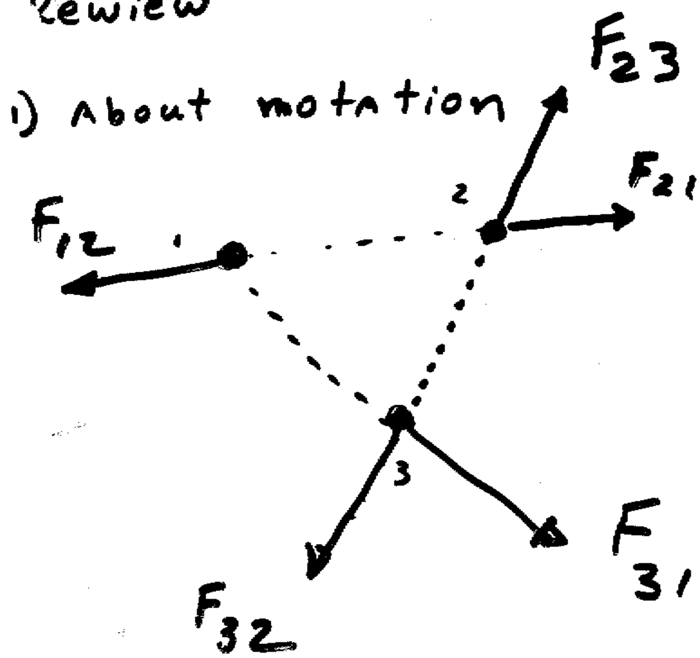
A charged plastic plate
B "
D "

C electrically neutral copper plate.

Smallest amount of charge in the world $e = 1.6 \times 10^{-19}\,C$

Rewiew

1) About motation



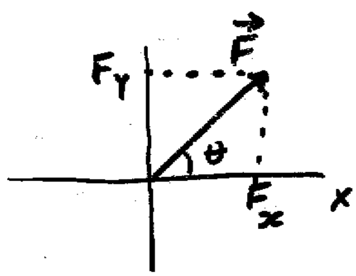
PROTON charge = e

ELECTRON charge = $-e$

How many protons will make 1 coulomb ?

ANSWER: $N = 6.25 \times 10^{18}$

2) sin and cos



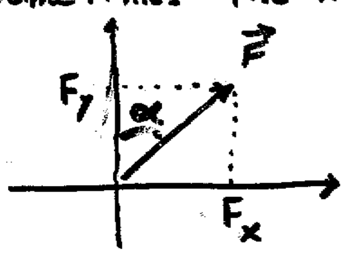
Horizontal component

$F_x = F\cos\theta$

vertical component

$F_y = F\sin\theta$

Sometimes the angle is specified in a diffent way:

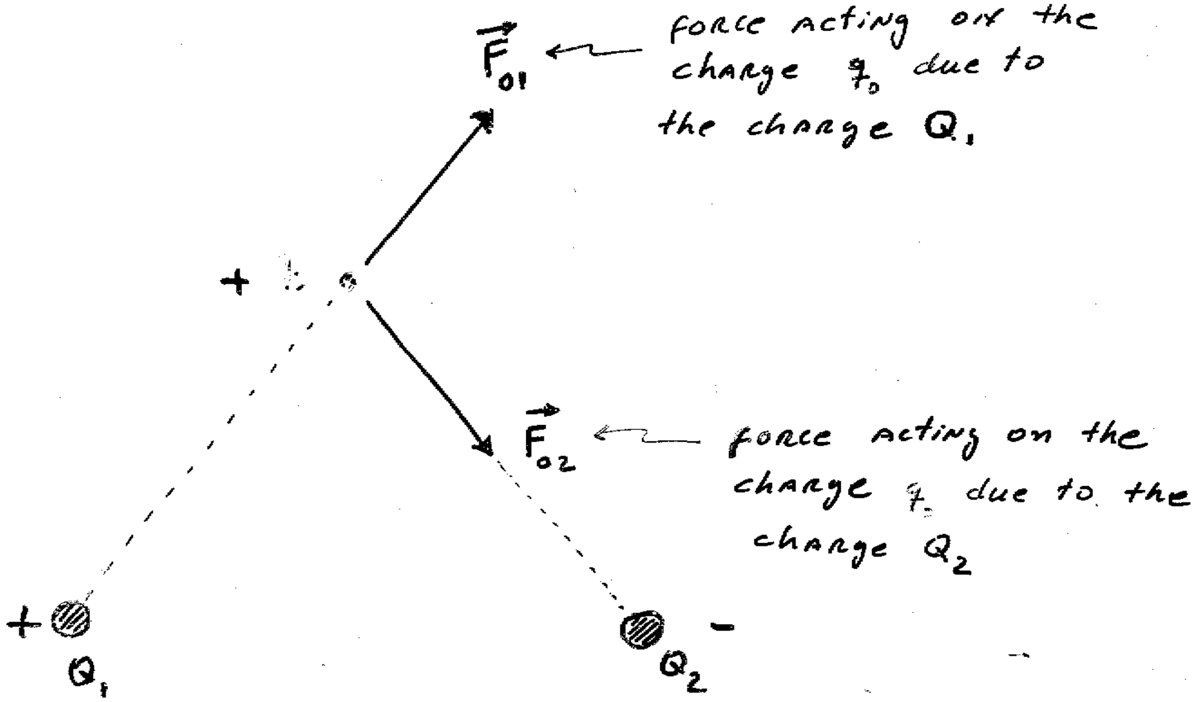


Horizontal component

$F_x = F\sin\alpha$

$F_y = F\cos\alpha$

* 3) Superposition principle



What is the total force acting on the charge q_0?

$$\vec{F} = \vec{F}_{01} + \vec{F}_{02}$$

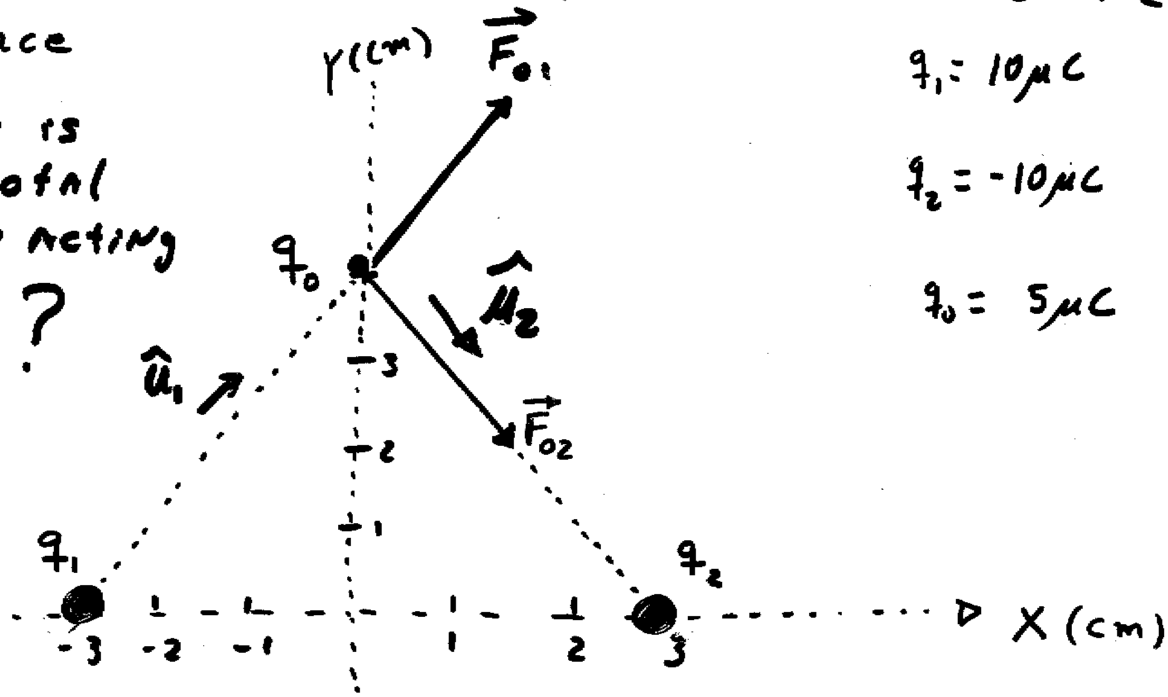
4) Instead of applying symmetry, we can alway use a long method to find the electrostatic force

what is the total force acting on q_0?

$q_1 = 10\mu C$

$q_2 = -10\mu C$

$q_0 = 5\mu C$

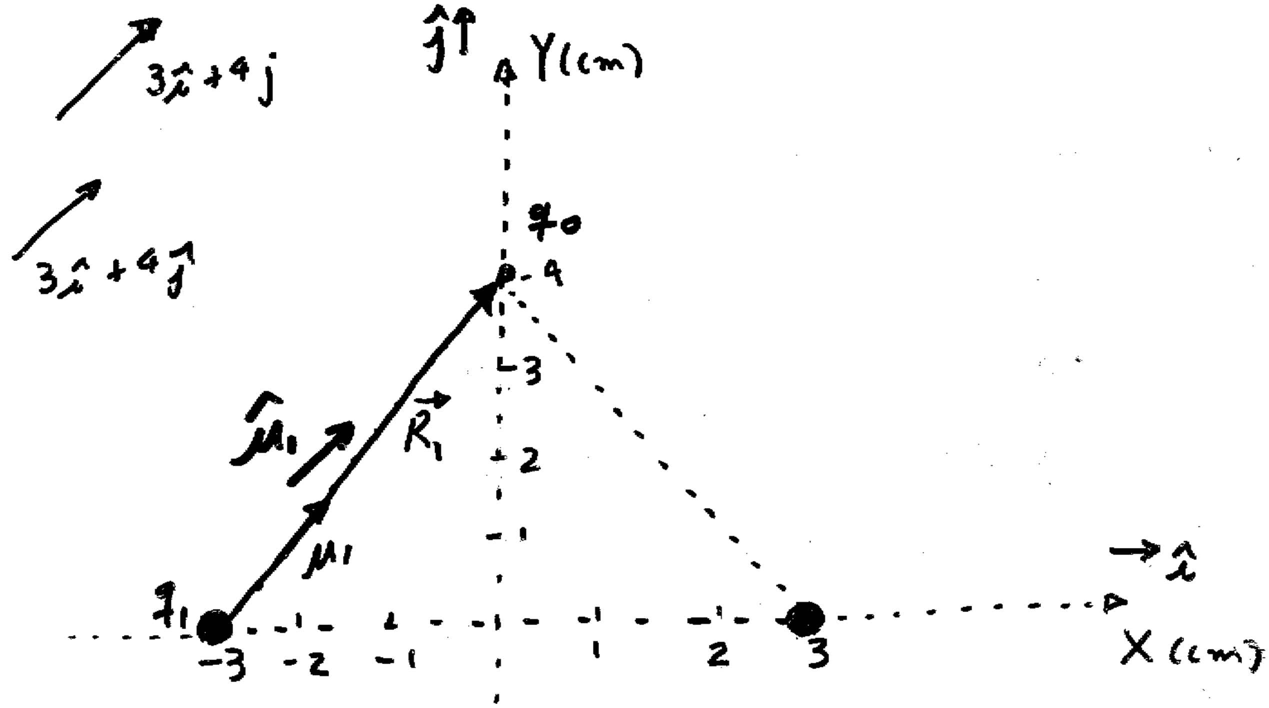


$\vec{F}_{01} = F_{01}\,\hat{u}_1$

magnitude

$F_{01} = \frac{1}{4\pi\epsilon_0}\frac{|q_0||q_1|}{r^2} = 180N$

How to find the proper unit vector :



Answer: Find any vector parallel to $\hat{\mu}_1$ and divide it by its magnitude

For example: let's take the vector $\vec{R}_1$

$$\vec{R}_1 = 3\hat{i} + 4\hat{j}$$

$$|\vec{R}_1| = \sqrt{3^2 + 4^2} = 5 \text{ cm}$$

$$\hat{\mu}_1 = \frac{\vec{R}_1}{|\vec{R}_1|} = \frac{3}{5}\hat{i} + \frac{4}{5}\hat{j}$$

10

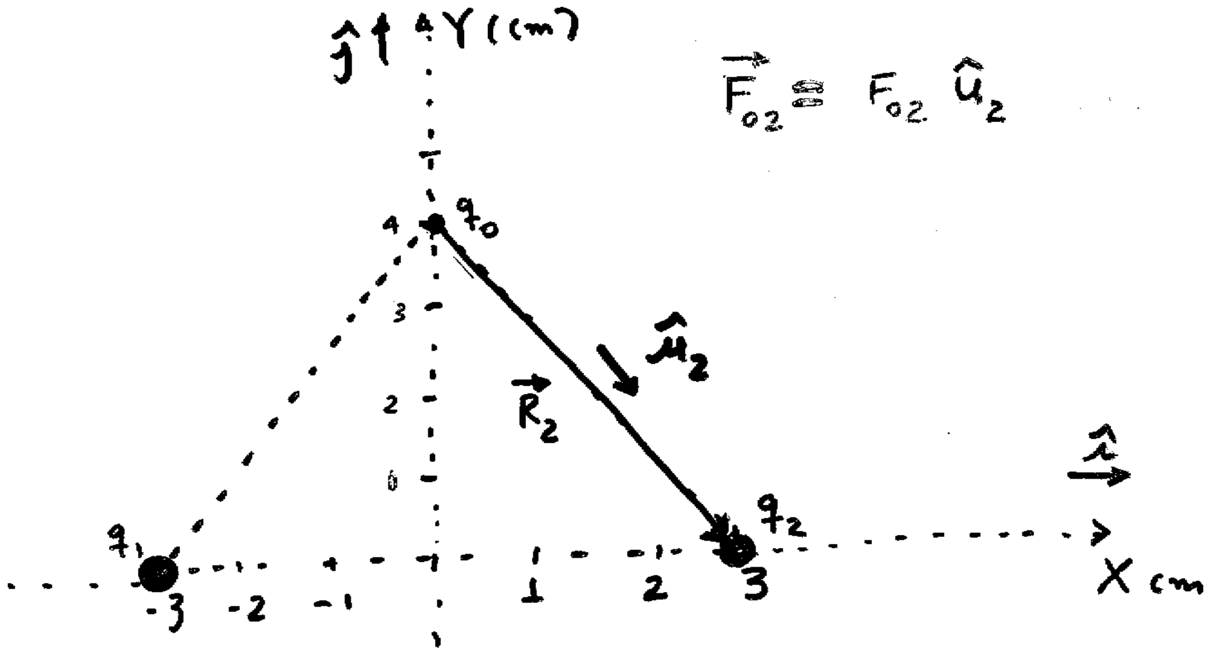
Therefore:

$$\vec{F}_{01} = F_{01}\,\vec{u}_1$$

$$= 180 \text{ Newtons} \times \left(\frac{3}{5}\hat{i} + \frac{4}{5}\hat{j}\right)$$

$$\vec{F}_{01} = 108\hat{i} + 144\hat{j} \qquad \text{(in Newtons)}$$

We apply the same procedure for $\vec{F}_{02}$:



$\vec{F}_{02} = F_{02}\,\hat{u}_2$

How to find $\hat{u}_2$?

$\vec{R}_2 = 3\,\hat{i} - 4\,\hat{j}$ ← R_2 is a vector that goes from the position of q_0 toward the position of q_2

$|\vec{R}_2| = 5$ cm

$$\hat{u}_2 = \frac{\vec{R}_2}{|\vec{R}_2|} = \frac{3}{5}\hat{i} - \frac{4}{5}\hat{j}$$

$$\vec{F}_{02} = F_{02}\,\hat{u}_2 = 180\left(\frac{3}{5}\hat{i} - \frac{4}{5}\hat{j}\right) \quad \text{in Newtons}$$

$$= 108\,\hat{i} - 144\,\hat{j}$$

#2

$$\vec{F}_{01} = 180\text{N}\,\hat{u}_1 = 180\text{N}\left(\frac{3}{5}\hat{i} + \frac{4}{5}\hat{j}\right)$$

$$\vec{F}_{02} = 180\text{N}\,\hat{u}_2 = 180\text{N}\left(\frac{3}{5}\hat{i} - \frac{4}{5}\hat{j}\right)$$

$$\vec{F}_{01} + \vec{F}_{02} = 2 \times 180 \times \frac{3}{5}\hat{i}$$

Practice problem: QUESTION #7, Textbook page 517 (such question is related to what we have done in class)

Read: sample problem 22-1 (page 511)

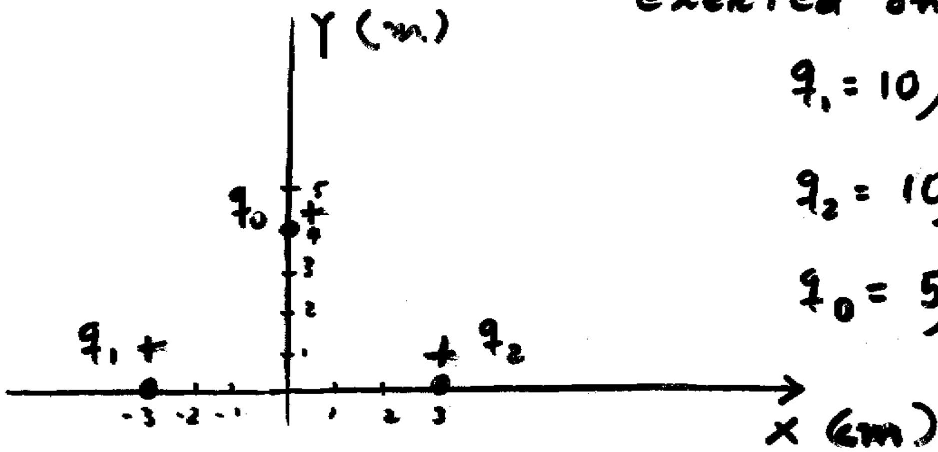
Practice questions: Q3, Q6 (page 517)

13 **EXERCISE** Find the electrostatic force exerted on charge q_0

$q_1 = 10\mu C$

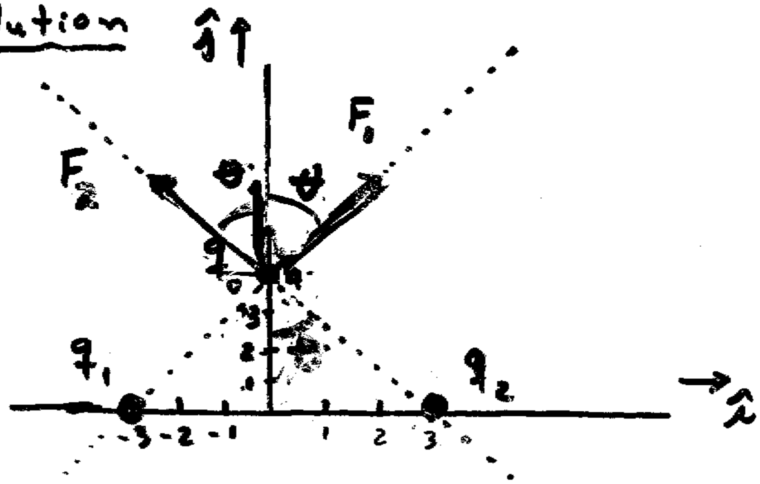
$q_2 = 10\mu C$

$q_0 = 5\mu C$



solution

0.4



Let's use symmetry

- Notice the horizontal components will cancel out
- So, let's calculate only the vertical component of each force $\vec{F}_1$ and $\vec{F}_2$

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$(F_2)_Y = F_2 \cos\theta$

$(F_2)_Y$: vertical component

F_2: magnitude of the ~~word~~ force $\vec{F_2}$

$$F_2 = \frac{1}{4\pi\epsilon_0} \frac{q_2 q_0}{r^2} = 180$$

$$9\times10^9 \times \frac{10\times10^{-6} \times 5\times10^{-6}}{(5\times10^{-2})^2} = 180\ N$$

$$\cos\theta = \frac{4}{5}$$

$$(\vec{F_2})_Y = F_2 \cos\theta = \frac{4}{5}\times 180\ N \leftarrow$$

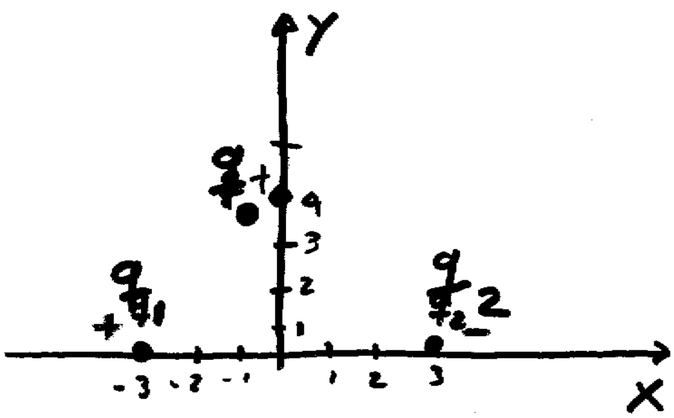
On the other hand

$$(\vec{F_1})_Y = \frac{4}{5}\times 180 \leftarrow$$

So, total force

$$\vec{F_1} + \vec{F_2} = \frac{8}{5}\times 180 \uparrow$$

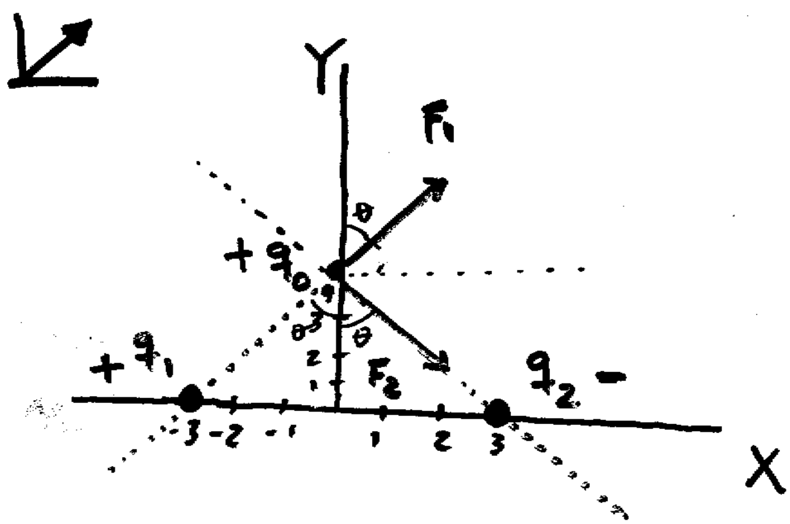
16 **Exercise** Find the electrostatic force exerted on charge q_0



$q_1 = 10 \mu C$

$q_2 = -10 \mu C$

$q_0 = 5 \mu C$



- Notice the vertical component of $\vec{F}_1$ will cancel out the vertical component of $\vec{F}_2$
- So, let's calculate only the horizontal components

16

$(\vec{F}_2)_x = F_2 \sin\theta$

horizontal component — magnitude of force $\vec{F}_2$

$$F_2 = \frac{1}{4\pi\epsilon_0} \frac{q_2 q_0}{r^2} =$$

$\sin\theta =$

$(\vec{F}_2)_x = F_2 \sin\theta =$

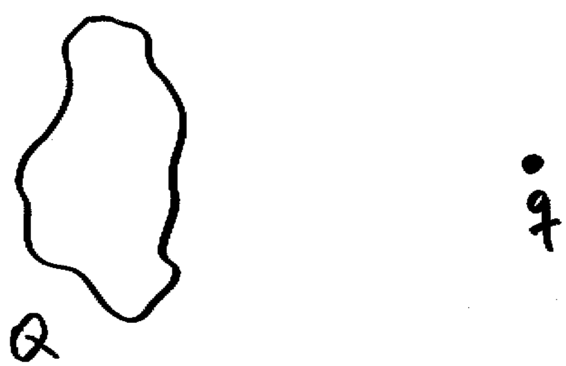
So, the total force

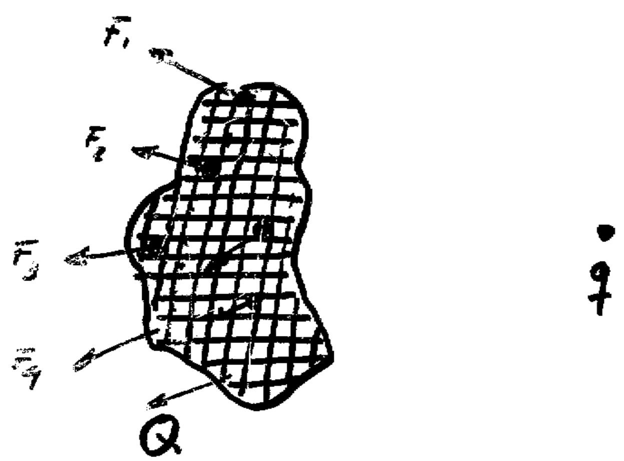
$\vec{F}_1 + \vec{F}_2 =$

Reading assignment:

sample problem 22-2, page 512 textbook

TOTAL FORCE ON charge Q ?

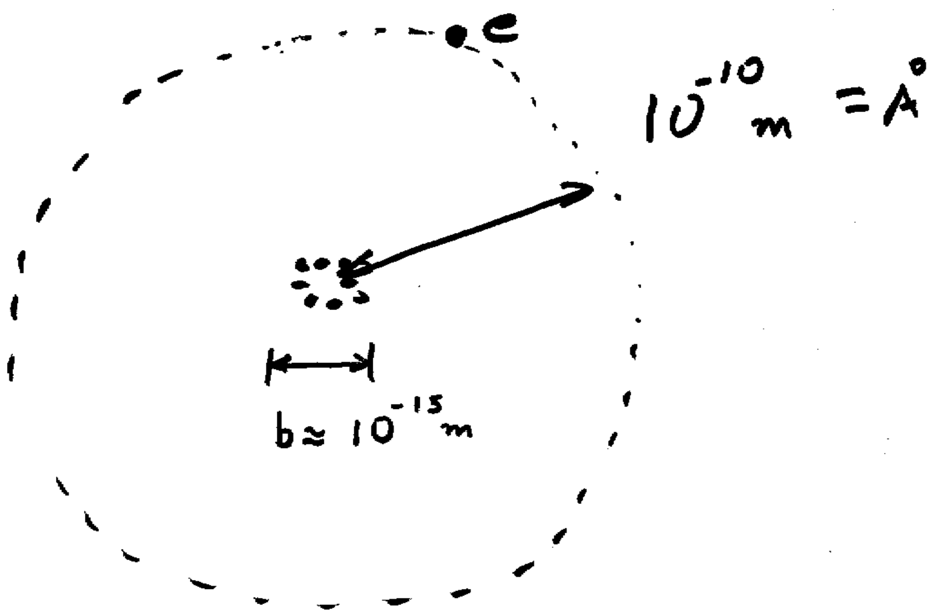




$$F_{Total} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \ldots$$

$$\sum_i \vec{F}_i$$

18



Is this figure drawn on scale ?

If b were the size of this classroom
(this is, the classroom were the nucleus)
THEN
the outermost electron of the atom
would be at Km far away from us
miles

Answer: NO