Introduction to Electromagnetism

"A physical understanding is a completely unmathematical, imprecise, and inexact thing, but absolutely necessary for a physicist"

Richard Feynman

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Why study electromagnetism?

Maxwell's Equations explain a diverse range of phenomena, from why a compass needle points north, to why a car starts when you turn the ignition key. They are the basis for the functioning of such electromagnetic devices as electric motors, cyclotrons, TV transmitters and receivers, telephones, fax machines, radar and microwave ovens.

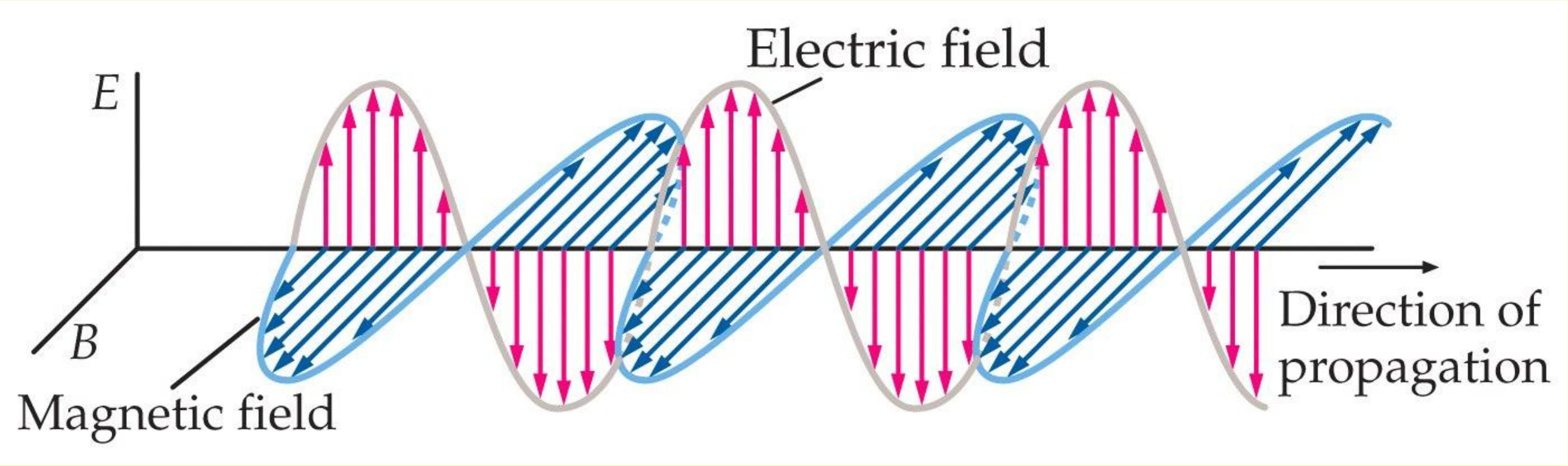


TABLE 29.2 Maxwell's Equations

Law	Mathematical Statement	What It Says	Equation Number
Gauss for $\vec{E}$	$\oint \vec{E} \cdot d\vec{A} = \frac{q}{\epsilon_0}$	How charges produce electric field; field lines begin and end on charges.	(29.2)
Gauss for $\vec{B}$	$\oint \vec{B} \cdot d\vec{A} = 0$	No magnetic charge; magnetic field lines don't begin or end.	(29.3)
Faraday	$\oint \vec{E} \cdot d\vec{r} = -\frac{d\Phi_B}{dt}$	Changing magnetic flux produces electric field.	(29.4)
Ampère	$\oint \vec{B} \cdot d\vec{r} = \mu_0 I + \mu_0 \epsilon_0 \frac{d\Phi_E}{dt}$	Electric current and changing electric flux produce magnetic field.	(29.5)

Our aim is to understand these equations, not necessarily remember them

Online resources:

(1) Weekly Reading Quiz

Take online quiz anytime each week: Quiz 1 in Week 1 etc.

Follow links from School page to first year units, course material

http://www.phys.soton.ac.uk/teach/year1/notes/phys1022/

then click on reading quizzes

Reading for Quiz 1: Wolfson 20.1 – 20.3

These are not counted in assessment for the course.

They are meant to test your understanding, so that you can return to the text if you get them wrong. You can take them more than once in order to correct your errors.

(2) Problem sets will be available online each week. The link to the problems is on the PHYS1022 front webpage. It is:

http://www.masteringphysics.com/

The presentation about MasteringPhysics and how to register is also on the webpage. A further notice about registering for the e-Book is contained in an Announcement on MasteringPhysics (which went out as an email).

These problems must be completed by the set deadline, which will be clearly stated (usually Friday at 12 midnight).

(3) Problems sheets will also be distributed at the Wednesday Workshop. They will be available online as well.

They contain conceptual problems to be discussed in your tutorials. The problems will be done in Wednesday Workshops, where help will be available. You may also get help with these from your tutor, who will have a copy of the answers.

Answers to these problems will be posted on the MasteringPhysics page after a suitable interval.

Hints on Lectures and note-taking

Taking notes is an important skill. The act of writing in a lecture should help fix the material in your memory so that it is easier to recall later. What you record in a lecture gives you a reminder of what to go over later, and understand better.

In lecture:
- No need to write everything. Note main facts, ideas, results.
- Listen to what is said. It is difficult to write and listen.
- Underline or highlight important points.
- Use simple diagrams.
- Most importantly, if you don't understand something, make a note of it.

Hints on Lectures and note-taking

After lecture:

- Read through notes as soon as possible.
- Copy them out again, especially if messy, adding to them from textbook.
- Sort out the points you don't understand, read up, ask me, or tutor.
- Discuss with friends, as this really helps understanding.

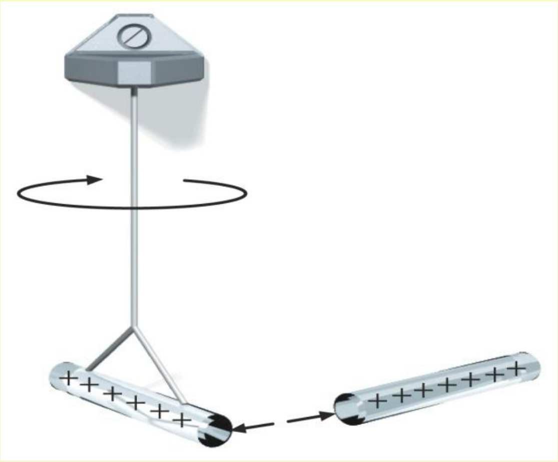
Summary sheets will be provided before the lectures each week, and lecture slides will appear on the web page for PHYS1022 after the lecture.

In this lecture you'll learn

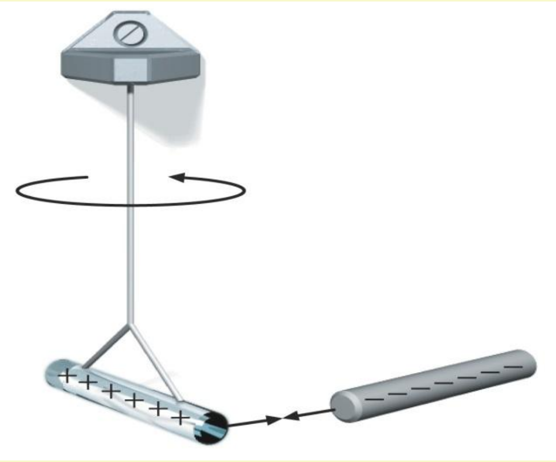
- How matter and many of its interactions are fundamentally electrical
- About electric charge as a fundamental property of matter
- To describe the electric force between charges

and by the end of this week:

- The concept of electric field
  - How to calculate the fields of discrete and continuous charge distributions
- How charges respond to electric fields



Same signs repel



Opposite signs attract

Coulomb's Law quantifies the forces drawn

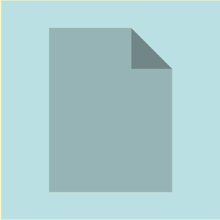
Compare with gravity

(see tutorial discussion question on Sheet 1)

Electric Charge, Force and Field

Wolfson chapter 20

Some spectacular holiday pictures…



One of these is untrue – which is it?

A. Insulators can be charged

B. Charged objects attract neutral objects

C. Neutral does not mean 'no charges'

D. Charge is not an object – it is a property of matter

E. There is no fundamental reason why electrons have to be negative

F. There is no difference between charge and current

Answer: F, current is <u>motion</u> of charge

A and B: e.g. balloon sticking to wall.

Charge conservation

– charge is transferred, not created

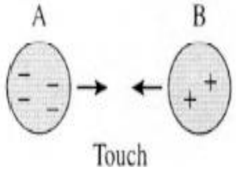
Charge quantisation

$$e = 1.602177 \times 10^{-19}\ \text{C} \approx 1.60 \times 10^{-19}\ \text{C} \qquad 21\text{-}1$$

FUNDAMENTAL UNIT OF CHARGE

EXERCISE:

Metal sphere A has 4 units of negative charge and metal sphere B has 2 units of positive charge. The two spheres are brought into contact. What is the final charge state of each sphere? Explain.



A. -1

B. -2

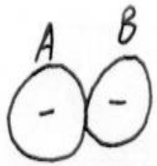
C. -3

D. -4

Answer: -1

1 Answer: -1

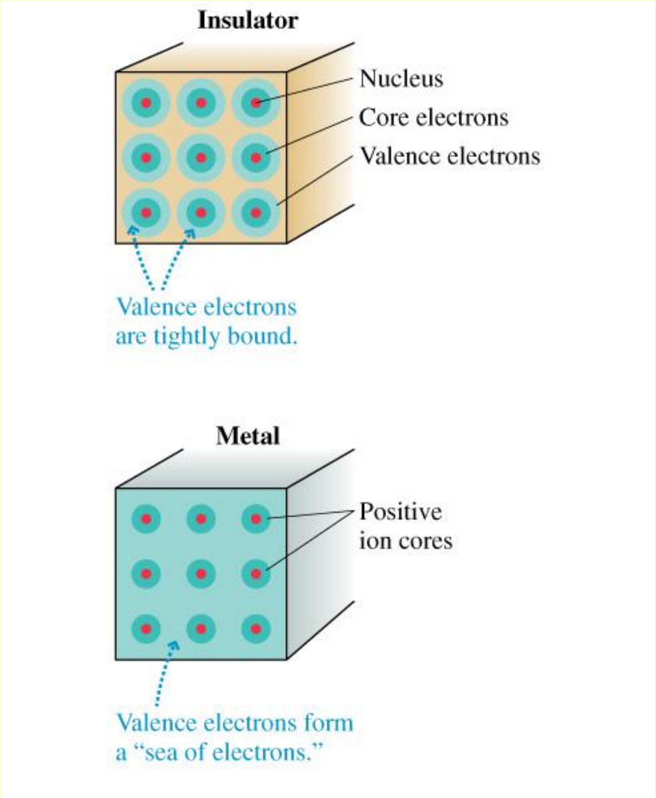
Each sphere ends up with 1 unit of negative charge. Once they touch, the two spheres become essentially one conductor. The overall net charge is $-4 + 2 = -2$. Charge is spread uniformly over the surface of a conductor.



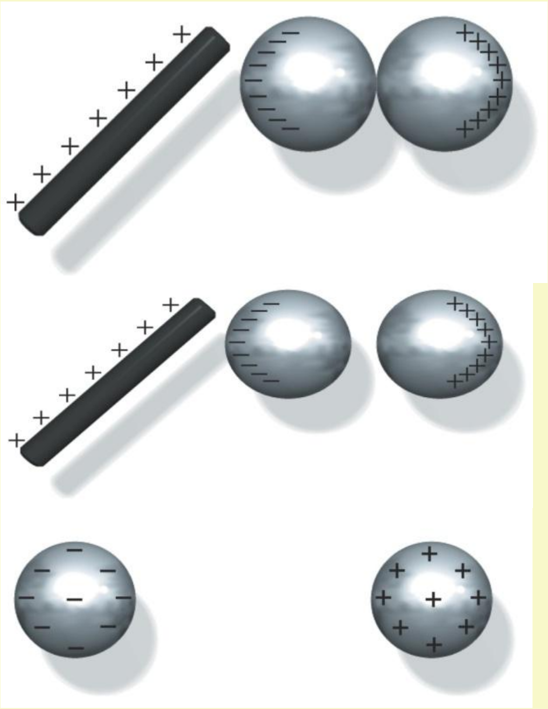
Conductors and Insulators

In materials such as wood or glass, all the electrons are bound to nearby atoms and none can move freely. These materials are called insulators.

In many materials, such as copper and other metals, some of the electrons are free to move about the entire material. Such materials are called conductors.



Charging by induction



(a) Conductors in contact become oppositely charged when a charged rod attracts electrons to the left sphere

(b) if the spheres are separated before the rod is removed, they will retain their equal and opposite charges

(c) When the rod is removed and the spheres are far apart, the distribution of the charge on each sphere approaches uniformity

EXERCISE: Two identical conducting spheres, one with an initial charge +Q, the other initially uncharged, are brought into contact.

(a) What is the new charge on each sphere?

A. +Q or

B. $+\frac{1}{2}Q$

$+\frac{1}{2}Q$. Since the spheres are identical, they must share the total charge equally.

(b) While the spheres are in contact, a negatively charged rod is moved close to one sphere, causing it to have a charge of +2Q. What is the charge on the other sphere?

A. –Q or

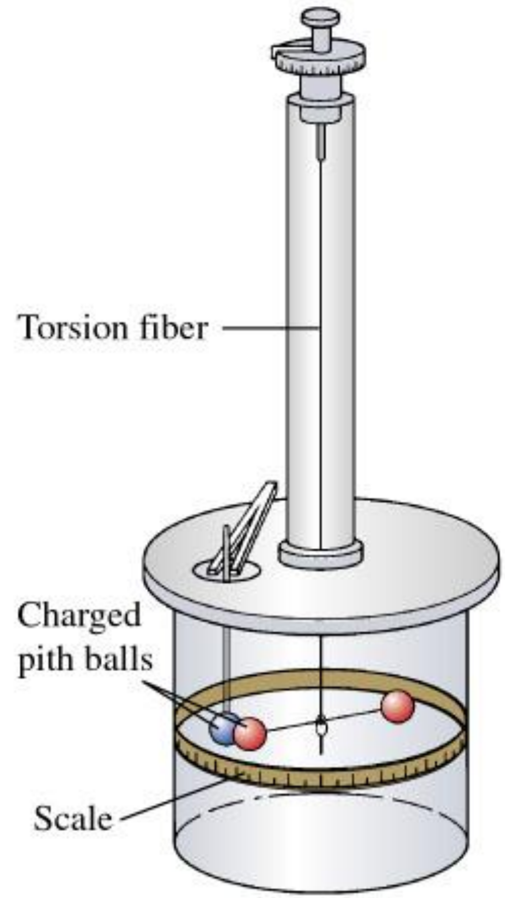
B. –2Q

C. other

–Q, necessary to satisfy the conservation of charge.

20.2 Coulomb's Law

Charles Coulomb (1736-1806) studied the force exerted by one charge on another using a torsion balance of his own invention.



(a)

EXERCISES using Coulomb's law – the concept

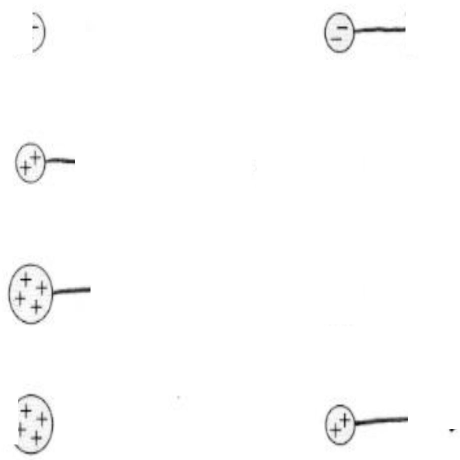
22. For each pair of charges, draw a force vector *on each charge* to show the electric force acting on that charge. The length of each vector should be proportional to the magnitude of the force. Each + and – symbol represents the same quantity of charge.

a.

b.

c.

d.



Coulomb's Law

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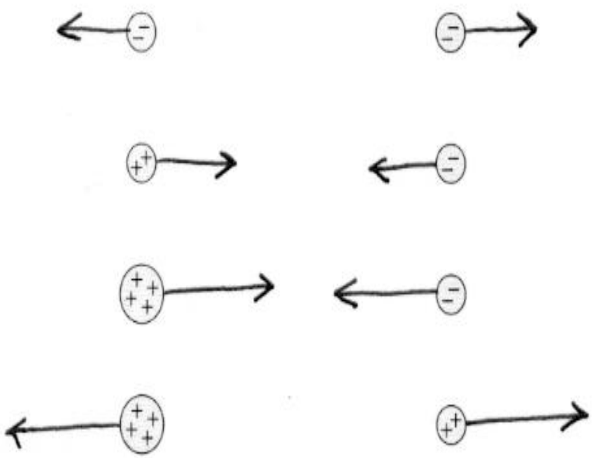


Equal and opposite forces

The force exerted by one point charge on another acts along the line between the charges. It varies inversely as the square of the distance separating the charges and is proportional to the product of the charges. The force is repulsive if the charges have the same sign and attractive if the charges have opposite signs.

COULOMB'S LAW

The **magnitude and direction** of the electric force exerted by a charge q_1 on another charge q_2 a distance $\underline{r}$ away is given by

$$\vec{F}_{12} = \frac{kq_1q_2}{r^2}\hat{r} \qquad \text{(Coulomb's law)} \qquad (20.1)$$

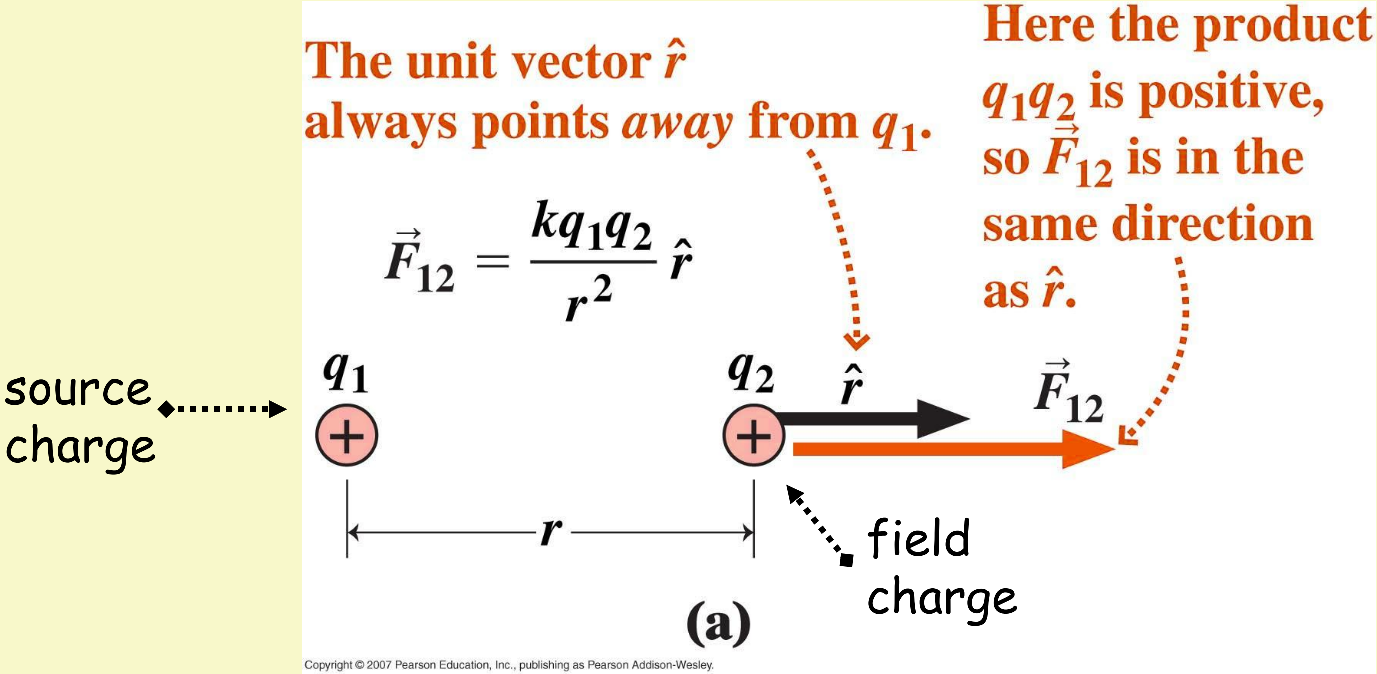
where k is an experimentally determined constant

$k = 9.0 \times 10^9\ N.m^2/C^2$ (we will abandon this later in the course)

notation

unit vector

Diagram needed!


The unit vector $\hat{r}$ always points *away* from q_1.
Here the product q_1q_2 is positive, so $\vec{F}_{12}$ is in the same direction as $\hat{r}$.
$\vec{F}_{12} = \frac{kq_1q_2}{r^2}\hat{r}$
q_1
q_2
$\hat{r}$
$\vec{F}_{12}$
r
source charge
field charge
(a)
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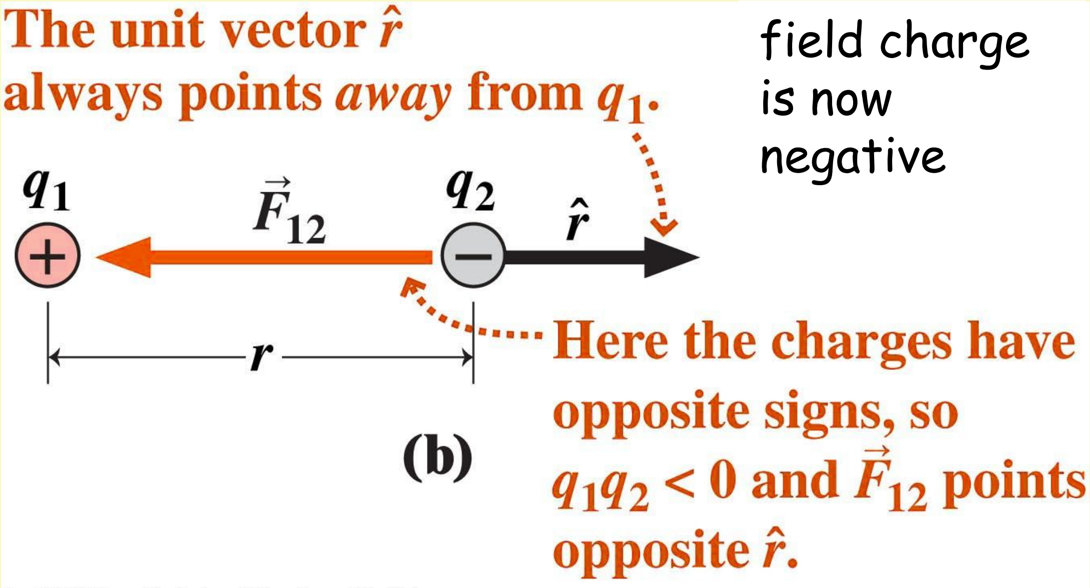
field charge
is now
negative



Example 20.1 p 331 Finding the electric force: two charges

A 1.0 μC charge is at x = 1.0 cm, and a -1.5 μC charge is at x = 3.0 cm. What force does the positive charge exert on the negative one?

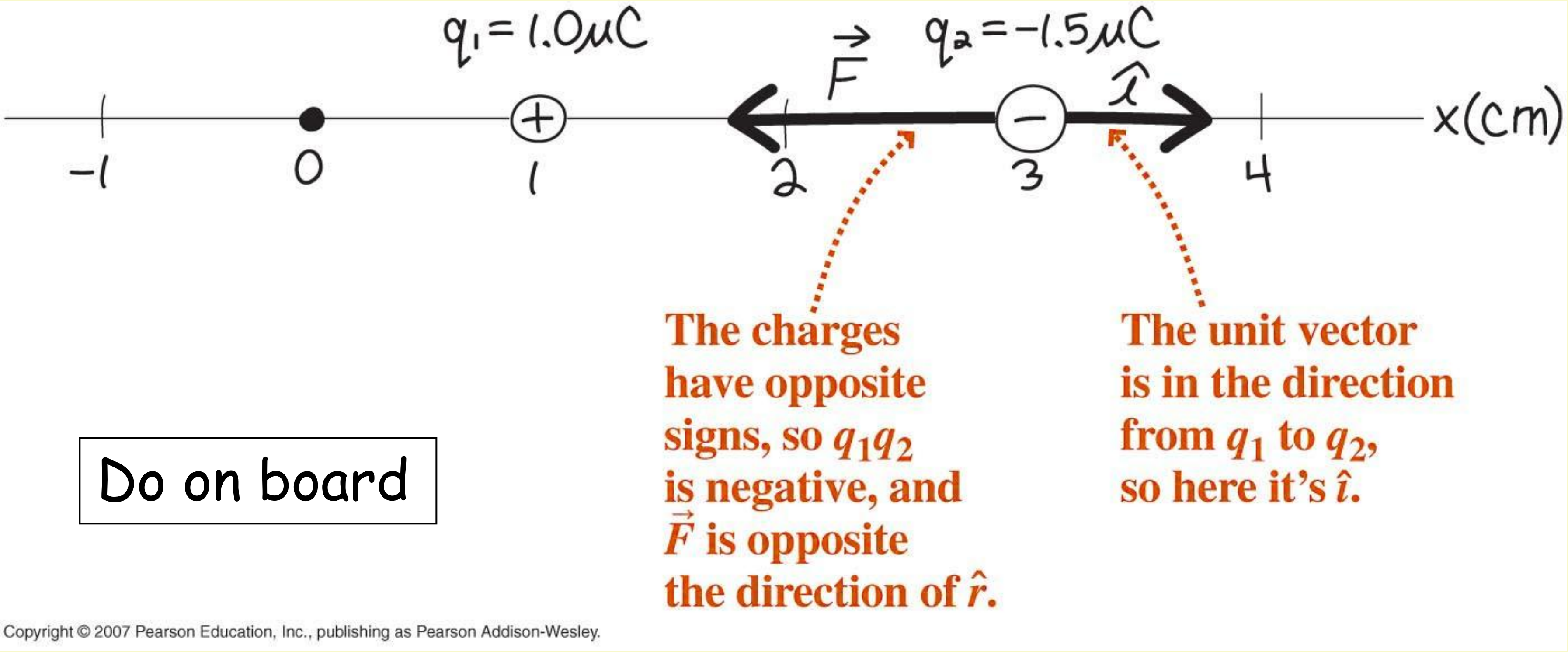
Read Problem-Solving Strategy for using Coulomb's Law on p 330

Interpret: identify the source charge

Develop: draw coordinates and position of charges
determine unit vectors (are any along the axes?)

Evaluate: using Coulomb's law remembering force is a vector

Assess: is the force in the direction you expect for the sign of the charges?



Do on board

End of Lecture 1

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