Purdue University Department of Physics

Physics 24100

Electricity & Optics

Fall 2012 Semester

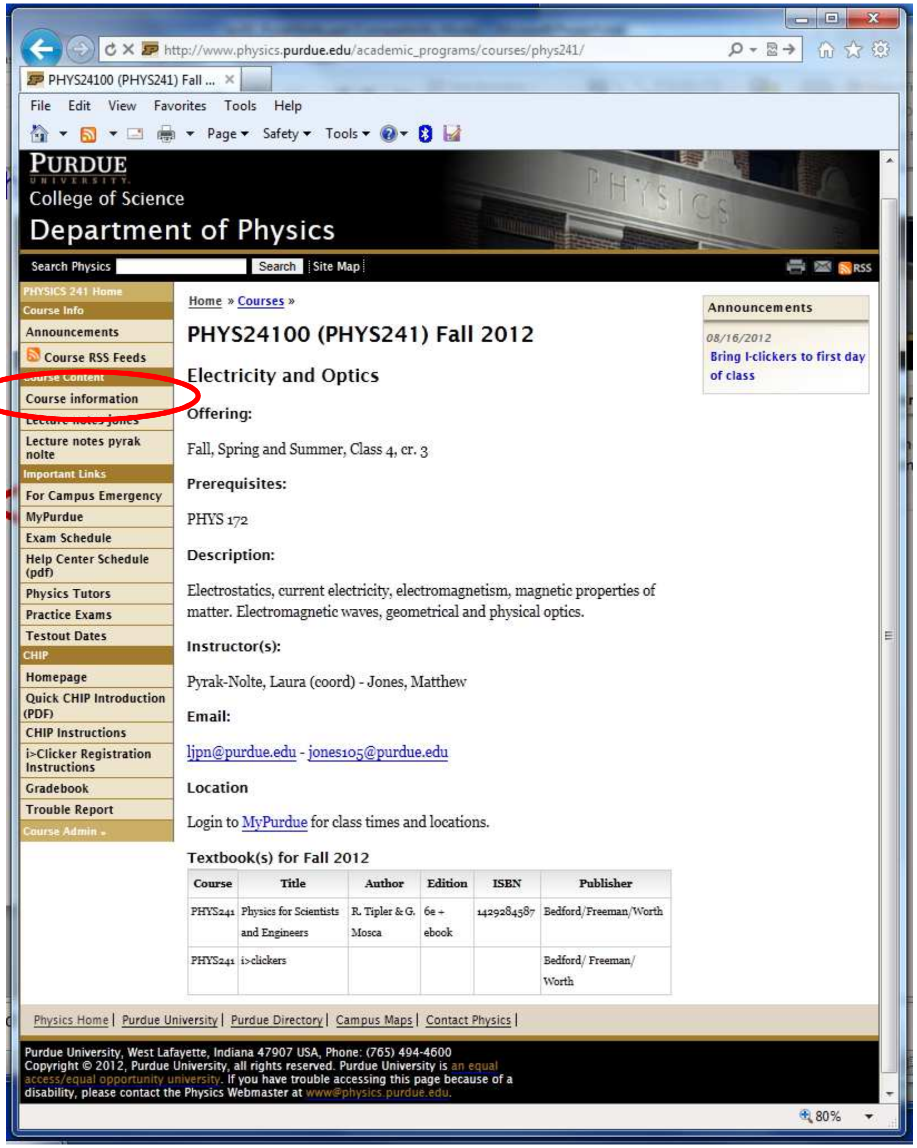
Matthew Jones

Physics 24100 – Electricity & Optics

Preliminary Information

- Physics Department home page:
  - http://www.physics.purdue.edu
- Course home page:
  - http://www.physics.purdue.edu/phys241
- CHIP home page:
  - http://chip.physics.purdue.edu/public/241/spring2012/
- Rooms:
  - Physics 112: Lecture theater
  - Physics 144: Undergraduate Office
  - Physics 11: Help center
  - Physics 290: Physics Library

Physics 24100 – Course home page



- Course information:
  - Schedule/calendar
  - Syllabus

Physics 24100 – Course schedule

Week: Dates	MONDAY	TUESDAY Reading for Lectures	WEDNESDAY Recitations	THURSDAY Reading for Lectures	FRIDAY CHIP HW
1: Aug 20-24		Lecture Ch. 21:1-3	Recitation	Lecture Ch. 21:4-6	CHIP HW 1
2: Aug 27-31		Lecture Ch. 22:1-2	Recitation	Lecture Ch. 22:3	CHIP HW 2
3: Sept 3-7	**HOLIDAY Labor Day**	Lecture Ch. 22:4-5	Recitation	Lecture Ch. 23:1-3	CHIP HW 3
4: Sept 10-14		Lecture Ch. 23:4-5	Recitation	Lecture Ch 23:6 Ch. 24:1-2	CHIP HW 4
5: Sept 17-21		Lecture Ch. 24:3-5	Recitation	Lecture Ch. 25:1-3	CHIP HW 5
6: Sept 24-28	**Exam at 8-10 PM Elliot Hall of Music**	Lecture Ch. 25:4-5	Recitation	Lecture Ch. 25:6 Ch 26:1	CHIP HW 6
7: Oct 1-5		Lecture Ch. 26:2-4	Recitation	Lecture Ch. 27:1-2	CHIP HW 7
8: Oct 8-12	**HOLIDAY October Break**	**HOLIDAY October Break**	Recitation	**No Lecture**	CHIP HW 8
9: Oct 15-19		Lecture Ch. 27:3-5	Recitation	Lecture Ch. 28:1-3	CHIP HW 9
10: Oct 22-26		Lecture Ch. 28:4-5	Recitation	Lecture Ch. 28:6-9	CHIP HW 10
11: Oct 29- Nov 2		Lecture Ch. 29:1,2,5	Recitation	Lecture Ch. 29:4,6,3	CHIP HW 11
12: Nov 5–9	**Exam at 8-10 PM Elliot Hall of Music**	Lecture Ch. 30:1-4	Recitation	Lecture Ch. 31:1-4,6	CHIP HW 12
13: Nov 12-16		Lecture Ch. 31:5,7	Recitation	Lecture Ch. 32:1-2	CHIP HW 13
14: Nov 19-23		**No Lecture**	**HOLIDAY Thanksgiving**	**HOLIDAY Thanksgiving**	**HOLIDAY Thanksgiving**
15: Nov 26-30		Lecture Ch. 32:3-4	Recitation	Lecture Ch. 33:1-4	CHIP HW 14
16: Dec 3-7		Lecture Ch. 33:7-8	Recitation	Lecture Review	CHIP HW 15
17: Dec 10-15	*Final Exam Week*	*Final Exam Week*	*Final Exam Week*	*Final Exam Week*	*Final Exam Week*

- Lectures
- Recitation
- Exams
- Homework

Physics 24100 - Syllabus

PURDUE UNIVERSITY
DEPARTMENT OF PHYSICS

PHYS241
Electricity & Optics (Fall 2012)
http://www.physics.purdue.edu/phys241/

Professor in Charge: Prof. Laura J. Pyrak-Nolte
Office: Room 166, Physics Building
Phone: 494-3005
Email: ljpn@purdue.edu
Office Hours: after class or by appointment

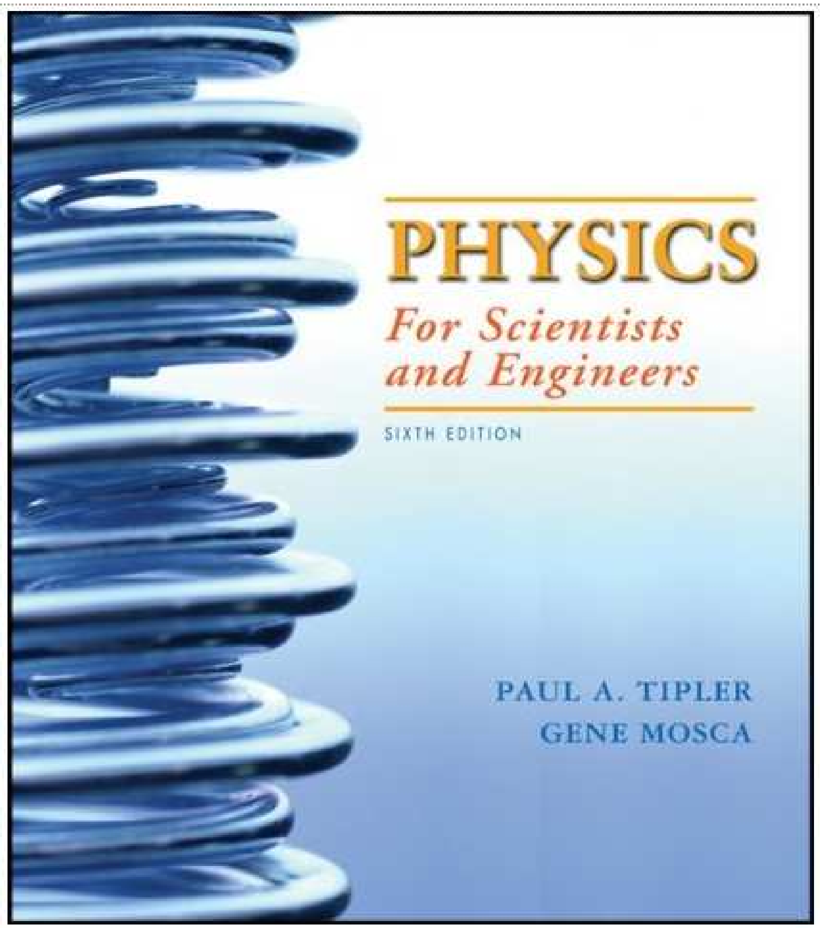
Administrator: Dr. V. K. Saxena
Office: Room 176, Physics Building
Phone: 494-9575
Email: chip241@purdue.edu
Office Hours: by appointment

1st Lecturer: Prof. Matthew Jones
Office: Room 378, Physics Building
Phone: 496-2464 (office) or 494-5971 (lab)
Email: mjones@physics.purdue.edu
Office Hours: by appointment

jones105@purdue.edu also works…

TEXTBOOK:
Physics for Scientists and Engineers, 6th Edition, Volume 2, Tipler and Mosca, Publisher: Bedford, Freeman and Worth, ISBN 1429284587.
I-Clicker, Audience response device, ISBN 0-7167-7939-0, Publishers: Macmillan MPS.

Physics 24100 - Syllabus



Always bring your iClicker!

5% of your grade is based on lecture quizzes

Physics 24100 - Syllabus

EXAMS:

There will be two 75-minute evening exams and a two-hour final exam. The evening exams are multiple-choice and should be able to be completed within 75 minutes by a well-prepared student; note that we're giving you 120 minutes. The times and locations of the evening exams are as follows:

Exam 1: Monday, September 24, 2012 @ 8-10 PM in Elliot Hall of Music

Exam 2: Monday, November 5, 2012 @ 8 – 10 PM in Elliot Hall of Music

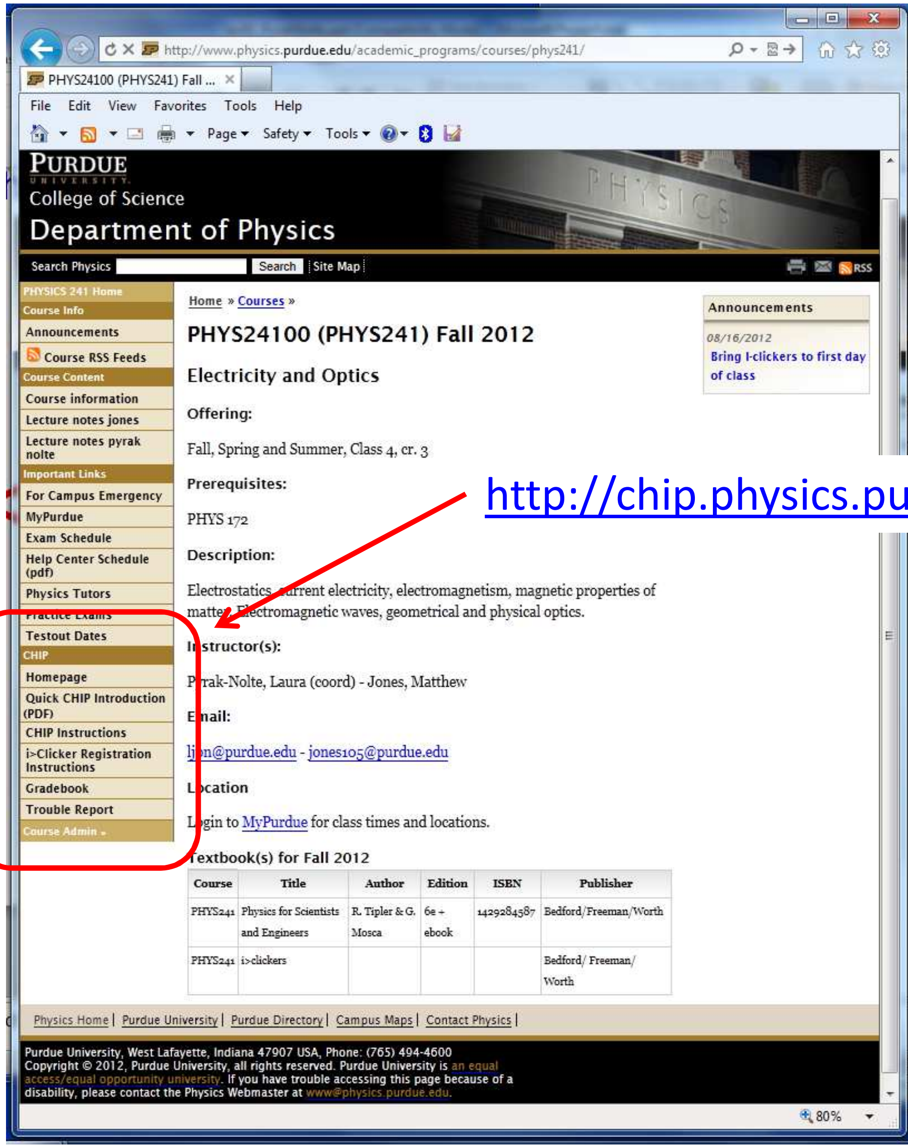
GRADING POLICY:

There are two evening exams and a final exam. The components of the letter grade and their maximum values are:

Two Evening Exams	200
Final Exam	100
CHIP Homework Assignments	100
Recitation quizzes	75
Lecture quizzes	25
TOTAL	**500**

Letter grades will be derived using a curve that has not yet been determined. It is possible to get a D or F in this course. We have no desire to give a certain percentage of C's and D's. We would like for all of you to earn A's.

Physics 24100 - Syllabus


http://www.physics.purdue.edu/academic_programs/courses/phys241/

PHYS24100 (PHYS241) Fall ...

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College of Science

Department of Physics

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PHYSICS 241 Home

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Course Content

Course information

Lecture notes jones

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Important Links

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Exam Schedule

Help Center Schedule (pdf)

Physics Tutors

Practice Exams

Testout Dates

CHIP

Homepage

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PHYS24100 (PHYS241) Fall 2012

Electricity and Optics

Offering:

Fall, Spring and Summer, Class 4, cr. 3

Prerequisites:

PHYS 172

Description:

Electrostatics, current electricity, electromagnetism, magnetic properties of matter. Electromagnetic waves, geometrical and physical optics.

Instructor(s):

Pyrak-Nolte, Laura (coord) - Jones, Matthew

Email:

ljpn@purdue.edu - jones105@purdue.edu

Location

Login to MyPurdue for class times and locations.

Textbook(s) for Fall 2012

Course	Title	Author	Edition	ISBN	Publisher
PHYS241	Physics for Scientists and Engineers	R. Tipler & G. Mosca	6e + ebook	1429284587	Bedford/Freeman/Worth
PHYS241	i>clickers				Bedford/ Freeman/ Worth

Announcements

08/16/2012

Bring I-clickers to first day of class

Physics Home | Purdue University | Purdue Directory | Campus Maps | Contact Physics |

Purdue University, West Lafayette, Indiana 47907 USA, Phone: (765) 494-4600

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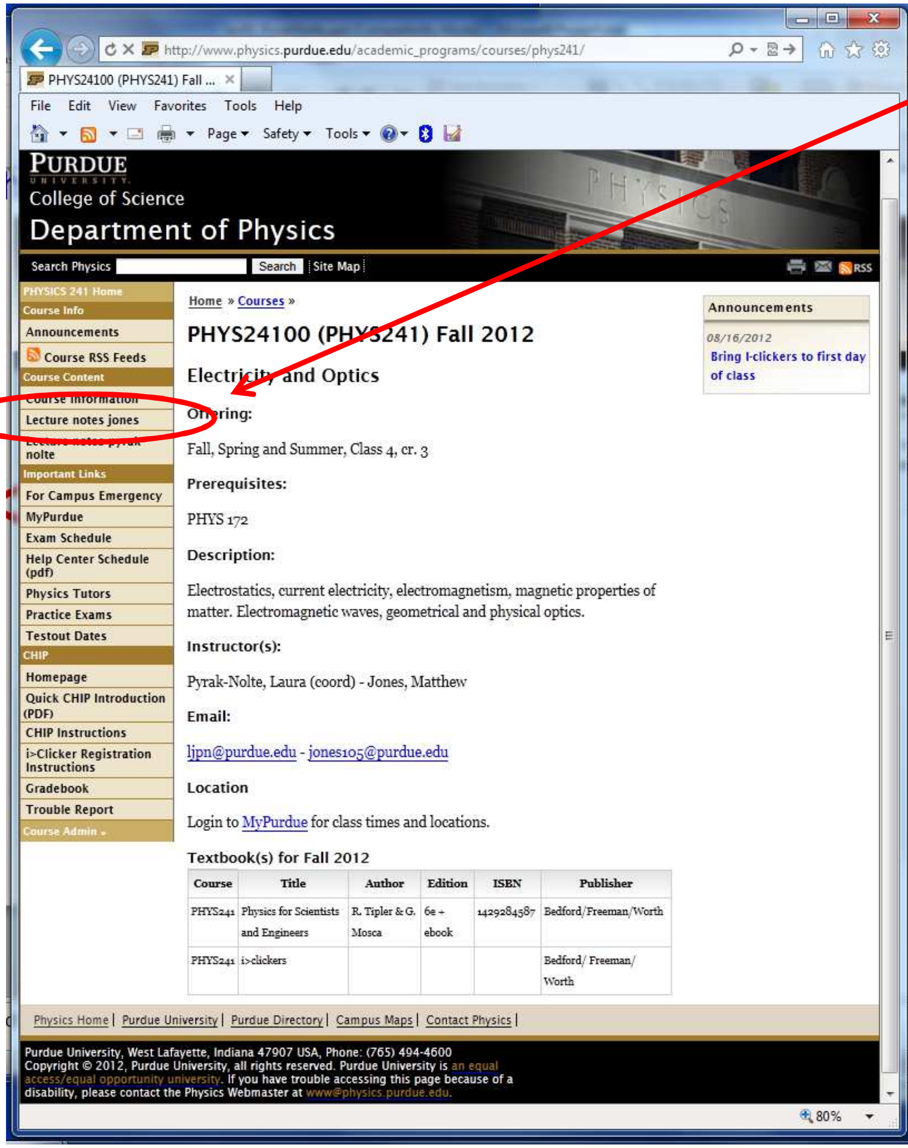
http://chip.physics.purdue.edu/public/241/fall2012/

Questions about grades?

Contact Prof. Laura Pyrak-Nolte…

…Not Prof. David Nolte

Physics 24100 – Lecture notes



Lectures will be posted on-line.

Generally not a good substitute for coming to class...

Electricity & Optics

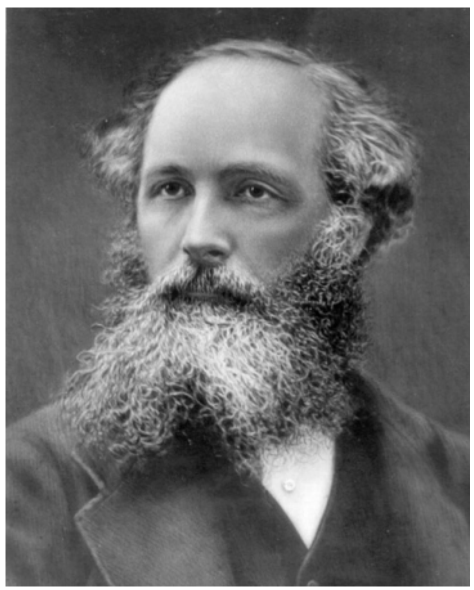
- Comparison with Newtonian mechanics:

$$\vec{F} = m\vec{a} = m\,\frac{d^2\vec{x}}{dt^2}$$

- Frequently, the goal is to solve for $\vec{x}$ as a function of t.
- How hard this is depends on $\vec{F}$:
  - Easy to solve when $\vec{F}$ is simple
  - When $\vec{F}$ is itself a function of $\vec{x}$ or t, things could get complicated…

Electricity & Optics

- Classical Electrodynamics:
  - Formulated by James Clerk Maxwell, Michael Faraday and others in the mid 1800's.



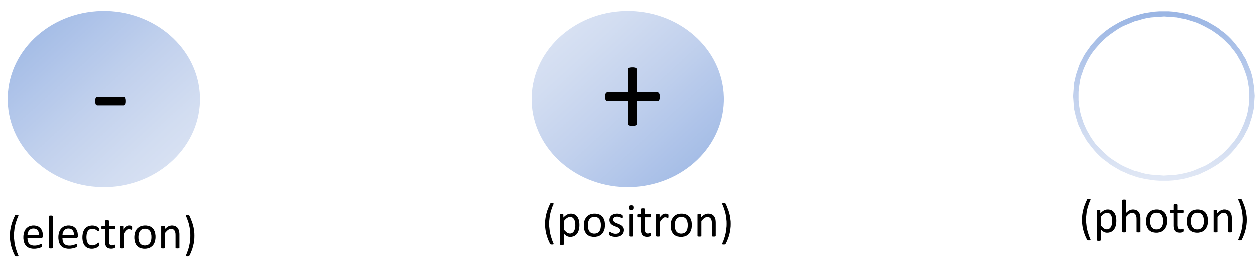
Electricity & Optics

- Maxwell's Equations: $$\nabla \cdot \vec{E} = \frac{\rho}{\epsilon_0}$$
$$\nabla \cdot \vec{B} = 0$$
$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$
$$\nabla \times \vec{B} = \mu_0(\vec{J} + \epsilon_0 \frac{\partial \vec{E}}{\partial t})$$
- Frequently, the goal is to solve for $\vec{E}$ or $\vec{B}$ as a function of t…
- $\vec{E}$ and $\vec{B}$ also exert forces on charged particles:
$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$$

http://dx.doi.org/10.1109/.2002.995632

Lecture 1 – Electric charges & Coulomb's Law

- ***Electric charge*** is an intrinsic property of fundamental particles that make up objects.
- Fundamental particles can be negatively charged, positively charged or neutral.



- The ***net charge*** of a system is the algebraic sum of all the charges of its constituents
  - An object is ***electrically neutral*** when it contains equal numbers of positively and negatively charged particles.
- Fundamental law of nature (***charge conservation***):
  - Electrical charge of a closed system never changes.

Clicker Question:

- Given that:
  - An electron has charge $-e$
  - An “up quark” has charge $+2/3e$
  - A “down quark” has charge $-1/3e$
  - A proton contains two up-quarks and one down-quark:

$$p = (uud)$$

- What is the charge of a hydrogen atom?

(a) Q = -e
(b) Q = +e
(c) Q = 4/3e
(d) Q = 0
(e) Q = 1.602×10^{-19} coulombs

Charges of Particles

Some examples of elementary particles

Particle	Charge
Electron, e^-	-e
Positron, e^+	+e
muon, μ^-	-e
anti-muon, μ^+	+e
up-quark, u	+2/3 e
down-quark, d	-1/3 e
strange-quark, s	-1/3 e
Photon, γ	0
Electron neutrino, ν_e	0
Muon neutrino, ν_μ	0

Anti-particles have opposite electric charge.
(*eg*, the anti-up quark has Q=-2/3 e)

Some examples of composite particles

Particle	Charge
Proton, $p = (uud)$	+e
Neutron, $n = (udd)$	0
Pion, $\pi^+ = (u\bar{d})$	+e
Pion, $\pi^- = (\bar{u}d)$	-e
Hydrogen nucleus, $H = (p)$	+e
Deuterium nucleus, $d = (pn)$	+e
Helium nucleus, $Z = 2$	+2e
Lithium nucleus, $Z = 3$	+3e
Xenon nucleus, $Z = 54$	+54e
Unionized Xenon atom	0

Another Clicker Question:

- Given that:
  - An "up quark" has charge $+2/3e$
  - A "down quark" has charge $-1/3e$
  - A "strange quark" has charge $-1/3e$
  - A "lambda hyperon" contains one of each quark:

$$\Lambda = (uds)$$

- What is the charge of a lambda hyperon?

(a) Q = -e
(b) Q = +e
(c) Q = 4/3e
(d) Q = 0
(e) Q = 1.602 x 10^{-19} coulombs

Electric Charge

- We will usually work with macroscopic objects which contain many, many fundamental particles…
  - Like Avagadro's number:

$$N_A = 6.02 \times 10^{23}$$

- Unit of electric charge is the ***coulomb (C):***

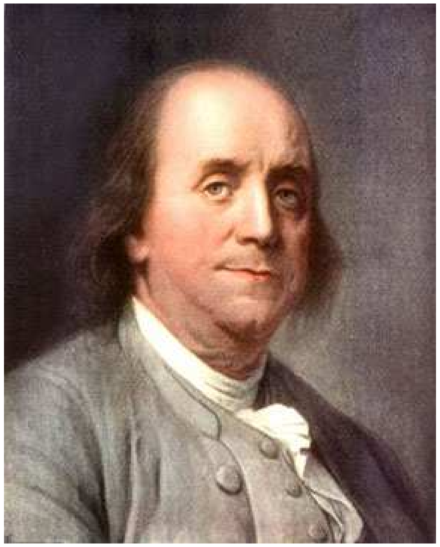
$$e = 1.602 \times 10^{-19} \text{ coulombs}$$

  - Defined (indirectly) in terms of magnetic forces on current carrying wires.
  - One coulomb is the charge flowing through the cross section of a wire carrying one ampere each second

1 coulomb = 1 ampere · second

1 ampere = 1 coulomb / second

Observing Electric Charge



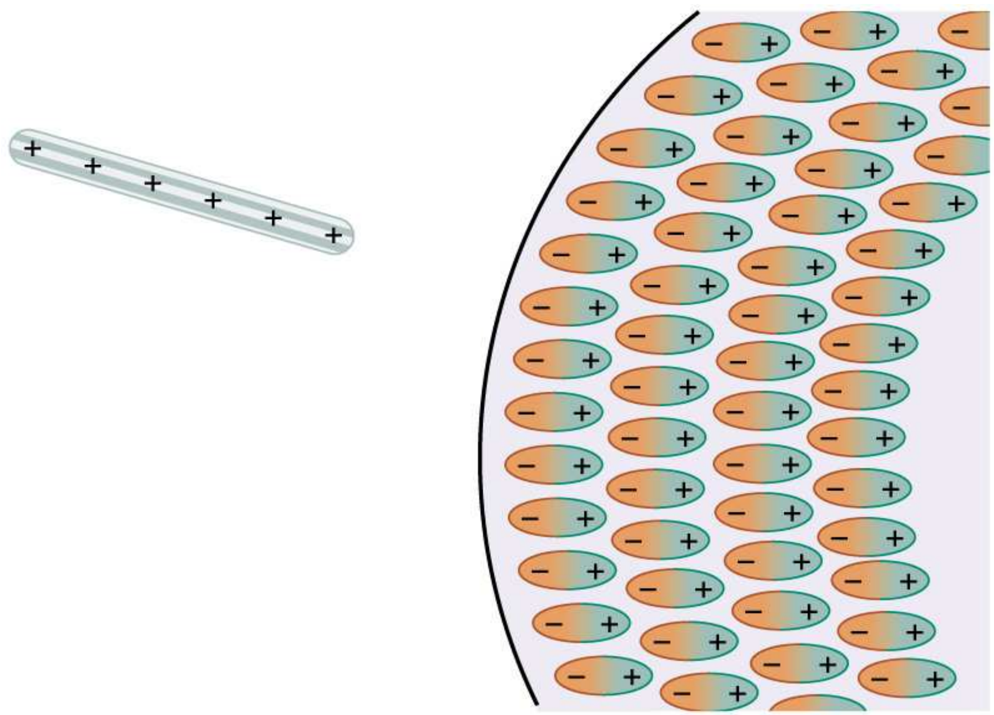
- *Electric charges exert* ***forces*** *on each other.*
- Charles DuFey classified types of charge (*vitreous/resinous*).
- Ben Franklin proposed that there was only one type of charge but that objects could have too much (+) or too little (-).
- Thought of charge as a fluid and electric forces cause it to move…

Conductors and Insulators

- In some materials the electric forces cause charges to move (***conductors***)
- In other materials the electric forces are balanced by other forces (*eg*, atomic bonds) and the charges can't move (***insulators***)
- In some materials, the charges move, but not easily (***semiconductors***)
- In other materials, charges move with no resistance at all (***superconductors***)

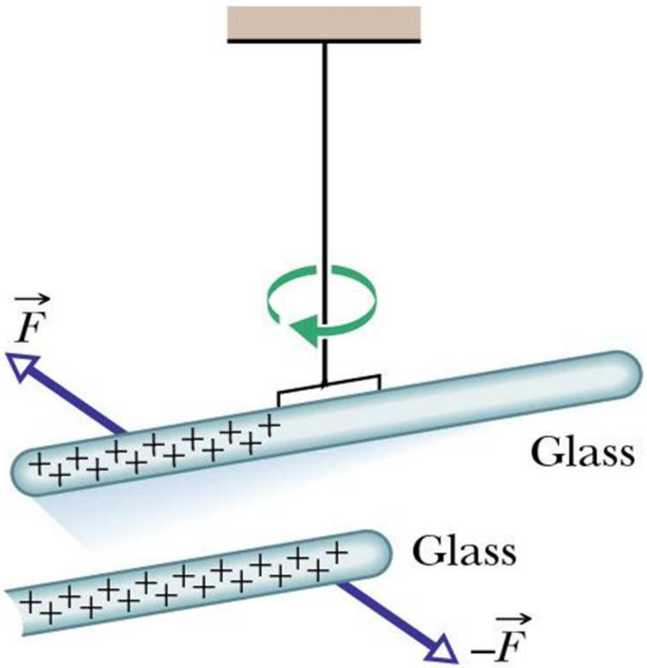
Charge Distributions in Insulators

- Individual charges are attached to atoms or molecules that cannot move
  - But the charges can be locally redistributed

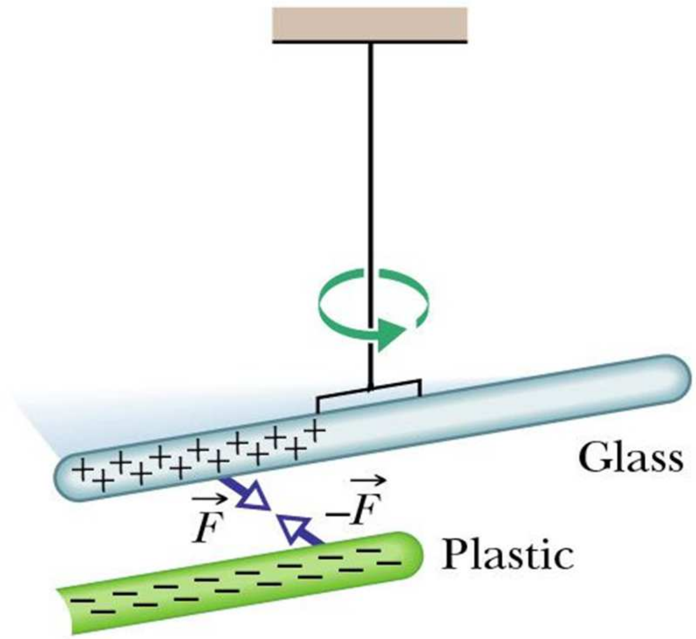


Forces on Charges in Insulators

Repulsive force



Attractive force



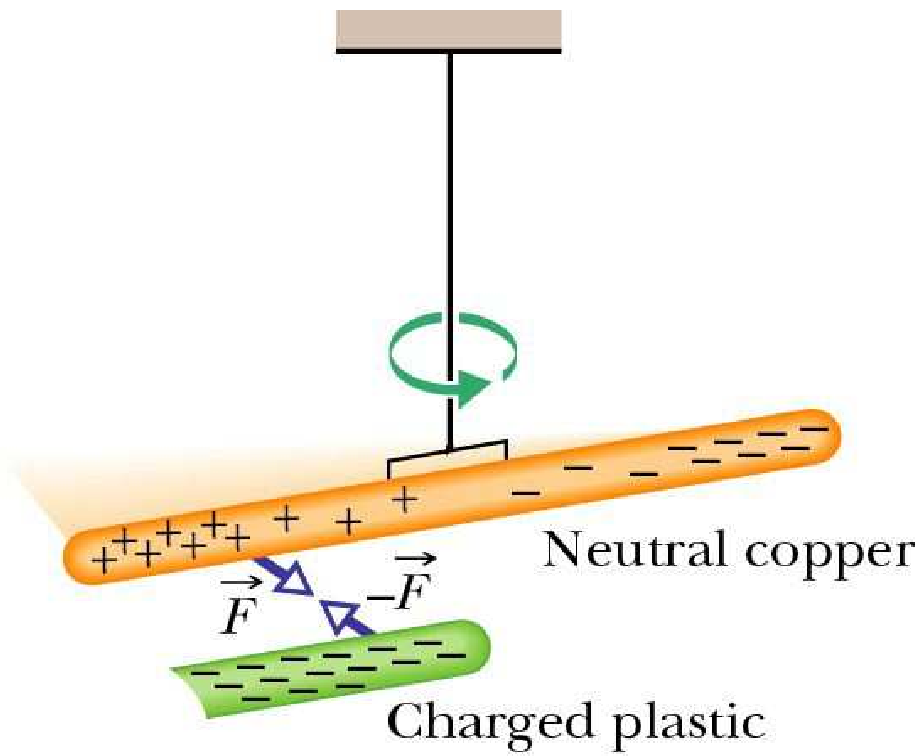
Charges with the same sign repel each other.

Charges with the opposite sign repel each other.

Sign convention is historical but arbitrary nonetheless.

Forces on Charges in Conductors

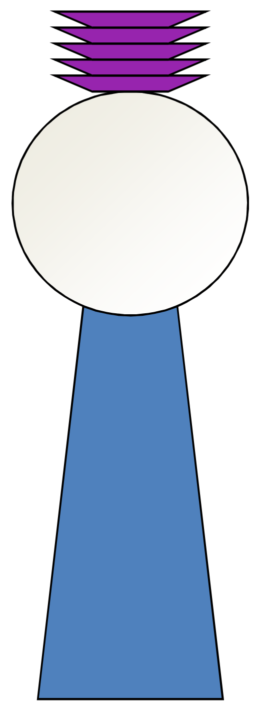
- Charges are easily redistributed over large distances in a conductor – they move “freely”.



A neutral conducting rod will always be attracted to a charged insulating rod.

The charges easily redistribute themselves.

Demonstration

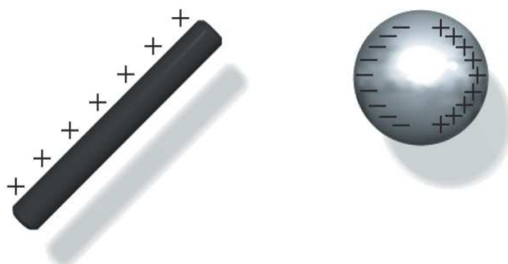


The Useful Concept of “Ground”

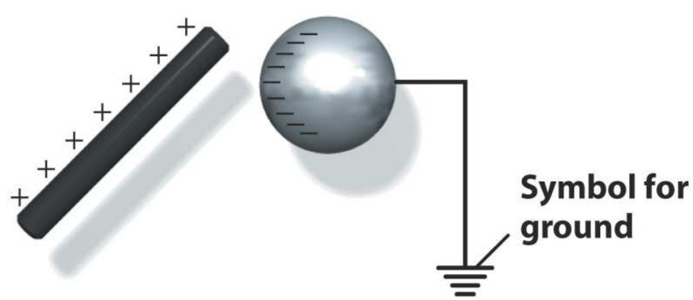
- The earth is a (relatively poor) conductor
  - Dissolved mineral salts are good conductors
- The earth is very large…
  - Macroscopic charges can flow into or out of the earth without changing its net charge by any significant degree
- This property can be quite useful!

Charging by Induction

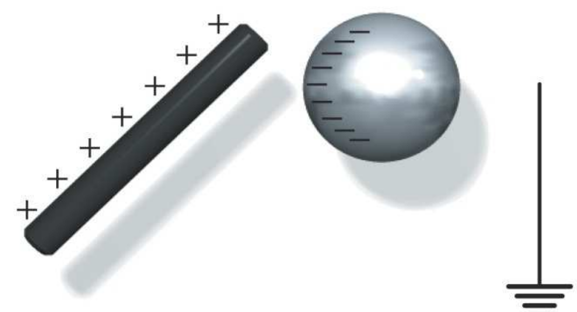
1. Bring a charged rod close to conductor.



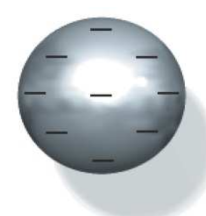
2. Ground the conductor.



3. Break connection to ground, keeping the charged rod in place.



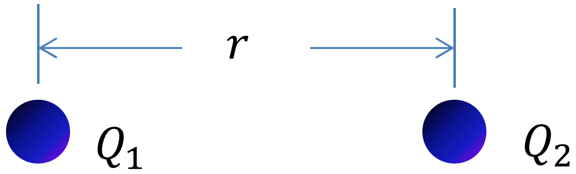
4. Remove the rod. The sphere is charged.



Forces on Charges

Charles-Augustin de Coulomb
(1736 - 1806)

- Coulomb's law of electrostatic force:



- The magnitude of the attractive/repulsive force is

$$\left|\vec{F}\right| = k \, \frac{|Q_1||Q_2|}{r^2}$$

where

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

and therefore

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

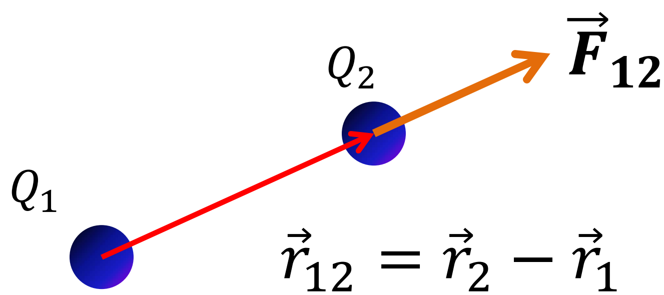
(This constant is called the "permittivity of free space")

Coulomb's Law of Electrostatic Force

$$\vec{F} = \frac{1}{4\pi\epsilon_0}\frac{Q_1 Q_2}{r^2}\hat{r}$$

But $\hat{r} = \vec{r}/r$ so we can also write this as:

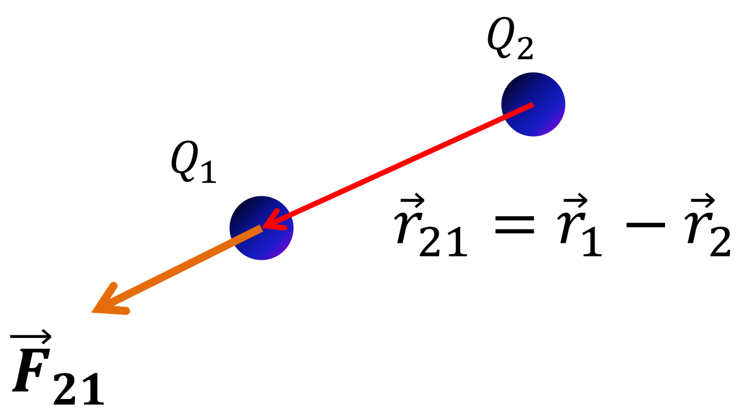
$$\vec{F} = \frac{1}{4\pi\epsilon_0}\frac{Q_1 Q_2}{r^3}\vec{r}$$



If $Q_1 Q_2 > 0$ then the force is in the same direction as $\vec{r}_{12}$. The force is repulsive, so $\vec{F}_{12}$ must be the force exerted **on** Q_2 **by** Q_1.

Coulomb's Law of Electrostatic Force

- Q_1 exerts a force on Q_2 but Q_2 also exerts a force on Q_1…

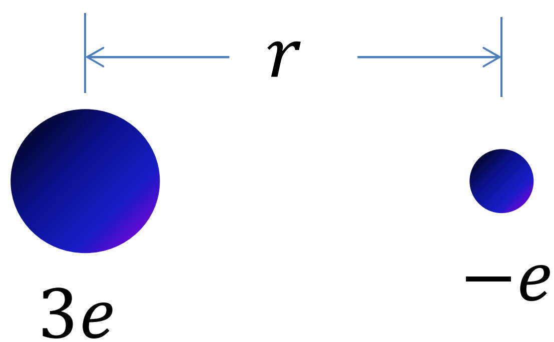


If $Q_1 Q_2 > 0$ then the force is in the same direction as $\vec{r}_{21}$. The force is repulsive, so $\vec{F}_{21}$ must be the force exerted **on** Q_1 **by** Q_2.

- The magnitudes of the two forces are equal.
- The forces form an action-reaction pair
  – recall Newton's laws.

Example: Force on an Electron

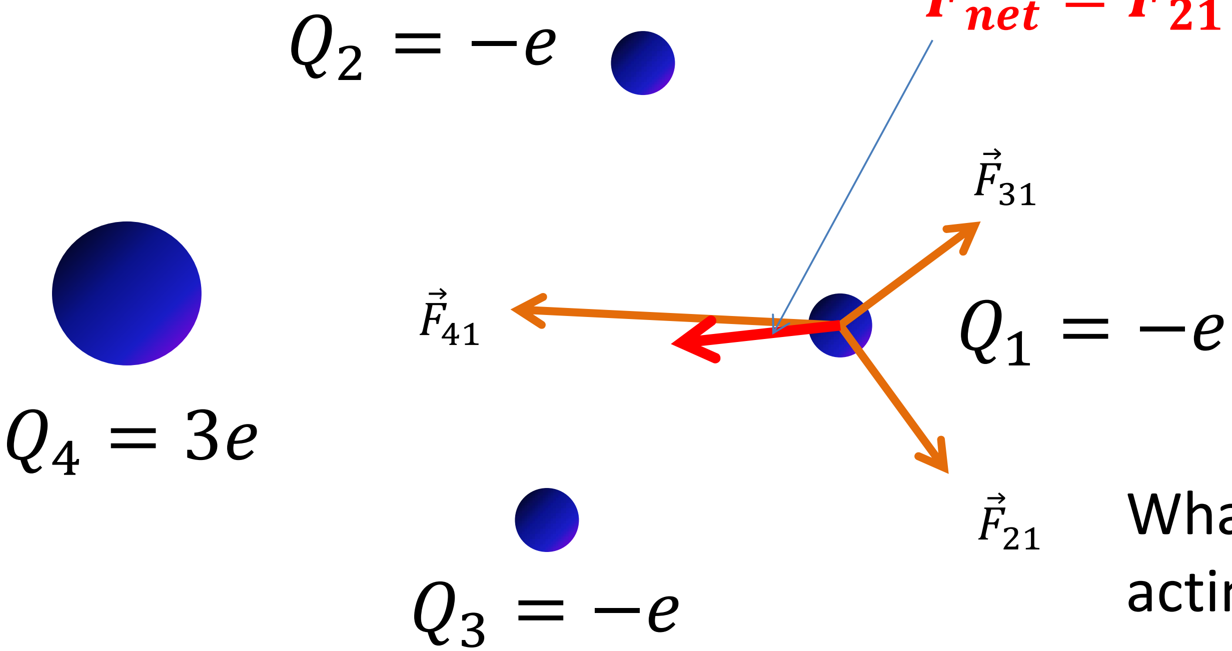
- What is the **magnitude** and **direction** of the force **on** an electron exerted **by** the nucleus of a lithium (Z=3) atom of the mean atomic radius is $r = 1.77 \times 10^{-11}\ m$?



Principle of Superposition

- When several point charges are present, the **total force** on any one charge is the **vector sum** of each of the separate forces acting on the charge.

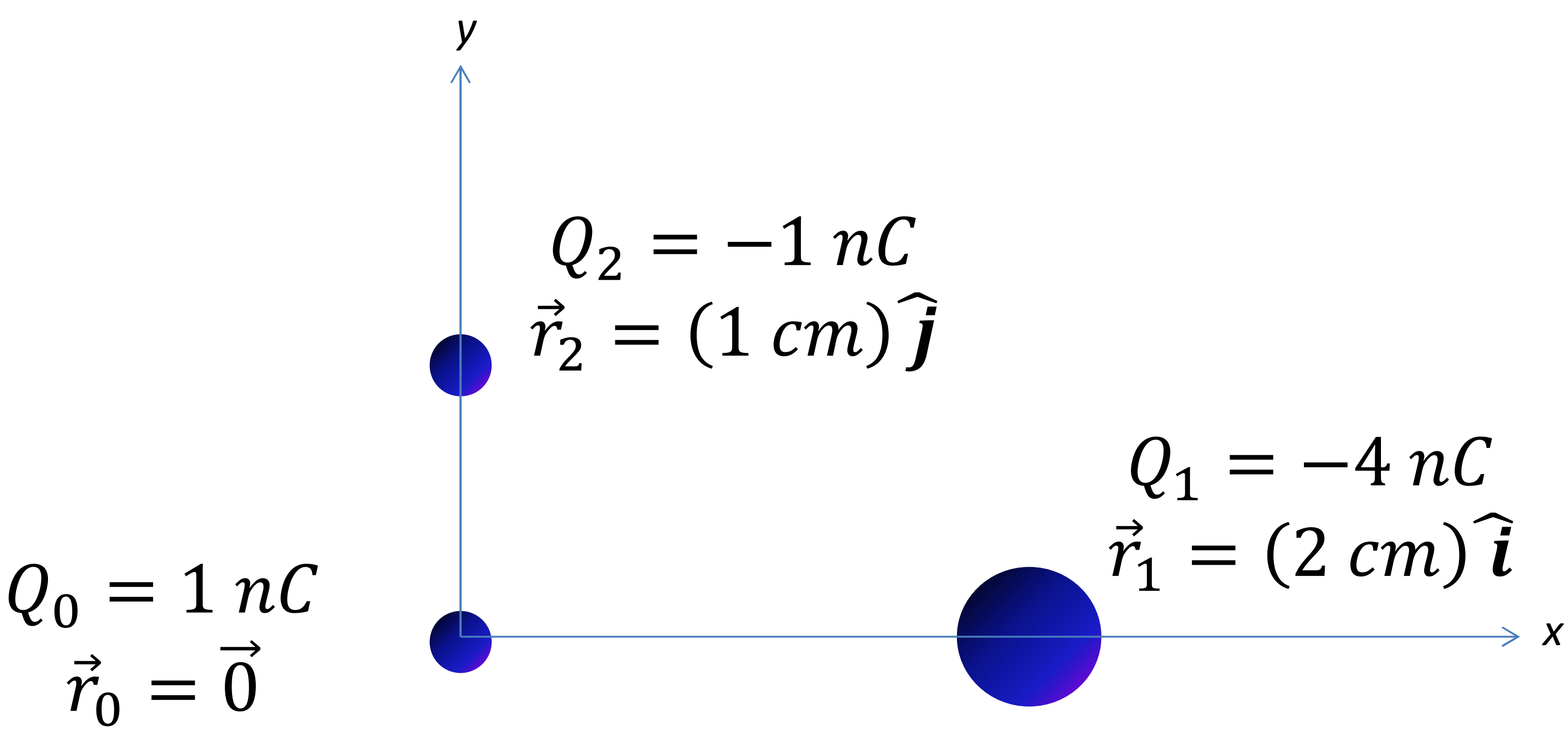
$$\vec{\boldsymbol{F}}_{net} = \vec{\boldsymbol{F}}_{21} + \vec{\boldsymbol{F}}_{31} + \vec{\boldsymbol{F}}_{41}$$



What's the net force acting on Q_1?

Example

- Calculate the magnitude and direction of the force on Q_0:



Final Clicker Question For Credit

- Which diagram most accurately shows the forces acting on the charges: