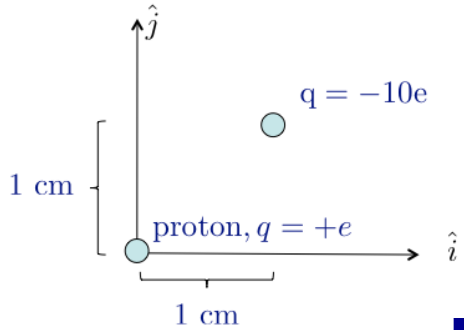

University Physics 227N/232N
Old Dominion University

Review and Starting Electrostatics

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http://www.toddsatogata.net/2014-ODU

Monday, January 13 2014

Happy Birthday to Wilhelm Wien, Orlando Bloom, Patrick Dempsey, Julia Louis-Dreyfus, and Trevor Rabin!

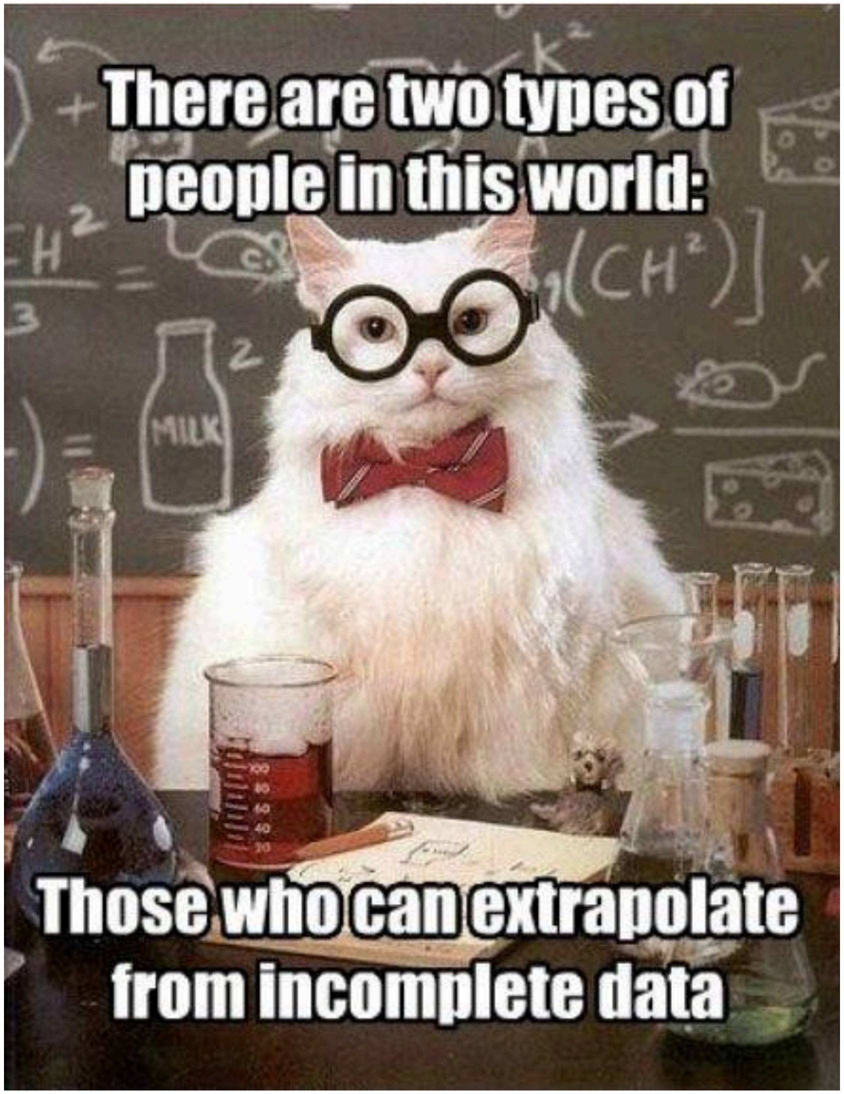
Review: SCALE-UP

- **Observation:** you're not seated in a lecture-style hall
  - Lectures are boring (yawn)
  - Lectures let you (the folks who are learning) become passive
  - Lectures isolate you from your peers
- In this class, we'll do it a bit differently
  - **Me:** less lecturer - more moderator, coach, mentor
  - **You:** regular, active, group participants in class activities
- So what do we do?
  - **(Some) Lectures:** Setting up the day's topics, and summaries
  - **Observations:** Related to the current class topic
  - **Ponderables:** Conceptual or calculating group exercises
  - **Tangibles:** Try it out and see group exercises
  - (And, most importantly, Preparation **outside** of class)

Preparation Outside of Class

- **Me:** Post reading, (some) of the class slides, and Mastering Physics homework
  - By evening after previous class

- **You**
  - Look through the reading before class
    - You can't engage a topic you haven't at least briefly thought about
  - Do the homework
    - ~half review, half new
    - Keep notebook (see syllabus)
  - ~Maybe 6-12 hours/week



Homework: Brain Exercise

- Do the homework.
  - You won't do well if you don't. 'Nuff said.
  - Keep a homework notebook: it **will** be checked later in the semester
  - Work through details of problems; review for quizzes/exams
- Homework for introductory electrostatics is up now
  - Due Thursday evening at midnight
  - Friday's quiz will be based on that content (chapter 20)

Class Website and Syllabus

http://www.toddsatogata.net/2014-ODU

ODU University Physics
PHYS 227N/232N

CRNs 20161/24396 and lab 22509/24397
Dr. Todd Satogata / satogata@jlab.org or tsatogat@odu.edu
TA: Fred Miller (fmill005@odu.edu)
Spring Semester, Jan 13-Apr 28 2014

- Class Information
  - Class Syllabus and Information [last updated 27 Dec 2013]
  - **Textbook:** Essential University Physics (2nd Ed), Richard Wolfson (strongly recommended but not required)
  - **Homework:** Weekly, online through Mastering Physics (required!)
    Some instructions for using MasteringPhysics are located here.
  - **Class:** MW 11:00-12:50, F 12:00-12:50 in OOCNPS 142-144 (SCALE-UP Classroom)
  - (Todd's previous 226N/231N class page is here)

Syllabus

Mastering Physics

- Class Schedule and Materials [last updated 6 Jan 2014]

Class Materials

Date	Chapter	Slides [pdf]	Topic and other notes	Quiz/Test
M Jan 13	--	[-- Mb]	Introduction, Review, Electricity and magnetism concepts Reading is the class syllabus.	
W Jan 15	20	[-- Mb]	Electric charge, Coulomb's Law	
F Jan 17	20	[-- Mb]	Electric Fields	Quiz 1
M Jan 20	--	--	Martin Luther King Day, No class	
W Jan 22	20	[-- Mb]	Dipole Fields, Continuous Media	
F Jan 24	21	[-- Mb]	Electric Flux, Gauss's Law	Quiz 2

Class Grading

- **Read the syllabus**:

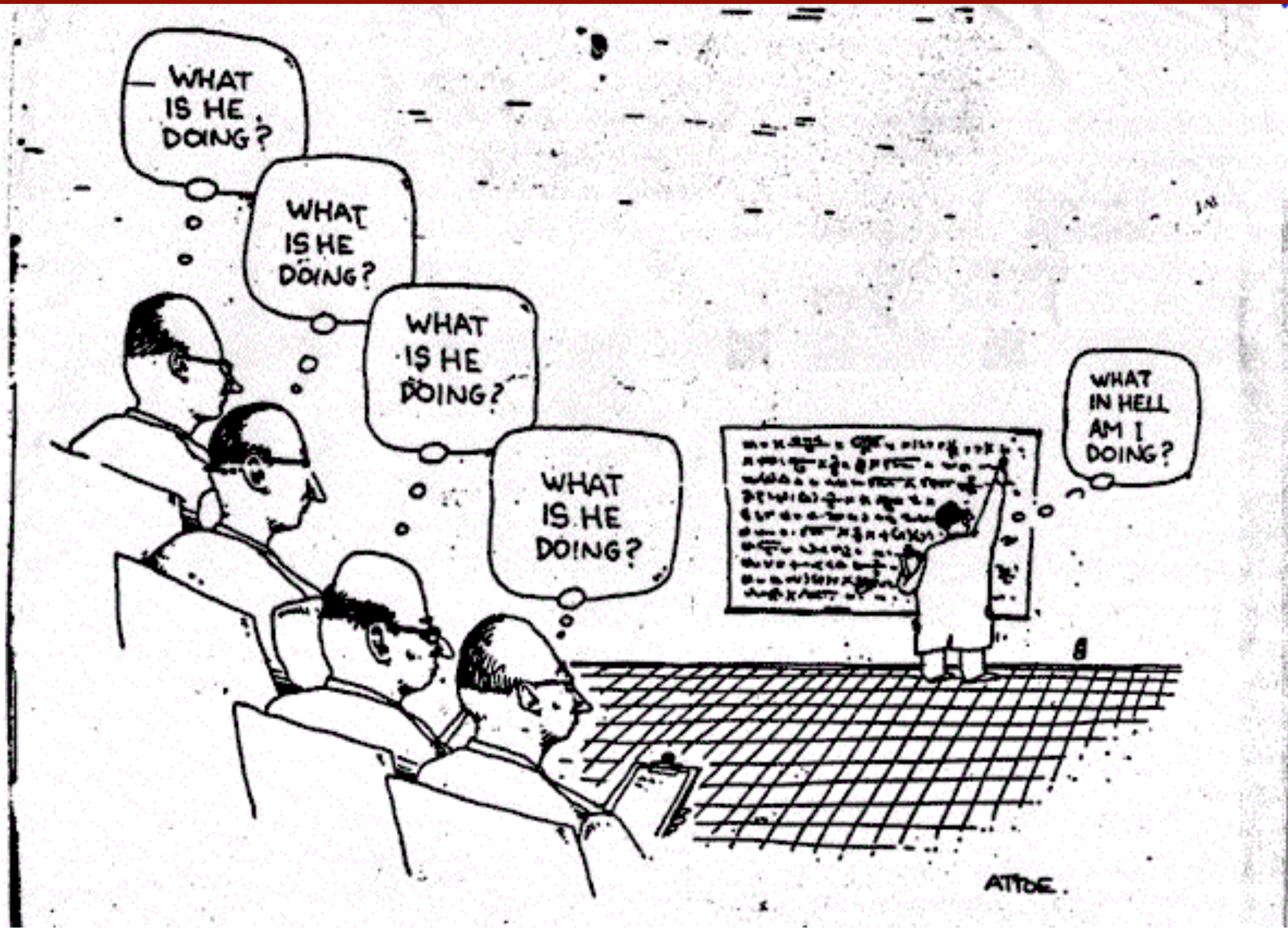
Course Grades The final grade is calculated on an absolute scale. There are 100 points possible for this course:

45 points – Three Midterm Exams (15 each)
30 points – Final Exam (comprehensive)
10 points – Weekly Quizzes
10 points – Homework Assignments (including journal)
05 points – Laboratory

The grading policy is non-competitive and fairly lenient, but there is no curve.
I can only assign a letter grade at the end of the term.

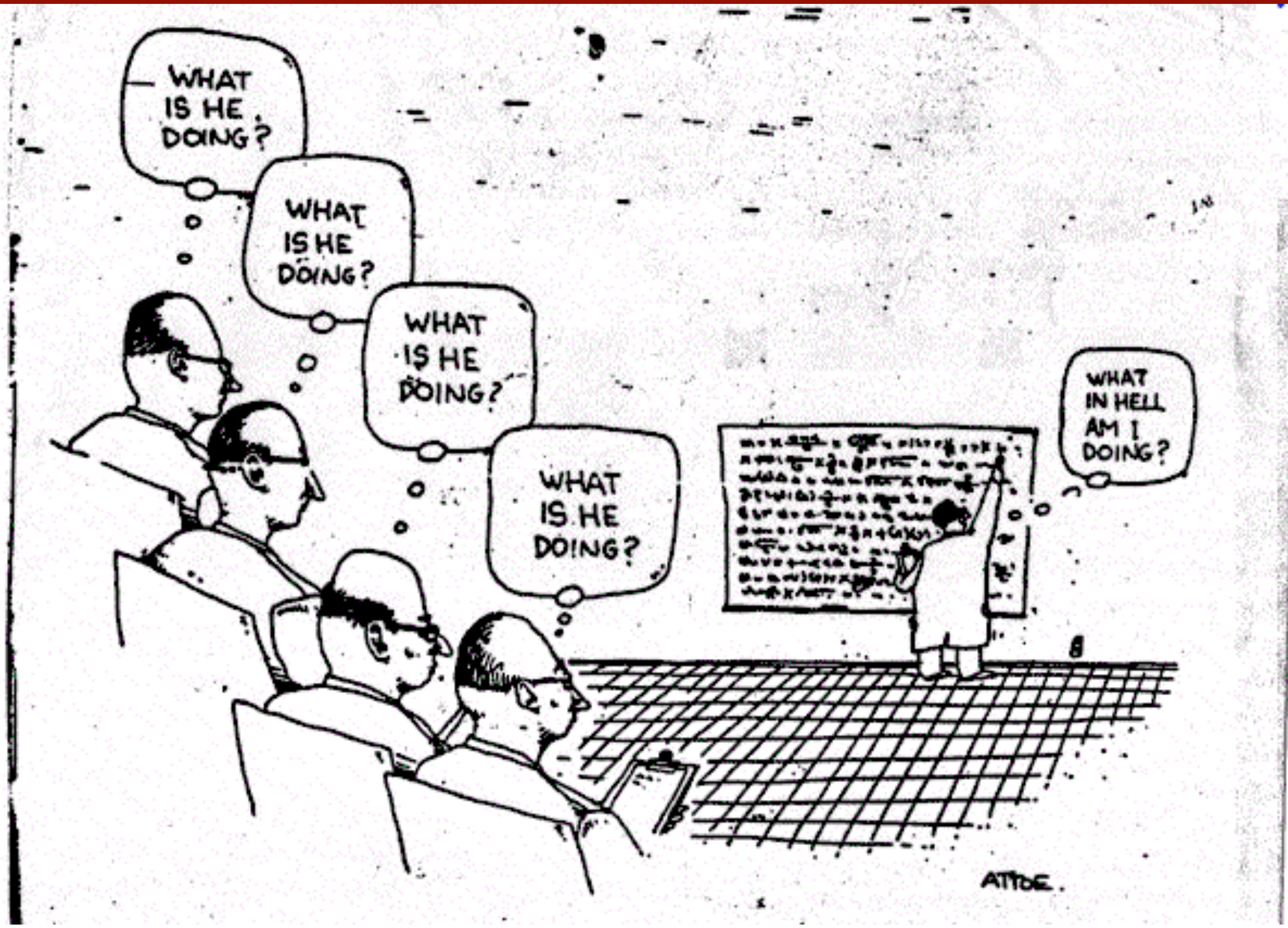
- There may also be some extra credit opportunities through the course of the semester
- Note that I do **not** drop any low grades
  - **Every grade counts!**

"Tangible" (5 minutes)



- Who are you? Why are you here? (5 minutes)
  - Introduce yourself to those around you and say hi!
  - Determine if you share a birthday with anyone else in class.
    - Use boards and markers in creative ways if you like.

Tangible



- Who are you? Why are you here? (boy, that was quick)
  - Introduce yourself to those around you and say hi!
  - Determine if you share a birthday with anyone else in class.
    - There is over a 99% chance that we have at least one pair!

Physics!

- Physics is a quantitative, predictive science of…
  - physical material and its motion through space and time
  - related abstract concepts such as energy and force
  - based on a fundamental belief in "rules" of objective reality

- Qualitative and predictive: numerical generality
  - Use mathematical models (we'll use a fair bit of calculus)
  - Test these models vs observation and experiment
    - "What happens if…?" becomes "Why does that happen?"

- Everything in physics is related to observations
  - These provide "data points" to test against vs models/intuition
  - In case of disagreement, either experiment or theory is wrong!
    - But reality is always right and does not care about your theory
  - Quantitative observations have **precision, accuracy, and units**

Review: SI and Metric Units

- The modern, scientific and engineering form of the metric system
  - You should get in the habit of writing units for **all** physical quantities!

- Length: meter [m]
- Time: second [s]
- Mass: kilogram [kg]

- Electric current: ampere [A]
- Charge: Coulomb [C]
- Capacitance: Farad [F]
- Voltage: Volt [V]
- Magnetic flux density: Tesla [T]
- Resistance: Ohm [Ω]

We'll deal with these for most of this semester

1 cm is about 2.54 inches
1 m is about 3.281 feet
1 km is about 0.6214 miles

$(100\ \mathrm{m})^2$ is about 2.471 acres

$(10\ \mathrm{cm})^3$ = 1 liter, about 0.264 gal

1 kg is about 2.205 lbs
1 g is about 0.0353 oz

1 year is about $\pi \times 10^7$ s
1 Hz is 1 s^{-1}

Google and Wolfram Alpha are both very useful!

Review: Converting Units

- Units matter! Measures of physical quantities must always have the correct units so we can compare them properly.
  - And calculate other quantities properly with them.
- Conversion tables or Google can be used to convert:
  - Example: What is the length of the Olympic 200 meter dash in feet?

$$(200\ \mathrm{m}) \boxed{\left(\frac{3.281\ \mathrm{feet}}{1\ \mathrm{m}}\right)} = 656.2\ \mathrm{feet}$$

Multiply by "1"

  - Example: What is 60 mph in feet/s? in m/s?

$$(60\ \mathrm{miles/hr}) \left(\frac{5288\ \mathrm{feet}}{1\ \mathrm{mile}}\right) \left(\frac{1\ \mathrm{hr}}{3600\ \mathrm{s}}\right) = \left(\frac{5288}{60}\right)\ \mathrm{ft/s} = 88\ \mathrm{ft/s}$$

$$(60\ \mathrm{miles/hr}) \left(\frac{5288\ \mathrm{feet}}{1\ \mathrm{mile}}\right) \left(\frac{1\ \mathrm{hr}}{3600\ \mathrm{s}}\right) \left(\frac{1\ \mathrm{m}}{3.281\ \mathrm{feet}}\right) = 27\ \mathrm{m/s}$$

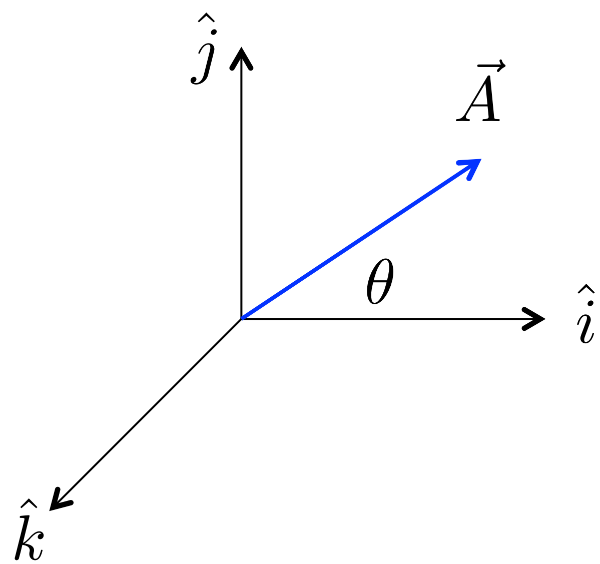
  - Units are an excellent double-check to your physics calculations.

Review: Significant Figures

- The answer to the last example is 27 m/s, **not** 26.86 m/s or 26.8617 m/s or $2.68617\text{x}10^3$ (units?) as a calculator might show.
  - That's because the given quantity, 60 mph, has only two **significant figures.**
  - That means we know that the actual value is closer to 60 mph than to 61 mph or 59 mph. (This matters when, say, you're speeding!)
  - If we had been given 60.00 mph, we would know that the value is closer to 60.00 mph than to 60.01 mph or 59.99 mph.
    - In that case, the number given has four significant figures.
  - Significant figures tell how precisely we know the values of physical quantities based on our observations (measurements).
    - Calculations can't increase that precision, so it's important to report the results of calculations with the correct number of significant figures.

Review: Vector Components

- Electricity and magnetism are rather vector heavy
  - Relationships of charged and moving objects in 3D space
  - You should remember/review **vector decomposition** and **unit vectors**



$$\vec{A} = A_x \hat{i} + A_y \hat{j}$$

$$\vec{A} = A \sin\theta \; \hat{i} + A \cos\theta \; \hat{j}$$

$$(\mathrm{Trig}: \quad \mathrm{soh\ cah\ toa})$$

$$\vec{A} = \begin{pmatrix} A_x \\ A_y \\ A_z \end{pmatrix}$$

Review: Vector Algebra

- Adding and subtracting vectors:

$$\vec{A} = \begin{pmatrix} A_x \\ A_y \\ A_z \end{pmatrix} \qquad \vec{B} = \begin{pmatrix} B_x \\ B_y \\ B_z \end{pmatrix} \qquad \vec{A} + \vec{B} = \begin{pmatrix} A_x + B_x \\ A_y + B_y \\ A_z + B_z \end{pmatrix}$$

- Multiplying vectors by a scaler

$$\vec{A} = \begin{pmatrix} A_x \\ A_y \\ A_z \end{pmatrix} \qquad n\vec{A} = \begin{pmatrix} nA_x \\ nA_y \\ nA_z \end{pmatrix}$$

- Multiplying vectors by a vector: dot product and cross product
  - We'll review these when we need them…
  - We'll even use differential calculus versions of these with $\vec{\nabla}$

Review of Kinematics

- Follows from a few ideas
  - Position, velocity, and acceleration are **vectors**, $\vec{v} = \frac{d\vec{x}}{dt} \quad \vec{a} = \frac{d\vec{v}}{dt}$
  - We can describe all motion with **constant acceleration** (including zero)
  - For each problem, **draw a picture** (including labeling axes, vectors, distances, and angles)
  - Figure out what's **known and unknown**
  - Break vectors down into **components**
- Then in each dimension of motion (e.g. horizontal/vertical) we have **two basic equations** to describe the motion in time

$$x - x_0 = v_0 t + \frac{1}{2} a t^2 \qquad v = v_0 + at$$

  - For **projectile motion** the horizontal acceleration is zero (which makes the equations easier) and the vertical acceleration is the acceleration of gravity (where we need to use the full equations)

Review: Kinematics Example

- Example:
  - With what speed do I need to throw a ball vertically upward so that it barely hits the ceiling 2.0m above my hand?

$$v_y = v_{y0} + at$$

$$y - y_0 = v_{y0}t + \frac{1}{2}at^2$$

$$a = -9.8 \text{ m/s}^2$$

Review: Use the Force, Newt!

Newton's three "laws" of motion (1687)

Newton's First Law

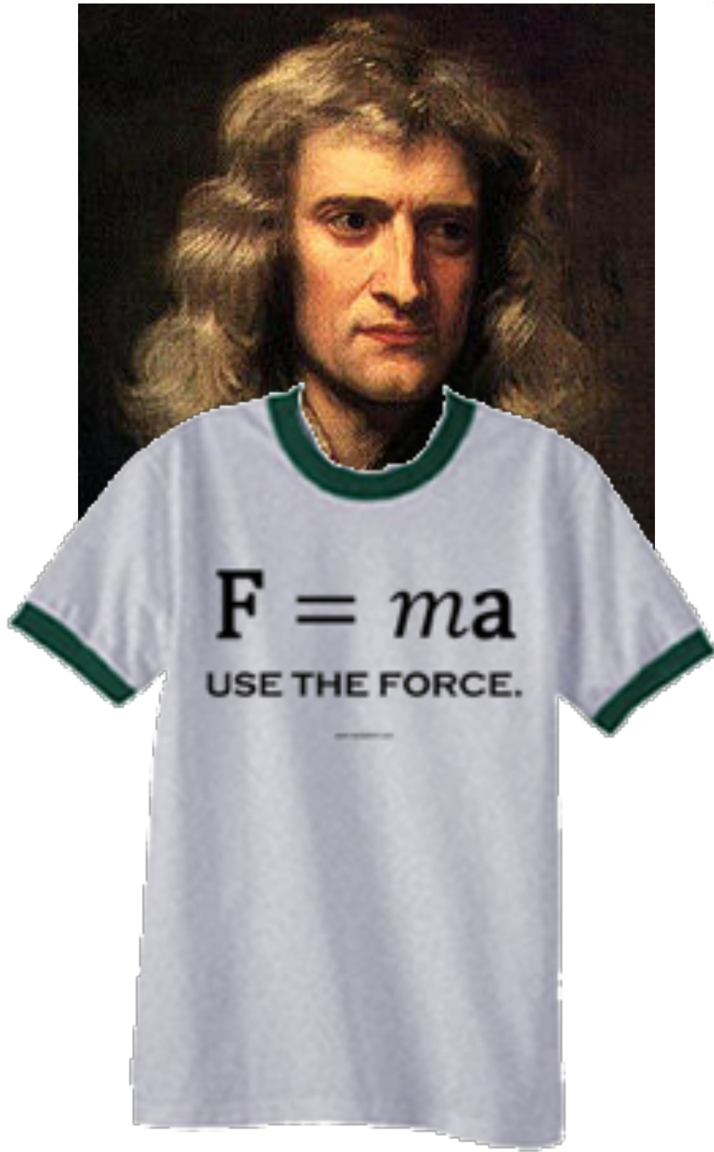
A body in uniform motion remains in uniform motion, and a body at rest remains at rest, unless acted on by a nonzero net force.

Newton's Second Law

- This was basically $\vec{F}_{\rm net} = m\vec{a}$

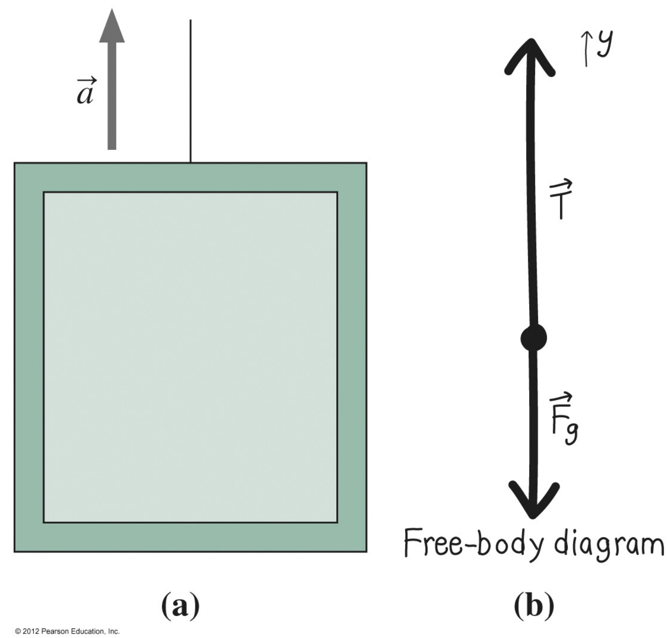
Newton's Third Law

If object A exerts a force on object B, then object B exerts an oppositely directed force of equal magnitude on A.



Newton's Second Law: Example

- A 740-kg elevator accelerates upward at 1.1 m/s^2, pulled by a cable of negligible mass. Find the tension force in the cable.
  - The object of interest is the elevator; the forces are gravity and the cable tension.
  - Newton's second law reads
$$\vec{F}_{\text{net}} = \vec{T} + \vec{F}_g = m\vec{a}$$
  - In a coordinate system with y-axis upward, Newton's Second Law is
$$T_{\text{y}} + F_{\text{gy}} = ma_{\text{y}}$$
  Solving gives
$$T_{\text{y}} = m(a_{\text{y}} + g) = 8.1\ \text{kN}$$



  - Does this make sense? Let's look at some cases:
    - When a = 0, T = mg and the cable tension balances gravity.
    - When T = 0, a = –g, and the elevator falls freely.

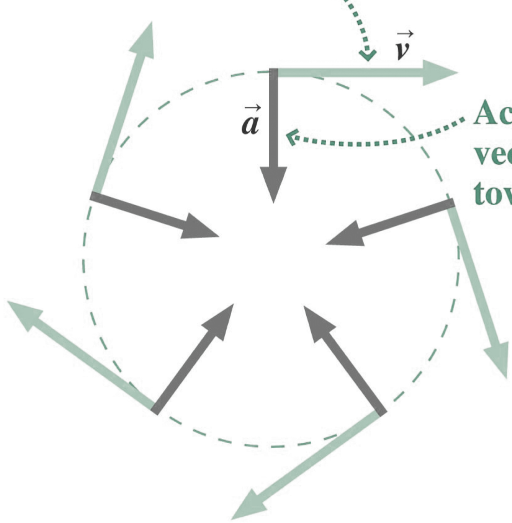
Review: Uniform Circular Motion

- When an object moves in a circular path of radius r at constant speed v, its acceleration has magnitude

$$a = \frac{v^2}{r} \qquad F = ma = \frac{mv^2}{r}$$

  - The acceleration vector points toward the center of the circle.
  - Since the direction of the acceleration keeps changing, this is **not** constant acceleration.

    – Constant acceleration in two dimensions implies a **parabolic** trajectory, not a **circular** one.



New Stuff! In Chapter 20, 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
- The concept of electric field
  - How to calculate the fields of discrete and continuous charge distributions
- How charges respond to electric fields

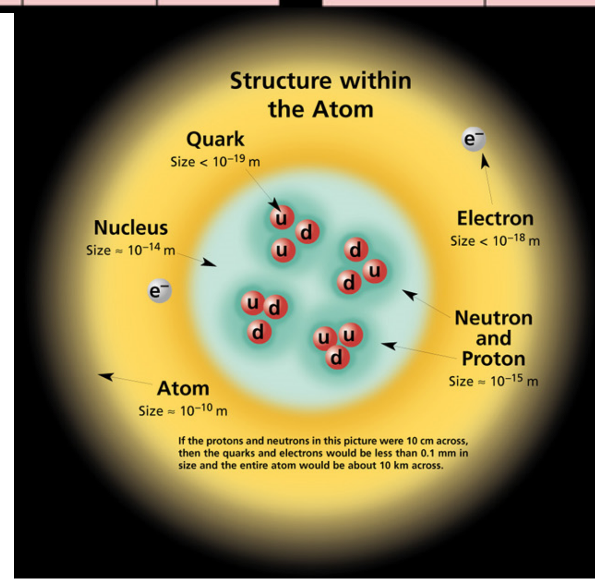
The Standard Model on One Convenient Slide

- All matter is made up of leptons and quarks

- All matter interacts via four forces (in order of range):
  - Gravity
  - **Electromagnetism**
  - (Weak Nuclear Force)
  - (Strong Nuclear Force)

Leptons spin = 1/2		
Flavor	Mass GeV/c^2	Electric charge
ν_e electron neutrino	$<1\times10^{-8}$	0
e electron	0.000511	−1
ν_μ muon neutrino	<0.0002	0
μ muon	0.106	−1
ν_τ tau neutrino	<0.02	0
τ tau	1.7771	−1

Quarks spin = 1/2		
Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.003	2/3
d down	0.006	−1/3
c charm	1.3	2/3
s strange	0.1	−1/3
t top	175	2/3
b bottom	4.3	−1/3



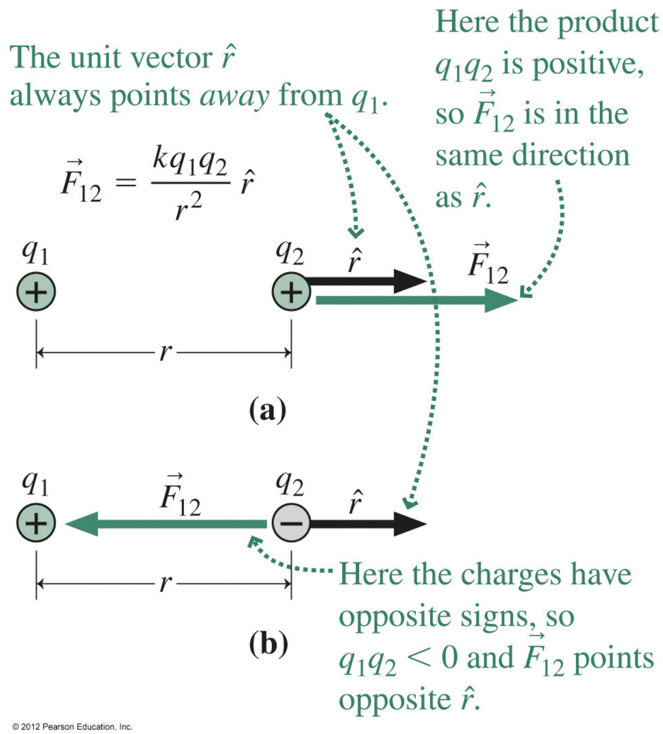
Electric Charge

- Electric charge is a fundamental property of matter.
  - Many particles, including the electron and proton, carry electric charge.
  - Charge comes in two varieties, **positive** and **negative.**
  - Most charged particles carry exactly one **elementary** charge, *e,* either positive or negative.
    - The proton carries exactly $+e$, the electron exactly $-e$.
    - The quarks, which make up protons, neutrons, and other subatomic particles, carry $\pm 1/3\ e$ or $\pm 2/3\ e$. But they're never observed in isolation.
  - The charge in a closed system is **conserved**
    - The algebraic sum of charges remains unchanged.
    - This is true even if new particles are created or destroyed.
  - The SI unit of charge is the **coulomb** (C), equal to approximately 6.25×10^{18} elementary charges.
    - **Thus e is approximately 1.602×10^{-19} C.**
  - Charges interact with electromagnetic radiation (light, radio, …)

Coulomb's Law and the Electric Force

- Like charges repel, and opposite charges attract, with a force that depends on
  - The product of the two charges
  - The inverse square of the distance between them
- Mathematically, the electric force is described by **Coulomb's law** (much like the force of gravity):

$$\vec{F}_{12} = \frac{kq_1q_2}{r^2}\,\hat{r}$$



Here $\vec{F}_{12}$ is the force q_1 exerts *on* q_2 and is a unit vector pointing *from* q_1 toward q_2. k is the Coulomb constant, approximately 9.0×10^9 N m^2/C^2.

Question 1

- Two charged particles attract each other with a force *F*. If the charges of both particles are doubled, and the separation between them is also doubled, the force between them will be

A. *F*/8.

B. *F*/2.

C. *F*.

D. 2*F*.

E. 8*F*.

$$\text{Recall} \quad \vec{F}_{12} = \frac{k q_1 q_2}{r^2}\,\hat{r}$$

Question 1: Answer

- Two charged particles attract each other with a force *F*. If the charges of both particles are doubled, and the separation between them is also doubled, the force between them will be

A. *F*/8.

B. *F*/2.

C. $\boxed{F.}$

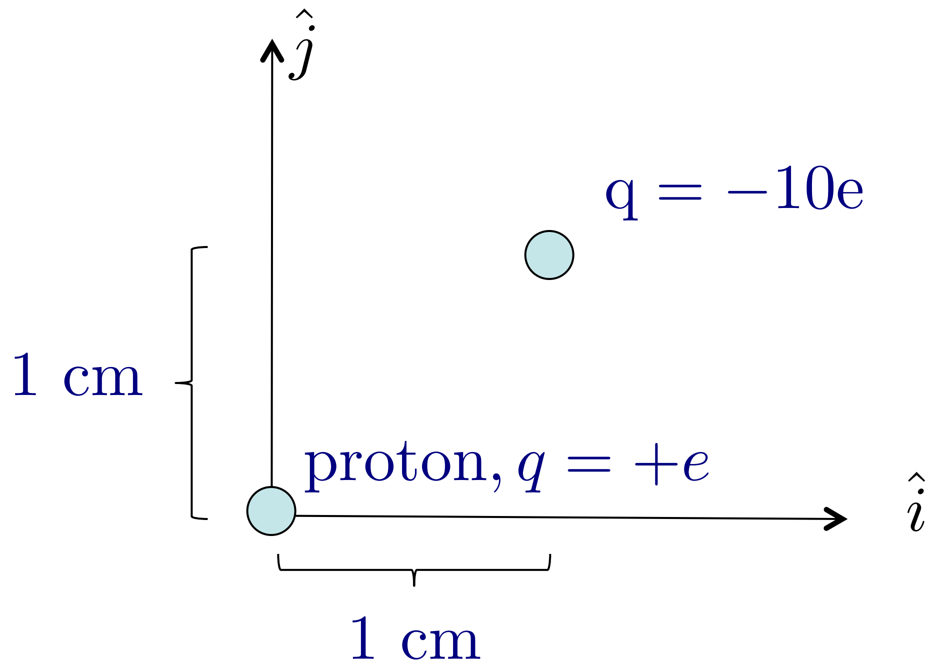
D. 2*F*.

E. 8*F*.

$$F = \frac{kq_1q_2}{r^2} \qquad F_{\text{new}} = \frac{k(2\,q_1)(2\,q_2)}{(2r)^2} = \frac{4}{4}\frac{kq_1q_2}{r^2} = F$$

Question 2:

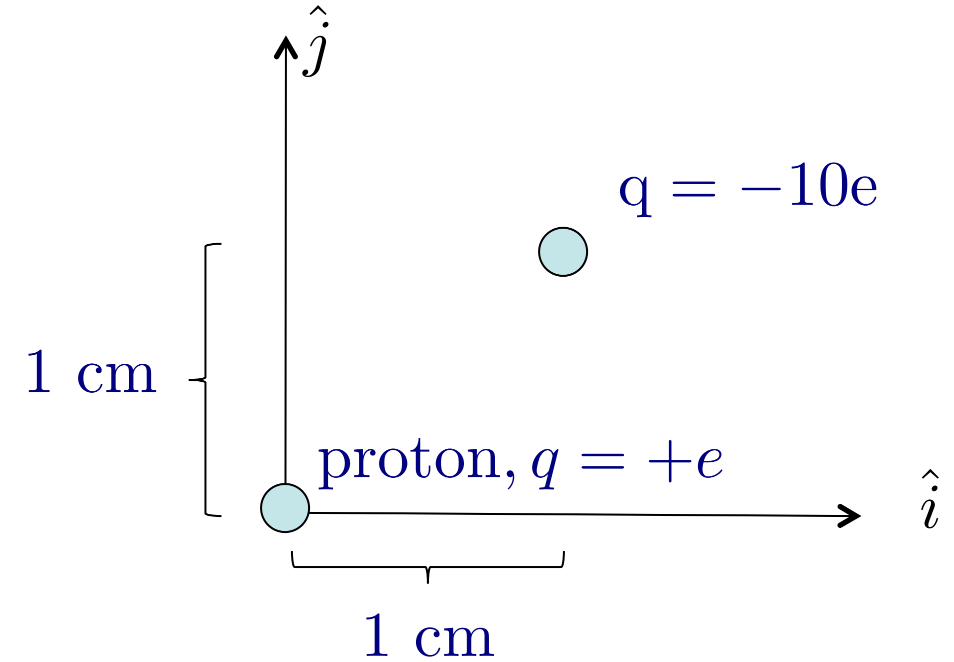
- What is the force (magnitude and direction; force is a vector!) on a proton at the origin, from a charge of -10e located at the position (1cm, 1cm)?

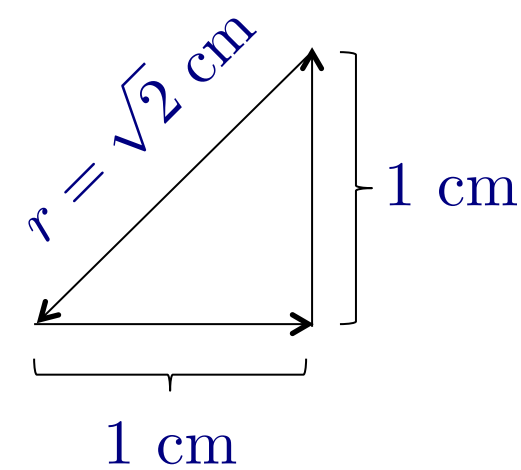


- Bonus: If both particles start at rest, the proton is free to move, and the -10 charge is fixed, how long does it take the proton to hit the other charge?

Kinematics with variable acceleration: calculus!

Question 2: Answer





$$\vec{F} = \frac{kq_1q_2}{r^2}\hat{r} = \frac{(9\times10^9\ \mathrm{N\ m^2/C^2})(1.6\times10^{-19}\ \mathrm{C})(-10\times1.6\times10^{-19}\ \mathrm{C})}{(2\ \mathrm{cm}^2)(1\ \mathrm{m}/100\ \mathrm{cm})^2}$$

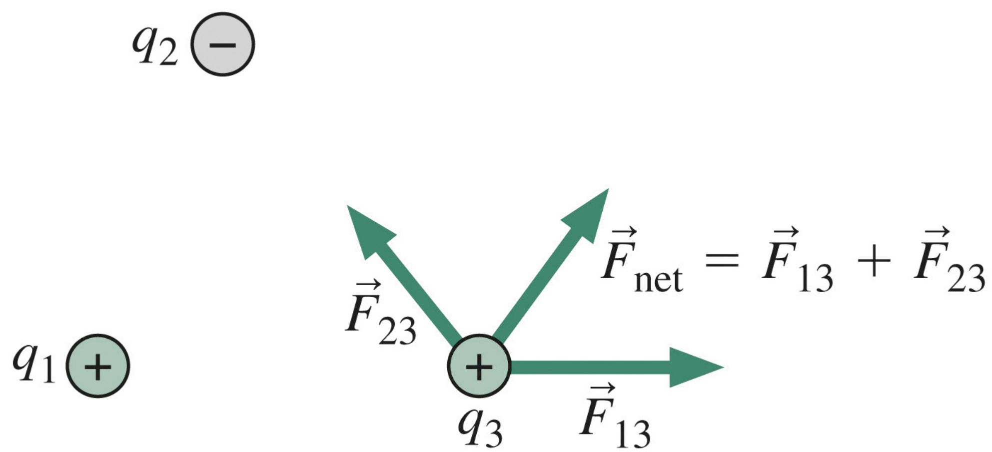
$$\boxed{\vec{F} = -(1.2\times10^{-23}\ \mathrm{N})\hat{r}}$$

The $-\hat{r}$ direction is attractive

$$m_p = 1.6\times10^{-27}\ \mathrm{kg} \quad \Rightarrow \quad \vec{a} = \frac{\vec{F}}{m_p} = 7.5\times10^3\ \mathrm{m/s^2}$$

The Superposition Principle

- The electric force obeys the **superposition principle.**
  - That means the force two charges exert on a third force is just the vector sum of the forces from the two charges, each treated without regard to the other charge.
  - The superposition principle makes it mathematically straightforward to calculate the electric forces exerted by distributions of electric charge.
    - The net electric force is the sum of the individual forces.



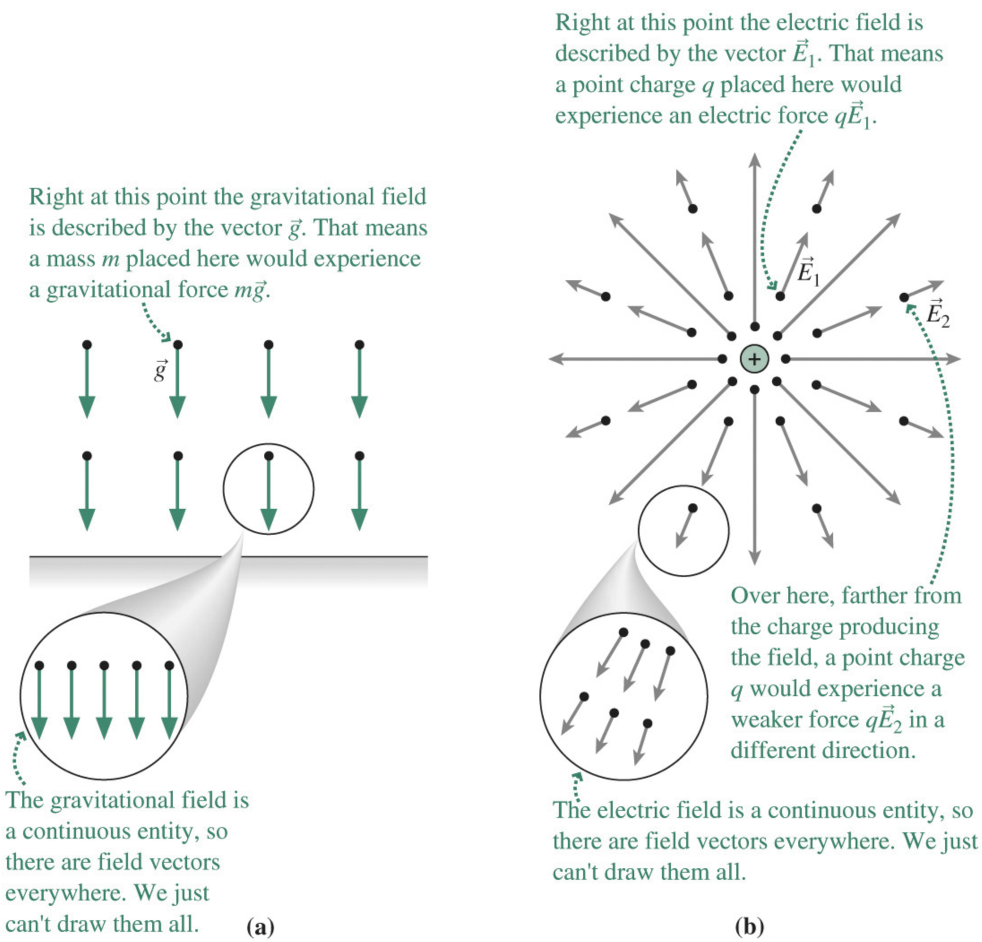
The Electric Field

- The electric field at a point in space is the force per unit charge that a charge *q* placed at that point would experience:

$$\vec{E} = \frac{\vec{F}}{q}$$

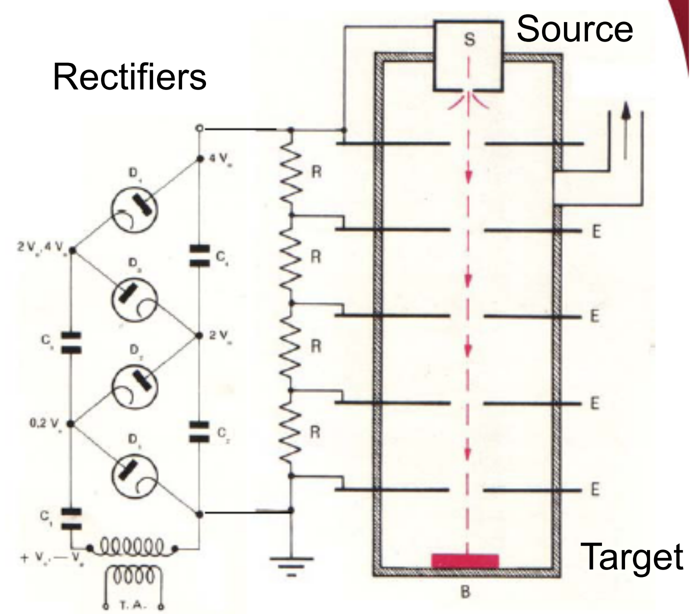
- The force on a charge *q* in an electric field $\vec{E}$ is $\vec{F} = q\vec{E}$

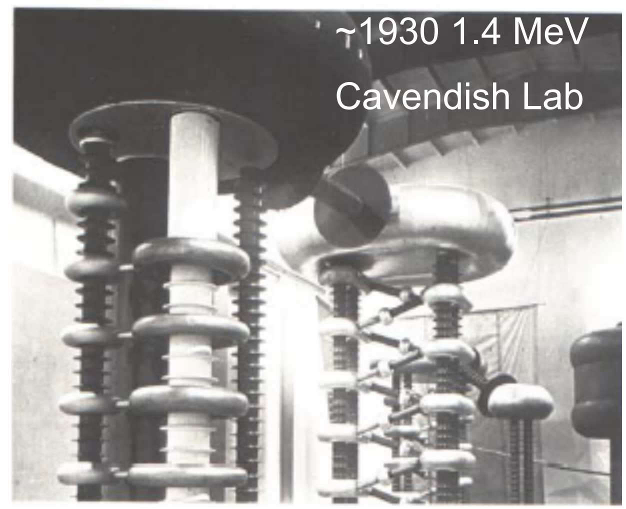
- The electric field is analogous to the gravitational field, which gives the force per unit mass.



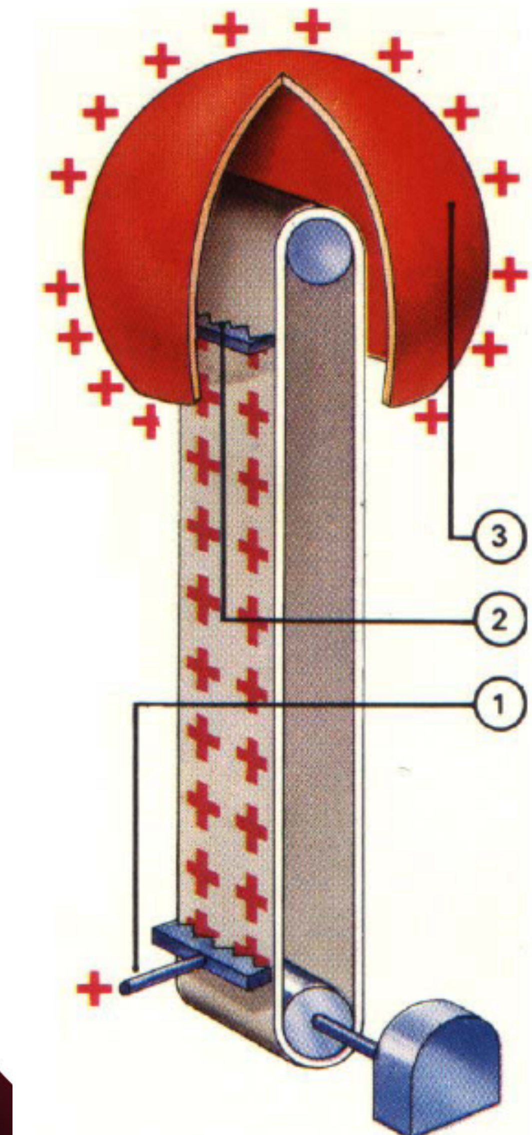
DC Accelerating Gaps: Cockcroft-Walton

- Accelerates ions through successive electrostatic voltages
  - First to get protons to >MeV
  - Continuous HV applied through intermediate electrodes
  - Rectifier-multipliers (voltage dividers)
  - Limited by HV sparking/breakdown
  - FNAL still uses a 750 kV C-W
- Also example of early ion source
  - H gas ionized with HV current
  - Provides high current DC beam





DC Accelerating Gaps: Van de Graaff

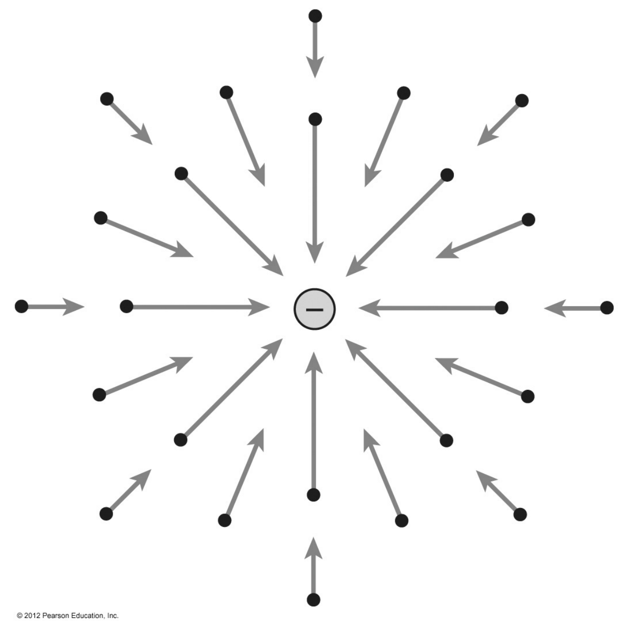


- How to increase voltage?
  - R.J. Van de Graaff: charge transport
  - Electrode (1) sprays HV charge onto insulated belt
  - Carried up to spherical Faraday cage
  - Removed by second electrode and distributed over sphere
- Limited by discharge breakdown
  - ~2MV in air
  - Up to 20+ MV in SF_6!
  - Ancestors of Pelletrons (chains)/ Laddertrons (stripes)

Van de Graaff Popularity

Fields of Point Charges and Charge Distributions

- The field of a point charge is radial, outward for a positive charge and inward for a negative charge.



$$\vec{E}_{\text{point charge}} = \frac{kq}{r^2}\,\hat{r}$$

- The superposition principle shows that the field due to a charge distribution is the vector sum of the fields of the individual charges.

$$\vec{E}_{\text{total}} = \sum_i \vec{E}_i = \sum_i \frac{kq_i}{r_i^2}\,\hat{r}_i$$

The Dipole: an Important Charge Distribution

- An **electric dipole** consists of two point charges of equal magnitude but opposite signs, held a short distance apart.
  - The dipole is electrically neutral, but the separation of its charges results in an electric field.
  - Many charge distributions, especially molecules, behave like electric dipoles.
  - The product of the charge and separation is the dipole moment: *p = qd.*
  - Far from the dipole, its electric field falls off as the inverse cube of the distance.