Outline for Day 3

Office hours: 1:30 -3

- Special Relativity
  - Lorentz Transforms
  - Relativistic energy and momentum
    - Fission and Fusion
    - Compton scattering
- Models of the atom
  - Plum pudding model
  - Rutherford model
    - Rutherford scattering equation

Outline for Day 3

Office hours: 2 - 4

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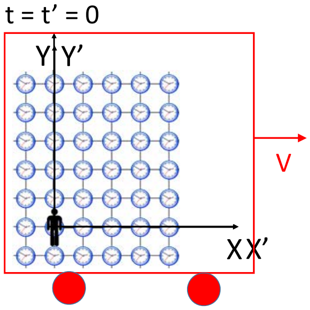
Lorentz Transforms

If you have coordinates (x, y, t) of an event (say appearance of yellow triangle) in one frame, how to find coordinates of same event in moving frame (x', y', t').

t = t' = 0



Lorentz transforms assume that
- t = 0 and t' = 0 when two frames lie on top of each other
- prime frame is moving to the right at speed v only in the x direction
- there is no motion in the y or z direction

Lorentz Transforms

If you have coordinates (x, y, t) of an event (say appearance of yellow triangle) in one frame, how to find coordinates of same event in moving frame (x', y', t').

Lorentz boost (*x direction*)

$$t' = \gamma\left(t - \frac{vx}{c^2}\right)$$
$$x' = \gamma(x - vt)$$
$$y' = y$$
$$z' = z$$

Inverse Lorentz boost (*x direction*)

$$t = \gamma\left(t' + \frac{vx'}{c^2}\right)$$
$$x = \gamma(x' + vt')$$
$$y = y'$$
$$z = z',$$

where v is the relative velocity between frames in the x-direction, c is the speed of light, and

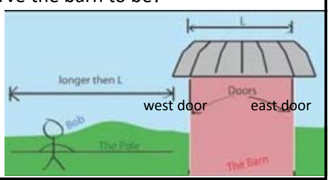
$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Example Using Lorentz Transforms

Bob has a 10 m pole that he holds horizontally. He runs at 0.8666c toward a barn that is 5 m wide and that has a door on either end. A farmer standing next to the barn observes the runner. Lengths given are proper lengths.

a) How long does the farmer observe the runner's pole to be? How wide does the farmer observe the barn to be?
b) Can the farmer observe both barn doors to be closed at the same time while the pole is entirely inside?
c) How long does the runner observe his pole to be? How wide does the runner observe the barn to be?

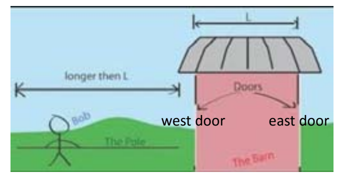
d) Can the runner observe both barn doors to be closed at the same time while the pole is entirely inside?



Example Using Lorentz Transforms

e) What sequence of events does the farmer observe? What about the runner? Be sure to define specific events that the farmer observes and then use the Lorentz transforms to find when and where the runner observes those events.
f) Draw a series of snapshots that show what the farmer sees and when and what the runner sees and when.

For this calculation let t = t' = 0 occur when the front of the pole reaches the west door of the barn. Let the coordinate system for the farmer have its origin at the west door of the barn and coordinate system of the runner have its origin at the front of the pole.



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Important Relations for Relativistic Energy and Momentum

We are going to accept that these are true without proof, and use them to solve problems.

Total energy of an object: $E = \gamma mc^2 = K + mc^2$

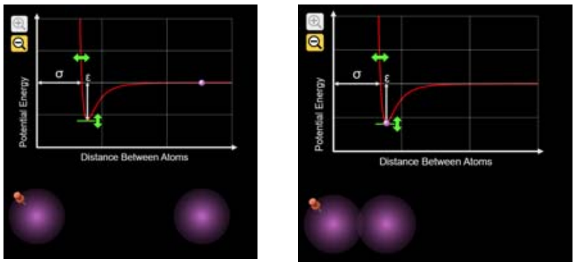
Relativistic momentum of an object: $\mathbf{p} = \gamma\ m\,\mathbf{u}$

Energy – momentum relation: $E^2 = (pc)^2 + (mc^2)^2$

Momentum of a massless particle: $p = E/c$

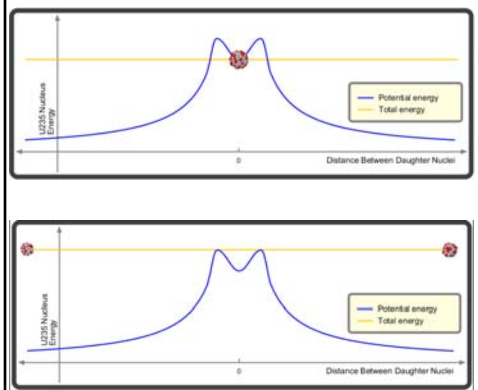
Velocity of a massless particle: $u = c$

Fusion or Chemical Bonding



This bound system weighs less than the two constituents. The extra mass/energy left the system somehow (radiation?).

Fission

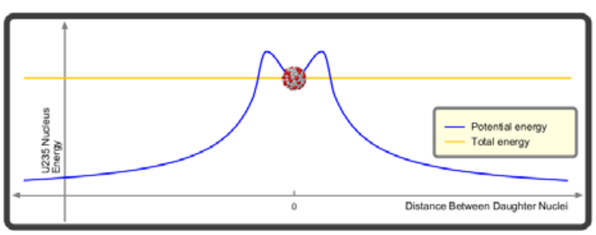


This bound nucleus weighs more than its constituents. The excess energy when the daughter nuclei fly apart is manifest as kinetic or other types energy.
If it is a bomb, then the BOOM comes from the released energy from fusion.

Book Example 2.6

The nuclei of certain atoms spontaneously fly apart tearing the whole atom into two pieces. The following reaction is one example:

$$^{232}Th \xrightarrow{\text{yields}} {}^{228}Ra + {}^{4}He + 4MeV$$



Deuteron Example

A deuteron consists of a neutron and a proton bound together by the strong nuclear force. The rest energy of a deuteron is 1875.613 MeV. The rest energy of a proton is 938.272 MeV. The rest energy of a neutron is 939.565 MeV.

a) How much energy is released or required during the formation of a deuteron?

b) Sketch the potential energy vs. constituent separation curve associated with deuteron formation. Label the energy you calculated in part a on the curve.

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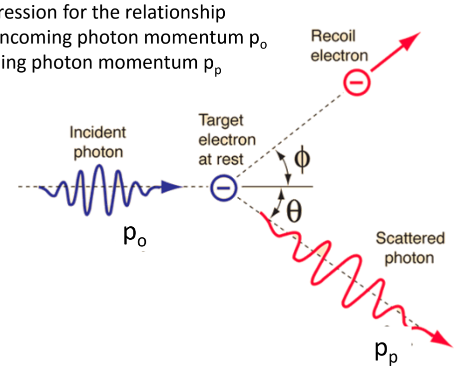
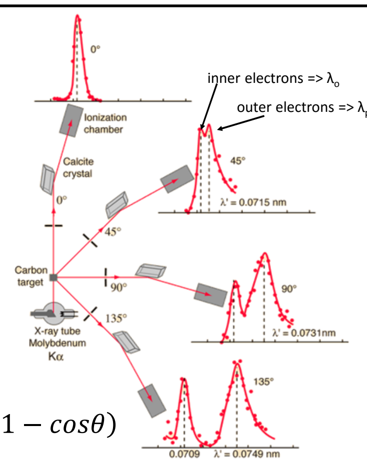
Compton Scattering Setup

Derive an expression for the relationship between the incoming photon momentum p_o and the outgoing photon momentum p_p



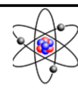
Derive Compton Scattering Equation

Compton Scattering Data



$$\lambda_p - \lambda_o = \frac{h}{mc}(1 - cos\theta)$$

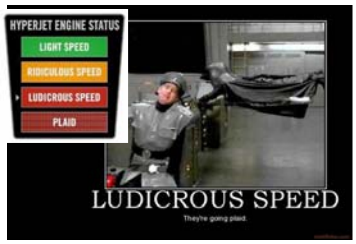
What is Modern Physics?



Study of motion & interaction of very small things (atoms,molecules &photons)
= quantum mechanics

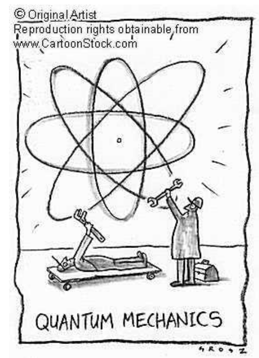
Study of motion & interaction of very fast objects (close to the speed of light)
= special relativity

Study of motion & interaction of very massive objects (star sized)
= general relativity



All started around 1900 and continue today = "modern physics"

Question which will occupy us for much of the rest of the block:
What is the structure of an atom?



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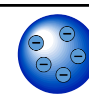
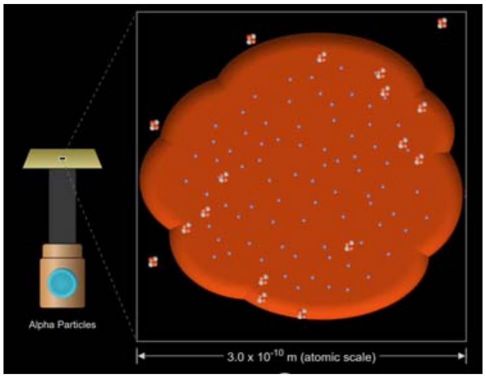
Models of the Atom



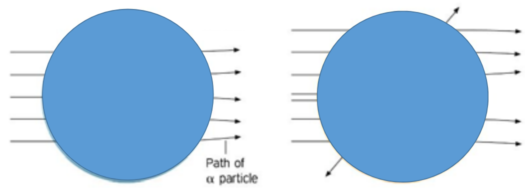
- Thomson – "Plum Pudding"
  – Why? Known that negative charges can be removed from atom.
  – Problem: Doesn't match scattering experiments

Thomson – "Plum Pudding"

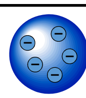


Phet: Rutherford scattering

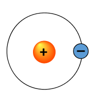
Scattering Experiments



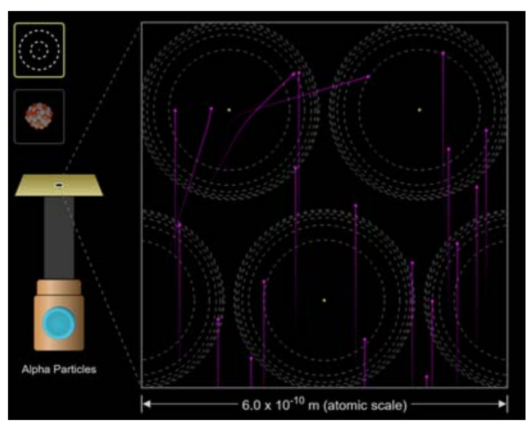
Models of the Atom



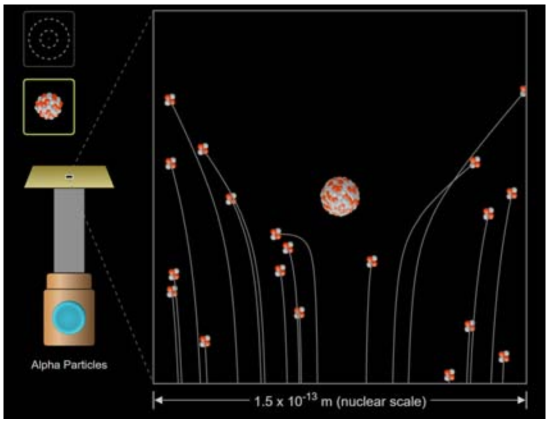
- Thomson – "Plum Pudding"
  - Why? Known that negative charges can be removed from atom.
  - Problem: Doesn't match scattering experiments
- Rutherford – Solar System
  - Why? Scattering showed a small, hard core.

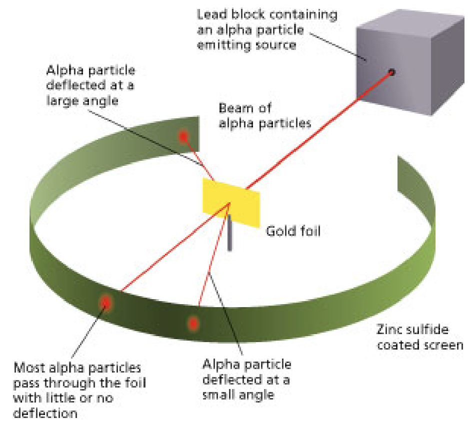


Rutherford – Solar System



Rutherford – Solar System (zoomed in)





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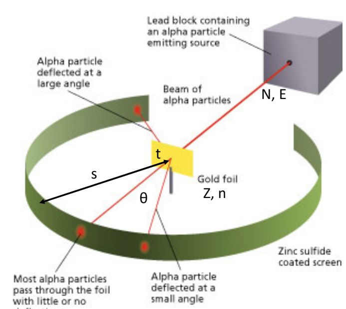
Rutherford Scattering Equation



$$n_{sc}(\theta) = \frac{Nnt}{4s^2}\left(\frac{Zke^2}{E}\right)^2 \frac{1}{sin^4(\theta/2)}$$

= number of alpha particles scattered per unit area at angle θ

Rutherford Scattering Data

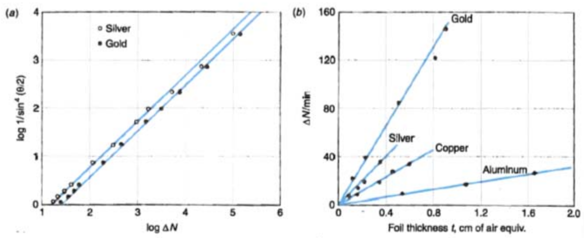


Figure 4-9 (a) Geiger and Marsden's data for α scattering from thin gold and silver foils. The graph is a log-log plot to show the data over several orders of magnitude. Note that scattering angle increases downward along the vertical axis. (b) Geiger and Marsden also measured the dependence of ΔN on t predicted by Equation 4-6 for foils made from a wide range of elements, this being an equally critical test. Results for four of the elements used are shown.

$$n_{sc}(\theta) = \frac{Nnt}{4s^2}\left(\frac{Zke^2}{E}\right)^2 \frac{1}{sin^4(\theta/2)}$$

Rutherford Scattering Example

In an α scattering experiment, the incident beam carries a current of 1.0 nA, and the energy of each α particle is 6.0 MeV. The beam is incident on 1.0 μm thick silver foil. The α particle detector is located 10 cm from the foil and has an area of 0.50 cm^2. How many α particles will be counted per second by the detector when it is placed at an angle of 60° to the incoming beam?