Chemical Engineering 412

Introductory Nuclear Engineering

Introduction

Hard Work + The Spirit

Face the future with optimism. I believe we are standing on the threshold of a new era of growth, prosperity, and abundance. Barring a calamity or unexpected international crisis, I think the next few years will bring a resurgence in the economy as new discoveries are made in communication, ***medicine***, ***energy***, ***transportation***, physics, ***computer technology***, and ***other fields*** of endeavor.

Many of these discoveries, as in the past, will be ***the result of the Spirit whispering insights into and enlightening the minds of truth-seeking individuals***. Many of these discoveries will be made for the purpose of helping to bring to pass the purposes and work of God and the quickening of the building of His kingdom on earth today. With these discoveries and advances will come new employment opportunities and prosperity *for those who work hard and especially to those who strive to keep the commandments of God*. This has been the case in other significant periods of national and international economic growth.

-Elder M. Russell Ballard

BYU Idaho Commencement Remarks

April 6, 2012

Objectives

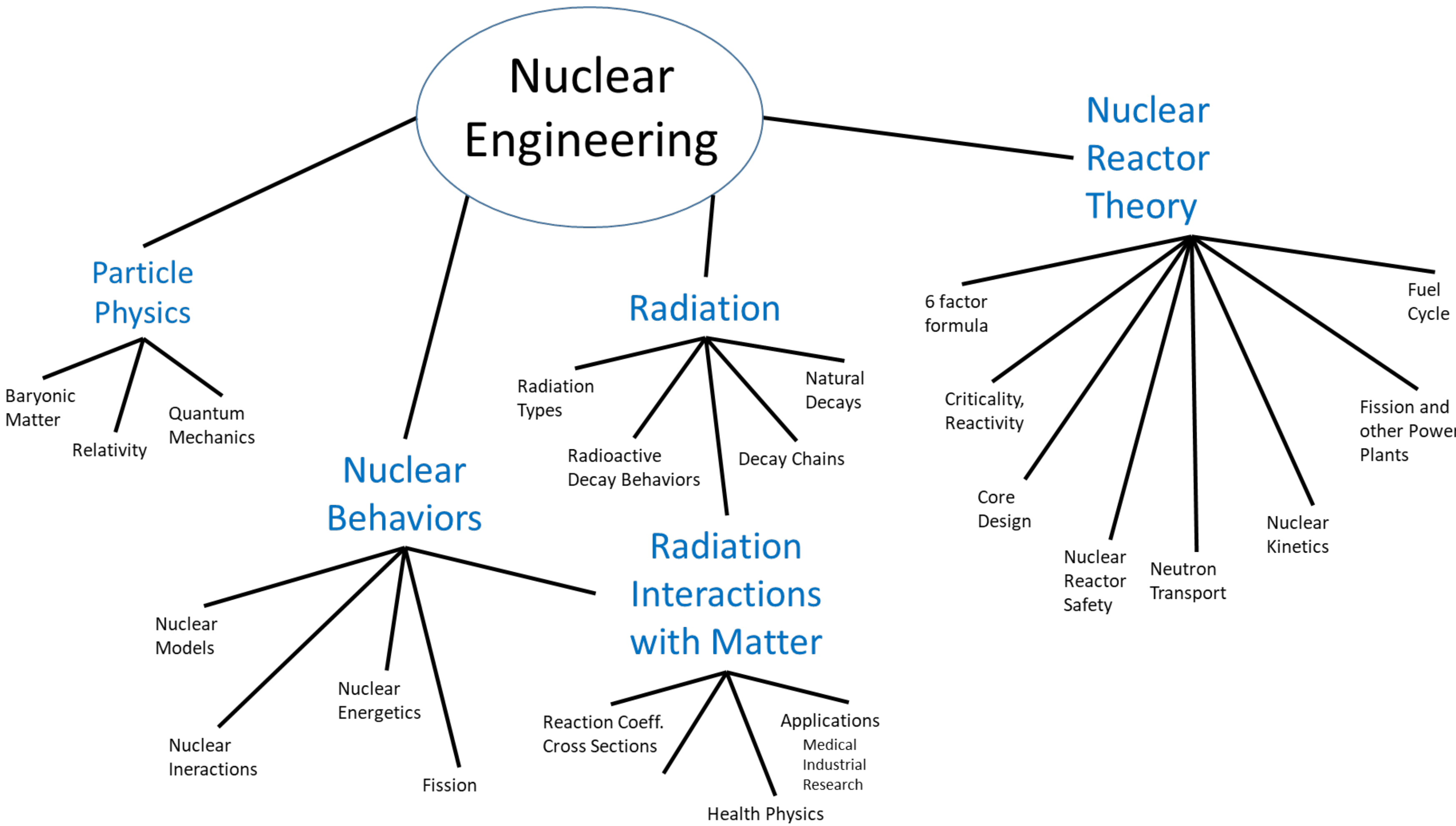
- Meet Dr. Memmott ☺
- Understand Nuclear-Scale Units
- Know and Recognize nuclear particles (especially fermions and nucleons)
- Know how to calculate number densities
- Understand how to use chart of nuclides
- Learn the background and implications of relativity

Family

Course Details

- http://www.et.byu.edu/~mjm82/che412/che412.html
- Office Hours/TA – Tom Carson
- Textbook/Readings
- Homework/Open Ended Problems
- Exams
- Final Project
- Attendance/Quizzes
- Field Trip???
- Grading

The BIG Picture



Nuclear Engineering Fundamentals

- New units and physical constants (pg 6 of text)
- New way of thinking!
  - Subatomic particles
  - Atomic vs. Molecular Weights
  - Atomic Mass & Size
  - Number Density
  - Isotopic Abundance
  - Particle Mass/Momentum
- Chart of Nuclides
- Cross Section Libraries
- Other Data, found via link on pg. 15 of text

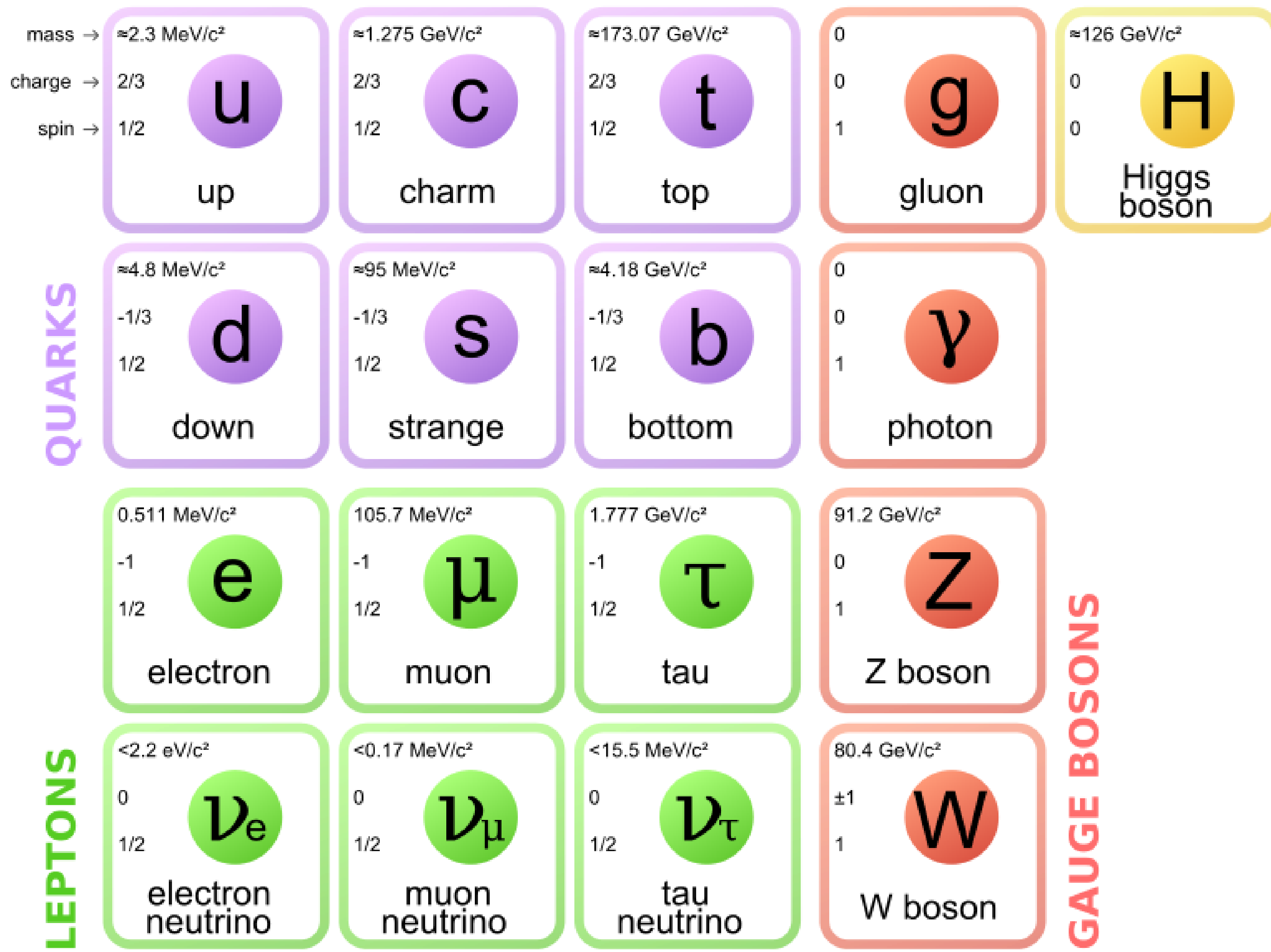
New Nuclear-Scale Units

Unit	Name	Dimension	magnitude in SI	note
eV	electron volt	energy	1.602×10^{-19} J	kinetic energy change in an electron (charge = 1.602×10^{-19} C) when accelerated/decelerated through a 1 V potential
b	barn	area	10^{-24} cm^2, or 10^{-28} m^2 or 100 fm^2	frequently used measure of area. Less frequently used related measures are the outhouse (1 μb) and shed (1 fb)
Da	dalton	atomic mass	1.66×10^{-27} kg	Approx the mass of a nucleon. Specifically, 1/12 the mass of a single atom of ^{12}C – similar to a molecular weight (mass)
u or amu	unified atomic mass unit	atomic mass	1.66×10^{-27} kg	identical to Dalton, except amu based on oxygen-16.
Bq	becquerel	activity	1/s	decay rate
Ci	curie	activity	3.7×10^{10} Bq	approximate activity of 1 g of radium 226 (or 3 tons of uranium-238)

Welcome to Wonderland, Alice!

- “You must unlearn what you have learned” - Yoda
- Crucial Assumptions no longer apply in nuclear world:
  - Mass not con
  - Energy not co
  - Elements not
  - Neutron trans
  - Energy not co   ms
    - radiated in   rgy
  - Relativistic ef
  - Quantum effe   ance
- Far more nuclid
- The top half of t   istry; nuclear engineering use   on to many things not on it

Elementary Particles



Fundamental Particles

- Fermions (matter) (spin of ½)
  - Quarks – up, down, charm, strange, top, bottom
    - Hadrons – Composite Particles
      - Mesons – composed of 2 particles – 1 quark, 1 antiquark
      - Baryons – Composed of 3 quarks
        - » Neutron = 1 up + 2 down quarks = 1.67492729(28) × 10−27 kg = 1.008664915(6) u = 939.56536 MeV/c2
        - » Proton = 2 up + 1 down quark = 1.67262171(29) × 10−27 kg = 1.007276466(13) u = 938.27203 MeV/c2
        - » Neutron mass > Proton + electron

“Nucleons”

  - Leptons – electron neutrino, electron, muon neutrino, muon, tau neutrino, tau
    - Muon, electron neutrino, electron are most important and “positrons”
      - Electron nuetrinos created from beta decay, very small non-zero mass, rare matter interactions
      - Muons created from high energy interactions – cosmic rays
        - » 200x more massive than e^-, but still moving at 0.998c
- Electron – lepton = 9.109 382 15(45) × 10^{-31} kg = 5.485 799 09(27) × 10^{-4} u = 0.51099892 MeV/c^2
- Bosons (force) (spin of 1)
  - Gauge bosons – gluon, W and Z bosons, photon
    - Photon – zero rest mass
  - Other bosons – Higgs boson, graviton

Isotopic Nomenclature

$$^{A}_{Z}E \qquad ^{12}_{6}C$$

Z = atomic number = number of protons (identifies element)
A = atomic mass number = nucleon number
E = symbol (redundant with Z, so Z sometimes dropped)
N = number of neutrons = A-Z
N generally ≥ Z for stable isotopes except ^{1}H
Atomic mass close to but ≠ A
Isotope – constant Z (and generic term)
Isotone – constant N
Isobar – constant A
Isodiapher – constant N-Z

Isotopic Abundance

Nucl.	Half-life	Abund. / Decay Mode
^{1}H	stable	**99.985**
^{2}H	stable	**0.015**
^{3}H	12.33 y	$\beta^-(100)$
^{3}He	stable	**0.000137**
^{4}He	stable	**99.999863**
^{6}Li	stable	**7.5**
^{7}Li	stable	**92.5**
^{7}Be	53.29 d	EC(100)
^{9}Be	stable	**100.**
^{10}Be	1.51 My	$\beta^-(100)$
^{10}B	stable	**19.9**
^{11}B	stable	**80.1**
^{12}C	stable	**98.89**
^{13}C	stable	**1.11**
^{14}C	5.73 ky	$\beta^-(100)$
^{14}N	stable	**99.634**
^{15}N	stable	**0.366**
^{16}O	stable	**99.762**
^{17}O	stable	**0.038**
^{18}O	stable	**0.200**
^{19}F	stable	**100.**
^{20}Ne	stable	**90.48**
^{21}Ne	stable	**0.27**
^{22}Ne	stable	**9.25**
^{22}Na	2.6019 y	$\beta^+(100)$
^{23}Na	stable	**100.**
^{24}Na	14.9590 h	$\beta^-(100)$
^{42}Ar	32.9 y	$\beta^-(100)$
^{42}K	12.360 h	$\beta^-(100)$
^{42}Ca	stable	**0.647**
^{43}K	22.3 h	$\beta^-(100)$
^{43}Ca	stable	**0.135**
^{43}Sc	3.891 h	$\beta^+(100)$
^{44}Ca	stable	**2.086**
^{44}Sc	3.927 h	$\beta^+(100)$
^{44m}Sc	58.6 h	IT(98.80) $\beta^+(1.20)$
^{44}Ti	64.8 y	EC(100)
^{45}Ca	162.67 d	$\beta^-(100)$
^{45}Sc	stable	**100.**
^{46}Ca	stable	**0.004**
^{46}Sc	83.79 d	$\beta^-(100)$
^{46}Ti	stable	**8.25**
^{47}Ca	4.536 d	$\beta^-(100)$
^{47}Sc	3.3492 d	$\beta^-(100)$
^{47}Ti	stable	**7.44**
^{48}Ca	51 Ey	**0.187**
^{48}Sc	43.67 h	$\beta^-(100)$
^{48}Ti	stable	**73.72**
^{48}V	15.9735 d	$\beta^+(100)$
^{48}Cr	21.56 h	$\beta^+(100)$
^{49}Ti	stable	**5.41**
^{49}V	330 d	EC(100)
^{50}Ti	stable	**5.18**
^{50}V	150 Py	**0.250** $\beta^+(83)$ $\beta^-(17)$

Atomic/molecular weight

- Atomic/Molecular Weight
  - Defined as mass of neutral atom relative to the mass of ^{12}C, where the latter is identically 12.
  - The unified atomic mass unit or Dalton is $1/N_A$ g or $1.660538782(83)\times 10^{-27}$ kg
- Atomic Number Density
  - MOST Important Number!
  - Atoms per cm^3 of substance

$$N\left(\frac{atoms}{cm^3}\right) = \frac{\rho \cdot Na}{A}$$

$$N_i\left(\frac{atoms}{cm^3}\right) = x_i\frac{\rho \cdot Na}{A}$$

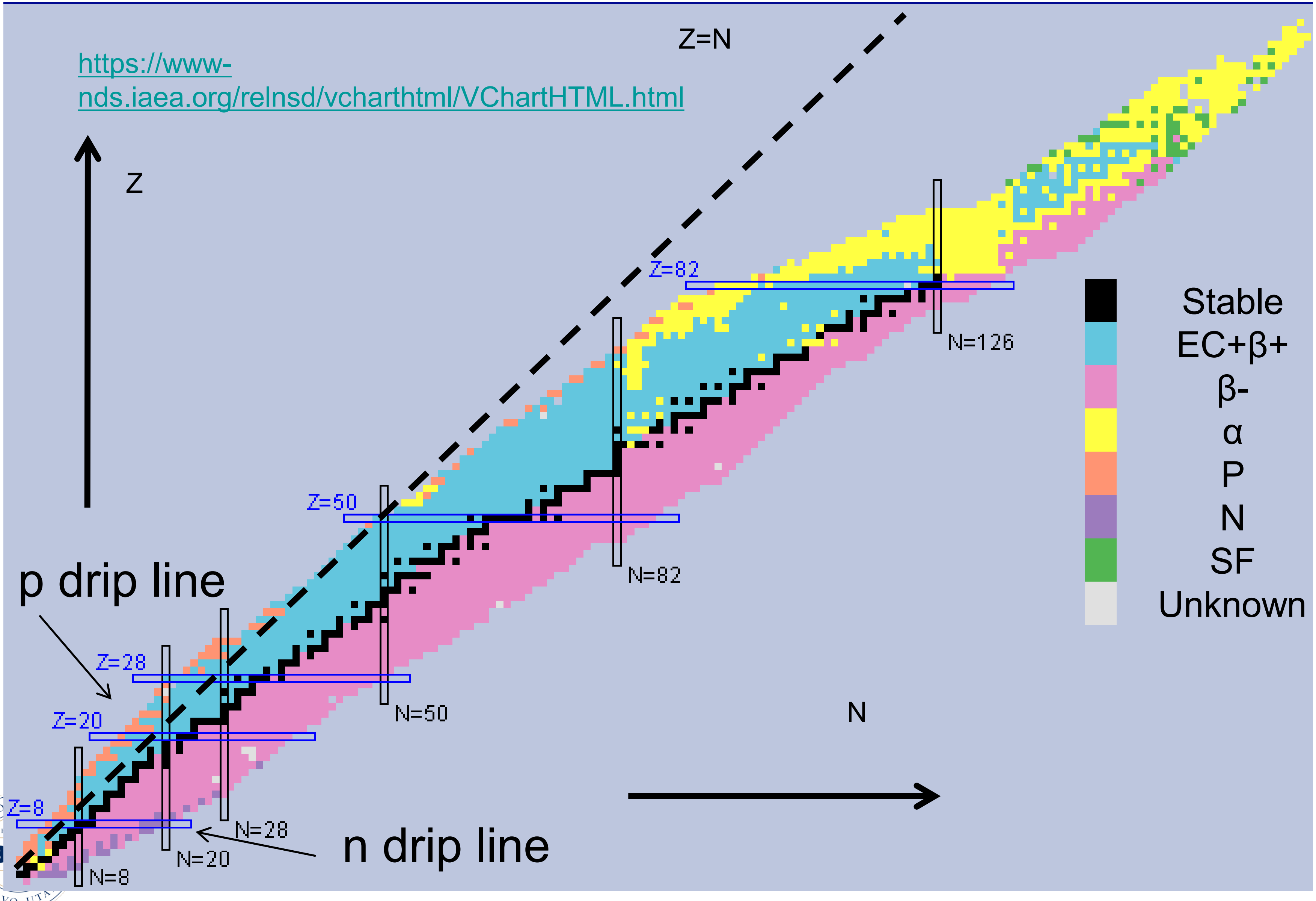
ρ = density
A = Atomic Number
Na = Avagadro's Number
X = component mass fraction

Examples:

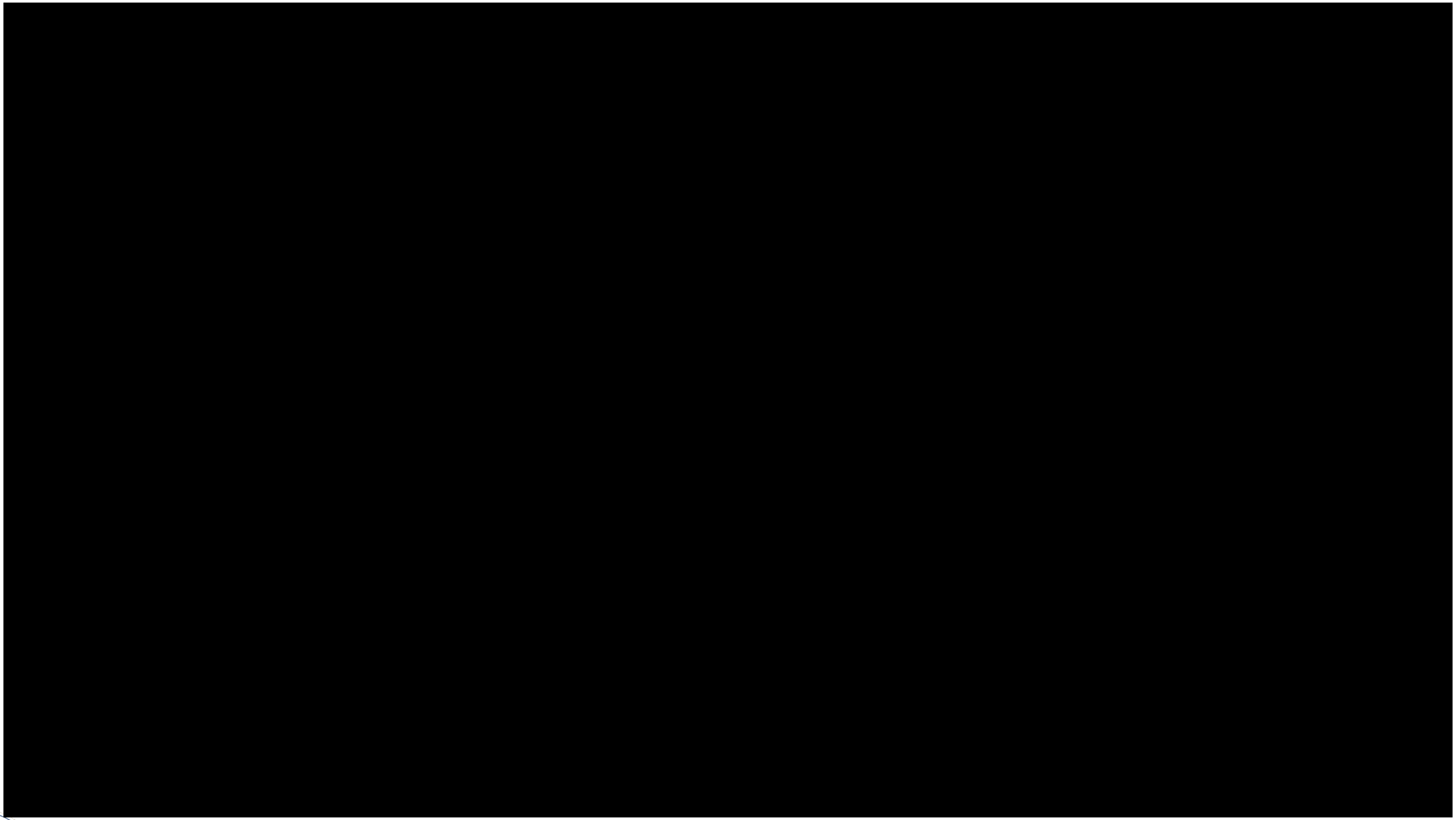
- Example 1: What is the number density of pure ^{235}U metal?
  - $= \frac{19.1 g/cm^3}{235 gm/mol} 6.022x10^{23} \ \frac{atom}{mol} = 4.894x10^{24} \frac{atom}{cm^3}$

- Example 2: What is the number density of ^{235}U in natural Uranium?
  - $= .0072 \frac{19.1 g/cm^3}{235 gm/mol} 6.022x10^{23} \ \frac{atom}{mol} = 3.52x10^{20} \frac{atom}{cm^3}$

Chart of the Nuclides



Web Problem (I)



Web Problem (II)

Open Ended Problem #1

Warp Speed

Individual work only, Due 1/17/23 at beginning of class

(Don't be afraid to "Google" good assumptions!)

Star Trek Voyager Clip

In the Star Trek universe, humans traverse the galaxy by traveling at “warp speed”. This is somewhat of a misnomer, however, since movement at faster than light speeds still isn’t possible. Rather, for warp speed, space is “bent” or warped, allowing for a ship to move along a shortcut between two points in space at sub-light speeds. The resulting combination of warped space and sub-light travel is a relative velocity that exceeds the speed of light if traveling along un-warped space. Based on the “Star Trek Voyager” clip shown above and characteristics of relativity, at what speed is the starship actually traveling, neglecting the considerations of warped-space?

Soccer Ball off a truck?

Newtonian vs. Maxwellian

- $\sum F = \frac{dm\vec{v}}{dt} = m\frac{d\vec{v}}{dt} = m\vec{a}$
  - One form/solution in non-moving reference
  - Same solution at any constant v reference
    - x’=x-vt, y’=y, z’=z, t’=t
- Maxwell Equations (electricity & magnetism)
  - One form/solution in non-moving reference
  - DIFFERENT form in constant v reference
    - Lorentz transformation:

$x' = \frac{x-vt}{\sqrt{1-{v^2}/{c^2}}}$, y’=y, z’=z, $t' = \frac{t-{vx}/{c^2}}{\sqrt{1-{v^2}/{c^2}}}$

Special Relativity Summary

2 Postulates:

- All physical laws should have the same form in any inertial (constant relative velocity) reference frame.
- The speed of light in free space (a vacuum) is independent of the relative velocity of the light source and the observer.

4 Results:

Relative to a fixed observer, moving objects exhibit

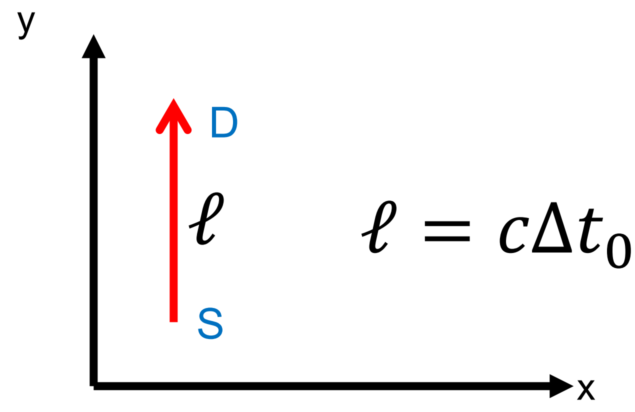
- Mass increase: $m = \frac{m_0}{\sqrt{1-v^2/c^2}}$
- Length decrease: $L = L_0\sqrt{1 - v^2/c^2}$
- Time dilation (slower): $\Delta t = \frac{\Delta t_0}{\sqrt{1-v^2/c^2}}$
- Energy and mass are equivalent: $E = mc^2$

Time Dilation Derivation

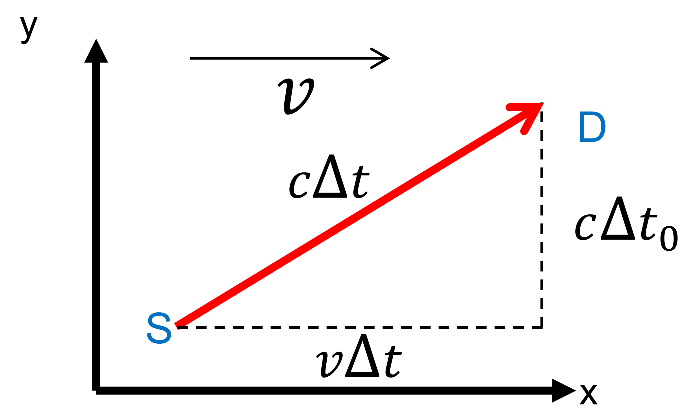
Measurements in stationary reference frames have subscript 0s and are called proper measurements.

$$(c\Delta t)^2 = (v\Delta t)^2 + (c\Delta t_0)^2$$

$$\Rightarrow \Delta t = \frac{\Delta t_0}{\sqrt{1 - v^2/c^2}}$$



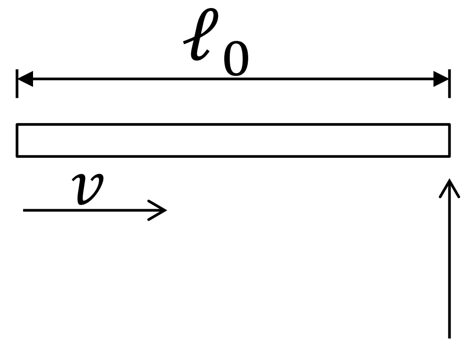
stationary system



constant velocity system

Length Decrease

The apparent length of a constant-velocity sled can be measured by a stationary observer as the time it takes to pass a fixed point times the velocity



$$\ell = v\Delta t_0 \Rightarrow v = \frac{\ell}{\Delta t_0}$$

A sled passenger measures the length (ℓ_0 - since there is no relative velocity) as the time it takes to pass a fixed point times the velocity.

$$\ell_0 = v\Delta t = v\frac{\Delta t_0}{\sqrt{1 - v^2/c^2}} = \frac{\ell}{\Delta t_0}\frac{\Delta t_0}{\sqrt{1 - v^2/c^2}}$$

$$\Rightarrow \ell = \ell_0\sqrt{1 - v^2/c^2}$$

Mass Increase

Two people, one static and one traveling at constant relative velocity v, toss identical and elastic balls towards each other, causing a head-on collision of the balls. The stationary observer tosses the ball at velocity $u = h/\Delta t_0$ and perceives the other ball to be approaching at a velocity $w = h/\Delta t$. The relationship between u and w is

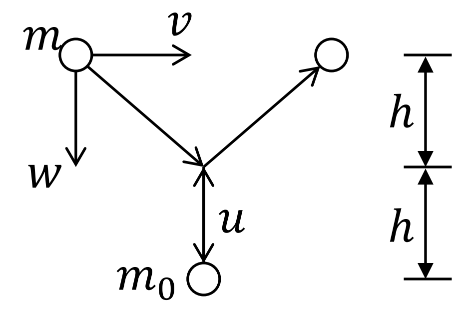
$$w = \frac{h}{\Delta t} = \frac{h\sqrt{1 - v^2/c^2}}{\Delta t_0} = u\sqrt{1 - v^2/c^2}$$

Conservation of momentum requires that the sum of the momentum (in any reference frame – by the first postulate) must be equal before and after the collision, that is,

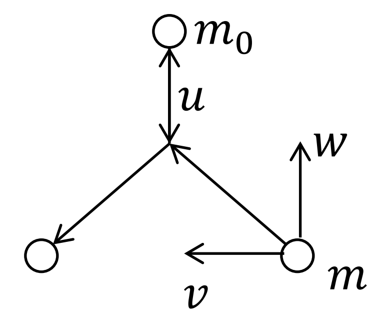
$$m_0 u - mw = -m_0 u + mw$$

$$m_0 u = mw = mu\sqrt{1 - v^2/c^2}$$

$$\Rightarrow m = \frac{m_0}{\sqrt{1 - v^2/c^2}}$$



stationary perspective



moving perspective

Illustrations