Chemical Engineering 412

Introductory Nuclear Engineering

Introduction

Spiritual Thought

"The sweetest experience I know in life is to feel a prompting and act upon it and later find out that it was the fulfillment of someone's prayer or someone's need. And I always want the Lord to know that if He needs an errand run, Tom Monson will run that errand for Him"

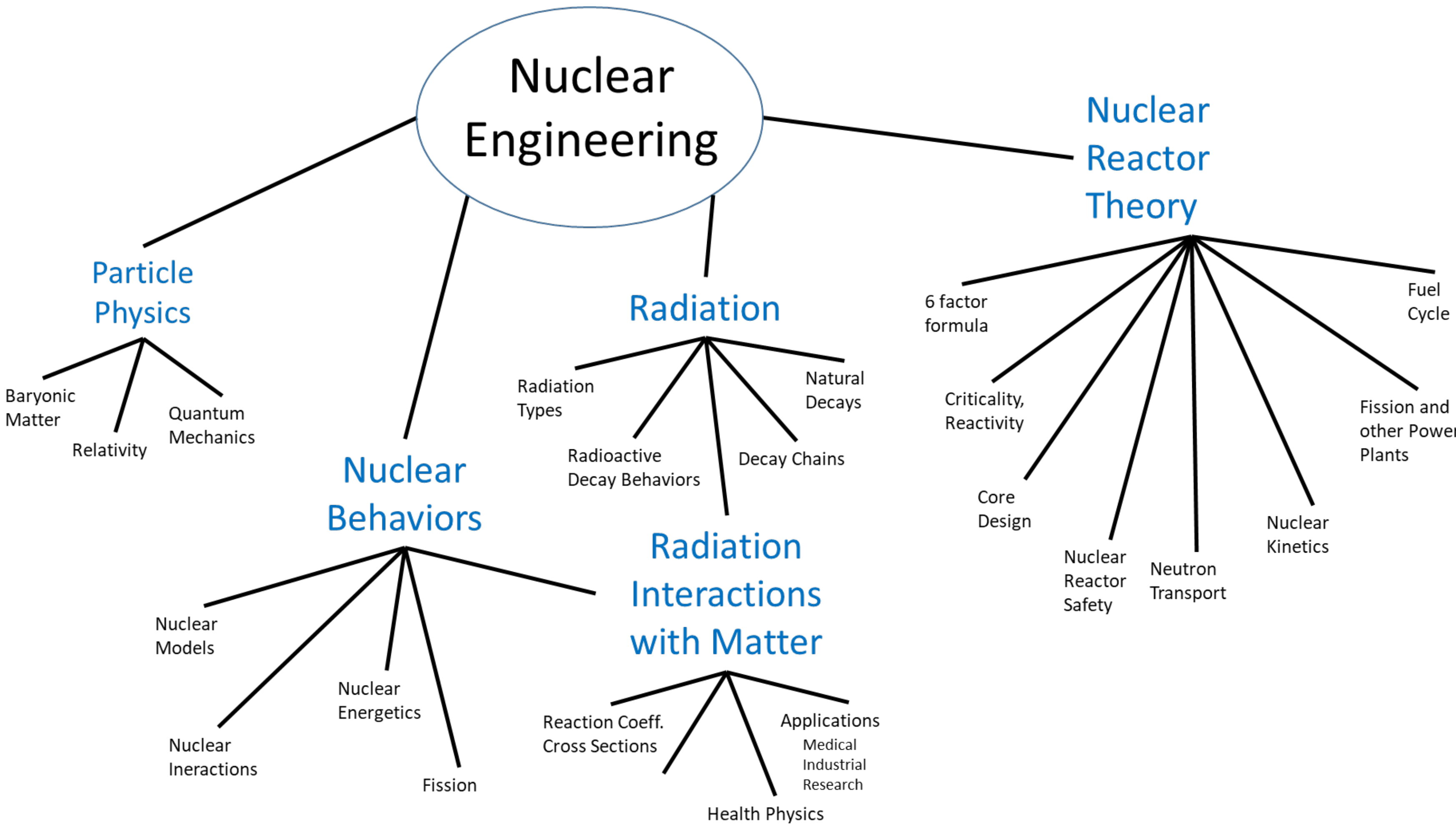
-President Thomas S. Monson

Family

Course Details

- Office Hours/TA – Richard Fitzhugh
- Textbook/Readings
- Homework/Open Ended Problems
- Exams
- Final Project
- Attendance/Quizzes
- Field Trip
- Grading
- Questions?

The BIG Picture



Nuclear Engineering Fundamentals

- New units and physical constants (pg 6 of text)
- New way of thinking!
- Atoms
- Subatomic particles
- Atomic vs. Molecular Weights
- Atomic Mass & Size
- Number Density
- Isotopic Abundance
- Nuclear Density
- Chart of Nuclides
- Other sources – (found on pg. 15 of book)

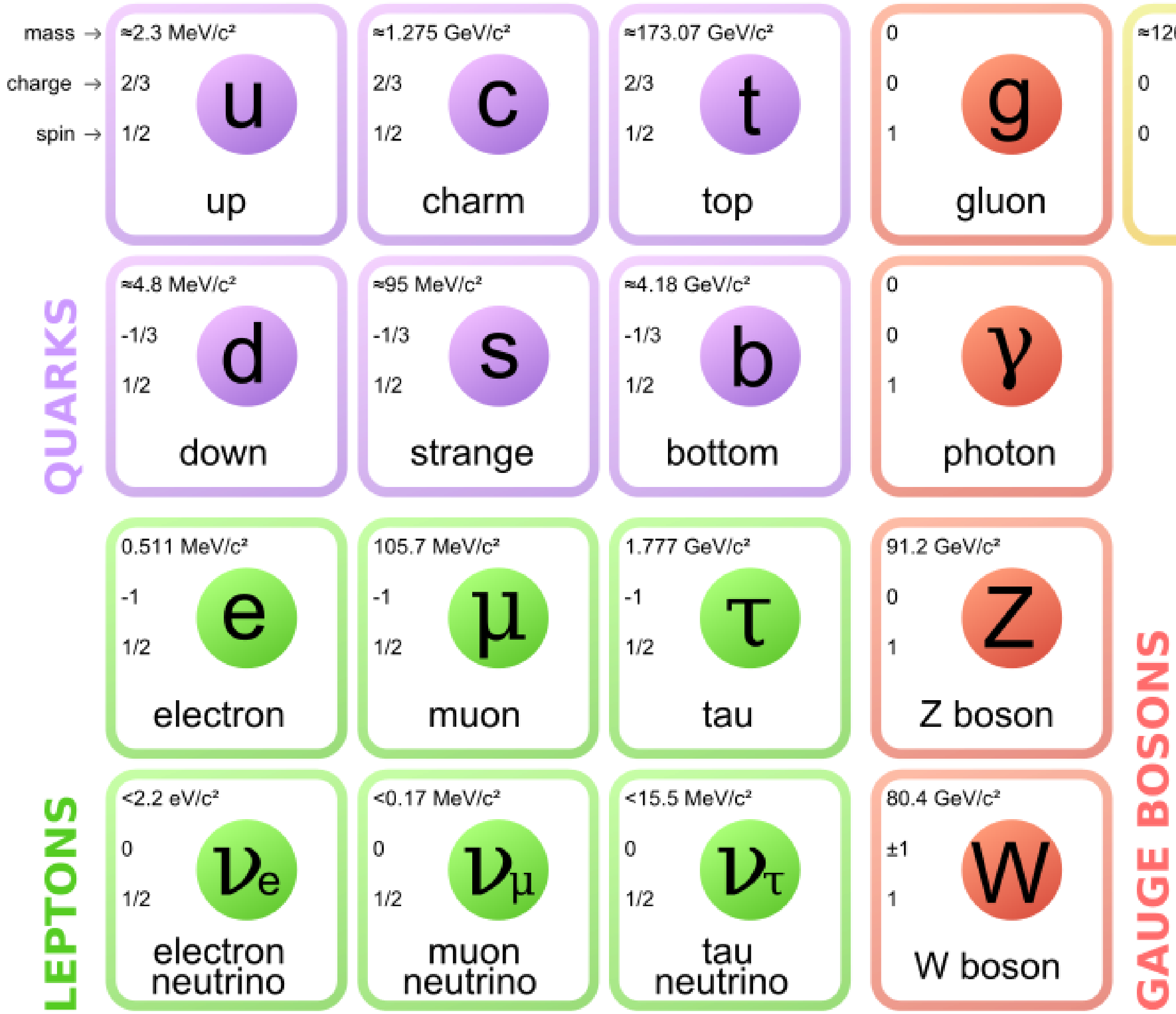
New Nuclear-Scale Units

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 technically is now obsolete and 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   nistry; 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

“Nucleons”

» 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

  - 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

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

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

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.
  - Conceptually the mass of a nucleon, but not quantitatively so.
  - Unitless (mass, not weight)
  - The unified atomic mass unit or Dalton is $1/N_A$ g or $1.660538782(83) \times 10^{-27}$ kg
- Atomic Number Density
  - Atoms per cm^3 of substance

$$N \ (\mathrm{atoms/cm^3}) = \frac{\rho}{A} N_a$$

- Example: What is the number density of pure ^{238}U metal?
  - $= \frac{19.1 g/cm^3}{235 gm/mol} 6.022x10^{23} \ \frac{atom}{mol} = 4.894x1024 \frac{atom}{cm^3}$

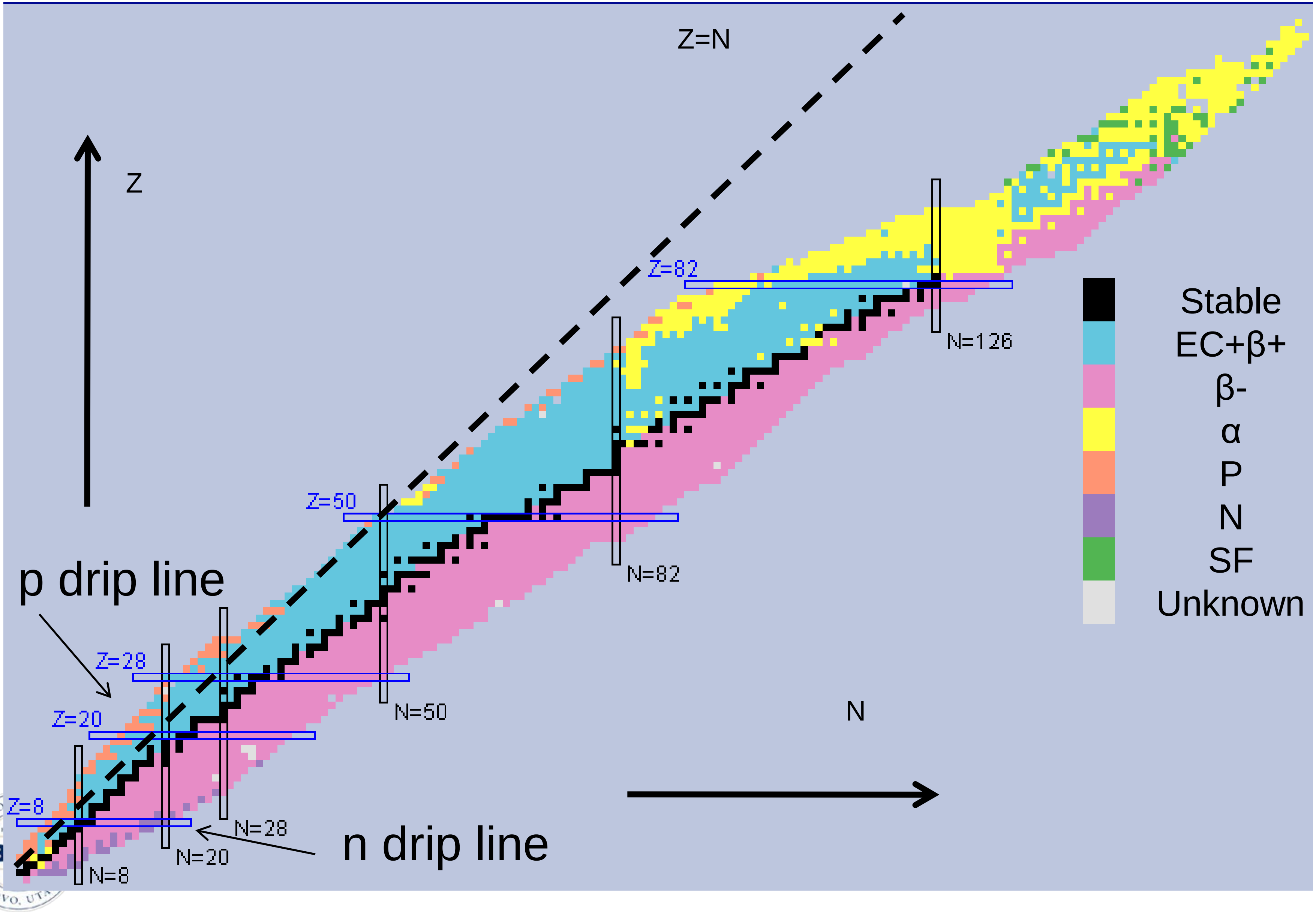
Energy = Mass

- Nuclear science commonly uses an energy unit called the electron volt (eV).
- An eV is the change in kinetic energy of an electron when it is accelerated by an electrical potential of 1 V.
- 1 eV = 1.60219×10^{-19} J
- Energies of particles in nuclear systems commonly range from <1 eV – 10 MeV
- 1 kg of mass has the equivalent energy of 8.9874×10^{16} J, or 5.6095×10^{29} MeV → 8 times the annual electricity consumption of the US

Summary of Isotopes

Stability Class	# of Isotopes	Running Total	Notes
Theoretically stable except to proton decay	90	90	Includes first 40 elements (up to Zr). Proton decay yet to be observed.
Theoretically could decay, but decay not yet observed. Spontaneous fission possible for "stable" nuclides > niobium-93; other mechanisms possible for heavier nuclides. All considered "stable" until decay detected.	164	254	Total of classically stable nuclides, includes at least one isotope of all elements up to lead except technetium (43) and promethium (61)
Radioactive nuclides created and existing in primordial times.	34	288	Total primordial elements include bismuth, uranium, thorium, plutonium, plus all stable nuclides.
Radioactive non-primordial, but naturally occurring on Earth.	~ 51	~ 339	Carbon-14 (and other isotopes generated by cosmic rays); daughters of radioactive primordials, such as francium, etc.
Radionuclides with half-life > 1 hour. Includes most useful radiotracers.	556		
Radionuclides with half-life < 1 hour.	>2400		Includes all well-characterized synthetic nuclides.

Chart of the Nuclides



Stable Isotope Highlights

- There are no stable isotopes with mass numbers 5 or 8
- Technetium (43) and promethium (61) are the only two elements with no stable isotopes with atomic numbers less than 82.
- One element (tin) has ten stable isotopes
- One element (xenon) has eight stable isotopes
- Four elements have seven stable isotopes apiece