22.02

INTRODUCTION TO APPLIED NUCLEAR PHYSICS

Spring 2012

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GOALS OF 22.02

INTRODUCTION TO APPLIED NUCLEAR PHYSICS

- Learn the basic principles of nuclear and radiation science
- After taking this class, you will able to study (and understand) any application of nuclear and radiation science

- Keyword: WHY?

YOUR GOALS?

- What are your goals and INTERESTS?

NUCLEAR PHYSICS

- Describes nuclear properties and radiation:
  - structure and characteristics of nuclei
  - radiation sources and interaction with matter
- To understand nuclear structure and radiation we study:
  - nuclei, nucleons and electrons
  - microscopic processes
- To understand we need *modern* physics
  - Quantum mechanics
  - (Special Relativity)

WHAT ARE THE MAGIC NUMBERS?

Image by MIT OpenCourseWare.

WHAT ARE THE MAGIC NUMBERS?

A computer
program variable ?

Rock band?

Iphone App?

Games to win to clinch the season?

Number of jobs?

WHAT ARE THE MAGIC NUMBERS?

Magic number (programming)

From Wikipedia, the free encyclopedia

For other uses of the term, see Magic number (disambiguation).

In computer programming, the term **magic number** has multiple meanings. It could refer to one or more of the following:

- A constant numerical or text value used to identify a file format or protocol; for files, see List of file signatures
- Distinctive unique values that are unlikely to be mistaken for other meanings (e.g., Globally Unique Identifiers)
- Unique values with unexplained meaning or multiple occurrences which could (preferably) be replaced with named constants

Magic number (sports)

From Wikipedia, the free encyclopedia

For other uses of the term, see Magic number (disambiguation).

In certain sports, a **magic number** is a number used to indicate how close a front-running team is to clinching a season title. It represents the total of additional wins by the front-running team or additional losses (or any combination thereof) by the rival team after which it is mathematically impossible for the rival team to capture the title in the remaining games. This assumes that each game results in a win or a loss, but not a tie. Teams other than the front-running team have what is called an **elimination number** (or **"tragic number"**) (often abbreviated *E#*). This number represents the number of wins by the leading team or losses by the trailing team which will eliminate the trailing team. The elimination number for the second place team is exactly the magic number for the leading team.

WHAT ARE THE MAGIC NUMBERS?

Obama's Magic Number May Be 150,000 Jobs Per Month

By NATE SILVER

No economic indicator is a political holy grail. The American economy is a hard thing to measure, and initial estimates of economic performance are subject to significant revisions. Noneconomic matters — wars, candidates, scandals and so forth — matter, too.

WHAT ARE THE MAGIC NUMBERS?

In nuclear physics?

2 8 20 28 50 82 126

- And **why** are they magic?

You'll find out at the end of this lecture

BINDING ENERGY

- Mass-energy equivalence
  - $E = mc^2$
- Nuclei are composed of protons and neutrons, ***held together by some energy***
  - $Z\ m_{\text{proton}} + N\ m_{\text{neutron}} \neq M_{\text{Nucleus}}$
  - Difference in mass ➜ difference in energy
  - This explains why we get energy from nuclear fission, from fusion, from radioactive decay products...

NUCLEAR NOMENCLATURE

- Atoms/nuclei are specified by # of
  - neutrons: N
  - protons: Z

  [Z electron in neutral atoms]

- Atoms of same element have same atomic number Z
- Isotopes of the same element have same atomic number Z but different number of neutrons N

NUCLEAR NOMENCLATURE

- Isotopes are denoted by

$${}^{A}_{Z}X$$

  - X is the chemical symbol
  - A = Z + N is the **mass number**

- E.g.: ${}^{235}_{92}U$, ${}^{238}U$ [Z is redundant here]

NUCLEAR NOMENCLATURE

- NUCLIDE
  - atom/nucleus with a specific N and Z
- ISOBAR
  - nuclides with same mass # A ($\neq$Z,N)
- ISOTONE
  - nuclides with same N, $\neq$Z
- ISOMER
  - same nuclide (but different energy state)

BINDING ENERGY

- Mass-energy equivalence
  - $E = mc^2$
- Nuclei are held together by the binding energy
  - $Z\ m_{\text{proton}} + N\ m_{\text{neutron}} \neq M_{\text{Nucleus}}$
  - Difference in mass ➜ difference in energy

  - Why is there a mass difference?

BINDING ENERGY

- Binding Energy = [Mass of its constituents-Nucleus Mass] x c^2

$$B = \left[Z m_p + N m_n - m_N(^A X) \right] c^2$$

- In terms of measurable quantities:

$$B = \left\{ Z m_p + N m_n - \left[m_A(^A X) - Z m_e \right] \quad c^2 \right.$$

- B is always positive for stable nuclei

SEMI-EMPIRICAL MASS FORMULA

$$M(Z,A) = Zm(^1H) + Nm_n - B(Z,A)/c^2$$

- From a simple model of the nucleus, described as a liquid drop

  ➜ formula for *B(Z,A)*

- 5 terms, plot B(Z,A) vs. A

SEMI-EMPIRICAL MASS FORMULA

$$M(Z,A) = Zm(^1H) + Nm_n - B(Z,A)/c^2$$

- With binding energy given by:

Surface Coulomb

$$B(A,Z) = a_v A - a_s A^{2/3} - \boxed{a_c Z(Z-1)A^{-1/3}}$$

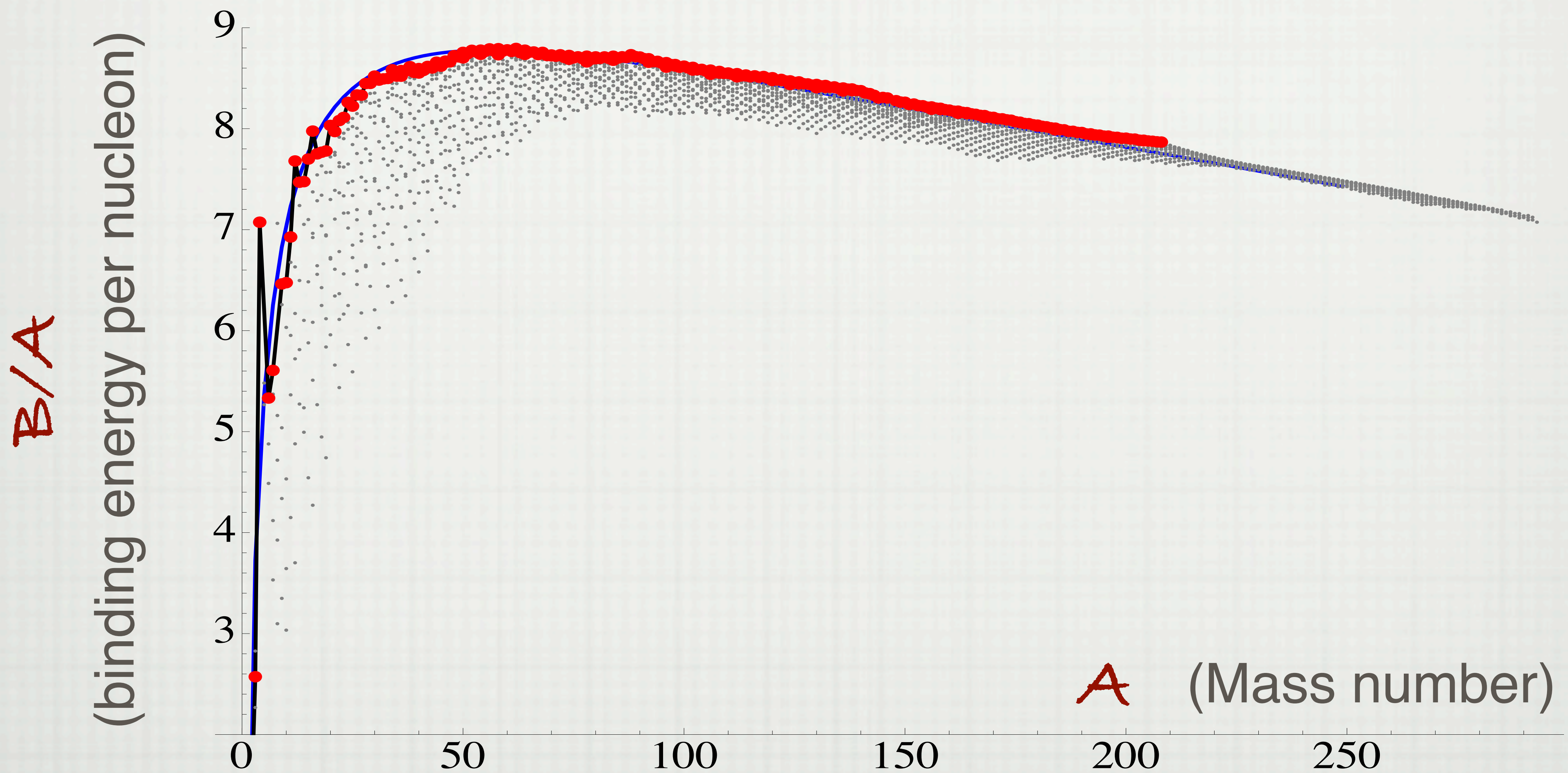
Volume

$$-\underbrace{a_{sym}\frac{(A-2Z)^2}{A}}_{\text{symmetry}} + \underbrace{\delta a_p A^{-3/4}}_{\text{pairing}}$$

SEMF: Binding Energy per Nucleon

- B(Z,A)/A ~ cst.(8 MeV) - corrections

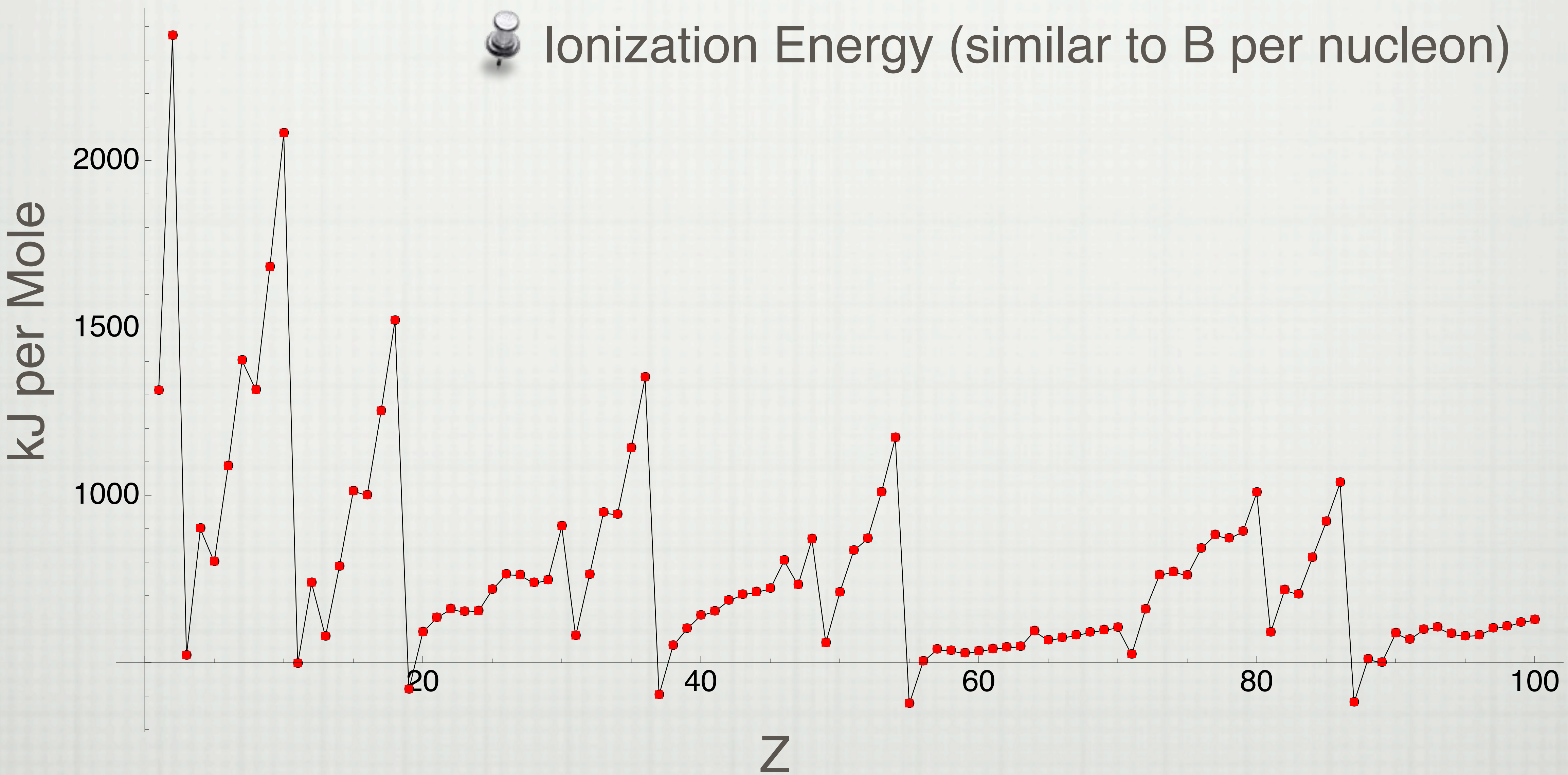
B/A: JUMPS



- "Jumps" in Binding energy from experimental data

ATOMS PERIODIC PROPERTIES

- Ionization Energy (similar to B per nucleon)



ATOMIC PERIODIC TABLE

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra																

- Periodic properties → atomic structure
- Ionization Energy (similar to B per nucleon)

CHART OF NUCLIDES

- *"Periodic"*, more complex properties → nuclear structure

WHAT ARE THE MAGIC NUMBERS?

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- And **why** are they magic?

WHAT ARE THE MAGIC NUMBERS?

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- And **why** are they called magic?

WHAT ARE THE MAGIC NUMBERS?

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- And **why** are they called magic?
  - Maria Goeppert Mayer "discovered" them in ~1945
    Observation of periodicity in binding energy
    ➜ **shell model** for nuclei
  - Eugene Wigner believed in **liquid-drop** model,
    did not trust new theory
    ➜ called these numbers *"magic"*
- Quantum mechanics only can explain them
  - As well as many other "misteries",
    e.g. randomness of radioactive decay

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- Class Logistics

RECITATIONS

- There will be weekly recitations
- Recitations will review some topics from lecture and mathematical background

TEXTBOOKS

- Lecture notes
  - Usually posted before the lecture
- Kenneth S. Krane,
  - Introductory Nuclear Physics, Wiley
- David J. Griffiths
  - Introduction to Quantum Mechanics,
    2nd edition Pearson Prentice Hall, 2005

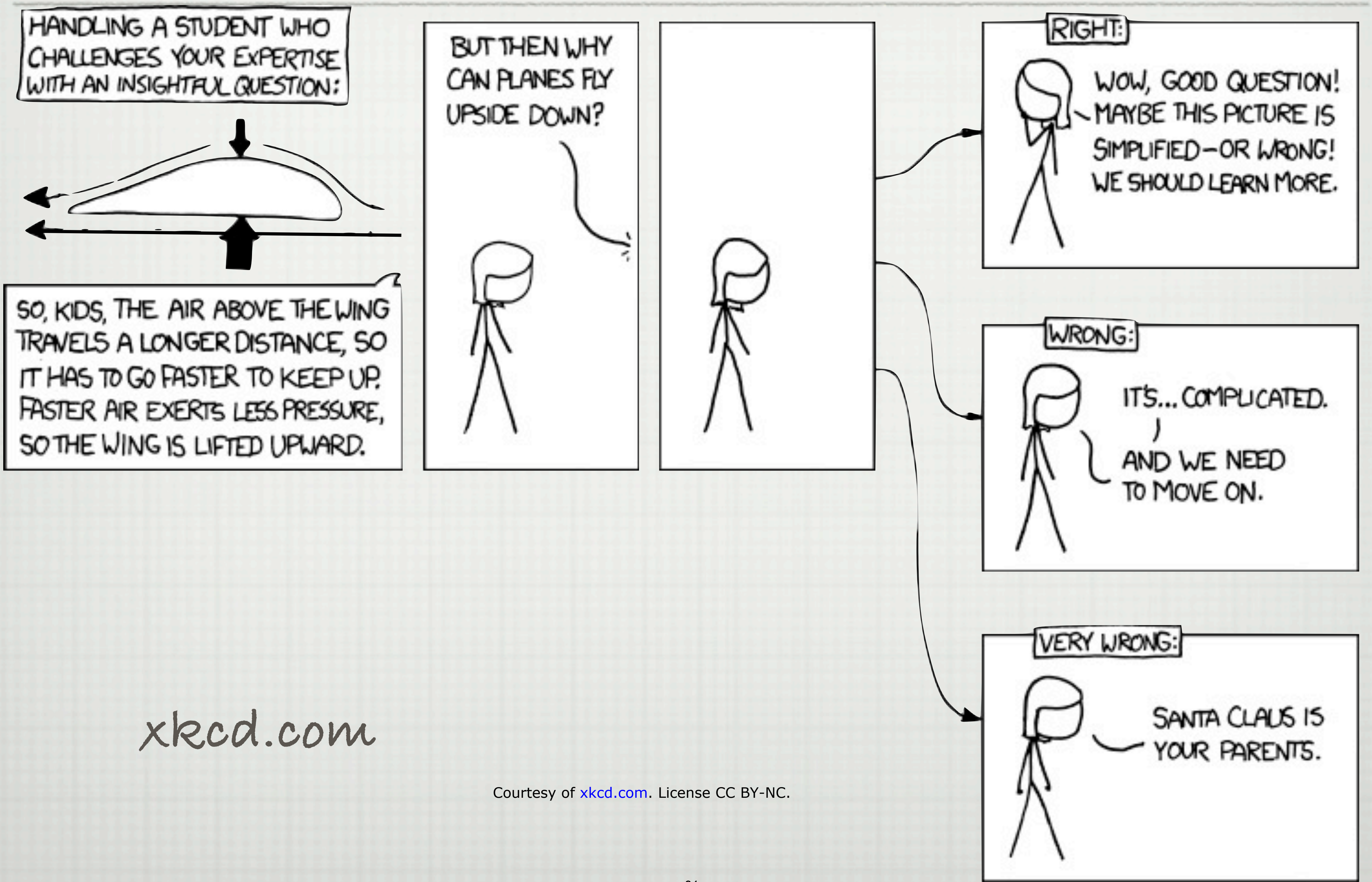
P-SETS

- The problem sets are an essential part of the course
  - Try solving the Pset on your own
  - Discuss with other students
  - Attend recitations
  - Ask TA and Professor
- P-sets will be posted
  - 9 P-sets, tentative schedule in Syllabus hand-out
  - P-set solutions will be posted
  - No p-sets will be accepted after the deadline
- Worst P-set grade will be dropped

GRADING

- Homework 25%
  - Worst P-set grade will be dropped
- Mid-Term 30%
  - Week before Spring Break: Conflicts?
- Final exam 40%
  - “Mostly” on second part of class
- Class Participation 5%

CLASS PARTICIPATION



xkcd.com

QUESTIONS?

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