Announcements

1. Presentation signups – Thursday 4/24/03 – 5:30 PM
   – Friday 4/25/03 – 4:00 PM
   – Sunday 4/27/03 – 1:30 PM
2. Reminder – bring your Thinkpads to lab this week
3. Nuclear physics – next three lectures

   Description of nuclei – mass deficit

   Nuclear decay processes – half life – α,β,γ particles
   – units Ci, rad, rem

   Nuclear reactions – fission and fusion

Motivation

- General education
- Opportunities and dangers
- Nuclear power possibilities
- Astrophysics connections

THREE MILE ISLAND: 1979 In 1979 a cooling malfunction caused part of the core to melt a 2 reactor at Three Mile Island near Harrisburg PA. The reactor was destroyed. Some radioactive gas was released a couple of days after the accident, but not enough to cause any dose above background levels to local residents. There were no injuries or adverse health effects from the accident.

THE CHERNOBYL DISASTER: On April 26, 1986 at 1:23 am technicians at the Chernobyl Power Plant in the Ukraine (former Soviet Union) allowed the power in the fourth reactor to fall to low levels as part of a controlled experiment which went wrong. The reactor overheated causing a meltdown of the core. The people of Chernobyl were exposed to radioactivity 100 times greater than the Hiroshima bomb. It is estimated that over 15 million people have been victimized by the disaster in some way and that it will cost over 60 Billion dollars to make these people healthy.

Period	1 IA 1A	2 IIA 2A	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8	9 VIII 8	10	11 IB 1B	12 IIB 2B	13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	18 VIIIA 8A
1	1 H 1.008																	2 He 4.003
2	3 Li 6.941	4 Be 9.012											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
3	11 Na 22.99	12 Mg 24.31											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
4	19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.88	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.47	28 Ni 58.69	29 Cu 63.55	30 Zn 65.39	31 Ga 69.72	32 Ge 72.59	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
5	37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (98)	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
6	55 Cs 132.9	56 Ba 137.3	57 La* 138.9	72 Hf 178.5	73 Ta 180.9	74 W 183.9	75 Re 186.2	76 Os 190.2	77 Ir 190.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.5	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (210)	85 At (210)	86 Rn (222)
7	87 Fr (223)	88 Ra (226)	89 Ac~ (227)	104 Rf (257)	105 Db (260)	106 Sg (263)	107 Bh (262)	108 Hs (265)	109 Mt (266)	110 --- ()	111 --- ()	112 --- ()		114 --- ()		116 --- ()		118 --- ()

Z

Ingredients of nucleus:

Z protons (each with mass m_p = 1.007276 u)

N neutrons (each with mass m_n = 1.0086556 u)

$A \equiv Z + N$

$u \equiv$ (1/12) x mass of C for A=12 (1.6605402 x 10^{-27} kg, 931.49432 MeV/c^2)

Note: in these units, m_e = 0.0005486 u

Notation: $^{A}_{Z}N$ examples: $^{12}_{6}C$, $^{238}_{92}U$

Atomic Weights and Isotopic Compositions for All El

Z	Isotope	A	Relative Atomic Mass	Isotopic Composition	Standard Atomic Weight
1	H	1	1.007 825 032 1(4)	99.9885(70)%	1.007 94(7)
	D	2	2.014 101 778 0(4)	0.0115(70)	
	T	3	3.016 049 2675(11)		
2	He	3	3.016 029 309 7(9)	0.000 137(3)	4.002 602(2)
		4	4.002 603 2497(10)	99.999 863(3)	
3	Li	6	6.015 122 3(5)	7.59(4)	6.941(2)
		7	7.016 004 0(5)	92.41(4)	
26	Fe	54	53.939 6148(14)	5.845(35)	55.845(2)
		56	55.934 9421(15)	91.754(36)	
		57	56.935 3987(15)	2.119(10)	
		58	57.933 2805(15)	0.282(4)	
27	Co	59	58.933 2002(15)	100	58.933 200(9)

mass of neutral atom
→ includes Z electrons

Z		A			
27	Co	59	58.933 2002(15)	100	58.933 200(9)

Mass of nucleus:

$$M_{sum} = Zm_p + (A\text{-}Z)m_n + Zm_e = 59.474281 \text{ u}$$

$$\Delta M = 0.5410806 \text{ u}$$

What should we do with this mass deficit?

(A) Chalk it up to inaccuracy of my calculator.

(B) Figure that NIST made a mistake.

(C) Give up on physics as a quantitative science.

(D) Find some meaning associated with ΔM.

mass of neutral atom
➔ includes Z electrons

Z		A			
27	Co	59	58.933 2002(15)	100	58.933 200(9)

Mass of nucleus:

$$M_{sum} = Zm_p + (A\text{-}Z)m_n + Zm_e = 59.474281\ \text{u}$$

$$\Delta M = 0.5410806\ \text{u} = 504.0135\ \text{MeV}/c^2$$

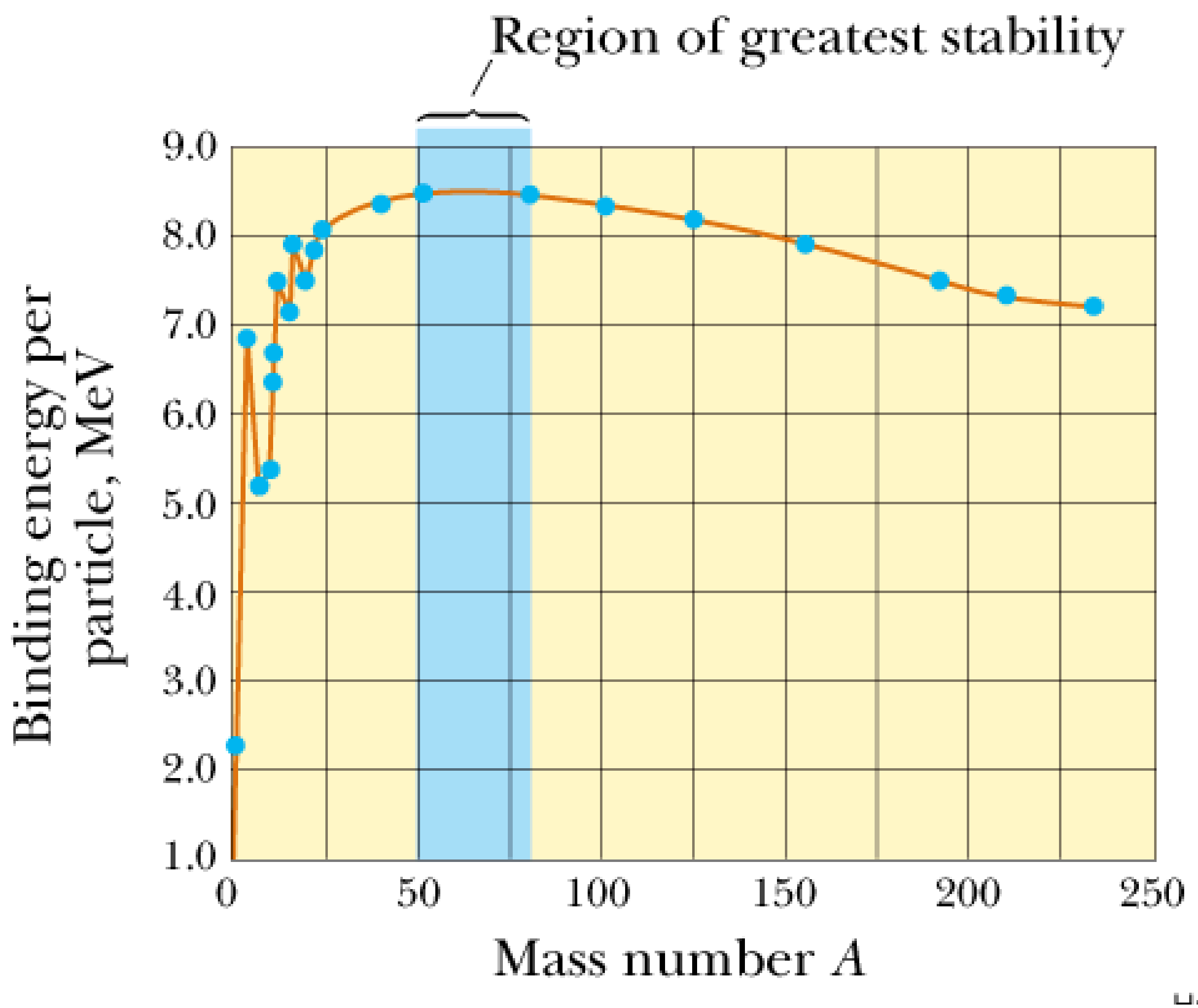
$$\Delta M/A = 8.5426\ \text{MeV}/c^2\ /\text{nucleon}$$ ➔ energy associated with nuclear "binding"

Another example:

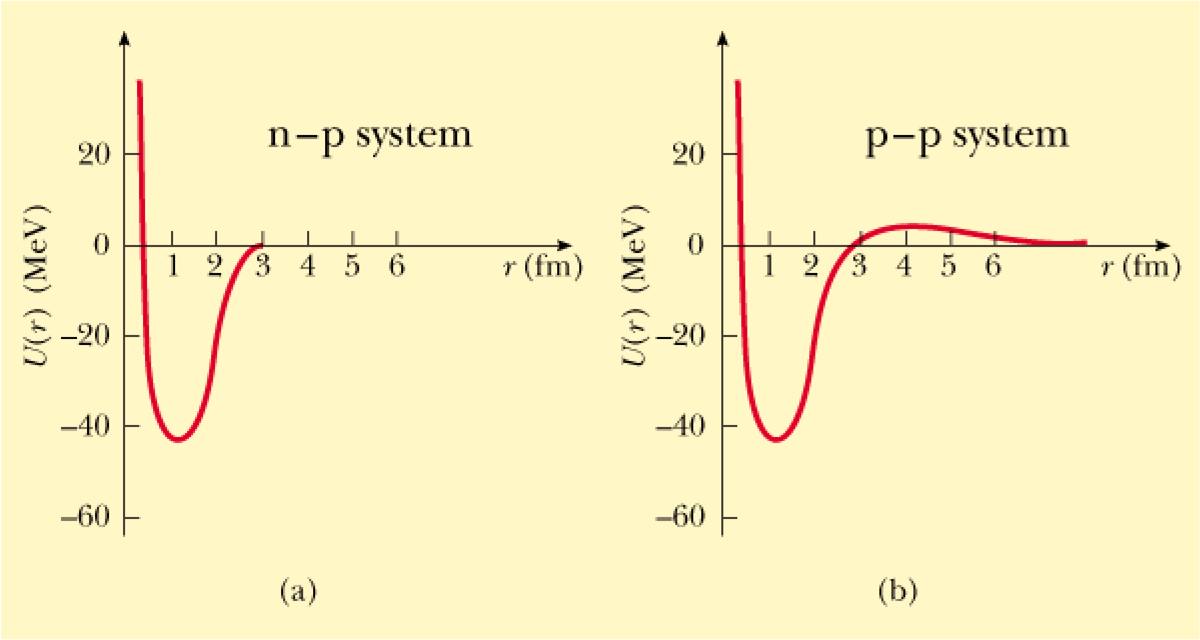
2	He	3	3.016 029 309 7(9)	0.000 137(3)	4.002 602(2)
		4	4.002 603 2497(10)	99.999 863(3)	

$$\Delta M/A({}^4_2\text{He}) = 7.1\ \text{MeV}/c^2/\text{nucleon}$$

$$\Delta M/A({}^3_2\text{He}) = 2.6\ \text{MeV}/c^2/\text{nucleon}$$


Region of greatest stability
Binding energy per particle, MeV
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
50
100
150
200
250
Mass number A

➔There must be a strong attraction between nuclear particles



Not all nuclei are stable:

Some types of nuclear decay

$\alpha \equiv {}^{4}_{2}He^{++}$ Ex: ${}^{238}_{92}U \rightarrow {}^{234}_{90}Th + \alpha$

$\beta \equiv e^{-}$ or e^{+} Ex: ${}^{14}_{6}C \rightarrow {}^{14}_{7}N + e^{-}$

$\gamma \equiv$ (photon) Ex: ${}^{12}_{5}B \rightarrow {}^{12}_{6}C^{*} + e^{-} + \bar{\nu}$

Measure of radioactive decays:

$$\text{Decay rate:} \quad \frac{dN}{dt} = -\lambda N$$

$$\text{Solution:} \quad N(t) = N_0 e^{-\lambda t}$$

$$\left| \frac{dN}{dt}(t) \right| = N_0 \lambda e^{-\lambda t}$$

Half-life:

When $N(t) = \frac{1}{2} N_0$:

$$N(T_{1/2}) = N_0 e^{-\lambda T_{1/2}} \equiv \tfrac{1}{2} N_0$$

$$\Rightarrow T_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.6931472}{\lambda}$$

$$\text{Note that: } N(t) = N_0 \left(\frac{1}{2}\right)^{\left(t/T_{1/2}\right)}$$

Some units of nuclear decay:

1 Ci (Curie) ≡ 3.7×10^{10} decays/s

1 Bq (Becquerel) ≡ 1 decay/s

Example:

Suppose that you have a sample of 10^{23} ${}^{14}_{6}C$ nuclei

each of which has a half-life of 5730 years. How many Curies of radiation is this?

$$T_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.6931472}{\lambda}$$

$$\lambda = \frac{0.6931472}{T_{1/2}} = 3.8\times 10^{-12}\,\text{decays/s}$$

$$\left|\frac{dN}{dt}\right| = \lambda N = 3.8\times 10^{-12}\times 10^{23}\,\text{decays/s} = 10.4\,\text{Ci}$$