

Lecture 1: RDCH 702 Introduction

- **Reading: Chart of the nuclides and Table of the isotopes**
(<http://radchem.nevada.edu/docs/course%20reading/TOI.PDF>)
 - **Provide blog input when lecture completed**
 - **Comments, questions, or statement that lecture completed**
 - <http://rdch702.blogspot.com/>
- **Class organization**
 - **Outcomes**
 - **Grading**
- **Chart of the nuclides**
 - **Description and use of chart**
 - **Data**
- **Radiochemistry introduction**
 - **Atomic properties**
 - **Nuclear nomenclature**
 - **X-rays**
 - **Types of decays**
 - **Forces**

RDCH 702: Introduction

- **Outcomes for RDCH 702**
 - **Understand chemical properties in radiation and radiochemistry**
 - **Use and application of chemical kinetics and thermodynamics to evaluate radionuclide speciation**
 - **Understand the influence of radiolysis on the chemistry of radioisotopes**
 - **Understand and evaluate radioisotope production**
 - **Evaluate and compare radiochemical separations**
 - **Utilization of radioisotope nuclear properties in evaluating chemical behavior**
 - **Use and explain the application of radionuclides in research**
 - **Discuss and understand ongoing radiochemistry research**

Grading

- **Homework (5 %)**
 - **PDF provide at end of lecture**
→ **E-mail response directly after lecture**
- **Quizzes (12.5 % each)**
 - **Take home quiz**
 - **Develop tools for research (spreadsheets)**
- **Presentation (20 %)**
 - **Based on recent literature**
 - **End of semester**
 - **20-25 minutes**
- **Participation (12.5 %)**
 - **Blog response, skype, in class**
- **Class developed to assist and compliment research activities**

#	Date	Topic
1	Monday	27-Aug Chart of the Nuclides
2	Wednesday	29-Aug Chemical Speciation and Thermodynamics
3	Monday	03-Sep Labor Day
4	Wednesday	05-Sep Chemical Speciation and Thermodynamics
5	Monday	10-Sep Quiz 1 (Chart of the Nuclides)
6	Wednesday	12-Sep Nuclear Reactions
7	Monday	17-Sep Nuclear Reactions
8	Wednesday	19-Sep Origin of the Elements
9	Monday	24-Sep Meet: Scifinder and literature search (Poineau)
10	Wednesday	26-Sep Quiz 2 (Speciation and Thermodynamics)
11	Monday	01-Oct Electron orbitals and energy
12	Wednesday	03-Oct Nuclear Models
13	Monday	08-Oct Meet: Topic review with Prof. Poineau
14	Wednesday	10-Oct Decay Kinetics
15	Monday	15-Oct Decay Kinetics
16	Wednesday	17-Oct Quiz 3 (Electron Orbitals and Decay Kinetics)
17	Monday	22-Oct Dosimetry and Interaction of Radiation with Matter
18	Wednesday	24-Oct Dosimetry and Interaction of Radiation with Matter
19	Monday	29-Oct Isotope production
20	Wednesday	31-Oct Meet: Topic review with Prof. Poineau
21	Monday	05-Nov Quiz 4 (Dosimetry, Radiation Interaction, Isotope Production)
22	Wednesday	07-Nov Separations
23	Monday	12-Nov Separations
24	Wednesday	14-Nov Separations
25	Monday	19-Nov Separations
26	Wednesday	21-Nov Meet: Separations and Nuclear Fuel Cycle with Prof. Poineau
27	Monday	26-Nov In Reactor Chemistry
28	Wednesday	28-Nov Reactors and Fuel Cycle
29	Monday	03-Dec Application of Nuclear Material
30	Wednesday	05-Dec Quiz 5 (Separations, Fuel Cycle)
31	Monday	Final Presentations (TBD)

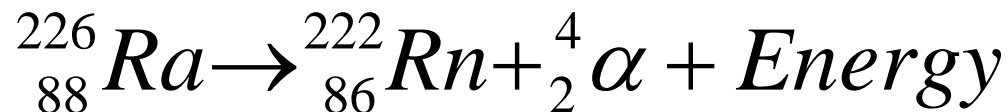
Radiochemistry Introduction

- **Radiochemistry**
 - **Chemistry of the radioactive isotopes and elements**
 - **Utilization of nuclear properties in evaluating and understanding chemistry**
 - **Intersection of chart of the nuclides and periodic table**
- **Atom**
 - **Z and N in nucleus (10^{-14} m)**
 - **Electron interaction with nucleus basis of chemical properties (10^{-10} m)**
 - **Electrons can be excited**
 - * **Higher energy orbitals**
 - * **Ionization**
 - **Binding energy of electron effects ionization**
 - **Isotopes**
 - **Same Z different N**
 - **Isobar**
 - **Same A (sum of Z and N)**
 - **Isotone**
 - **Same N, different Z**
 - **Isomer**
 - **Nuclide in excited state**
 - **^{99m}Tc**

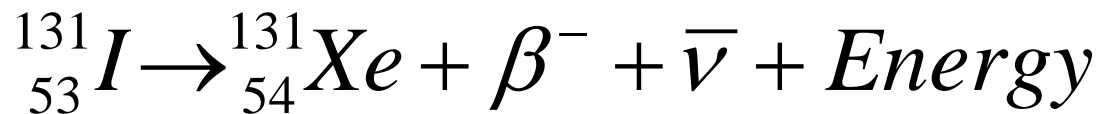


Types of Decay

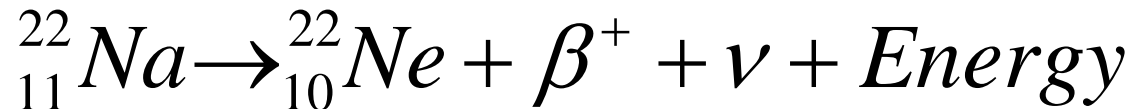
1. α decay (occurs among the heavier elements)



2. β^- decay



3. Positron emission



4. Electron capture

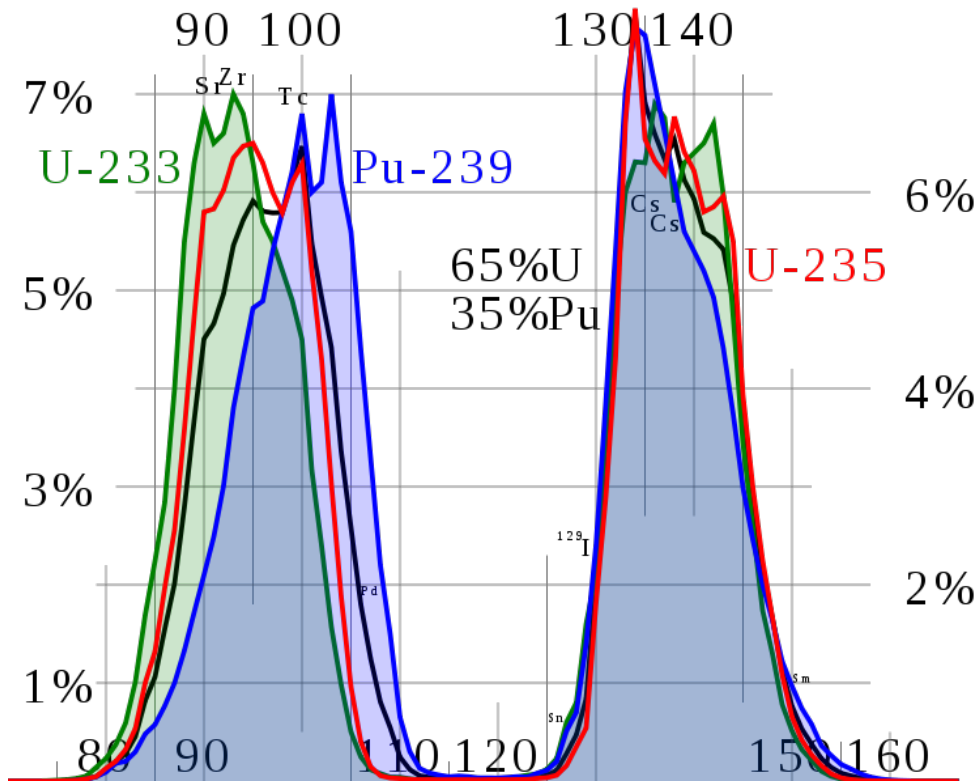


5. Spontaneous fission

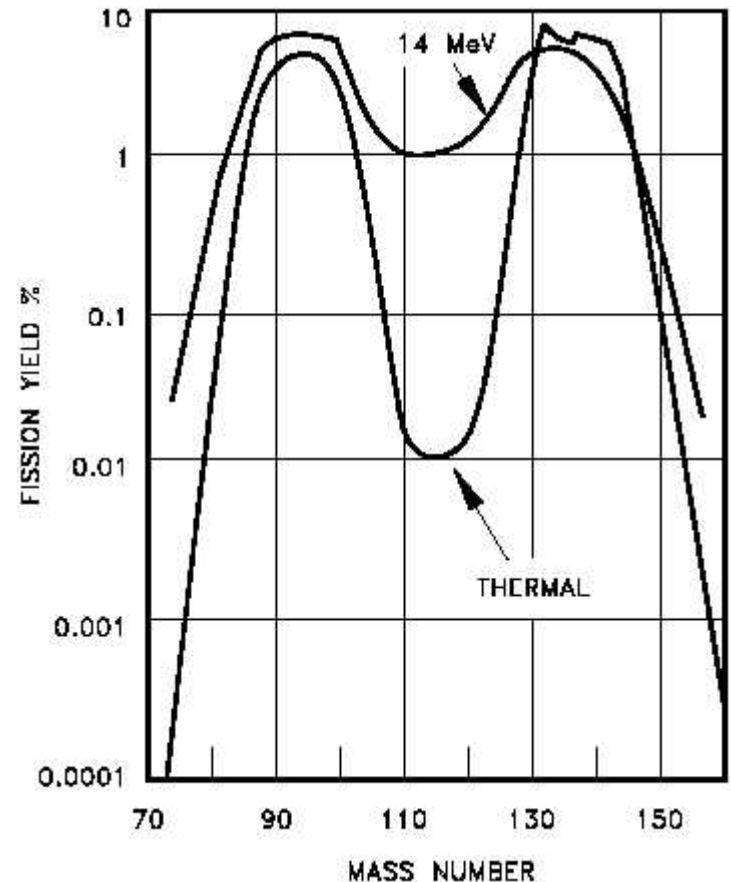


Fission Products

- Fission yield curve varies with fissile isotope
- 2 peak areas for U and Pu thermal neutron induced fission
- Variation in light fragment peak
- Influence of neutron energy observed

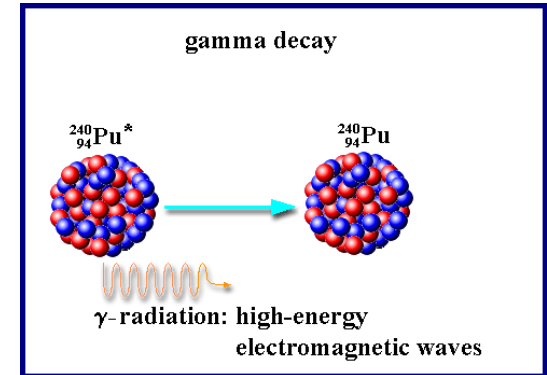


²³⁵U fission yield



Photon emission

- **Gamma decay**
 - **Emission of photon from excited nucleus**
 - Metastable nuclide (i.e., ^{99m}Tc)
 - Following decay to excited daughter state
- **X-ray**
 - **Electron from a lower level is removed**
 - electrons from higher levels occupy resulting vacancy with photon emission
 - **De-acceleration of high energy electrons**
 - **Electron transitions from inner orbitals**
 - **X-ray production**
 - Bombardment of metal with high energy electrons
 - Secondary x-ray fluorescence by primary x-rays
 - Radioactive sources
 - Synchrotron sources



X-rays

- Removal of K shell electrons
 - Electrons coming from the higher levels will emit photons while falling to this K shell
 - series of rays (frequency ν or wavelength λ) are noted as K_α , K_β , K_γ
 - If the removed electrons are from the L shell, noted as L_α , L_β , L_γ
- In 1913 Moseley studied these frequencies ν , showing that:

$$\sqrt{\nu} = A(Z - Z_0)$$

- where Z is the atomic number and, A and Z_0 are constants depending on the observed transition.
- K series, $Z_0 = 1$, L series, $Z_0 = 7.4$.

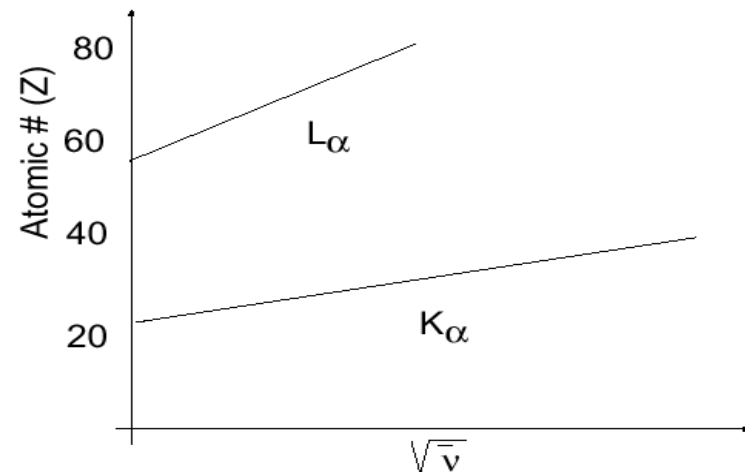
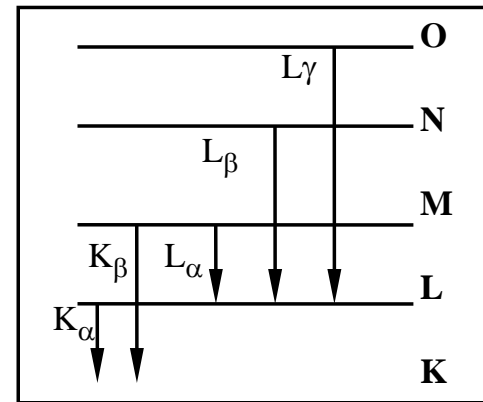
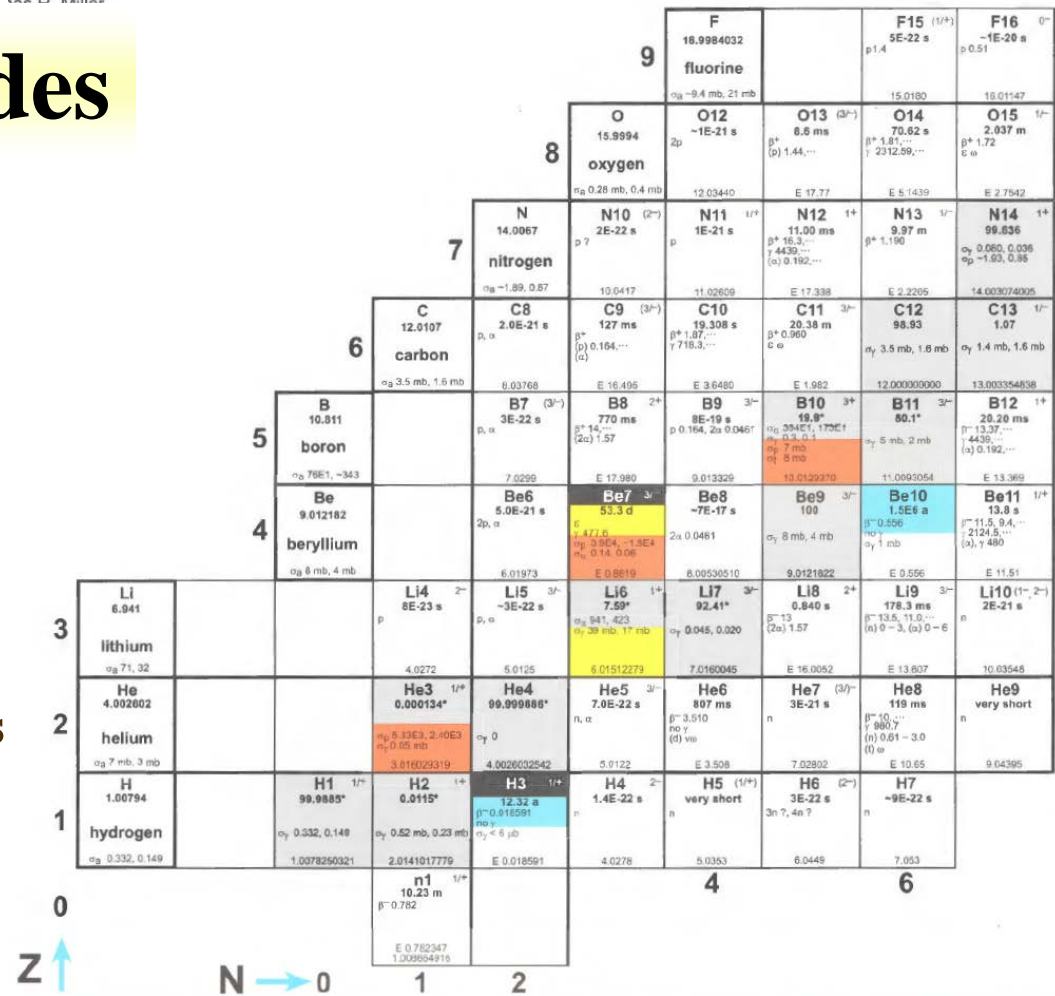


Figure 4 Moseley relationship for K_α and L_α radiation

Chart of the Nuclides

- **Presentation of data on nuclides**
 - **Information on chemical element**
 - **Nuclide information**
 - Spin and parity (0^+ for even-even nuclides)
 - Fission yield
 - **Stable isotope**
 - Isotopic abundance
 - Reaction cross sections
 - Mass
- **Radioactive isotope**
 - **Half-life**
 - **Modes of decay and energies**
 - **Beta disintegration energies**
 - **Isomeric states**
 - **Natural decay series**
 - **Reaction cross sections**
- **Fission yields for isobars**



Po 208 2.898 a α 5.1152... ϵ γ (292; 571...) θ	Po 209 102 a α 4.881... ϵ γ (895; 261; 263...) θ	Po 210 138.38 d α 5.30438... γ (803); σ <0.0005 ϵ <0.030; θ_n, α 0.002; σ_f <0.1	Po 211 25.2 s α 7.275; 8.883... γ 570; 1064... θ ϵ 7.450... 570...
Bi 207 31.55 a ϵ β^+ ... γ 570; 1064; 1770...	Bi 208 3.68 · 10 ⁸ a ϵ γ 2615	Bi 209 100 σ 0.011 + 0.023 σ_n, α <3E-7	Bi 210 3.0 · 10 ⁶ a 5.013 d α 4.946; β^- 1.2 4.908...; α 4.649; γ 266; 4.686 304...; γ (305); θ 0.054; 266
Pb 206 24.1 σ 0.027	Pb 207 22.1 σ 0.61	Pb 208 52.4 σ 0.00023 σ_n, α <8E-6	Pb 209 3.253 h β^- 0.6 no γ

Chart of Nuclides

- Decay modes
 - Alpha
 - Beta
 - Positron
 - Photon
 - Electron capture
 - Isomeric transition
 - Internal conversion
 - Spontaneous fission
 - Cluster decay

Displacements Caused by Nuclear Bombardment Reactions

$\alpha - 3n$	$\alpha - 2n$	$\alpha - n$
$p - n$	$p - \gamma$ $d - n$	$\alpha - n, p$
$\gamma - n$ $n - 2n$	Original nucleus	$d - p$ $n - \gamma$
$\gamma - p, n$	$\gamma - p$	$n - p$
$n - \alpha$		

Relative Location of the Products of Various Nuclear Reactions

				α in
	$\beta^- + n$ out	β^- out	p in	d in
		n out	Original nucleus	n in
$\beta^- + \alpha$ out	H^3 out	d out	p out	β^+ out, EC
	α out			EC + p out

Chart of the nuclides

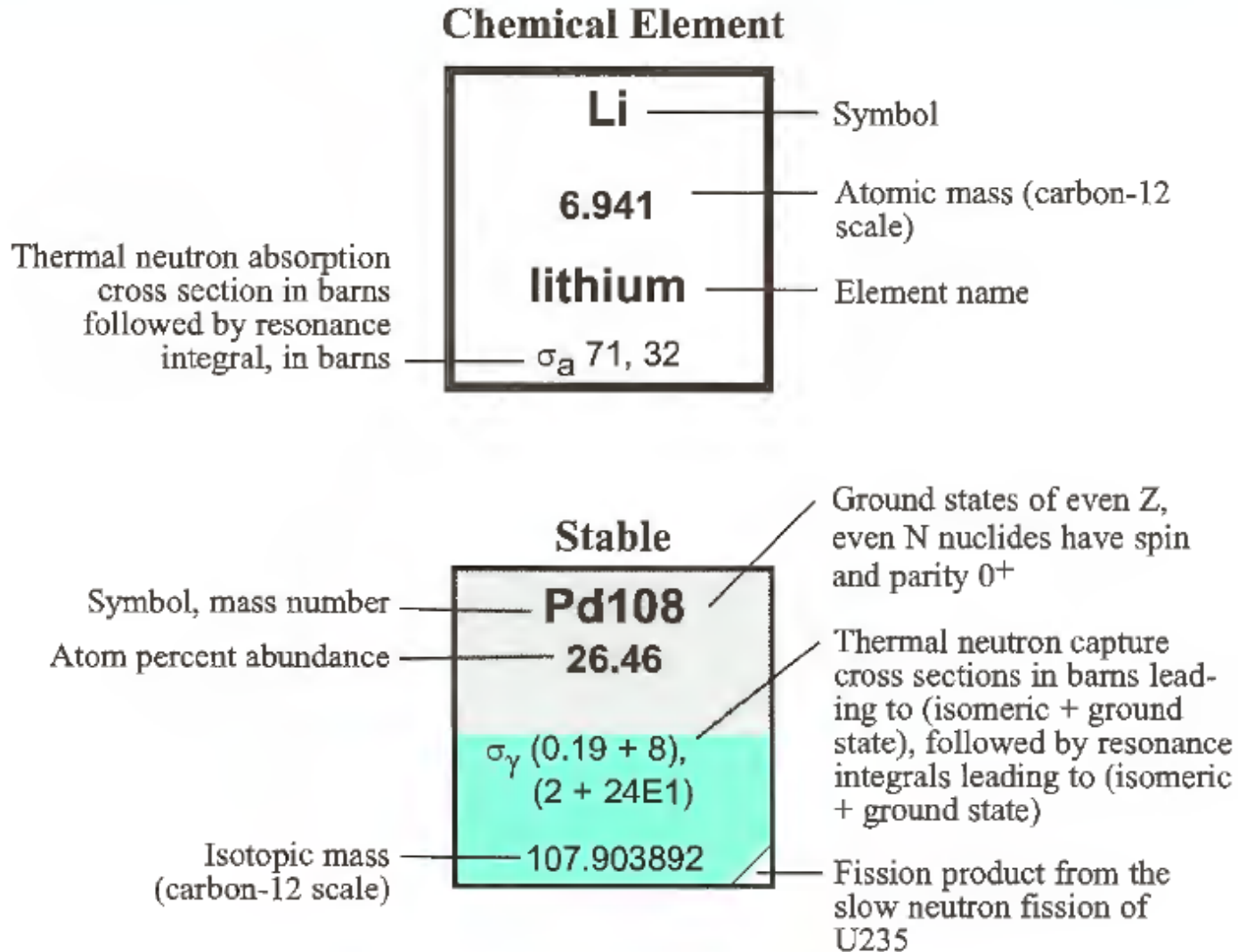
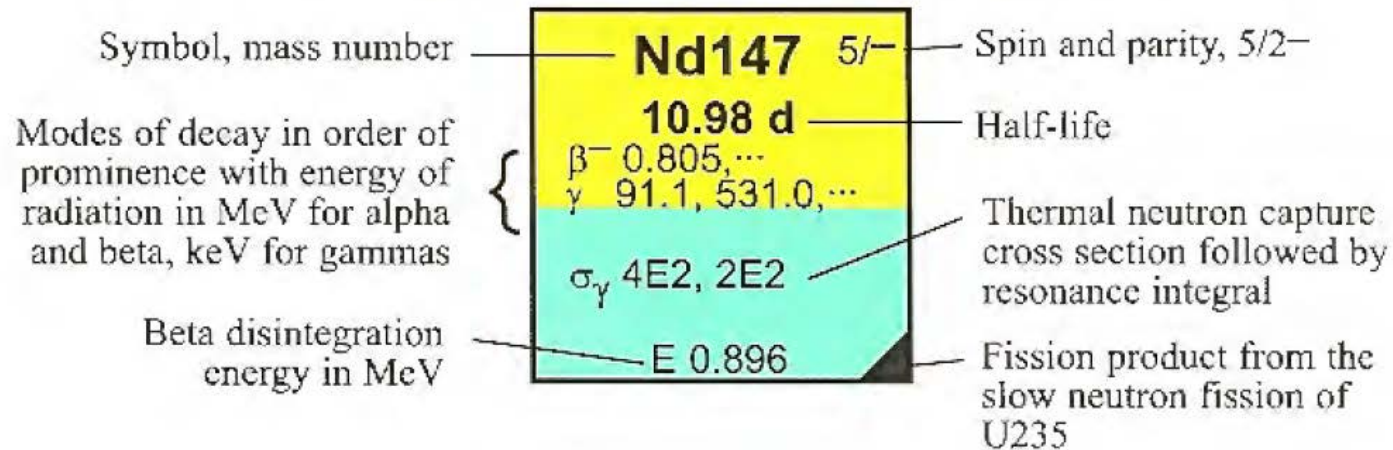


Chart of the nuclides

Artificially Radioactive



Naturally Occurring or Otherwise Available but Radioactive

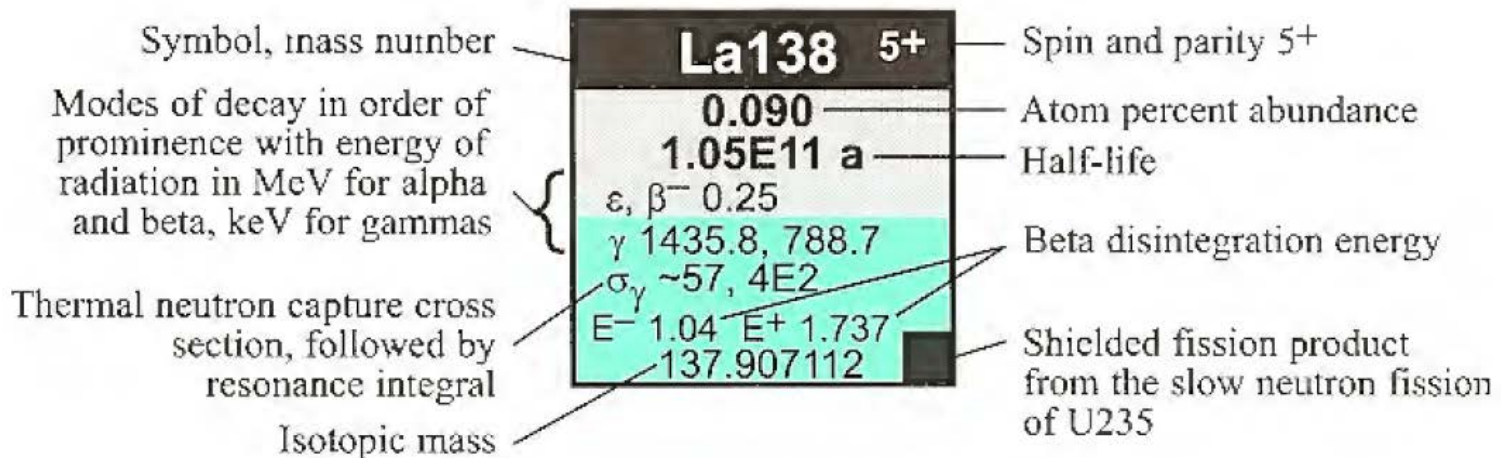
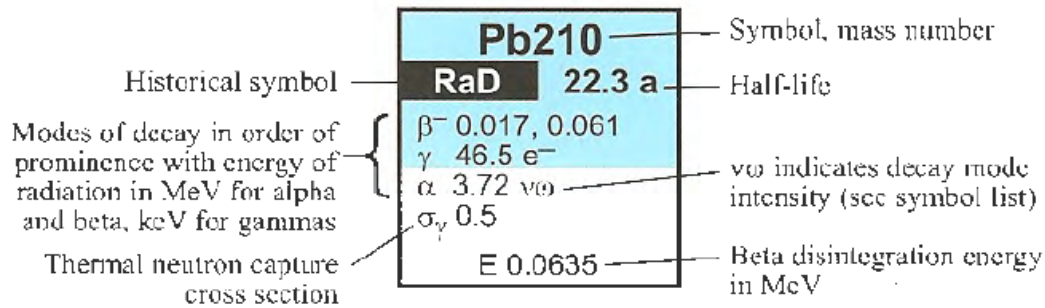
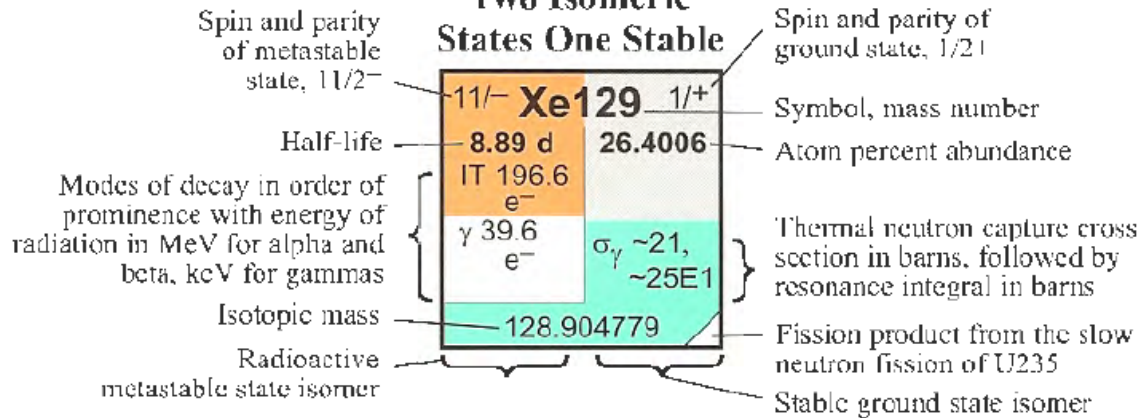


Chart of the nuclides

Member of Naturally Radioactive Decay Chain



Two Isomeric States One Stable



Two Isomeric States Both Radioactive

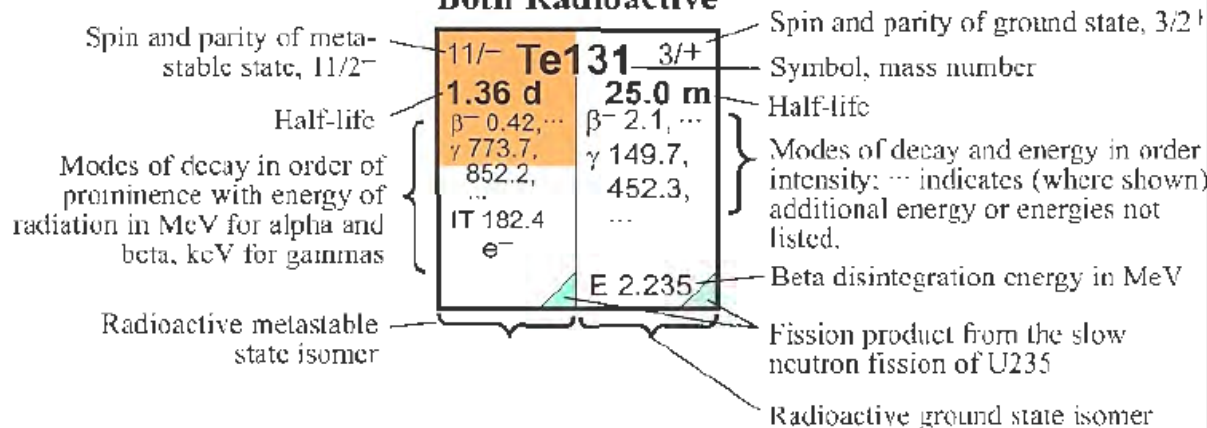
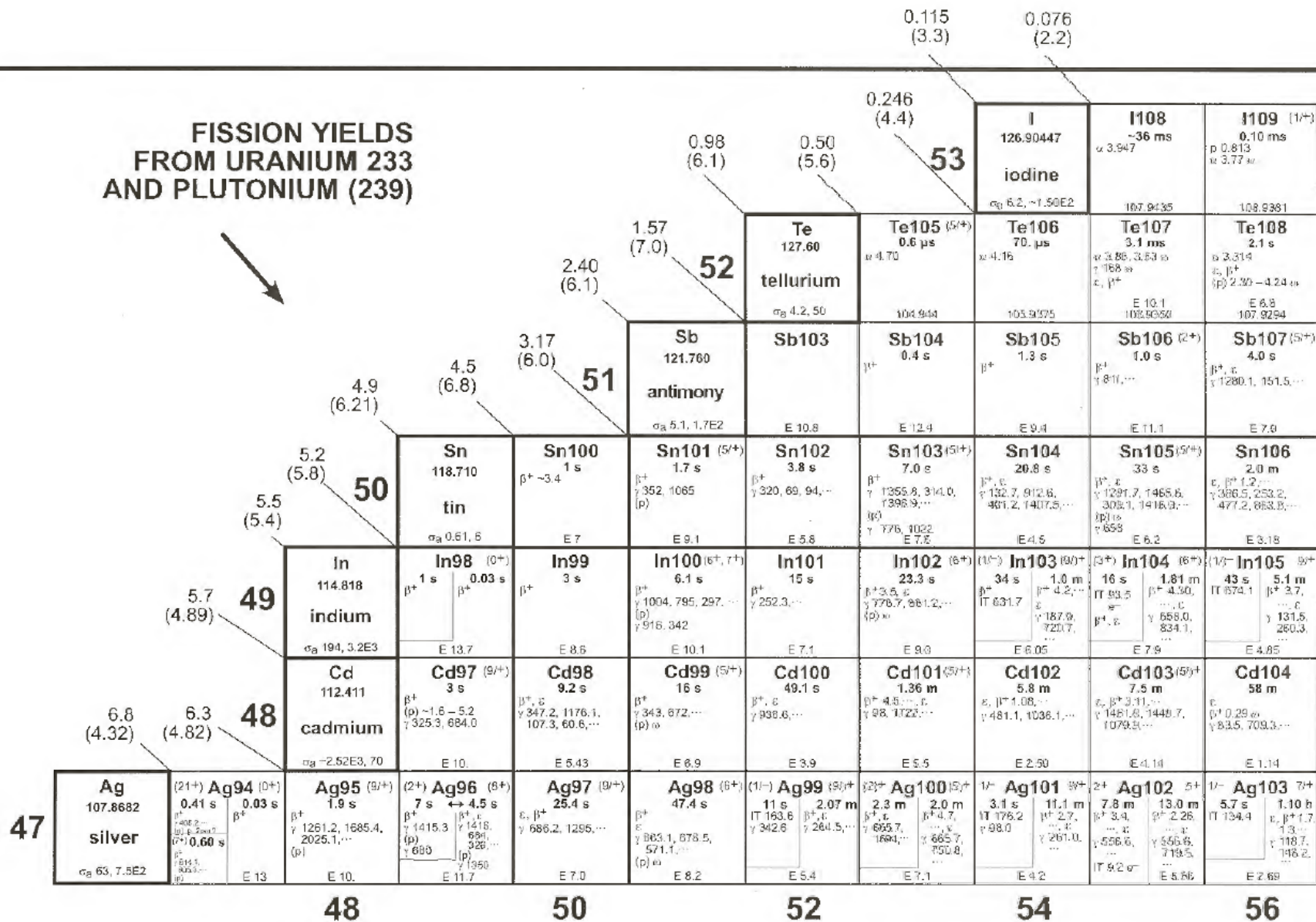
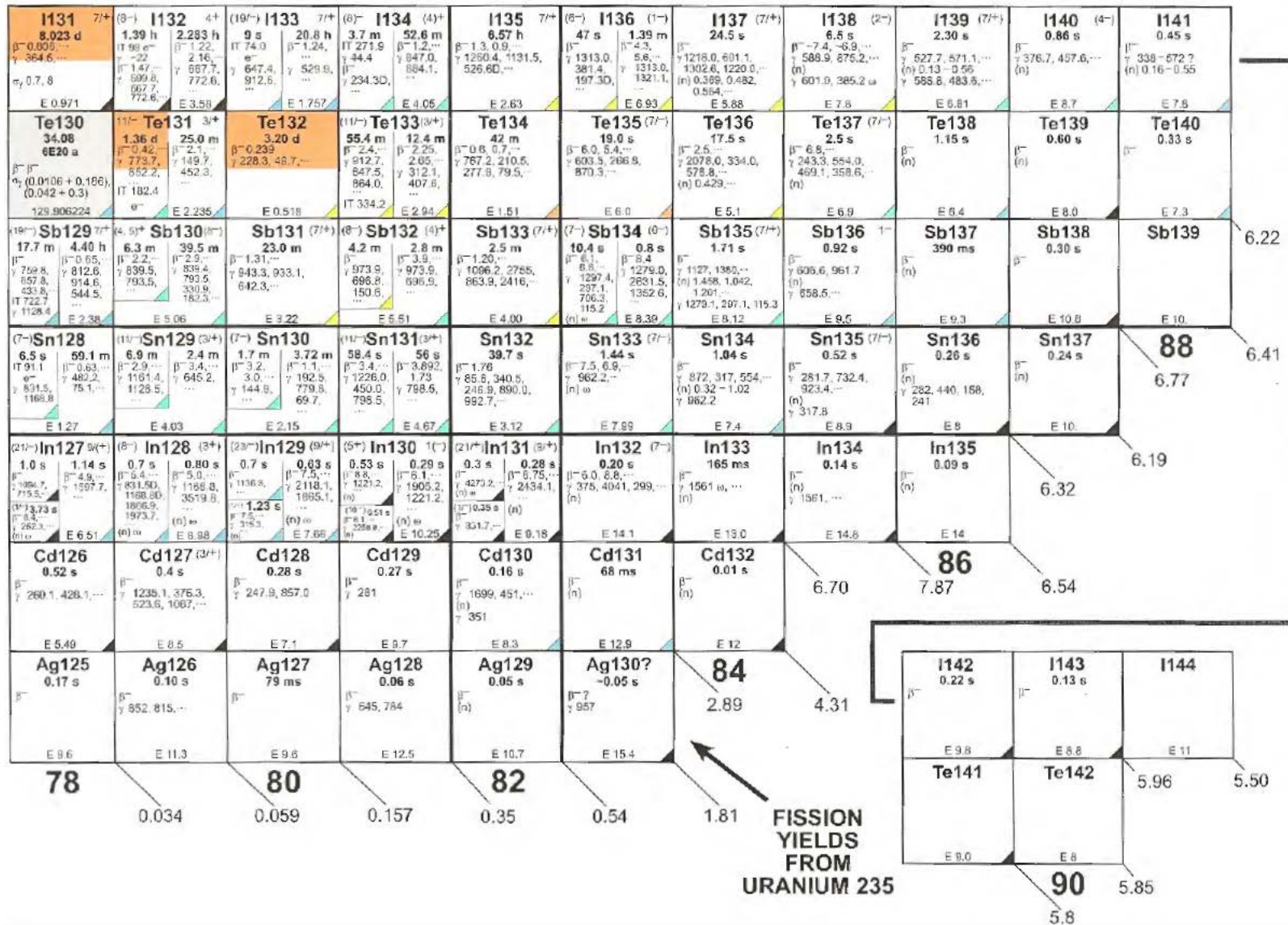


Chart of the Nuclide: Fission yields

FISSION YIELDS
FROM URANIUM 233
AND PLUTONIUM (239)



Fission yields



Terms and decay modes: Utilization of chart of the nuclides

- Identify the isomer, isobars, isotones, and isotopes
 - ^{60m}Co , ^{57}Co , ^{97}Nb , ^{58}Co , ^{57}Ni , ^{57}Fe , ^{59}Ni , ^{99m}Tc
- Identify the daughter from the decay of the following isotopes
 - ^{210}Po (alpha decay, ^{206}Pb)
 - ^{196}Pb
 - ^{204}Bi (EC decay, ^{204}Pb)
 - ^{209}Pb
 - ^{222}At
 - ^{212}Bi (both alpha and beta decay)
 - ^{208}Pb (stable)
- How is ^{14}C naturally produced
 - Reactions with atmosphere (^{14}N as target)
- Identify 5 naturally occurring radionuclides with $Z < 84$

Chart of the Nuclides Questions

- How many stable isotopes of Ni?
- What is the mass and isotopic abundance of ^{84}Sr ?
- Spin and parity of ^{201}Hg ?
- Decay modes and decay energies of ^{212}Bi
- What are the isotopes in the ^{235}U decay series?
- What is the half-life of ^{176}Lu ?
- What is the half-life of ^{176}Yb
- How is ^{238}Pu produced?
- How is ^{239}Pu made from ^{238}U
- Which actinide isotopes are likely to undergo neutron induced fission?
- Which isotopes are likely to undergo alpha decay?

Te130 34.08 6E20 a $\beta^- \beta^-$ $\alpha_\gamma (0.0106 + 0.186),$ $(0.042 + 0.3)$ 129.906224	11/- Te131 3/+ 1.36 d $\beta^- 0.42, \dots$ $\gamma 773.7,$ 852.2, ... IT 182.4 e-	25.0 m $\beta^- 2.1, \dots$ $\gamma 149.7,$ 452.3, ... E 2.235
--	--	---

- What is the half life of ^{130}Te
 - What is its decay mode?
- What cross section data is provided for ^{130}Te ?

Table of the Isotopes

- **Detailed information about each isotope**
 - **Mass chain decay scheme**
 - **mass excess (M-A)**
 - **Mass difference, units in energy (MeV)**
 - **particle separation energy**
 - **Populating reactions and decay modes**
 - **Gamma data**
 - **Transitions, % intensities**
 - **Decay levels**
 - **Energy, spin, parity, half-life**
 - **Structure drawing**

Table of the isotopes

TOLPDF - Adobe Acrobat Pro

File Edit View Window Help

Create [Icons]

1 / 14193 [Icons] 95.9% [Icons]

Tools Comment Share


Bookmarks


- TOICD
- Author Title page
- Help Page
- CD-ROM Readme
- Preface
- Introduction to the CD-ROM
- Nuclear Chart Index**
- Summary Scheme Index
- Reaction and Decay Daughter Index
- Decay Parent Index
- Reference Index
- Appendix Index

Table of Isotopes[†]
CD ROM Edition

Version 1.0
March, 1996

by Richard B. Firestone
Virginia S. Shirley Editor
S.Y. Frank Chu CD-ROM Editor
Coral M. Baglin and Jean Zipkin Assistant Editors

To see brief instructions for Acrobat Reader please click on this green square 

To see README for Table of Isotopes please click on this green square 

[†] This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Nuclear Physics Division of the US Department of Energy under contract DE-AC03-76SF00098, subcontract LBL no. 4573810.





Table of the isotopes

TOI.PDF - Adobe Acrobat Pro
File Edit View Window Help

Create [Icons]

25 / 14193 112% [Icons] Tools

Bookmarks

- TOICD
- Author Title page
- Help Page
- CD-ROM Readme
- Preface
- Introduction to the CD-ROM
- Nuclear Chart Index
- Summary Scheme Index
- Reaction and Decay Daughter Index
- Decay Parent Index
- Reference Index
- Appendix Index

Chart of Nuclides

Z=0-28	A=1	A=38	A=75	A=112	A=149	A=186	A=223	A=260
Z=28-45	A=2	A=39	A=76	A=113	A=150	A=187	A=224	A=261
Z=45-60	A=3	A=40	A=77	A=114	A=151	A=188	A=225	A=262
Z=60-74	A=4	A=41	A=78	A=115	A=152	A=189	A=226	A=263
Z=74-83	A=5	A=42	A=79	A=116	A=153	A=190	A=227	A=264
Z=83-91	A=6	A=43	A=80	A=117	A=154	A=191	A=228	A=265
Z=91-111	A=7	A=44	A=81	A=118	A=155	A=192	A=229	A=266
	A=8	A=45	A=82	A=119	A=156	A=193	A=230	A=267
	A=9	A=46	A=83	A=120	A=157	A=194	A=231	A=268
	A=10	A=47	A=84	A=121	A=158	A=195	A=232	A=269
	A=11	A=48	A=85	A=122	A=159	A=196	A=233	A=271
	A=12	A=49	A=86	A=123	A=160	A=197	A=234	A=272
	A=13	A=50	A=87	A=124	A=161	A=198	A=235	
	A=14	A=51	A=88	A=125	A=162	A=199	A=236	
	A=15	A=52	A=89	A=126	A=163	A=200	A=237	
	A=16	A=53	A=90	A=127	A=164	A=201	A=238	
	A=17	A=54	A=91	A=128	A=165	A=202	A=239	
	A=18	A=55	A=92	A=129	A=166	A=203	A=240	
	A=19	A=56	A=93	A=130	A=167	A=204	A=241	
	A=20	A=57	A=94	A=131	A=168	A=205	A=242	
	A=21	A=58	A=95	A=132	A=169	A=206	A=243	
	A=22	A=59	A=96	A=133	A=170	A=207	A=244	
	A=23	A=60	A=97	A=134	A=171	A=208	A=245	
	A=24	A=61	A=98	A=135	A=172	A=209	A=246	
	A=25	A=62	A=99	A=136	A=173	A=210	A=247	
	A=26	A=63	A=100	A=137	A=174	A=211	A=248	
	A=27	A=64	A=101	A=138	A=175	A=212	A=249	
	A=28	A=65	A=102	A=139	A=176	A=213	A=250	
	A=29	A=66	A=103	A=140	A=177	A=214	A=251	
	A=30	A=67	A=104	A=141	A=178	A=215	A=252	
	A=31	A=68	A=105	A=142	A=179	A=216	A=253	
	A=32	A=69	A=106	A=143	A=180	A=217	A=254	
	A=33	A=70	A=107	A=144	A=181	A=218	A=255	
	A=34	A=71	A=108	A=145	A=182	A=219	A=256	
	A=35	A=72	A=109	A=146	A=183	A=220	A=257	
	A=36	A=73	A=110	A=147	A=184	A=221	A=258	
	A=37	A=74	A=111	A=148	A=185	A=222	A=259	

Summary Scheme Index

A=186	A=187	A=188	A=189	A=190	A=191	A=192	A=193	A=194	A=195	A=196	A=197	A=198	A=199	A=200	A=201	A=202	A=203	A=204	A=205	A=206	A=207	A=208	A=209	A=210	A=211	A=212	A=213	A=214	A=215	A=216	A=217	A=218	A=219	A=220	A=221	A=222
-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------

[Taskbar icons: Windows, PowerPoint, Internet Explorer, Google Chrome, Outlook, Word, PDF Reader, Media Center, File Explorer, Recycle Bin, Excel]

60
27Co

A=60
NDS 48, 251(1986)

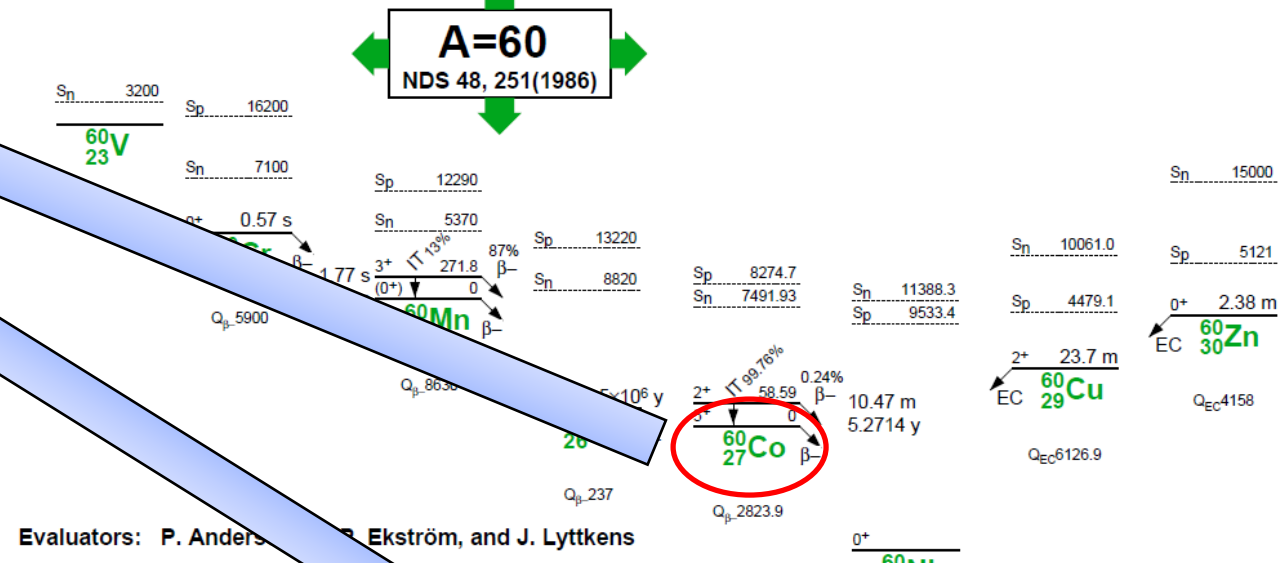
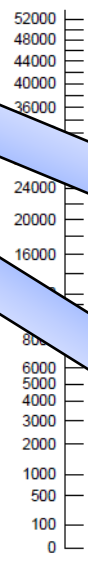
Δ : -61644.5 14 S_n : 7491.93 8 S_p : 36000
 Q_{β^-} : 2823.9 5
 σ_{γ} (for 0): 2.02 b, σ_{γ} (for 58.58 b)

Populating Reactions and Decays

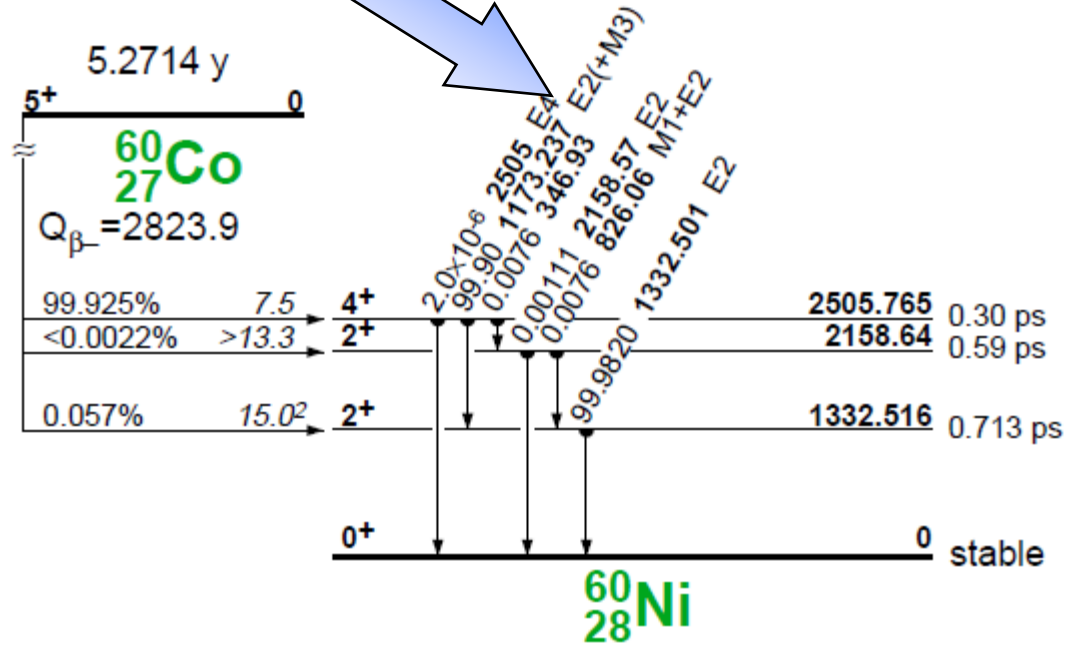
- A $^{60}\text{Fe} \beta^-$ decay (57Ro54, 60Me05)
- B ^{60}Co IT decay (62Ha46, 63Sc14, 71PI02, 73Ha69)
- C $^{48}\text{Ca}(^{15}\text{N}, 3n\gamma)$ (75Ki19, 77Wa10)
- D $^{57}\text{Fe}(\alpha, p)$ (73Ma38)
- E $^{57}\text{Fe}(\alpha, p\gamma)$ (75Ki19, 78Ta03)
- F $^{58}\text{Fe}(^3\text{He}, p)$ (72Se05, 73Ca07, 78Ta02)
- G $^{59}\text{Co}(n, \gamma)$, (pol n, γ) E=Thermal (66Sh15, 68Wa20, 69Ei01, 69Ko05, 69Me05, 69Sa10, 69Sm05, 72St05, 73Ho24, 73Re06, 78Bo08, 84Ko29)
- H $^{59}\text{Co}(n, \gamma)$ E=24 keV (84Ko29)
- I $^{59}\text{Co}(n, \gamma)$ E=132 keV (68Wa20, 69Sa10, 75Pr02)
- J $^{59}\text{Co}(d, p)$ (60En05, 64Bj01, 75Jo08, 75Ue01, 78Ro18, 78Ta02)
- K $^{61}\text{Ni}(d, ^3\text{He})$ (78Ta02)
- L $^{62}\text{Ni}(d, \alpha)$, (pol d, α) (72Se05, 83Na12)

Levels and γ -ray branchings:

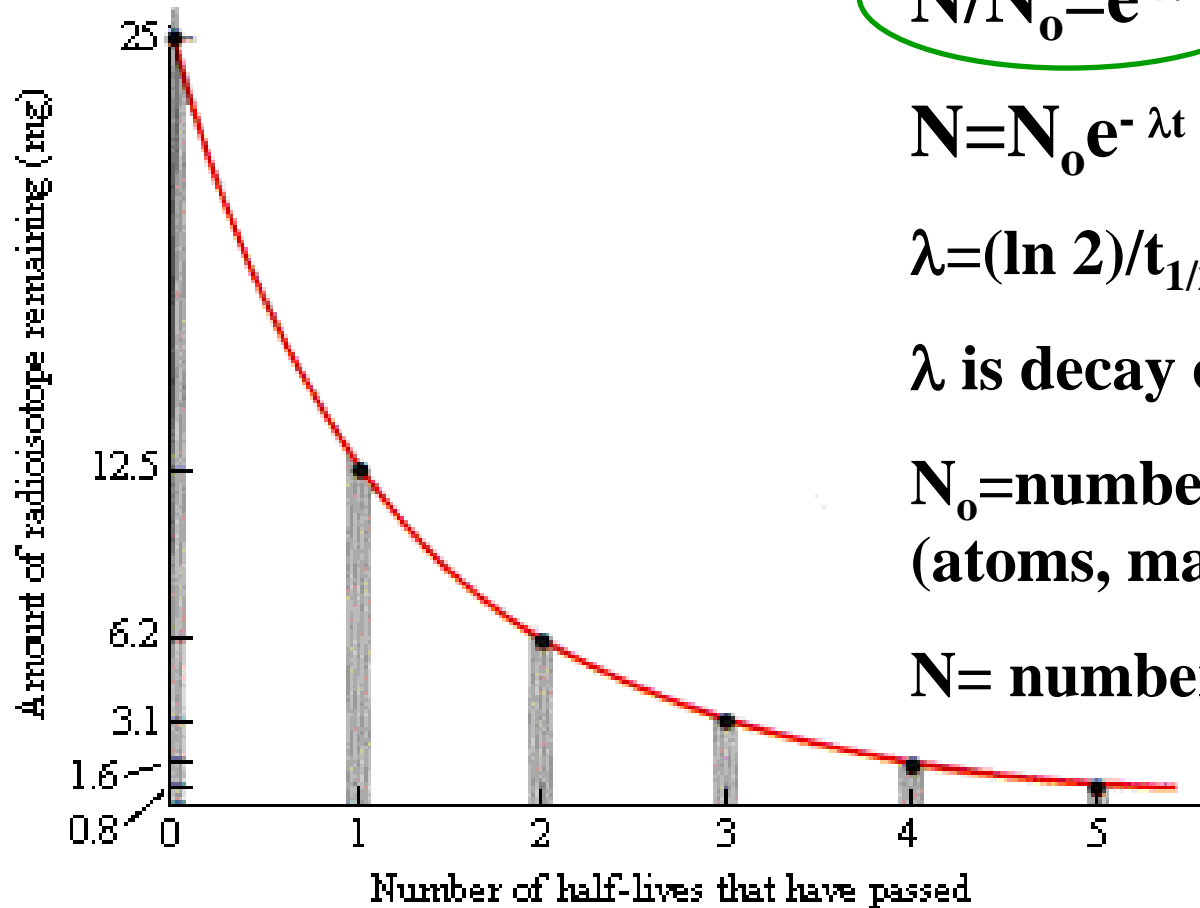
- 0, 5⁺, 5.2714 5 y, [ABCDEFGHIJKL], $\mu=+3.799$ 8, $Q=+0.44$ 5, $\% \beta=100$
 - 58.59 1, 2⁺, 10.47 4 m, [ABCDEFGHKL], $\mu=+4.40$ 9, $Q=+0.3$ 5, $\% \text{IT}=99.76$ 3, $\% \beta=0.24$ 3
 $\gamma_{58.6037}$ (\dagger_{γ} 100) M3(+E4): $\delta < 0.02$
 - 277.20 2, 4⁺, [CEGHJL]
 $\gamma_{277.083}$ (\dagger_{γ} 100) M1+E2
 - 288.40 2, 3⁺, [CEGHJKL]
 $\gamma_{289.724}$ (\dagger_{γ} 100) M1+E2
 - 435.71 4, 5⁺, [CEGHJKL]
 $\gamma_{277.158.465}$ (\dagger_{γ} 100.07) M1+E2
 $\gamma_{435.715}$ (\dagger_{γ} 64.0 13) M1+E2
- $\gamma(^{60}\text{Ni})$ from ^{60}Co (5.2714 y) β^- decay < for $I_{\gamma}\%$ multiply by 1.0 >
- 346.937 (\dagger_{γ} 0.0076 5)
 - 826.289 (\dagger_{γ} 0.0076 8) M1+E2: $\delta=+0.81$ 17
 - 1173.2374 (\dagger_{γ} 99.90 2)
E2(+M3): $\delta=-0.0025$ 22
 - 1332.5015 (\dagger_{γ} 99.9820 10) E2
 - 2158.779 (\dagger_{γ} 0.00111 18)
 - 2505 (\dagger_{γ} 2.0 $\times 10^{-6}$ 4) E4



Evaluators: P. Andersson, B. Ekström, and J. Lyttkens



Half Lives



$$N/N_0 = e^{-\lambda t}$$

$$N = N_0 e^{-\lambda t}$$

$$\lambda = (\ln 2)/t_{1/2}$$

λ is decay constant

N_0 = number at time zero
(atoms, mass, moles)

N = number at time t

Rate of decay of ^{131}I as a function of time.

Equation questions

- Calculate decay constant for the following

Isotope	$t_{1/2}$	λ	λ (s^{-1})
^{75}Se	119.78 days	$5.79\text{E-}3 \text{ d}^{-1}$	$6.78\text{E-}8$
$^{74\text{m}}\text{Ga}$	10 seconds	$6.93\text{E-}2 \text{ s}^{-1}$	$6.93\text{E-}2$
^{81}Zn	0.32 seconds	2.17 s^{-1}	2.17
^{137}Cs	30.07 years	$2.31\text{E-}2 \text{ a}^{-1}$	$7.30\text{E-}10$
^{239}Pu	$2.41\text{E}4$ years	$2.88\text{E-}5 \text{ a}^{-1}$	$9.11\text{E-}13$

- ^{75}Se example

$$\rightarrow \lambda = \ln(2)/119.78 \text{ day} = 0.00579 \text{ d}^{-1}$$

$$\rightarrow \lambda = 0.00579 \text{ d}^{-1} * 1\text{d}/24 \text{ hr} * 1 \text{ hr}/3600 \text{ s} \\ = 6.7\text{E-}8 \text{ s}^{-1}$$

Equation Questions

- What percentage of ^{66}As remains from a given amount after 0.5 seconds
 - Use $N/N_0 = e^{-\lambda t}$
 - $t_{1/2} = 95.6 \text{ ms}; \lambda = 7.25 \text{ s}^{-1}$
 - $N/N_0 = e^{-\lambda t} = N/N_0 = e^{-7.25(.5)} = 0.0266 = 2.66 \%$
 - * After 5.23 half lives
- How long would it take to decay 90 % of ^{65}Zn ?
 - Use $N/N_0 = e^{-\lambda t}$
 - 90 % decay means 10 % remains
 - Set $N/N_0 = 0.1, t_{1/2} = 244 \text{ d}, \lambda = 2.84\text{E-}3 \text{ d}^{-1}$
 - $0.1 = e^{-2.84\text{E-}3 t}$
 - $\ln(0.1) = -2.84\text{E-}3 \text{ d}^{-1} t$
 - $= -2.30 / -2.84\text{E-}3 \text{ d}^{-1} = t = 810 \text{ days}$

Equation Questions

- If you have 1 g of ^{72}Se initially, how much remains in 12 days?
 - $t_{1/2} = 8.5 \text{ d}, \lambda = 8.15\text{E-}2 \text{ d}^{-1}$
 - $N = N_0 e^{-\lambda t}$
 - $N = (1 \text{ g}) e^{-8.15\text{E-}2(12)}$
 - $N = 0.376 \text{ g}$
- What if you started with 10000 atoms of ^{72}Se , how many atoms after 12 days?
 - 0.376 (37.6 %) remains
 - $10000(0.376) = 3760 \text{ atoms}$

What holds the nucleus together: Forces in nature

- Four fundamental forces in nature
- Gravity
 - Weakest force
 - interacting massive objects
- Weak interaction
 - Beta decay
- Electromagnetic force
 - Most observable interactions
- Strong interaction
 - Nuclear properties

<i>Strong</i>	<p>Force which holds nucleus together</p>	Strength 1	Range (m) 10^{-15} (diameter of a medium sized nucleus)	Particle gluons, π (nucleons)
<i>Electro-magnetic</i>		Strength $\frac{1}{137}$	Range (m) Infinite	Particle photon mass = 0 spin = 1
<i>Weak</i>	<p>neutrino interaction induces beta decay</p>	Strength 10^{-6}	Range (m) 10^{-18} (0.1% of the diameter of a proton)	Particle Intermediate vector bosons W^+ , W^- , Z_0 , mass > 80 GeV spin = 1
<i>Gravity</i>		Strength 6×10^{-39}	Range (m) Infinite	Particle graviton ? mass = 0 spin = 2

Particle Physics: Boundary of Course

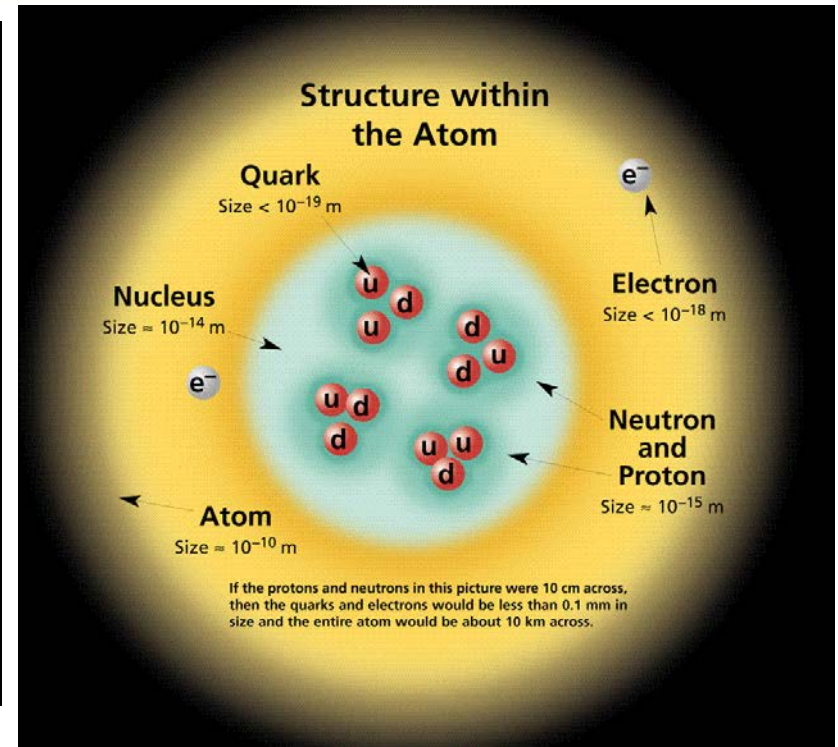
- **fundamental particles of nature and interaction symmetries**
- **Particles classified as fermions or bosons**
 - **Fermions obey the Pauli principle**
 - antisymmetric wave functions
 - half-integer spins
 - * **Neutrons, protons and electrons**
 - **Bosons do not obey Pauli principle**
 - * **symmetric wave functions and integer spins**
 - **Photons**

Standard Model

FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2			Quarks spin = 1/2		
Flavor	Mass GeV/c ²	Electric charge	Flavor	Approx. Mass GeV/c ²	Electric charge
ν_e electron neutrino	$<1 \times 10^{-8}$	0	u up	0.003	2/3
e electron	0.000511	-1	d down	0.006	-1/3
ν_μ muon neutrino	<0.0002	0	c charm	1.3	2/3
μ muon	0.106	-1	s strange	0.1	-1/3
ν_τ tau neutrino	<0.02	0	t top	175	2/3
τ tau	1.7771	-1	b bottom	4.3	-1/3



- **Boson are force carriers**
 - **Photon, W and Z bosons, gluon**
 - **Integer spin**
- **What are the quarks in a proton and a neutron?**¹⁻²⁹

Topic review

- **Definition of radiochemistry**
- **Types of radioactive decay**
- **Understand and utilize the data presented in the chart of the nuclides and table of the isotopes**
 - **Units for data**
 - **Relationships between isotopes**
 - **Fission yields**
- **Identify common fission products**
- **Define X-rays**

- **Read introduction to chart of the nuclides and table of the isotopes**

Study Questions

- **What are the course outcomes?**
- **What are 3 isotones of ^{137}Cs**
- **What are the different types of radioactive decay?**
- **Provide 5 radioelements**
- **Why is Tc naturally radioactive**
- **What are the stable isotopes of Sn?**
- **What is the beta decay energy of ^{90}Sr ?**
- **Which has more stable isotopes, Cr or Fe?**

Questions

- **Comment on blog**
- **Respond to PDF quiz**