**TEACHER NOTES**

**LAB NR 10**

# RELATED TOPICS Isotopes

 Half-lives

 Decay processes

# STANDARDS ADDRESSED

**Science and Technology**

3.1.10, 3.1.12

3.4.12

# CONSIDERATIONS

As an introduction to nuclear physics, this experiment with the Chart of Nuclides provides students with a greater understanding and appreciation of isotopes, half-lives, decay processes, and other aspects of the field.

The Chart of Nuclides provides a great deal more information than required for an introductory lab. You may wish to explain some of the unfamiliar terms or processes to your students, or simply allow them to pick out the items they know or that are referred to in the experiment. In addition, you may wish to omit certain exercises to shorten the experiment.

**ANSWERS TO QUESTIONS**

# PRELIMINARY QUESTIONS

1. *What is a nuclide?*

* 1. nucleus with a unique number of protons (Z) and neutrons (N).

1. *What is the chart of nuclides?*

* 1. chart of the known nuclides – plotted in terms of number of neutrons, N, on the horizontal axis and number protons, Z, on the vertical axis with considerable nuclear information provided.

1. *How are natural stable isotopes and natural long-lived radioactive isotopes distinguished on the chart?*

 With gray shading for stable and radioactive down to t½  > 5E8 yrs.

1. *How are artificially produced isotopes and natural short-lived radioactive isotopes distinguished on the chart?*

 White squares.(some charts use upper half partial square color shading to indicate half-life categories)

1. *What are nuclear isomers, and how are they distinguished on the chart?*

Nuclides, with the same N and Z numbers, with different radioactive properties such as energies and different corresponding t½ values. The squares are vertically subdivided with the particular property values given.

1. *What is the difference between the mass number and the atomic weight of a nuclide?*

Mass number (A) is the number or count of protons (Z) plus the number of neutrons (N), that is, A = Z + N; atomic mass is the actual mass of the nuclide in terms of the nuclide, Carbon-12 = 12.00000 unified mass units(u).

1. *List the change(s) in the proton number (Z) and/or the neutron number (N) for the following nuclear processes and give the relative location of the daughter nucleus to that of the parent nucleus on the chart.*

alpha decay Z-2, N-2 diagonal – left two spaces, down two spaces beta minus (β-) decay Z+1, N-1 diagonal – left one space, up one space beta plus (β+) decay Z-1, N+1 diagonal – right one space, down one space gamma decay Z, N do not change no change in position

# THE CHART OF NUCLIDES

1. *How are the isotopes of an element arranged on the chart?*

 **On the same horizontal line.**

1. *Nuclides with the same number of neutrons are called isotones. How are they arranged on the chart?*

 **On the same the same vertical line.**

1. *Nuclides with the same mass number are called isobars. What would be the orientation of a line connecting an isobaric series?*

 **On the same 45º diagonal line with negative slope.**

1. *List all of the naturally occurring generally stable nuclides\* that have an odd number of protons and an odd number of neutrons. Also, comment on the ratio of neutrons to protons for increasingly heavier nuclides. (\*Stable or with extremely long half-lives > 109 years). List the stable nuclides and the long-life radioactive nuclides separately.)*

 2 6 10 14

1*H*, 3*Li* , 5*B* , 7 *N* These indicated as completely stable.

 40 9 138 11 180 15

19 ½= 1.27 x 10 yr 57*La*, t½= 1.05 x 10 yr 73*Ta*, t½ >1.2 x 10 yr *K*, t

 50 17 176 10

23 ½= 1.4 x 10 yr 71*Lu*, t½= 3.75 x 10 yr *V*, t

N number to Z number gradually increases from a ratio of 1 (exception 11*H* ) to~1.5.

1. *List the percent abundances of the naturally occurring nuclides of (a) oxygen; (b) uranium. Do they add up to 100 percent? If not, explain.*

 **16O 99.757% 234U 0.0055%**

 **17O 0.038 235U 0.7200 18O 0.205 238U 99.2745**

 **100.000% 100.0000%**

1. *List the elements that have only one stable isotope.*

**9 19 23 27 31 45 50 51 55 59 75 89 93**

**Be, F, Na, Al, P, Sc, V (t½=1.4 E 17 yr), V, Mn, Co, As, Y, Nb,**

**103 113 115 127 133 138 139 141**

 **Rh, In, In (t½=4.4 E 14 yr), I, Cs, La (t½=1.05 E 11 yr), La, Pr,**

**159 165 169 175 180 181 185 187**

 **Tb, Ho, Tm, Lu, Ta (t½>1.2 E 15 yr), Ta, Re, Re (4.12 E 10 yr),**

**197 209 232 234 235**

 **Au, Bi, Th (t½ = 1.40 E 10 yr), U(t½ = 2.46 E 5 yr), U(t½ = 7.04 E 8 yr),**

**238**

**U (t½ = 4.47 E 9 yr)**

1. *Which element(s) has the greatest number of stable isotopes? Give the number of isotopes.*

 **Sn (tin) has 10 stable isotopes**

1. *Which element(s) has the greatest number of radioactive isotopes? Give the number of isotopes.*

 **Cesium (55Cs) has 36**

1. *List an example radioactive nuclide and its half-life for each of the following half-life ranges:*
	1. *μs (microseconds, 10-6)* **113Cs 17µs**
	2. *s* **115Cs ~1.4s**
	3. *min* **126Cs 1.64 min**
	4. *h* **127Cs 6.2 h**
	5. *days* **132Cs 6.48 d**
	6. *years*  **228Th 1.912 yr**

1. *Which nuclide on the chart has (a) the shortest half- life; (b) the longest half-life?*

*List their half-lives.*

 **Shortest** **t½: 4Li (8 x 10-23 s)**

 **5Li (3 x 10-22 s) Longest t½: 50V (1.4 x 1017 yr)**

 **7B (3 x 10-22 s)**

 **15F (5 x 10-22 s)**

 **12O (~1 x 10-21 s)**

 **8C (2.0 x 10-21 s)**

 **10He (2 x 10-21 s)**

 **16Ne (4 x 10-21 s)**

 **6Be (5.0 x 10-21 s)**

 **16F (~1 x 10-20 s)**

 **216Fr (70 ns, 0.70 µs; isomers) 219Pa (~53 ns)**

 **217Ac (0.7 μs, 0.07 µs; isomers)**

  **215Fr (0.09 µs)**

 **9He (very short)**

 **39Sc (very short)**

1. *A large number of different product nuclides typically result from the slow neutron fission of U-235, U-233, and Pu-239. In analyzing “The Chart of Nuclides”(16th edition), nearly 550 such product nuclides are noted with 100 of these indicated as stable. Such fission products from slow neutron fission of U-235, U-233, and Pu-239 are indicated on the chart by small black triangles or squares in the lower right corner of the nuclide squares. Whether the nuclide is stable is denoted by some gray shading in the nuclide squares. Answer the following regarding these stable fission product nuclides.*
	1. range of:

 Z, 32 to 68

 N, 40 to 99 A, 72 to 167

* 1. ratio of N to Z : from ~1.50 to ~1.25
	2. Regarding odd and even counts of N and Z with respect to the stability, one notes that 79 of these nuclides are even Z and 21 are odd Z which suggests that even Z are about ~3.7 times more likely than odd Z.

 Further, for these even Z nuclides, 72 have even N and 28 have odd N so that for the even Z even N is about 2.6 times more likely than odd N.

1. *For the following fission reactions, fill in the blanks with the missing isotopes, including Z and N numbers.*

|  |  |  |
| --- | --- | --- |
| 235 1 *U* + *n* →92 0 | 236*U*92 | → 14456*Ba* + 3689*Kr* + 3 01*n* |
| 235 1 *U* + *n* →92 0 | 236*U*92 | → 14054 *Xe* + 3894*Sr* + 2 01*n* |

1. (Do the following on a separate sheet of paper and attach to the Laboratory Report.) Beginning with the following radioactive parent nuclei, trace their decay processes and depict the mode and direction of each decay process on the chart. For example,

## 14N

 β-

##  14C

(

a)O-20,

13

a.

20

O

20

O

20

Ne

β

-

β

-

20

F

(

b) Fe-52,

b.

13

52

Fe

52

Cr

52

Fe

β

+

β

+

52

Mn

 (c) Po-197,

193

Hg

193

Pb

193

Tl

193

Pt

ε

,

β

+

193

Au

193

Ir

α

197

Po

c.

13

197

Po

ε

ε

,

β

+

ε

ε

 MeV

6.381

1. Dy-150

 (list the energies of the emitted alpha particles in this decay process beside the directional arrows.

146

Sm

146

Gd

146

Eu

α

150

Dy

ε

,

β

+

ε

4.233

 MeV

2.455

 MeV

α

142

Na

d.

13

150

Dy

ε

,

β

+

150

Tb

150

Gd

ε

,

β

+

 MeV

3.49

α

2.73

 MeV

α

1. Ho-162.

|  |
| --- |
| 13e. 162Ho 162Ho ε, β+162Dy  |

1. *(Do the following exercises in the rectangular spaces.) Beginning with the following radioactive parent nuclei, trace the decay “chains.” List the modes and direction of the process on the chart as on part 13. The first three decay chains are found in nature, but the fourth chain is not.*

14

 (a).

238

U (Uranium s

eries)

234

Th

234

U

α

β

-

α

β

-

234

P

a

230

Th

α

α

α

2

26

R

a

218

P

o

214

P

b

β

-

214

Po

210

Pb

α

β

-

β

-

(

stable)

206

Hg

α

210

Bi

206

Tl

α

β

-

β

-

β

-

214

Bi

210

Tl

218

At

218

Rn

α

β

-

α

222

Rn

α

210

Po

206

Pb

α

β

-

β

-

238

U

238

U, t

½

 = 4.47 x 10

9

 yr

α

14

 (b).

235

U (Actinium series)

235

U

231

Th

231

Pa

α

β

-

α

227

Ac

223

Fr

219

At

215

Bi

α

α

223

Ra

219

Rn

227

Th

α

α

215

Po

215

A

t

211

Pb

211

Bi

211

Po

207

Tl

207

Pb

α

α

α

α

α

α

β

-

β

-

β

-

β

-

β

-

β

-

β

-

β

-

235

U, t

½

 = 7.04 x 10

8

 yr

s

(

tab

l

e)

 (c).

14

244

Pu (Plutonium series – originally called thorium series)

244

Pu

240

U

240

Pu

α

β

-

α

β

-

240

Np

α

α

236

U

23

2

Th

228

Ra

β

-

β

-

228

Ac

228

Th

α

α

β

-

224

Ra

224

Fr

α

220

Rn

216

Po

α

α

212

Pb

β

-

β

-

212

Bi

212

Po

α

α

β

-

208

Pb

208

Tl

stable

(

)

244

Pu, t

½

 = 8.0 x 10

7

yr

237

Np

233

P

a

233

U

α

β

-

α

α

229

Th

22

5

R

a

β

-

225

Ac

α

α

221

F

r

α

213

Bi

213

Po

217

Rn

α

α

β

-

β

-

β

-

21

7

A

t

209

Tl

209

Pb

209

Bi

β

-

(

stab

l

e)

 (d).

14

237

Np (Neptunium series)

237

Np, t

½

 = 2.14 x 10

6

yr

Not found in nature with the t

½

 = 2.14 x 10

6

yr giving it

adequate time on a cosmic scale to decay. (Earth age: ~4.6

x 10

9

yrs.)

α

1. Using the chart of nuclides, supply the product nucleus of each of the following reactions. Also, give the compound nucleus of each reaction.

 Reaction Product Nucleus Compound Nucleus

* 1. 10B(*n,*α) 7Li 11B
	2. 16O(*n*,*p*) 16N 17O
	3. 7Li(*p,*γ) 8Be 8Be
	4. 17O(γ,*np*) 15N 17O
	5. 32S(*n,p*) 32P 33S
	6. 3H(*d,n*) 4He 5He
	7. 2H(*t,n*) 4He 5He