Nuclear chemistry question bank

(chapter one, chapter two and chapter three)

1- The most common kind of iron nucleus has a mass number of 56. Find the radius, approximate mass, and approximate density of the nucleus?

2- Assuming that a nucleus is a sphere of nuclear matter of radius $1.2xA^{1/3}$ Fm, express the average nuclear density in SI unit?

3- How many protons and how many neutrons are there in a nucleus of the most common isotope of $^{28}_{14}Si$, $^{85}_{37}Rb$ and $^{205}_{81}Tl$? then estimate (a) the radius, (b)the volume of each nucleus, (c) the mass density (in Kg/m3) and (d) the nucleon density (in nucleons per cubic meter) for each nucleus?

4- Calculate magnetic dipole moment for deuteron nucleus $^{2}_{1}H$ and $^{4}_{2}He$ nucleus?

5- Calculate the value of nuclear magneton (μ_N) in units of $J\,T^{-1}$ and $eV\,T^{-1}$, where (T) is tesla?

6- Calculate the distance of closest approach of alpha particle of kinetic energy 7.7 MeV from gold $^{197}_{79}$ Au in head on collision and which is scattering at angle of 180^0?

7- The atomic mass of $^{16}_{8}O$ is 15.99494amu. Find (a) Its binding energy and (b) Its binding energy per nucleon?

8- Show that 1 amu unit is equivalent to 931.48 MeV?

9- Define each of the following? isotopes, isotones and isobars (Give these element (${}^{16}_{8}O$, ${}^{14}_{7}N$, ${}^{14}_{6}C$, ${}^{17}_{8}O$, ${}^{15}_{7}N$) as an example for each of them).

10- What are the properties of nuclear force?

11- Calculate the separation energy of the neutron and proton from ${}^{57}_{26}Fe$?

12- The binding energy of neon isotope ${}^{20}_{10}Ne$ is 160.647 MeV. Find its atomic mass?

13- Find the mass defect and mass excess of ${}^{4}_{2}He$ nucleus?

14- What angular momentum and parities are predicted by the shell model for the ground state of ${}^{12}_{6}C$, ${}^{11}_{5}B$, ${}^{67}_{30}Zn$ and ${}^{16}_{7}N$?

15- Predict the characteristics of the ground state of ${}^{17}_{8}O$, ${}^{63}_{29}Cu$?

16- Calculate the total binding energy of ${}^{27}_{13}Al$ nucleus from the semi-empirical binding energy formula?

17- Calculate the mass of ${}^{9}_{4}Be$ nucleus from the semi –empirical mass formula?

18- Calculate the repulsive potential energy due to coulomb force among the protons of ${}^{235}_{92}U$ nucleus?

19- According to the shell model, calculate the orbital angular momentum (L), spin angular momentum(S), total angular momentum(J), magnetic moment (μn) and parity in ground state of ${}^{45}_{21}Sc$ nuclei?

Constants:

- *Mass of proton = 1.007276 amu*
- *Mass of hydrogen atom M_H = 1.007825 amu*
- *Mass of neutron ${}^{1}_{0}n$ = 1.008665 amu*
- *Electron =0.000549 amu*
- $Atomic\ mass\ of\ ({}^{4}_{2}He) = 4.002603\ a.m.u$
- $Atomic\ mass\ of\ ({}^{20}_{10}Ne) = 19.992440\ a.m.u$
- $Atomic\ mass\ of\ ({}^{64}_{28}Ni) = 63.927969\ a.m.u$
- $Atomic\ mass\ of\ ({}^{64}_{29}Cu) = 63.929766\ a.m.u$
- $Atomic\ mass\ of\ ({}^{64}_{30}Zn) = 63.929146\ a.m.u$
- $Atomic\ mass\ of\ ({}^{222}_{86}Rn) = 222.017570\ a.m.u$
- $Atomic\ mass\ of\ ({}^{226}_{88}Ra) = 226.025402\ a.m.u$
- Mass of ${}_{92}{}^{235}$ U atom=235.0439 amu
- Mass of Manganese Atom M (${}_{25}{}^{56}$Mn) = 55.938907 amu
- M (${}_{8}{}^{16}$ O) =15.9949 amu

Radiation Chemistry

Example 1: 1) Find the energy released in the alpha decay of ${}^{232}_{92}U$:

$$^{232}_{92}U_{140} \rightarrow {}^{228}_{90}Th_{138} + \alpha$$

Answer:

1- $Q\alpha = (M_P - M_D - M_\alpha)\, c^2$

$$Q = (232.0371463 - 228.0287313 - 4.002603)uc^2 \frac{931.502MeV}{uc^2} = 5.414MeV$$

2- Find the kinetic energy of alpha particle:

$$^{232}_{92}U_{140} \rightarrow {}^{228}_{90}Th_{138} + \alpha \qquad T_\alpha = Q\left(1 - \frac{4}{A}\right) = 5.414MeV\left(1 - \frac{4}{228}\right) = 5.32MeV$$

Example 2: What is the maximum energy of the electron emitted in the β-decay of ${}^{3}_{1}H$?

Answer:

The reaction is: ${}^{3}_{1}H \rightarrow {}^{3}_{2}He + e^{-} + \overline{\nu}$

$$Q = (M_{\mathrm{H}} - M_{\mathrm{He}})c^2 \quad = (3.016050\,u - 3.016030\,u)(931.5MeV/u)$$

$$= 0.0186\,MeV = K_{\mathrm{He}} + K_e + K_\nu$$

Neglecting the kinetic energy of the nucleus, and mass of the neutrino the Q is shared between ***e*** *and* $\boldsymbol{\nu}$. K_e *at maximum when* $K_\nu \rightarrow 0$, so

$$K_e^{\max} = 0.0186\,MeV$$

Example 3 :

${}^{240}_{94}$P decays with a half-life of 6760 Y by emitting two groups of alpha particles, with energy 5.17 MeV and 5.12 MeV.

a) What are the decay energy (disintegration energy)?

b) Calculate the recoil kinetic energy of the daughter nucleus.

Answer ; The decay energy Q_α is given by;

(**a)** $Q_\alpha = \frac{A}{A-4} T_\alpha$

For $^{240}_{94}P$, A=240 .The kinetic energy of the first group of α-particles ; $T_{\alpha 1} = 5.17\ Mev$

The decay energy of first group of emitted alpha particles $Q_{\alpha 1}$ is

$Q_{\alpha 1} = \frac{240}{240-4}$ x5.17 = 5.25 Mev

The decay energy of second group of emitted alpha particles $Q_{\alpha 2}$ is

$Q_{\alpha 2} = \frac{A}{A-4} T_{\alpha 2}$

Where $T_{\alpha 2}$ is the kinetic energy of the second group of α-particles ; $T_{\alpha 2} = 5.12\ Mev$

$Q_{\alpha 2} = \frac{240}{240-4}\ x\ 5.12$ = 5.20 MeV

(b) The recoil kinetic energy of the first group of daughter nuclei T_{D1} is ;

$Q_{\alpha 1} = T_{\alpha 1} + T_{D1}$

5.25 = 5.17 + T_{D1}

$T_{D1} = 0.08\ MeV$

For $Q_{\alpha 2 =}$ 5.2 MeV and $T_{\alpha 2} = 5.12\ MeV$

The recoil kinetic energy of the second group of daughter nuclei T_{D2} is

$Q_{\alpha 2 =} T_{\alpha 2} + T_{D2}$

$T_{D2} = 5.2 - 5.12 = \ 0.08\ MeV$

Example 4:

Show that a radioactive isotope $_{29}^{64}Cu$ satisfied the conditions for decaying by $\boldsymbol{\beta^-}$, $\boldsymbol{\beta^+}$ and electron capture processes.

Answer: The value of atomic masses is;

M($_{29}^{64}$Cu) = 63.9297 amu,   M($_{28}^{64}$ Ni) = 63.928 amu
M(e) =0.000548 amu   M($_{30}^{64}$Zn) =63.9291 amu

For $\boldsymbol{\beta^-}$ - decy of $_{29}^{64}$Cu ;

$$_{29}^{64}Cu \rightarrow\ _{30}^{64}Zn + \beta^- + \bar{\nu}$$

The Q-value of β^- -decay is , Q_{β^-} = (M_p - M_D) c^2

$$Q_{\beta^-} = (63.9297- 63.9291)\ c^2$$

Since 1 amu x c^2 =931.48 MeV or $c^2 = \frac{931.4 MeV}{1\ amu}$

$\therefore\ Q_{\beta^-} =$ (63.9297- 63.9291) x 931.48 = 0.558 MeV

Since the value of Q_{β^-} is positive quantity , therefor β^- −decay is possible .

For $\boldsymbol{\beta^+}$ -decay of $_{29}^{64}$Cu ;

$_{29}^{64}Cu \rightarrow\ _{28}^{64}Ni + \beta^+ + \nu$

The Q-value of β^+ -decay is ; $Q_{\beta^+ =}$ [(M_p - M_D -2m_o) c^2

$Q_{\beta^+ =}$ [63.9297 - 63.928 - 2x 0.000548] c^2

$Q_{\beta^+ =}$ [63.9297 - 63.928 - 2x 0.000548] x 931.48

$Q_{\beta^+ =}$ 0.562 MeV

Since Q_{β^+} is positive quantity ,therefor β^+ −decay is possible .

For electron capture decay of $_{29}^{64}$Cu ;

$_{29}^{64}Cu + e^- \rightarrow\ _{28}^{64}Ni + \nu$

The Q-value of β^+ -decay is ; $Q_{e.c =}$ [M_p - M_D] c^2

$Q_{e.c}$ = [63.9297 - 63.928] c^2

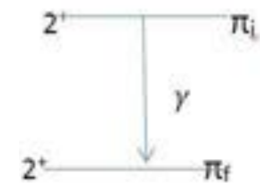
$Q_{e.c}$ = [63.9297 - 63.928] x931.48

$Q_{e.c}$ = 1.58 MeV

Since the value of $Q_{e.c}$ is positive quantity ,therefor $Q_{e.c}$ – decay is possible .

Example 5:

What is the most predominate multipole transition in the $2^+ \rightarrow 2^+$ gamma transition ?



Answer:

For the $2^+ \rightarrow 2^+$ gamma transition we have ;

Initial nuclear angular momentum $J_i = 2$, and initial parity is , π_i = +1

Final nuclear angular momentum $J_f = 2$. and final parity is, π_f = +1

$|J_i - J_f| \leq L_\gamma \leq J_i + J_f$

$|2 - 2| \leq L_\gamma \leq 2 + 2$

$0 \leq L_\gamma \leq 4$

L_γ =0,1,2, 3, 4 or L_γ =1,2, 3, 4 because $L_\gamma = 0$ not allowed

From conservation of parity the parity of the system π_γ ,

$\pi_\gamma = \pi_i \ \pi_f$

$\pi_\gamma = (+1)(+1) = +1$ parity is positive (not changed)

for electric multipole transition **EL** the parity of the system is ; $\pi_\gamma = (-1)^{L_\gamma}$,

since, $\pi_\gamma = (-1)^2$ = +1 and $\pi_\gamma = (-1)^4$=+1 which means that L_γ = 2, 4 gives π_γ positive ,therefor we have **EL = E2 , E4** allowed Electric transition.

for magnetic multipole transition ML ,the parity of the system ; $\pi_\gamma = (-1)^{L_\gamma+1}$

since ; $\pi_\gamma = (-1)^{1+1}$ = +1 and $\pi_\gamma = (-1)^{3+1}$=+1

$\therefore L_\gamma = 1\,,3$ gives no change in the parity of the system, the ML –transitions will be **ML = M1, M3** probable etic multipole transition.

It is well known that; E2$\gg E4$ and $M1 \gg M3$

Therefor we have the most mixed predominate (E2+ M1) gamma multipole –transition.

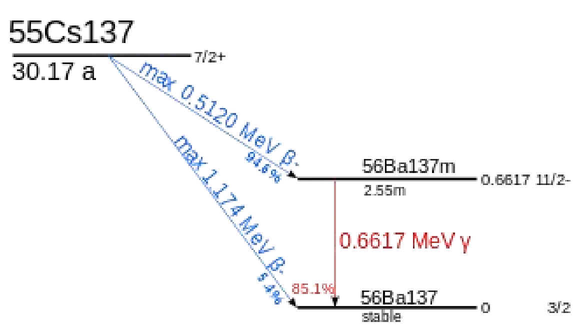
Example 6:

^{137}Cs decays by $\boldsymbol{\beta^-}$- emission ,as shown in the figure .When the nucleus left in excited state, its decay to the ground state via gamma transition .What are the energies between of the beta rays ? Given that

Answer:

The mass of ^{137}Cs and ^{137}Ba from physical tables are ; M(^{137}Cs) = 136.90677 amu , M(^{137}Ba) =136. 9055 amu

1/ The Q- value of β_0^- -decay is ; $Q_{\beta 0^-}$



The decay Scheme of ^{137} Cs

$Q_{\beta 0^-}$ = (M_p - M_D) c^2

$Q_{\beta 0^-}$ = (136.90677 – 136.9055) c^2

Since 1 amu x c^2 =931.48 MeV or $c^2 = \frac{931.4 MeV}{1\ amu}$

$\therefore\ Q_{\beta 0^-} =$ (136.90677 – 136.9055) x 931.48 = 1.1829 MeV

2/ $E_\gamma = E_i - E_f$

E_γ = 0.661- 0 = 0.661 MeV

3 / The Q- value of β_1^- -decay is ; $Q_{\beta 1^-} = Q_{\beta 0^-} - E_\gamma$

$Q_{\beta 1^-}$ = 1.1829 - 0.662 = 0.521 MeV

Example 7:

In terms of the parent and daughter rest masses, determine the Q-values for β^- decay, β^+ decay, and electron capture.

Ans. The three reactions are (P = parent, D = daughter):

$$\begin{aligned} {}^A_ZP &\rightarrow {}_{Z+1}^{\ \ A}D + e^- + \bar{\nu} && (\beta^- \text{ decay}) \\ {}^A_ZP &\rightarrow {}_{Z-1}^{\ \ A}D + e^+ + \nu && (\beta^+ \text{ decay}) \\ {}^A_ZP + e^- &\rightarrow {}_{Z-1}^{\ \ A}D + \nu && (\text{electron capture}) \end{aligned}$$

The corresponding mass–energy relations are, after subtracting the electron masses from the atomic masses to obtain the nuclear masses,

$$\left.\begin{aligned} (M_P - Zm_e)c^2 &= [M_D - (Z+1)m_e]c^2 + m_ec^2 + Q \\ Q &= (M_P - M_D)c^2 \end{aligned}\right\} (\beta^- \text{ decay})$$

$$\left.\begin{aligned} (M_P - Zm_e)c^2 &= [M_D - (Z-1)m_e]c^2 + m_ec^2 + Q \\ Q &= (M_P - M_D - 2m_e)c^2 \end{aligned}\right\} (\beta^+ \text{ decay})$$

$$\left.\begin{aligned} (M_P - Zm_e)c^2 + m_ec^2 &= [M_D - (Z-1)m_e]c^2 + Q \\ Q &= (M_P - M_D)c^2 \end{aligned}\right\} (\text{electron capture})$$

Example 8:

Determine the energy and momentum of the daughter and the neutrino that are produced when ${}^{7}_{4}\mathrm{Be}$ undergoes electron capture at rest.

Ans. The electron capture reaction is

$${}^{7}_{4}\mathrm{Be} + e^{-} \rightarrow {}^{7}_{3}\mathrm{Li} + \nu$$

From Problem 19.8

$$Q = (M_{\mathrm{Be}} - M_{\mathrm{Li}})c^2$$
$$= (7.016\,929\,\mathrm{u} - 7.016\,004\,\mathrm{u})(931.5\,\mathrm{MeV/u}) = 0.862\,\mathrm{MeV}$$

This energy is split between the neutrino and the ${}^{7}_{3}\mathrm{Li}$ nucleus. However, because of the large mass of the ${}^{7}_{3}\mathrm{Li}$ nucleus and the zero rest mass of the neutrino, almost all the energy is carried by the neutrino, so that

$$E_{\nu} \approx 0.862\,\mathrm{MeV}$$

Assuming that the ${}^{7}_{4}\mathrm{Be}$ nucleus was initially at rest, the magnitudes of the momenta of the neutrino and ${}^{7}_{3}\mathrm{Li}$ nucleus must be equal. Using $p_{\nu} = E_{\nu}/c$, we then have

$$p_{\nu} = p_{\mathrm{Li}} = 0.862\,\mathrm{MeV}/c$$

The kinetic energy of the ${}^{7}_{3}\mathrm{Li}$ nucleus can now be found from

$$K_{\mathrm{Li}} = \frac{p_{\mathrm{Li}}^2}{2M_{\mathrm{Li}}} = \frac{(p_{\mathrm{Li}}c)^2}{2M_{\mathrm{Li}}c^2} = \frac{(0.862\,\mathrm{MeV})^2}{2(7.02\,\mathrm{u} \times 931.5\,\mathrm{MeV/u})} = 5.68 \times 10^{-5}\,\mathrm{MeV} = 56.8\,\mathrm{eV}$$

H.W.Ch.1,2 (Radiation Chemistry)

Q1/ How much time is required for 5gm of ^{22}Na ($T_{1/2}$=2.6y) to reduce to 1gm.

Q2/ A sample of Radium contains 1gm. If its half-life is 1620y, find:

a-The initial activity.

b-The mean life time.

C-The activity of ^{226}Ra after $t=T_{1/2}$.

d-The activity after 810y.

Q3/ The radioactive isotope ^{57}Co decays by electron capture with a half-life of 272days. (a) Find the decay constant and the life-time. (b) If you have a radiation source containing ^{57}Co, with radioactivity 2.0μCi, how many radioactive nuclei does it contain. (c) what will be the activity of your source after one year.

Q4/ What is the energy of the alpha particle emitted in the alpha decay of $^{226}_{88}Ra$? if the recoil energy of the radium nucleus is neglected.

Q5/What nuclide is produced in the following radioactive decays?

1) α decay of $^{239}_{94}Pu$. 2) β-decay of $^{24}_{11}Na$. 3) β+decay of $^{15}_{8}O$

Q6/ Determine the energy of neutrino emitted in E.C for $^{41}_{20}Ca$?

Q7/What particle (α, β-or β+) is emitted in the following radiation decays?

$$\boldsymbol{^{27}_{14}Si \rightarrow {}^{27}_{13}Al\ ,\ {}^{238}_{92}U \rightarrow {}^{234}_{90}Th\ ,\ {}^{74}_{33}As \rightarrow {}^{74}_{34}Sc}.$$

Q8/Calculate the activity of ^{40}K in 100kg. man assuming that 0.35% of the body weight is potassium. The abundance of ^{40}K is 0.012%, its half-life is 1.31*109years?

Q9/ What is the maximum energy of the positron emitted in the β-decay of $^{3}_{2}He$?

Q10/ Show that $^{236}_{94}Pu$ is unstable and will α decay?

Q11/ Determine the Q values of (α, proton, neutron) decays of Uranium ${}^{232}_{92}U$?

Q12/What is the type of radioactivity equilibrium where occurs between ^{226}Ra (with half-life 1620 years) and ^{222}Rn (with half-life 3.8 days). Why?

Q13/The half-life of radioactive element ^{60}Co is 5.26 years, what is the radioactivity of a (1gm) sample of ^{60}Co in units of curie, and its activity after 3 years?

Q14/ Calculate the mean life-time for ^{210}Po nucleus?

Q15/ The activity of 20 g of ^{232}Th is 2.18 μci .Calculate the disintegration constant and the half-life of ^{232}Th?

Q16/ Calculate the maximum kinetic energy of electron **(T_{e-})**, and positron, **(T_{e+}),** in the following decays:

$\beta^- - decay$, and β^+-decay of ${}_{29}{}^{64}$Cu .

Q17/ What is the most predominate multipole transition in the $3^- \rightarrow 1^-$ gamma transition for the indicated transition in ^{16}O?

Q18/ ${}^{226}_{88}$Ra nucleus undergoes alpha decay to ${}^{222}_{86}$Rn, calculate:

1- Find the amount of energy liberated in this decay (Q-value)?

2- Calculate the recoil kinetic energy of the daughter nucleus?

3- What is the activity of one gram of ${}^{226}_{88}$Ra , whose half-life is 1621y?

Q19/ Explain the interaction of gamma rays with matter?

Q20/ Draw the distinguishing graph of the three types of radiations (alpha, beta and gamma rays) from a radium sample?

Q21/ Plutonium^{239}Pu, has a half-life of 24,360 years.

1.What is the decay constant?

2.How much of 1kg ^{239}Pu is left after 100 years?

Appendix

SOME FUNDAMENTAL CONSTANTS IN CONVENIENT UNITS

$$c = \text{speed of light} = 2.998 \times 10^8\ \text{m/s}$$
$$e = \text{electron charge} = 1.602 \times 10^{-19}\ \text{C}$$
$$h = \text{Planck's constant} = 6.626 \times 10^{-34}\ \text{J} \cdot \text{s}$$
$$= 4.136 \times 10^{-15}\ \text{eV} \cdot \text{s}$$
$$\hbar = \frac{h}{2\pi} = 1.055 \times 10^{-34}\ \text{J} \cdot \text{s} = 0.658 \times 10^{-15}\ \text{eV} \cdot \text{s}$$
$$k = \frac{1}{4\pi\epsilon_0} = \text{Coulomb constant} = 8.988 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2$$
$$k = \frac{R}{N} = \text{Boltzmann's constant} = 1/38 \times 10^{-23}\ \text{J/K}$$
$$= 8.617 \times 10^{-5}\ \text{eV/K}$$

SOME USEFUL CONVERSIONS

$$1\ \text{eV} = 1.602 \times 10^{-19}\ \text{J}$$
$$1\ \text{Å} = 10^{-10}\ \text{m} = 10^5\ \text{fm}$$
$$hc = 19.865 \times 10^{-26}\ \text{J} \cdot \text{m} = 12.41 \times 10^3\ \text{eV} \cdot \text{Å} = 1241\ \text{MeV} \cdot \text{fm}$$
$$\hbar c = 3.165 \times 10^{-26}\ \text{J} \cdot \text{m} = 1973 \times 1\ \text{eV} \cdot \text{Å} = 197.3\ \text{MeV} \cdot \text{fm}$$
$$ke^2 = 1.44\ \text{MeV} \cdot \text{fm}$$
$$\frac{ke^2}{\hbar c} = \text{fine structure constant} \approx \frac{1}{137}$$
$$\frac{e\hbar}{2m_e} = \text{Bohr magneton} = 9.27 \times 10^{-24}\ \text{J/T}$$
$$= 5.79 \times 10^{-5}\ \text{EV/T}$$

MASSES OF SOME PARTICLES

Particle	Rest Mass, m_0 (kg)	m_0c^2 (MeV)
Electron	9.109×10^{-31}	0.511
Proton	1.673×10^{-27}	938.3
Neutron	1.675×10^{-27}	939.6
Atomic mass unit (1 u)	1.661×10^{-27}	931.5

MASSES OF NEUTRAL ATOMS

In the fifth column of the table an asterisk on the mass number indicates a radioactive isotope, the half-life of which is given in the seventh column.

Z	Element	Symbol	Chemical Atomic Weight	A	Mass (u)	$T_{1/2}$
0	(Neutron)	n		1*	1.008 665	12 min
1	Hydrogen	H	1.0079	1	1.007 825	
	Deuterium	D		2	2.014 102	
	Tritium	T		3*	3.016 050	12.26 y
2	Helium	He	4.0026	3	3.016 030	
				4	4.002 603	
				6*	6.018 892	0.802 s
3	Lithium	Li	6.939	6	6.015 125	
				7	7.016 004	
4	Beryllium	Be	9.0122	7*	7.016 929	53.4 d
				9	9.012 186	
				10*	10.013 534	2.7×10^6 y
5	Boron	B	10.811	10	10.012 939	
				11	11.009 305	
6	Carbon	C	12.01115	12	12.000 000	
				13	13.003 354	
				14*	14.003 242	5730 y
7	Nitrogen	N	14.0067	14	14.003 074	
				15	15.000 108	
8	Oxygen	O	15.9994	15*	15.003 070	122 s
				16	15.994 915	
				17	16.999 133	
				18	17.999 160	
9	Fluorine	F	18.9984	19	18.998 405	
10	Neon	Ne	20.183	20	19.992 440	
				21	20.993 849	
				22	21.991 385	
11	Sodium	Na	22.9898	22*	21.994 437	2.60 y
				23	22.989 771	
12	Magnesium	Mg	24.312	23*	22.994 125	12 s
				24	23.985 042	
				25	24.986 809	
				26	25.982 593	
13	Aluminum	Al	26.9815	26*	25.986 892	7.4×10^5 y
				27	26.981 539	
14	Silicon	Si	28.086	28	27.976 929	
				29	28.976 496	
				30	29.973 763	
				32*	31.974 020	≈700 y
15	Phosphorus	P	30.9738	31	30.973 765	
16	Sulfur	S	32.064	32	31.972 074	
				33	32.971 462	
				34	33.967 865	
				36	35.967 089	
17	Chlorine	Cl	35.453	35	34.968 851	
				36*	35.968 309	3×10^5 y
				37	36.965 898	
18	Argon	A	39.948	36	35.967 544	
				38	37.962 728	
				39*	38.964 317	270 y
				40	39.962 384	
				42*	41.963 048	33 y
19	Potassium	K	39.102	39	38.963 710	
				40*	39.964 000	1.3×10^9 y

Z	Element	Symbol	Chemical Atomic Weight	A	Mass (u)	$T_{1/2}$
(19)	(Potassium)			41	40.961 832	
20	Calcium	Ca	40.08	39*	38.970 691	0.877 s
				40	39.962 589	
				41*	40.962 275	7.7×10^4 y
				42	41.958 625	
				43	42.958 780	
				44	43.955 492	
				46	45.953 689	
				48	47.952 531	
21	Scandium	Sc	44.956	45	44.955 920	
				50*	49.951 730	1.73 min
22	Titanium	Ti	47.90	44*	43.959 572	47 y
				46	45.952 632	
				47	46.951 768	
				48	47.947 950	
				49	48.947 870	
				50	49.944 786	
23	Vanadium	V	50.942	50*	49.947 164	$\approx 6 \times 10^{15}$ y
				51	50.943 961	
24	Chromium	Cr	51.996	50	49.946 055	
				52	51.940 513	
				53	52.940 653	
				54	53.938 882	
25	Manganese	Mn	54.9380	50*	49.954 215	0.29 s
				55	54.938 050	
26	Iron	Fe	55.847	54	53.939 616	
				55*	54.938 299	2.4 y
				56	55.939 395	
				57	56.935 398	
				58	57.933 282	
				60*	59.933 964	$\approx 10^5$ y
27	Cobalt	Co	58.9332	59	58.933 189	
				60*	59.933 813	5.24 y
28	Nickel	Ni	58.71	58	57.935 342	
				59*	58.934 342	8×10^4 y
				60	59.930 787	
				61	60.931 056	
				62	61.928 342	
				63*	62.929 664	92 y
				64	61.927 958	
29	Copper	Cu	63.54	63	62.929 592	
				65	64.927 786	
30	Zinc	Zn	65.37	64	63.929 145	
				66	65.926 052	
				67	66.927 145	
				68	67.924 857	
				70	69.925 334	
31	Gallium	Ga	69.72	69	68.925 574	
				71	70.924 706	
32	Germanium	Ge	72.59	70	69.924 252	
				72	71.922 082	
				73	72.923 462	
				74	73.921 181	
				76	75.921 405	
33	Arsenic	As	74.9216	75	74.921 596	
34	Selenium	Se	78.96	74	73.922 476	
				76	75.919 207	
				77	76.919 911	
				78	77.917 314	
				79*	78.918 494	7×10^4 y

Z	Element	Symbol	Chemical Atomic Weight	A	Mass (u)	$T_{1/2}$
(34)	(Selenium)			80	79.916 527	
				82	81.916 707	
35	Bromine	Br	79.909	79	78.918 329	
				81	80.916 292	
36	Krypton	Kr	83.80	78	77.920 403	
				80	79.916 380	
				81*	80.916 610	2.1×10^5 y
				82	81.913 482	
				83	82.914 131	
				84	83.911 503	
				85*	84.912 523	10.76 y
				86	85.910 616	
37	Rubidium	Rb	85.47	85	84.911 800	
				87*	86.909 186	5.2×10^{10} y
38	Strontium	Sr	87.62	84	83.913 430	
				86	85.909 285	
				87	86.908 892	
				88	87.905 641	
				90*	89.907 747	28.8 y
39	Yttrium	Y	88.905	89	88.905 872	
40	Zirconium	Zr	91.22	90	89.904 700	
				91	90.905 642	
				92	91.905 031	
				93*	92.906 450	9.5×10^5 y
				94	93.906 313	
				96	95.908 286	
41	Niobium	Nb	92.906	91*	90.906 860	(long)
				92*	91.907 211	$\approx 10^7$ y
				93	92.906 382	
				94*	93.907 303	2×10^4 y
42	Molybdenum	Mo	95.94	92	91.906 810	
				93*	92.906 830	$\approx 10^4$ y
				94	93.905 090	
				95	94.905 839	
				96	95.904 674	
				97	96.906 021	
				98	97.905 409	
				100	99.907 475	
43	Technetium	Tc		97*	96.906 340	2.6×10^6 y
				98*	97.907 110	1.5×10^6 y
				99*	98.906 249	2.1×10^5 y
44	Ruthenium	Ru	101.07	96	95.907 598	
				98	97.905 289	
				99	98.905 936	
				100	99.904 218	
				101	100.905 577	
				102	101.904 348	
				104	103.905 430	
45	Rhodium	Rh	102.905	103	102.905 511	
46	Palladium	Pd	106.4	102	101.905 609	
				104	103.904 011	
				105	104.905 064	
				106	105.903 479	
				107*	106.905 132	7×10^6 y
				108	107.903 891	
				110	109.905 164	
47	Silver	Ag	107.870	107	106.905 094	
				109	108.904 756	
48	Cadmium	Cd	112.40	106	105.906 463	
				108	107.904 187	

Z	Element	Symbol	Chemical Atomic Weight	A	Mass (u)	$T_{1/2}$
(48)	(Cadmium)			109*	108.904 928	453 d
				110	109.903 012	
				111	110.904 188	
				112	111.902 762	
				113	112.904 408	
				114	113.903 360	
				116	115.904 762	
49	Indium	In	114.82	113	112.904 089	
				115*	114.903 871	6×10^{14} y
50	Tin	Sn	118.69	112	111.904 835	
				114	113.902 773	
				115	114.903 346	
				116	115.901 745	
				117	116.902 958	
				118	117.901 606	
				119	118.903 313	
				120	119.902 198	
				121*	120.904 227	25 y
				122	121.903 441	
				124	123.905 272	
51	Antimony	Sb	121.75	121	120.903 816	
				123	122.904 213	
				125*	124.905 232	
52	Tellurium	Te	127.60	120	119.904 023	
				122	121.903 064	
				123*	122.904 277	1.2×10^{13} y
				124	123.902 842	
				125	124.904 418	
				126	125.903 322	
				128	127.904 476	
				130	129.906 238	
53	Iodine	I	126.9044	127	126.904 070	
				129*	128.904 987	1.6×10^{7} y
54	Xenon	Xe	131.30	124	123.906 120	
				126	125.904 288	
				128	127.903 540	
				129	128.904 784	
				130	129.903 509	
				131	130.905 085	
				132	131.904 161	
				134	133.905 815	
				136	135.907 221	
55	Cesium	Cs	132.905	133	132.905 355	
				134*	133.906 823	2.1 y
				135*	134.905 770	2×10^{6} y
				137*	133.906 770	30 y
56	Barium	Ba	137.34	130	129.906 245	
				132	131.905 120	
				133*	132.905 879	7.2 y
				134	133.904 612	
				135	134.905 550	
				136	135.904 300	
				137	136.905 500	
				138	137.905 000	
57	Lanthanum	La	138.91	137*	136.906 040	6×10^{4} y
				138*	137.906 910	1.1×10^{11} y
				139	138.906 140	
58	Cerium	Ce	140.12	136	135.907 100	
				138	137.905 830	
				140	139.905 392	

Z	Element	Symbol	Chemical Atomic Weight	A	Mass (u)	$T_{1/2}$
(58)	(Cerium)			142*	141.909 140	5×10^{15} y
59	Praseodymium	Pr	140.907	141	140.907 596	
60	Neodymium	Nd	144.24	142	141.907 663	
				143	142.909 779	
				144*	143.910 039	2.1×10^{15} y
				145	144.912 538	
				146	145.913 086	
				148	147.916 869	
				150	149.920 960	
61	Promethium	Pm		145*	144.912 691	18 y
				146*	145.914 632	1600 d
				147*	146.915 108	2.6 y
62	Samarium	Sm	150.35	144	143.911 989	
				146*	145.912 992	1.2×10^{8} y
				147*	146.914 867	1.08×10^{11} y
				148*	147.914 791	1.2×10^{13} y
				149*	148.917 180	4×10^{14} y
				150	149.917 276	
				151*	150.919 919	90 y
				152	151.919 756	
				154	153.922 282	
63	Europium	Eu	151.96	151	150.919 838	
				152*	151.921 749	12.4 y
				153	152.921 242	
				154*	153.923 053	16 y
				155*	154.922 930	1.8 y
64	Gadolinium	Gd	157.25	148*	147.918 101	85 y
				150*	149.918 605	1.8×10^{6} y
				152*	151.919 794	1.1×10^{14} y
				154	153.920 929	
				155	154.922 664	
				156	155.922 175	
				157	156.924 025	
				158	157.924 178	
				160	159.927 115	
65	Terbium	Tb	158.925	159	158.925 351	
66	Dysprosium	Dy	162.50	156*	155.923 930	2×10^{14} y
				158	157.924 449	
				160	159.925 202	
				161	160.926 945	
				162	161.926 803	
				163	162.928 755	
				164	163.929 200	
67	Holmium	Ho	164.930	165	164.930 421	
				166*	165.932 289	1.2×10^{3} y
68	Erbium	Er	167.26	162	161.928 740	
				164	163.929 287	
				166	165.930 307	
				167	166.932 060	
				168	167.932 383	
				170	169.935 560	
69	Thulium	Tm	168.934	169	168.934 245	
				171*	170.936 530	1.9 y
70	Ytterbium	Yb	173.04	168	167.934 160	
				170	169.935 020	
				171	170.936 430	
				172	171.936 360	
				173	172.938 060	
				174	173.938 740	
				176	175.942 680	

Z	Element	Symbol	Chemical Atomic Weight	A	Mass (u)	$T_{1/2}$
71	Lutecium	Lu	174.97	173*	172.938 800	1.4 y
				175	174.940 640	
				176*	175.942 660	2.2×10^{10} y
72	Hafnium	Hf	178.49	174*	173.940 360	2.0×10^{15} y
				176	175.941 570	
				177	176.943 400	
				178	177.943 880	
				179	178.946 030	
				180	179.946 820	
73	Tantalum	Ta	180.948	180	179.947 544	
				181	180.948 007	
74	Wolfram (Tungsten)	W	183.85	180	179.947 000	
				182	181.948 301	
				183	182.950 324	
				184	183.951 025	
				186	185.954 440	
75	Rhenium	Re	186.2	185	184.953 059	
				187*	186.955 833	5×10^{10} y
76	Osmium	Os	190.2	184	183.952 750	
				186	185.953 870	
				187	186.955 832	
				188	187.956 081	
				189	188.958 300	
				190	189.958 630	
				192	191.961 450	
				194*	193.965 229	6.0 y
77	Iridium	Ir	192.2	191	190.960 640	
				193	192.963 012	
78	Platinum	Pt	195.09	190*	189.959 950	7×10^{11} y
				192	191.961 150	
				194	193.962 725	
				195	194.964 813	
				196	195.964 967	
				198	197.967 895	
79	Gold	Au	196.967	197	196.966 541	
80	Mercury	Hg	200.59	196	195.965 820	
				198	197.966 756	
				199	198.968 279	
				200	199.968 327	
				201	200.970 308	
				202	201.970 642	
				204	203.973 495	
81	Thallium	Tl	204.19	203	202.972 353	
				204*	203.973 865	3.75 y
				205	204.974 442	
		Ra E″		206*	205.976 104	4.3 min
		Ac C″		207*	206.977 450	4.78 min
		Th C″		208*	207.982 013	3.1 min
		Ra C″		210*	209.990 054	1.3 min
82	Lead	Pb	207.19	202*	201.927 997	3×10^{5} y
				204*	203.973 044	1.4×10^{17} y
				205*	204.974 480	3×10^{7} y
				206	205.974 468	
				207	206.975 903	
				208	207.976 650	
		Ra D		210*	209.984 187	22 y
		Ac B		211*	210.988 742	36.1 min
		Th B		212*	211.991 905	10.64 h
		Ra B		214*	213.999 764	26.8 min
83	Bismuth	Bi	209.980	207*	206.978 438	30 y

Z	Element	Symbol	Chemical Atomic Weight	A	Mass (u)	$T_{1/2}$
(83)	(Bismuth)			208*	207.979 731	3.7×10^5 y
				209	208.980 394	
		Ra E		210*	209.984 121	5.1 d
		Th C		211*	210.987 300	2.15 min
				212*	211.991 876	60.6 min
		Ra C		214*	213.998 686	19.7 min
				215*	215.001 830	8 min
84	Polonium	Po		209*	208.982 426	103 y
		Ra F		210*	209.982 876	138.4 d
		Ac C′		211*	210.986 657	0.52 s
		Th C′		212*	211.989 629	0.30 μs
		Ra C′		214*	213.995 201	164 μs
		Ac A		215*	214.999 423	0.0018 s
		Th A		216*	216.001 790	0.15 s
		Ra A		218*	218.008 930	3.05 μs
85	Astatine	At		215*	214.998 663	≈ 100 μs
				218*	218.008 607	1.3 s
				219*	219.011 290	0.9 min
86	Radon	Rn				
		An		219*	219.009 481	4.0 s
		Tn		220*	220.011 401	56 s
		Rn		222*	222.017 531	3.823 d
87	Francium	Fr				
		Ac K		223*	223.019 736	22 min
88	Radium	Ra	226.05			
		Ac X		223*	223.018 501	11.4 d
		Th X		224*	224.020 218	3.64 d
		Ra		226*	226.025 360	1620 y
		Ms Th_1		228*	228.031 139	5.7 y
89	Actinium	Ac		227*	227.027 753	21.2 y
		Ms Th_2		228*	228.031 080	6.13 h
90	Thorium	Th	232.038			
		Rd Ac		227*	227.027 706	18.17 d
		Rd Th		228*	228.028 750	1.91 y
				229*	229.031 652	7300 y
		Io		230*	230.033 087	76 000 y
		UY		231*	231.036 291	25.6 h
		Th		232*	232.038 124	1.39×10^{10} y
		UX_1		234*	234.043 583	24.1 d
91	Proactinium	Pa	231.0359	231*	231.035 877	32 480 y
		UZ		234*	234.043 298	6.66 h
92	Uranium	U	238.03	230*	230.033 937	20.8 d
				231*	231.036 264	4.3 d
				232*	232.037 168	72 y
				233*	233.039 522	1.62×10^5 y
				234*	234.040 904	2.48×10^5 y
		Ac U		235*	235.043 915	7.13×10^8 y
				236*	236.045 637	2.39×10^7 y
		UI		238*	238.048 608	4.51×10^9 y
93	Neptunium	Np	237.0480	235*	235.044 049	410 d
				236*	236.046 624	5000 y
				237*	237.048 056	2.14×10^6 y
94	Plutonium	Pu	239.0522	236*	236.046 071	2.85 y
				238*	238.049 511	89 y
				239*	239.052 146	24 360 y
				240*	240.053 882	6700 y
				241*	241.056 737	13 y
				242*	242.058 725	3.79×10^5 y
				244*	244.064 100	7.6×10^7 y