NAME:_____   Student Number:_____

Fall 2017   **Chemistry 1000 Midterm #1A**   ____/ 60 marks

INSTRUCTIONS:
1) Please read over the test carefully before beginning. You should have 6 pages of questions and a formula/periodic table sheet.
2) If your work is not legible, it will be given a mark of zero.
3) Marks will be deducted for incorrect information added to an otherwise correct answer.
4) Marks will be deducted for improper use of significant figures and for missing or incorrect units.
5) Show your work for all calculations. Answers without supporting calculations will not be given full credit.
6) You may use a calculator.
7) You have 90 minutes to complete this test.

Confidentiality Agreement:
I agree not to discuss (or in any other way divulge) the contents of this test until after 8:00pm Mountain Time on Tuesday, October 17th, 2017 (i.e. 24 hours **after** you finish writing this test). I understand that breaking this agreement would constitute academic misconduct, a serious offense with serious consequences. The minimum punishment would be a mark of 0/60 on this exam and removal of the "overwrite midterm mark with final exam mark" option for my grade in this course; the maximum punishment would include expulsion from this university.

Signature: _____   Date: _____
Course: CHEM 1000 (General Chemistry I)
Semester: Fall 2017
The University of Lethbridge

Spelling matters!

Fluorine = F   Fluorene = $C_{13}H_{10}$

Flourine =

Question Breakdown

Q1	/ 18
Q2	/ 3
Q3	/ 4
Q4	/ 5
Q5	/ 5
Q6	/ 4
Q7	/ 4
Q8	/ 9
Q9	/ 8

Total	/ 60

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1.   Fill in each blank with the word or short phrase that best completes the sentence.

[18 marks]

(a)   Scandium (Sc) has a single naturally occurring isotope. A naturally occurring neutral atom of scandium has _21_ protons, _24_ neutrons and _21_ electrons.

(b)   The breakdown of an atom of $^{235}_{92}U$ into two smaller nuclides and several neutrons is an example of a nuclear reaction that would be classified as _fission_.

(c)   The radiation weighting factor (W_R) is used to convert the _absorbed_ dose of radiation into the _equivalent_ dose.

(d)   The photoelectric effect experiment showed that light can behave as a _particle/photon_.

(e)   Electromagnetic radiation that is slightly lower in energy than visible light is called _infrared_.

(f)   Heisenberg's uncertainty principle says that is impossible to simultaneously determine the location and the _momentum_ of an electron with high accuracy.

(g)   The principle that tells us that only two electrons with opposite spin can occupy an orbital is called the _Pauli exclusion_ principle.

(h)   The angular momentum quantum number (l) for an f orbital is _3_.

(i)   The number of $6f$ orbitals in one atom is _7_, and the allowable values for their magnetic quantum numbers (m_l) are _-3, -2, -1, 0, +1, +2 and +3_. *(List them all.)*

(j)   Write the electron configuration for a neutral atom of bromine (Br) using line notation. **Do not use the noble gas abbreviation.**

     $_1s^22s^22p^63s^23p^64s^23d^{10}4p^5_$

(k)   For each of the ions below, write the electron configuration in line notation **using the noble gas abbreviation**.

     i. Fe^{3+} _[Ar] 3d^5_   ii. Ag^+ _[Kr] 4d^{10}_

(l)   For each of the ions in part (k), indicate whether it is paramagnetic or diamagnetic.

     i. Fe^{3+} _paramagnetic_   ii. Ag^+ _diamagnetic_

2. Complete the table below.   **[3 marks]**

Isotope	$^{78}Se^{2-}$	$^{85}Rb^{+}$
Number of electrons	36	36
Number of neutrons	44	48
Number of protons	34	37
Overall charge	-2	+1

3.   **[4 marks]**

(a) Write a balanced nuclear equation for the alpha decay of $^{229}_{90}Th$.

$$^{229}_{90}Th \rightarrow\ ^{225}_{88}Ra + ^{4}_{2}\alpha$$

Your alpha must look like an alpha (α) not the letter a.

(b) Write a balanced nuclear equation for the beta decay of $^{223}_{87}Fr$.

$$^{223}_{87}Fr \rightarrow\ ^{223}_{88}Ra + ^{0}_{-1}\beta$$

Your beta must look like a beta (β) not the letter B.

4. Draw and label a complete set of 3d orbitals. Your pictures must include phase and labeled axes. DO NOT draw radial nodes. **[5 marks]**
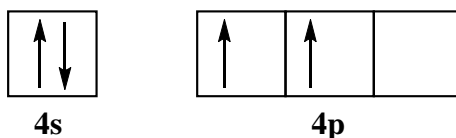
Drawings that are not accompanied by a label (name) for the specific orbital will not get full credit.
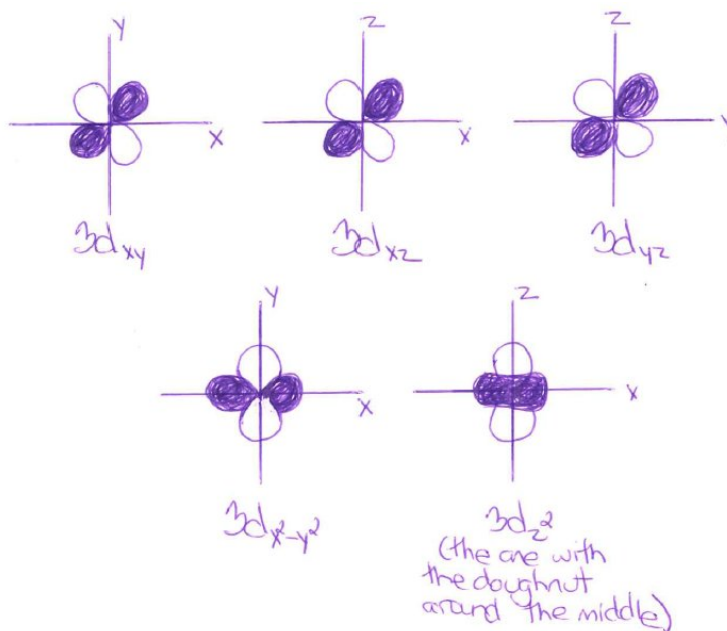
5.   Consider the following valence orbital occupancy diagram: **[5 marks]**

$$\boxed{\uparrow\downarrow}\qquad\boxed{\uparrow\;|\;\uparrow\;|\;}$$

4s   **4p**

(a)   Which neutral element is this diagram describing?   *[1 mark]*

       Ge

*This is a **valence** orbital occupancy diagram, so it only shows the element's **valence** electrons!*

(b)   Fill in the blanks on the diagram below to assign a valid set of quantum numbers to each
       electron on this valence orbital occupancy diagram: *[4 marks]*

$$\boxed{n = 4 \quad l = 0 \quad m_l = 0 \quad m_s = +\tfrac{1}{2}}$$

$$\boxed{n = 4 \quad l = 1 \quad m_l = +1 \quad m_s = +\tfrac{1}{2}}$$

$$\boxed{\uparrow\downarrow}\qquad\boxed{\uparrow\;|\;\uparrow\;|\;}$$

4s   **4p**

$$\boxed{n = 4 \quad l = 0 \quad m_l = 0 \quad m_s = -\tfrac{1}{2}}$$

$$\boxed{n = 4 \quad l = 1 \quad m_l = 0 \quad m_s = +\tfrac{1}{2}}$$
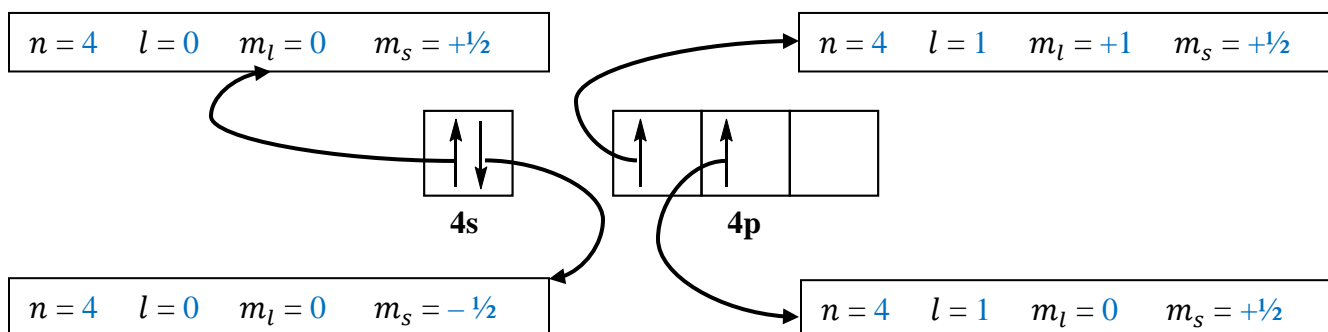
m_l values were marked based on legality and compatibility. (The two $4p$ electrons had to have different values.)

m_s values were marked based on legality and consistency. (All 'spin up' electrons had to have the same value. All 'spin down' electrons had to have the other value.)

6.   **[4 marks]**

(a)   Calculate the energy change for the reaction in which a positron and electron are annihilated. Report your answer in J.   *[3 marks]*

Step 1: Write a balanced equation for the reaction

$$^{0}_{+1}\beta + ^{0}_{-1}\beta \rightarrow energy$$
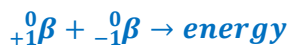
Step 2: Calculate the difference between masses of products and reactants

$$\Delta m = \sum m_{products} - \sum m_{reactants}$$

$$\Delta m = (0\ u) - (m_{positron} + m_{electron})$$

$$\Delta m = (0\ u) - (0.000\ 548\ 579\ 9\ u + 0.000\ 548\ 579\ 9\ u)$$

$$\Delta m = -0.001\ 097\ 159\ 8\ u \qquad\qquad\qquad\qquad \text{10 decimal places}$$

(or 7 sig. fig. if multiply electron mass by two instead of adding masses)

Step 3: Convert mass difference into kg (since $1\ J = 1\ \frac{kg \cdot m^2}{s^2}$)

$$\Delta m = -0.001\ 097\ 159\ 8\ u \times \frac{1.660\ 539 \times 10^{-27}\ kg}{1\ u} = -1.821\ 877 \times 10^{-30}\ kg \quad \text{7 sig. fig.}$$

Step 4: Calculate the energy change for the reaction in J

$$\Delta E = \Delta m c^2$$

$$\Delta E = (-1.821\ 877 \times 10^{-30}\ kg)\left(2.997\ 925 \times 10^8\ \frac{m}{s}\right)^2 \left(\frac{1J}{1\frac{kg \cdot m^2}{s^2}}\right)$$

$$\Delta E = -1.637\ 422 \times 10^{-13}\ J \qquad\qquad\qquad\qquad \text{7 sig. fig.}$$

This is a small energy change – which makes sense given the scale of the reaction (one electron reacting with one positron).

(b)   Does your answer indicate that energy is absorbed or released by this reaction? How do you know?   *[1 mark]*

Energy is released by this reaction because ΔE is negative.

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7. Rhenium has two naturally occurring isotopes: ^{185}Re and ^{187}Re. The isotopic masses of ^{185}Re and ^{187}Re are 184.952 955 u and 186.955 750 u, respectively.

Calculate the percent abundances of the two naturally occurring isotopes of rhenium. *Your answer must make it clear which abundance is for which isotope.*   **[4 marks]**

Step 1: Look up average atomic mass of rhenium (Re) on periodic table

$$M_{Re} = 186.207\ u$$

Step 2: Set up equations relating percent abundances to average atomic mass and to each other

$$M_{Re} = \frac{x}{100\%}M_{Re-185} + \frac{y}{100\%}M_{Re-187}$$

There are only two naturally occurring isotopes, so $x + y = 100\%$

Step 3: Solve for one of the two percent abundance values (solving for x is shown)

$$M_{Re} = \frac{x}{100\%}M_{Re-185} + \frac{100\%-x}{100\%}M_{Re-187}$$

$$186.207\ u = \frac{x}{100\%}(184.952\ 955\ u) + \frac{100\%-x}{100\%}(186.955\ 750\ u)$$

$$18620.7\ \% = x(184.952\ 955) + 18695.5750\ \% - x(186.955\ 750)$$

$$2.002795\ x = 74.9\ \%$$ 1 decimal place for percentage

$$x = 37.4\ \%$$ 3 sig. fig.

Therefore, the natural abundance of ^{185}Re is 37.4 %

Step 4: Solve for the other percent abundance value

The natural abundance of ^{187}Re is 100 % − 37.4 % = 62.6 %   1 decimal place

The average atomic mass of Re is closer to the mass of ^{187}Re, so there should be more ^{187}Re than ^{185}Re.

If you solved for the abundance of ^{187}Re first, you should have 4 sig. fig. instead of 3 sig. fig.

100% is an exact number (has infinite sig. fig.) so it does not limit your sig. fig. in any way.

8.   The ^{18}F isotope is regularly used in positron emission tomography (PET).   **[9 marks]**

(a)   Write a balanced nuclear equation for the reaction in which ^{18}F emits a positron.

[2 marks]

$$^{18}_{9}F \rightarrow \,^{18}_{8}O + \,^{0}_{+1}\beta$$

Your beta must look like a beta (β) not the letter B.

A lot of students had $^{18}_{10}Ne$ as the other product. Pay attention to the signs of numbers!

(b)   Briefly explain why ^{18}F undergoes positron emission.   *[2 marks]*

Positron emission occurs when a proton in an unstable nuclide decays to give a neutron and a positron: $^{1}_{1}p \rightarrow \,^{1}_{0}n + \,^{0}_{+1}\beta$

Positron emission, therefore, occurs when the $\frac{N}{Z}$ ratio for the nuclide is too low (not enough neutrons for the number of protons/too many protons for the number of neutrons).

By converting a proton into a neutron, the $\frac{N}{Z}$ ratio is raised.

Some students commented on the fact that $^{18}_{9}F$ has an odd number of protons and an odd number of neutrons whereas the product of positron emission ($^{18}_{8}O$) has an even number of protons and an even number of neutrons. This is also true and is likely why a small element with $\frac{N}{Z} = 1$ is unstable.

Some students commented on the fact that $^{18}_{9}F$ is a small nuclide and, while it is true that large nuclides tend to undergo alpha decay rather than positron emission when their $\frac{N}{Z}$ ratio is too low, it was still necessary to address the $\frac{N}{Z}$ ratio for full credit.

(c)   Based on your answer to part (b), there should be one other type of nuclear decay that you might predict ^{18}F to undergo. If you didn't have experimental data that told you a positron was emitted, what would be the other type of nuclear decay predicted for ^{18}F?

[1 mark]

electron capture

(d) ^{18}F has a half life of 109.8 minutes. If you start with a sample containing 5.34 mmol ^{18}F, how much ^{18}F will be left after 5 hours?   *[4 marks]*

Step 1: Organize your information

$t_{\frac{1}{2}} = 109.8 \; min$ $k = ???$

$n_1 = 5.34 \; mmol$ $n_2 = ???$

$t_1 = 0 \; h \; (no \; time \; passed)$ $t_2 = 5 \; h$

The units for half-life and time are not the same! It is necessary to convert one of them to fix this problem. So, either $t_{\frac{1}{2}} = 1.83 \; h$ or $t_2 = 300 \; min$.

Some people converted both into seconds – which was also acceptable mathematically but more work than was necessary.

Step 2: Calculate the rate constant (k) from half-life (t½)

$$ln(2) = k \cdot t_{\frac{1}{2}}$$

$$k = \frac{ln(2)}{t_{\frac{1}{2}}} = \frac{ln(2)}{109.8 \ min} = 0.006313 \ min^{-1} \qquad\qquad or \ k = 0.3788 \ h^{-1}$$

Step 3: Calculate the amount of ^{18}F left after 5 hours

$$ln\left(\frac{n_2}{n_1}\right) = -k(t_2 - t_1)$$

$$ln\left(\frac{n_2}{n_1}\right) = -(0.006313 \ min^{-1})(300 \ min - 0 \ min)$$

$$ln\left(\frac{n_2}{n_1}\right) = -2$$

$$\frac{n_2}{n_1} = e^{-2}$$

$$n_2 = n \cdot e^{-2} = (5.34 \ mmol)(e^{-2}) = 0.8 \ mmol$$

As expected, the amount of ^{18}F is lower after time has passed.

*Even though rounded answers are presented here, **ALL DIGITS IN THE CALCULATOR WERE USED IN ALL STEPS**. **NEVER** use a rounded value from a previous step; that causes "premature rounding error".*

Sig. fig. were not marked for this question as we did not discuss how to deal with sig. fig. in exponents.   Your lab manual does have information on this topic, though.   (Technically, following the sig. fig. rules gives this answer 0 sig. fig. – which is difficult to represent.)

It is important to note that converting a time in hours to a time in minutes does *not* increase the number of significant figures. $5.00 \ hours = 300 \ minutes$. $5 \ hours =$ any time between $4.5 \ hours$ and $5.4\bar{9} \ hours$ ($270 \ minutes$ to $330 \ minutes$).   In future, we will try to remember to say "exactly 5 hours" which would mean that $t_2 - t_1$ had an infinite number of sig. fig.

Some students took a different approach using a formula that they had learned in physics class. This was completely acceptable, and looked like this:

Step 1: Organize your information

$$t_{\frac{1}{2}} = 109.8 \ min$$

$$n_1 = 5.34 \ mmol \qquad\qquad n_2 = ???$$

$$\Delta t = 5 \ h = 300 \ min$$

Step 2: Calculate the amount of ^{18}F left after 5 hours

$$n_2 = n_1 \cdot \left(\frac{1}{2}\right)^{\frac{\Delta t}{t_{\frac{1}{2}}}} = (5.34 \ mmol)\left(\frac{1}{2}\right)^{\frac{300 \ min}{109.8 \ min}} = (5.34 \ mmol)\left(\frac{1}{2}\right)^{3} = 0.8 \ mmol$$

This approach suffers the same sig. fig. issues as the first approach.

9.   **[8 marks]**

(a)   Calculate the energy of an electron in a $2s$ orbital in a hydrogen atom.   *[1 mark]*

$$E_{n=2} = -R_H \frac{Z^2}{n^2} = -(2.179872 \times 10^{-18} \, J)\frac{1^2}{2^2} = -5.449\,680 \times 10^{-19} \, J$$

(b)   Calculate the energy of an electron in a $4s$ orbital in a hydrogen atom.   *[1 mark]*

$$E_{n=4} = -R_H \frac{Z^2}{n^2} = -(2.179872 \times 10^{-18} \, J)\frac{1^2}{4^2} = -1.362\,420 \times 10^{-19} \, J$$

(c)   What wavelength of light should you use to excite an electron in a hydrogen atom from the $2s$ orbital to the $4s$ orbital?

Express your final answer using an appropriate SI prefix so that the value is between 0.1 and 1000.   *[4 marks]*

Step 1: Calculate the difference in energy between the two orbitals

$$\Delta E = E_{final} - E_{initial}$$
$$\Delta E = E_{n=4} - E_{n=2}$$
$$\Delta E = (-1.362\,420 \times 10^{-19} \, J) - (-5.449\,680 \times 10^{-19} \, J)$$
$$\Delta E = 4.087\,260 \times 10^{-19} \, J$$

Step 2: Calculate the energy of the photon released

Since the sign of ΔE is positive, energy is absorbed.

The energy of the photon absorbed is $4.087\,260 \times 10^{-19} \, J$.

Step 3: Calculate the frequency of light absorbed

$$E = h\nu$$

$$\nu = \frac{E}{h} = \frac{4.087\,260 \times 10^{-19} \, J}{6.626\,070 \times 10^{-34} \, \frac{J}{Hz}} = 6.168\,453 \times 10^{14} \, Hz$$

Step 4: Calculate the wavelength of light absorbed

$$c = \nu\lambda$$

$$\lambda = \frac{c}{\nu} = \frac{2.997\,925 \times 10^8 \, \frac{m}{s}}{6.168\,453 \times 10^{14} \, Hz} \times \frac{1 \, Hz}{1 \, s^{-1}} = 4.860\,092 \times 10^{-7} \, m$$

Step 5: Convert the units from meters to a unit that gives a number between 0.1 and 1000

$$\lambda = 4.860\,092 \times 10^{-7} \, m \times \frac{10^6 \, \mu m}{1 \, m} = 0.486\,0092 \, \mu m$$

or $$\lambda = 4.860\,092 \times 10^{-7} \, m \times \frac{10^9 \, nm}{1 \, m} = 486.0092 \, nm$$

If you prefer to combine Steps 3 and 4 by using $E = \frac{hc}{\lambda}$, that is completely acceptable.

(d)   Does the wavelength change if the electron is excited from the $2s$ to the $4p$ orbital of the hydrogen atom? If so, does it get longer or shorter? If not, why not?   *[2 marks]*

No. The same wavelength of light would be required to excite an electron from $2s$ to $4p$.

Since a hydrogen atom only has one electron, all orbitals with the same principal quantum number (n) have the same energy.

NAME:_____   Student Number:_____

Some Useful Constants and Formulae

Fundamental Constants and Conversion Factors

Atomic mass unit (u)	$1.660\,539 \times 10^{-27}$ kg	Planck's constant	$6.626\,070 \times 10^{-34}$ J·Hz^{-1}
Avogadro's number	$6.022\,141 \times 10^{23}$ mol^{-1}	Proton mass	$1.007\,277$ u
Bohr radius (a_0)	$5.291\,772 \times 10^{-11}$ m	Neutron mass	$1.008\,665$ u
Electron charge (e)	$1.602\,177 \times 10^{-19}$ C	Rydberg Constant (R_H)	$2.179\,872 \times 10^{-18}$ J
Electron mass	$5.485\,799 \times 10^{-4}$ u	Speed of light in vacuum	$2.997\,925 \times 10^{8}$ m·s^{-1}

Formulae

$$c = \nu\lambda \qquad E = h\nu \qquad p = mv \qquad \lambda = \frac{h}{p} \qquad \Delta x \cdot \Delta p > \frac{h}{4\pi}$$

$$r_n = a_0\frac{n^2}{Z} \qquad E_n = -R_H\frac{Z^2}{n^2} \qquad E_k = \frac{1}{2}mv^2$$

$$\Delta E = \Delta mc^2 \qquad A = -\frac{\Delta N}{\Delta t} \qquad A = kN \qquad \ln\left(\frac{N_2}{N_1}\right) = -k(t_2 - t_1) \qquad \ln(2) = k \cdot t_{1/2}$$

Chem 1000 Standard Periodic Table

1												13	14	15	16	17	18
1.0079 **H** 1	2																4.0026 **He** 2
6.941 **Li** 3	9.0122 **Be** 4											10.811 **B** 5	12.011 **C** 6	14.0067 **N** 7	15.9994 **O** 8	18.9984 **F** 9	20.1797 **Ne** 10
22.9898 **Na** 11	24.3050 **Mg** 12	3	4	5	6	7	8	9	10	11	12	26.9815 **Al** 13	28.0855 **Si** 14	30.9738 **P** 15	32.066 **S** 16	35.4527 **Cl** 17	39.948 **Ar** 18
39.0983 **K** 19	40.078 **Ca** 20	44.9559 **Sc** 21	47.88 **Ti** 22	50.9415 **V** 23	51.9961 **Cr** 24	54.9380 **Mn** 25	55.847 **Fe** 26	58.9332 **Co** 27	58.693 **Ni** 28	63.546 **Cu** 29	65.39 **Zn** 30	69.723 **Ga** 31	72.61 **Ge** 32	74.9216 **As** 33	78.96 **Se** 34	79.904 **Br** 35	83.80 **Kr** 36
85.4678 **Rb** 37	87.62 **Sr** 38	88.9059 **Y** 39	91.224 **Zr** 40	92.9064 **Nb** 41	95.94 **Mo** 42	(98) **Tc** 43	101.07 **Ru** 44	102.906 **Rh** 45	106.42 **Pd** 46	107.868 **Ag** 47	112.411 **Cd** 48	114.82 **In** 49	118.710 **Sn** 50	121.757 **Sb** 51	127.60 **Te** 52	126.905 **I** 53	131.29 **Xe** 54
132.905 **Cs** 55	137.327 **Ba** 56	**La-Lu**	178.49 **Hf** 72	180.948 **Ta** 73	183.85 **W** 74	186.207 **Re** 75	190.2 **Os** 76	192.22 **Ir** 77	195.08 **Pt** 78	196.967 **Au** 79	200.59 **Hg** 80	204.383 **Tl** 81	207.19 **Pb** 82	208.980 **Bi** 83	(210) **Po** 84	(210) **At** 85	(222) **Rn** 86
(223) **Fr** 87	226.025 **Ra** 88	**Ac-Lr**	(265) **Rf** 104	(268) **Db** 105	(271) **Sg** 106	(270) **Bh** 107	(277) **Hs** 108	(276) **Mt** 109	(281) **Ds** 110	(280) **Rg** 111	(285) **Cn** 112	(284) **Nh** 113	(289) **Fl** 114	(288) **Mc** 115	(293) **Lv** 116	(294) **Ts** 117	(294) **Og** 118

138.906 **La** 57	140.115 **Ce** 58	140.908 **Pr** 59	144.24 **Nd** 60	(145) **Pm** 61	150.36 **Sm** 62	151.965 **Eu** 63	157.25 **Gd** 64	158.925 **Tb** 65	162.50 **Dy** 66	164.930 **Ho** 67	167.26 **Er** 68	168.934 **Tm** 69	173.04 **Yb** 70	174.967 **Lu** 71
227.028 **Ac** 89	232.038 **Th** 90	231.036 **Pa** 91	238.029 **U** 92	237.048 **Np** 93	(240) **Pu** 94	(243) **Am** 95	(247) **Cm** 96	(247) **Bk** 97	(251) **Cf** 98	(252) **Es** 99	(257) **Fm** 100	(258) **Md** 101	(259) **No** 102	(262) **Lr** 103

Developed by Prof. R. T. Boeré (updated 2016)

Some Useful Masses

$^4_2\alpha$	4.001 506 179 u
^1_1p	1.007 276 467 u
^1_0n	1.008 664 916 u
$^0_{+1}\beta$	0.000 548 579 9 u
$^0_{-1}\beta$	0.000 548 579 9 u

Band of Stability Graph

The graph below shows the band of stability. Stable isotopes are in black. Isotopes that exist but are not stable are shown in varying shades of gray with the shades of gray corresponding to different half-lives.

The original version of the graph used a rainbow colour scale.

http://commons.wikimedia.org/wiki/File:Isotopes_and_half-life_eo.svg