Answers to Practice Test Questions 2
Atoms, Isotopes and Nuclear Chemistry

1. Fluorine has only one stable isotope. Its mass number is _19_. A neutral atom of fluorine has __9__ protons, __10__ neutrons and __9__ electrons. Fluorine can only form one kind of ion. The charge of this ion is -1, and it is formed when fluorine ___gains one___ electron(s).

2. Most elements exist as a mixture of isotopes (atoms with the same number of protons, but different numbers of neutrons) which have different masses.

   The mass reported on the periodic table is a weighted average of the isotopic masses.

3.

(a) **Step 1: Work out the percent abundance for each isotope**

If the percent abundance of ^{235}U is 80.00% and the percent abundance of ^{234}U is negligible (i.e. ~0%) then the percent abundance of ^{238}U must be 20.00% (since the sum of the percent abundances must be 100%).

Step 2: Calculate the average atomic mass of the enriched uranium

$$M_U = \frac{\%_{U-235}}{100\%} M_{U-235} + \frac{\%_{U-238}}{100\%} M_{U-238}$$

$$M_U = \left(\frac{80.00\%}{100\%}\right)(235.043923u) + \left(\frac{20.00\%}{100\%}\right)(238.050783u)$$

$$M_U = 188.0u + 47.61u$$

$$M_U = 235.6u$$

Step 3: Check your work

Does your answer seem reasonable? Are sig. fig. correct?

The major isotope in this sample is ^{235}U so it makes sense that the average atomic mass is close to 235 u.

(b) The average atomic mass of the uranium will decrease, approaching 235.043923 u (the mass of ^{235}U).

4. **Step 1: Look up average atomic mass of copper (Cu) on periodic table**

$M_{Cu} = 63.546u$

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

$$M_{Cu} = \frac{x}{100\%} M_{Cu-63} + \frac{y}{100\%} M_{Cu-65}$$

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)

$$M_{Cu} = \frac{x}{100\%} M_{Cu-63} + \frac{100\% - x}{100\%} M_{Cu-65}$$

$$63.546u = \frac{x}{100\%}(62.9296u) + \frac{(100\% - x)}{100\%}(64.9278u)$$

$$6354.6\% = 62.9296x + 6492.78\% - 64.9278x$$

$$1.9982x = 138.2\%$$

$$x = 69.15\%$$

Therefore, the natural abundance of ^{63}Cu is 69.15%

Step 4: Solve for the other percent abundance value

The natural abundance of ^{65}Cu is 100% - 69.15% = 30.85%

Step 5: Check your work

Does your answer seem reasonable? Are sig. fig. correct?

The average atomic mass of Cu is less than 64 u (the "halfway point" between 63 and 65), so we expect the natural abundance of ^{63}Cu to be greater than that of ^{65}Cu.

5.

(a) $^{100}_{40}Zr \rightarrow {}^{100}_{41}Nb + {}^{0}_{-1}\beta$

(b) $^{212}_{82}Pb \rightarrow {}^{212}_{83}Bi + {}^{0}_{-1}\beta$

(c) $^{181}_{82}Pb \rightarrow {}^{177}_{80}Hg + {}^{4}_{2}\alpha$

(d) $^{11}_{7}N \rightarrow {}^{10}_{6}C + {}^{1}_{1}p$ *$^{1}_{1}p$ is a proton*

(e) $^{24}_{11}Na \rightarrow {}^{23}_{11}Na + {}^{1}_{0}n$ *$^{1}_{0}n$ is a neutron*

6.

(a) $^{26}_{13}Al + {}^{0}_{-1}e \rightarrow {}^{26}_{12}Mg$ *It is also acceptable to write $^{0}_{-1}\beta$ instead of $^{0}_{-1}e$*

(b) $^{208}_{79}Au \rightarrow {}^{208}_{80}Hg + {}^{0}_{-1}\beta$

(c) $^{82}_{40}Zr \rightarrow {}^{82}_{39}Y + {}^{0}_{+1}\beta$

(d) $^{253}_{99}Es + {}^{4}_{2}He \rightarrow {}^{256}_{101}Md + {}^{1}_{0}n$

(e) $^{236}_{92}U \rightarrow {}^{138}_{54}Xe + {}^{95}_{38}Sr + 3{}^{1}_{0}n$

7.

(a) $^1_1H + {}^1_1H \rightarrow {}^2_1H + {}^{\;\,0}_{+1}\beta + {}^0_0\nu$

or $2\,^1_1H \rightarrow {}^2_1H + {}^{\;\,0}_{+1}\beta + {}^0_0\nu$

You were only expected to include the neutrino because you were told it was produced and provided with the symbol.

(b) $^2_1H + {}^1_1H \rightarrow {}^3_2He + {}^0_0\gamma$

(c) $^3_2He + {}^3_2He \rightarrow {}^4_2He + {}^1_1H + {}^1_1H$

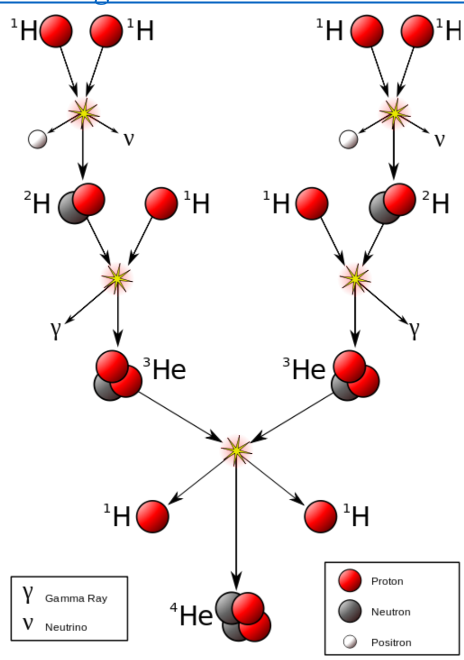
or $2\,^3_2He \rightarrow {}^4_2He + 2\,^1_1H$

or $^3_2He + {}^3_2He \rightarrow {}^4_2He + {}^1_1p + {}^1_1p$

or $2\,^3_2He \rightarrow {}^4_2He + 2\,^1_1p$

To balance the equation, you need a second product to add 2 to the mass number and 2 to the atomic number. ^2_2He is not a reasonable choice. Two ^1_1H (or two ^1_1p) is.

(d) *You can answer this question with a picture like the one shown below (original image at https://commons.wikimedia.org/wiki/File:FusionintheSun.svg):*



Or you can answer by showing how all the equations add up to give the overall equation. If doing this, you will want to show the proton produced in part (c) as ^1_1H instead of ^1_1p. Note that the reactions shown in parts (a) and (b) must each be done twice to generate the two ^3_2He needed for part (c).

	$^1_1H + {}^1_1H \rightarrow \cancel{^2_1H} + {}^{\;\,0}_{+1}\beta + {}^0_0\nu$	(a)
+	$^1_1H + {}^1_1H \rightarrow \cancel{^2_1H} + {}^{\;\,0}_{+1}\beta + {}^0_0\nu$	(a)
+	$\cancel{^2_1H} + \cancel{^1_1H} \rightarrow \cancel{^3_2He} + {}^0_0\gamma$	(b)
+	$\cancel{^2_1H} + \cancel{^1_1H} \rightarrow \cancel{^3_2He} + {}^0_0\gamma$	(b)
+	$\cancel{^3_2He} + \cancel{^3_2He} \rightarrow {}^4_2He + \cancel{^1_1H} + \cancel{^1_1H}$	(c)
	$4\,^1_1H \rightarrow {}^4_2He + 2\,{}^{\;\,0}_{+1}\beta + 2\,^0_0\nu + 2\,^0_0\gamma$	overall

8.

(a) $^{208}_{82}Pb + ^{70}_{30}Zn \rightarrow ^{277}_{112}Cn + ^{1}_{0}n$

(b) **Step 1: Calculate the mass change for this reaction**

$\Delta m = (M_{Cn-277} + M_n) - (M_{Pb-208} + M_{Zn-70})$

$\Delta m = \left(277.16364\frac{g}{mol} + 1.008664916\frac{g}{mol}\right) - \left(207.9766525\frac{g}{mol} + 69.9253192\frac{g}{mol}\right)$

$\Delta m = 0.27033\frac{g}{mol}$

Step 2: Calculate the energy change for this reaction

$\Delta E = \Delta mc^2$

$\Delta E = \left(0.27033\frac{g}{mol}\right)\left(2.997925 \times 10^8\frac{m}{s}\right)^2 \times \frac{1kg}{1000g} \times \frac{1J}{1\frac{kg\cdot m^2}{s^2}}$

$\Delta E = 2.4296 \times 10^{13}\frac{J}{mol}$

Therefore, 2.4296×10^{13} J/mol of energy is absorbed.

Step 3: Check your work

Does your answer seem reasonable? Are sig. fig. correct?

9. For each of the isotopes listed below, use the band of stability graph to determine whether or not it is expected to be stable. For each unstable isotope, predict which mode(s) of decay are most likely.

(a) Z = 42 N = 53 stable (falls along band of stability – i.e. the black dots)

(b) Z = 4 N = 3 unstable (underneath the band of stability = not enough neutrons; also, N/Z < 1 which is very uncommon among stable isotopes)

predict decay by either electron capture of positron emission (to increase N/Z); nuclide is too small for alpha emission

actually decays by positron emission

(c) Z = 19 N = 28 unstable (above the band of stability = too many neutrons)

predict beta emission (to decrease N/Z)

actually decays by beta emission

(d) Z = 19 N = 16 unstable (underneath the band of stability = not enough neutrons; also, N/Z < 1 which is very uncommon among stable isotopes)

predict decay by either electron capture of positron emission (to increase N/Z); nuclide is too small for alpha emission

actually decays by positron emission

(e) Z = 99 N = 141 unstable (underneath the band of stability = not enough neutrons)

predict decay by alpha emission (since nuclide is large)

actually decays by alpha emission

10.

(a) Penetrating power decreases with increasing mass and charge. That is because particles with greater mass and charge are more likely to interact with the atoms/molecules in matter rather than travel past them through the material.

(b) Since it has neither mass nor charge, gamma radiation should have the highest penetrating power.

Neutrinos also have no charge and have very small mass, so they are also expected to have high penetrating power. In fact, their penetrating power is even higher than that of gamma radiation!

(c) The penetrating power of the types of radiation emitted by the radioactive isotopes affects the amount and type of safety equipment required to handle those isotopes.

e.g. Alpha radiation can be stopped by cloth so, as long as the radioactive isotope(s) will not be inhaled or ingested, proper clothing may suffice to protect the worker.

On the other hand, if the radioactive isotope(s) emit beta radiation, they will likely be kept behind a protective shield since they would penetrate both clothing and skin.

Note that higher penetrating power does not necessarily mean "more dangerous". Neutrinos, for example, have such high penetrating power that they tend to pass right through matter (including humans) without interacting with it.

Also note that there are other factors to consider beyond the penetrating power of the radiation – how much radiation is there? how much energy is the radiation carrying?

11.

(a) Absorbed dose (the amount of radiation absorbed by a given mass of biological tissue) is reported using the gray.

1 Gy = 1 J/kg (energy absorbed divided by mass of tissue)

(b) Equivalent dose (the amount of gamma radiation that would do the same amount of biological damage if absorbed by the same mass of tissue) is measured using the sievert.

1 Sv = 1 J/kg (energy of gamma rays required to do same amount of damage divided by mass of tissue)

12. To compare the activities of the wooden artifact and of living wood, you need to convert them into the same units! Either convert the activity of the artifact into Bq/g *or* use the activity of living wood to calculate the activity of 25.0 g of living wood (in Bq).

Step 1: Calculate the activity of the artifact in Bq/g

$$A_2 = \frac{4.65\ Bq}{25.0\ g} = 0.186\ \frac{Bq}{g}$$

Step 2: Calculate the decay constant for ^{14}C

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

$$k = \frac{ln(2)}{t_{1/2}} = \frac{ln(2)}{5730\ y} = 1.21 \times 10^{-4}\ y^{-1}$$

Step 3: Organize your information

$k = 1.21 \times 10^{-4}\ y^{-1}$

$A_1 = 0.255\ \frac{Bq}{g}$ $\quad$ $A_2 = 0.186\ \frac{Bq}{g}$

$t_1 = 0\ y$ *(no time passed)* $\quad$ $t_2 = ???\ y$ $\quad$ *Make sure units for time and k "match"*

Step 4: Calculate time required for activity of ^{14}C to drop from 840 Bq/g to 748 Bq/g

$$ln\left(\frac{A_2}{A_1}\right) = -k(t_2 - t_1)$$

$$ln\left(\frac{0.186\ \frac{Bq}{g}}{0.255\ \frac{Bq}{g}}\right) = -(1.21 \times 10^{-4}\ y^{-1})(t_2 - 0\ y)$$

$$ln(0.729) = -1.21 \times 10^{-4}\ y^{-1} \cdot t_2$$

$$t_2 = -\frac{ln(0.729)}{1.21 \times 10^{-4}\ y^{-1}} = 2608\ y = 2.61 \times 10^3\ y$$

This makes the object made from wood chopped down in about 600 BC.

Step 5: Check your work

Does your answer seem reasonable? Are sig. fig. correct?

Less than half the ^{14}C activity has been lost so the age of the wood should be less than the half-life of ^{14}C.

13. **Step 1: Organize your information**

$k = ???$

$A_1 = 46.1\ Bq$ $\quad$ $A_2 = 39.8\ Bq$

$t_1 = 0\ min$ *(no time passed)* $\quad$ $t_2 = 35\ min$

Step 2: Calculate the decay constant for ^{93}Tc

$$ln\left(\frac{A_2}{A_1}\right) = -k(t_2 - t_1)$$

$$ln\left(\frac{39.8\ Bq}{46.1\ Bq}\right) = -k(35\ min - 0\ min)$$

$$ln(0.863) = -35\ \text{min} \cdot k$$

$$k = -\frac{ln(0.863)}{35\ min} = 0.0042\ min^{-1} = 4.2 \times 10^{-3}\ min^{-1}$$

Step 3: Calculate the half-life of ^{93}Tc

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

$$t_{1/2} = \frac{ln(2)}{k} = \frac{ln(2)}{4.2 \times 10^{-3}\ min^{-1}} = 165\ min = 1.7 \times 10^2\ \text{min} = 2.8\ hours$$

14.

(a) $^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}\alpha$

(b) $t_{1/2} = 4.468 \times 10^9 y \times \frac{365.25d}{1y} \times \frac{24h}{1d} \times \frac{60min}{1h} \times \frac{60s}{1min} = 1.410 \times 10^{17} s$

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

$$k = \frac{\ln(2)}{t_{1/2}} = \frac{\ln(2)}{1.410\times10^{17}s} = 4.916 \times 10^{-18}s^{-1}$$

(d) $M_{U-238} = 238.0507882\frac{g}{mol}$

$$n_{U-238} = 3.5g \times \frac{1mol}{238.0507882g} = 0.015mol$$

$$N_{U-238} = 0.015mol \times \frac{6.022141\times10^{23}atoms}{1mol} = 8.9 \times 10^{21}atoms$$

(e) $A = kN = (4.916 \times 10^{-18}s^{-1})(8.9 \times 10^{21}) = 4.4 \times 10^{4}s^{-1} = 4.4 \times 10^{4}Bq$

(f) $absorbed\ dose = \frac{(\#particles)(E_{particle})}{mass\ worker}$

$$absorbed\ dose = \frac{(6\times10^{9})(6.836\times10^{-13}J)}{85kg} = 5 \times 10^{-5}\frac{J}{kg} = 5 \times 10^{-5}Gy$$

(g) $equivalent\ dose = RBE \times absorbed\ dose = (20)(5 \times 10^{-5}) = 1 \times 10^{-3}Sv$

(h) *The following answer is *far* more in-depth than was required for the 1 mark when this was used as a test question.*

If you eat food off a plate with a uranium glaze, you will ingest uranium. There are two mechanisms for this: First of all, you will scrape some of the glaze off the plate with your utensils. Secondly, some foods may leach uranium out of the plate. Uranium that you have ingested will emit alpha particles. This uranium will certainly move through your digestive tract, but some of it will also end up in your bloodstream. Most of the uranium in the bloodstream is eliminated by the kidneys within 24 hours, so the urinary system will also have significant radiation exposure. The RBE (W_R) values we used in calculations of equivalent dose are whole-body averages, but some tissues have higher RBEs than others. It is thus very likely that some of the alpha particles emitted by the uranium you ingest will damage organs that are more sensitive to this form of radiation than your skin.

There are two other factors that make ingestion worse than external exposure. One is that, if you are sitting in front of a plate, or even holding it while washing it, many of the alpha particles will travel in directions that do not intersect your body. On the other hand, every alpha particle emitted internally will be absorbed by your body. This increases the absorbed dose by a large factor in and of itself. The other factor has to do with the fact that alpha particles are easily stopped, and that you wear clothes, so external exposure if mitigated by the protection afforded by your clothes, while you have no such protection against alpha particles emitted internally.

The important thing here is to note the mechanism: By eating off of uranium-glazed plates, you will ingest some uranium. Decay of the uranium atoms results in alpha emission, and this emission occurs inside your body if the uranium was ingested. It is the alpha particles arising from uranium decay that cause the damage.

Some students wrote answers that suggested that the radiation did something to the food. Certainly, the radiation may damage the molecules of which your food is made, but so does digestion. Irradiating a material does not make it radioactive. The food you eat off a radioactive plate does not radiate alpha particles that it "picked up" earlier.