Exercises with Chart of Nuclides – Suggested Solutions

1) Make a table from the chart of nuclides that explains what the different colors mean.
The color gives information about the type of disintegration.

Red	Blue	Yellow	Orange	Green
β^+ / ε	β^-	α	proton	fission

2) The Chart of nuclides is organized with number of neutrons along the x axis and number of protons along the y axis. Explain the following terms and how to find them in the map. Use ^{28}Si as a point of reference and give examples of the following:

1. **Isotope:** Isotopes are nuclides with an equal number of protons, but with a different number of neutrons. They are aligned on a horizontal line in the Chart of the Nuclides, e.g. ^{28}Si and ^{29}Si.
2. **Isotone:** Isotones are nuclides with the same number of neutrons but different number of protons. They can be found along a vertical line in the Chart of the Nuclides, e.g. ^{28}Si and ^{29}P.
3. **Isobar:** Isobars are nuclides of different elements that have the same number of nucleons and can be found a diagonal line from the left top corner to the bottom right corner, e.g. ^{28}Si and ^{28}P.

3) Use the chart of nuclides to find the heaviest naturally occurring element (the half-life must be longer than the age of the earth).
Uranium, with the isotopes ^{234}U,^{235}U and^{238}U, is the heaviest naturally occurring element. Half of the square is black, and the other half indicates what kind of radiation that is emitted. The above-mentioned color marking means that the nuclide exists natural but is radioactive and slowly disintegrates towards stability. ^{238}U has approximately ten times longer half- life than ^{235}U and this is the reason why there is much more ^{238}U than ^{235}U (the amount was similar during the formation of the earth.^{234}U exists as a daughter product in the ^{238}U series.

4) Find the heaviest stable nuclide.
Bismuth was long thought to be the heaviest stable elements with the nuclide ^{209}Bi. α-decay from this nuclide has been observed and therefore ^{208}Pb is the heaviest stable nuclide [1].

5) What can the chart of nuclides tell you about Ar:

1. **Which stable isotope of Ar is the most abundant?**
   ^{40}Ar is the most abundant isotope of Ar, 99.6%. per atom.
2. **Which radioactive isotope of Ar has the longest half-life?**
   ^{39}Ar has the longest half-life, which is 269 years.
3. **List the different Ar isotopes that have half-lives with seconds as order of magnitude**
   ^{35}Ar, ^{45}Ar,^{46}Ar, and ^{47}Ar

4. **What is the energy of the γ-radiation emitted when ^{43}Ar disintegrates and which is the most intense?**
   ^{43}Ar emits γ-quants, 975 keV, 738 keV and 1440 keV, when disintegrating. These values can be read in the Chart of the Nuclides and they are the most common energy levels (highest intensity), in reality there exists numerous more which can be found in various tables. The gamma rays are arranged from decreasing intensity. In this example 975 keV has the highest probability of being emitted.

6) Find information about the following from the chart of nuclides:

1. **What kind of information is given in the square for stable nuclides?**
   The square to the stable nuclides contains information about chemical symbol, isotope number, abundance and cross section absorbance for thermal neutrons, which means the probability of a nuclide to absorb a thermal neutron and form the isotope with one more neutron.
2. **If a nuclide emits β-radiations how is it possible to determine the type of β-radiation and its strength? Which unit is used to describe the energy?**
   The color of the square indicates the type of radiation it can emit. The energy of the radiation is given after the symbols ($\beta^{+/-}$) in MeV.

3. **When a nuclide disintegrates is it possible to determine whether it will emit γ-radiation or not? If so, what unit is used to describe the energy?**
   An eventual γ-radiation is noted under the particle radiation, arranged in decreasing intensity with keV as energy units.

7) Which radioactive isotope of Si has the longest half-life, and how will it disintegrate until it reaches stability?

^{32}Si has the longest half-life, 172 years and disintegrates according to the following: $^{32}Si \longrightarrow {}^{32}P \longrightarrow {}^{32}S$

8) A radionuclide unable to form by disintegration of another radionuclide is said to be shielded. The element Promethium (Pm, Z=61) has no stable isotopes. Find the isotope with the longest half-life and make a disintegration chain until stability. Are any of the Pm isotopes shielded?

There are three shielded Pm isotopes, namely ^{144}Pm,^{146}Pm and ^{148}Pm. The Pm isotope with the longest half-life is ^{145}Pm (17.7 years), ^{146}Pm (5.53 years) and ^{147}Pm (2.62 years). They disintegrate according to the following:

$^{145}Pm \xrightarrow{\varepsilon} {}^{145}Nd$

$^{145}Pm \xrightarrow{\alpha} {}^{141}Pr$

$^{146}Pm \xrightarrow{\varepsilon} {}^{146}Nd$

$^{146}Pm \xrightarrow{\beta} {}^{146}Sm \xrightarrow{\alpha} {}^{142}Nd$

$^{147}Pm \xrightarrow{\beta} {}^{147}Sm \xrightarrow{\alpha} {}^{143}Nd$

9) Some radionuclides compete between β^+ and β^- disintegration, where are these located?
β^- disintegration occurs mainly on the neutron rich side in the Chart of Nuclides and β^+ on the neutron poor side. A nucleus that can emit both positrons and negatrons usually have odd-odd configuration of protons and neutrons. In addition, it has to lie close to the valley of stability.

10) List the most likely decay chains from ^{179}Hg until it reaches stability.
See the Chart of the Nuclides. Notice it can disintegrate with α, $\beta^+$and βp, in addition some of the daughters have several ways to disintegrate.

11) In the chart of nuclides, the isomeric state (m) is listed on the left side of the square, while the ground state (g) is listed on the right side. For those cases that are characterized, m and g describes which state the decay of the mother will primarily lead to. Regarding this, list the chain of disintegration from ^{121}Ag until stability.

$$^{121}\mathrm{Ag} \xrightarrow{\beta} {}^{121g}\mathrm{Cd} \xrightarrow{\beta} {}^{121m}\mathrm{In} \xrightarrow{\beta} {}^{121g}\mathrm{Sn} \xrightarrow{\beta} {}^{121}\mathrm{Sb}$$

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12) Some nuclides have a square divided with several colors. Use ^{211}Ra and ^{214}Ra to explain what this means (hint; check the explanation to the chart of nuclides).
A nucleus can reach stability in several different ways, by different kinds of radiation. When a square is divided in two equal parts, as with ^{211}Ra, each part stands for between 5% and 95 % of the disintegration. When one of the colors only covers a small size of the square, like with ^{214}Ra, it means the radiation stands for less than 5% of the disintegration.

13) List the disintegration chain from a nucleus of ^{232}Th until stability (branching of 5% and less intensity can be ignored).
See the Chart of the Nuclides.

14) A pure, freshly produced thorium salt with ^{232}Th as the only thorium isotope will not emit any γ-radiation, but an old thorium salt will emit strong high energetic γ-radiation. Explain why this occurs and specify the amount of energy on the radiation.
From the answer to question 13 it can be seen that ^{232}Th disintegrates through a long chain of daughter products, where ^{232}Th has no high intensity γ-lines. Not until the disintegration of the 3rd daughter, ^{224}Ac, can any high intensity γ-lines be seen. In a newly prepared salt, none of the daughters will have had time to be formed in detectable amounts, and no γ-radiation can be seen. Though over time, equilibrium between Th and the daughters will be established. Several of the daughters have strong γ and high energetic γ lines, for instance ^{228}Ac (911, 969…keV).

15) Neutron poor nuclides may disintegrate with both β^+ and EC and close to stability only EC is possible. List the disintegration of ^{201}Tl and ^{197}Tl. What kind of radiation is emitted in each of these cases?

Due to energetic reasons β^+decay can only happen if the mass of the mother nucleus is at least two electron masses larger than that of the daughter. If the difference in mass is less than the above-mentioned electron capture becomes a competing alternative disintegration mechanism. ^{201}Tl disintegrates only with electron capture; ^{197}Tl has less than 1 % β^+. In both situations γ is also emitted.

[1] http://www.nature.com/nature/journal/v422/n6934/full/nature01541.html