CHEM-630 Assignment 5

Matthew J. Urffer
murffer@utk.edu
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2.07: Radioactivity - Predict Probable Decay

(a) Predict the probable decay of ^{55}Mn, ^{123}Sn, ^{66}Ga, ^{185}Os, ^{242}Pu, ^{55}Fe, and ^{249}Cm

(b) Check the above nuclides in a nuclide table or chart to see how they actually decay[1]

Isotope	Reason	Predicted Decay Mode	Decay modes
$^{55}_{25}$Mn	Odd Z with W-A = 0	Stable	Stable
$^{123}_{50}$Sn	Even Z with W-A = 4 indicating instability, but Sn has 10 stable isotopes	Stable	β^-: 100.00%
$^{66}_{31}$Ga	Odd Z with W-A = -4 indicating instability with an abundance of neutrons probably β^-	β^-	β^+: 100.00%
$^{185}_{76}$Os	Even Z with W-A = -5 indicating instability with an abundance of neutrons, but probably alpha decay and not beta due to being so far from stability	α	β^+: 100.00%
$^{242}_{94}$Pu	Even Z with W-A = -2, but all elements above Z=82 are unstable, predominately through alpha decay	α	α: 100.00% , SF: 5.5×10^{-4}%
$^{55}_{26}$Fe	Even Z with W-A = 1	Stable	β^+: 100.00%
$^{249}_{96}$Cm	Even Z with W-A = 2, but all elements above Z=82 are unstable, predominately through alpha decay	α	β: 100.00%

2.09: Radioactivity - Reaction Energy

The reaction energies are calculated as the mass difference between the parents and the daughters.

$$Q = M_{\text{parents}} - M_{\text{daughters}}$$

The mass excess of the nuclides, Δ, (differences between actual mass and atomic number) was used instead of the actual nuclide mass. The nuclide mass, if desired could be recovered by adding on the mass excess. It is assumed that the mass of the neutrino is negligible.

[1] Decay schemes for this problem where taken from the Nuclear Data Sheets,2003. (http://www.nndc.bnl.gov/chart/chartNuc.jsp)

(a) Calculate the reaction energy involved in the beta decay of ^{110}Ag

$$\begin{aligned} {}^{110}_{47}\text{Ag} &\rightarrow {}^{110}_{48}\text{Cd}^{+} + \beta + \bar{\nu} + Q \\ Q &= M_{^{110}\text{Ag}} - \left(M_{^{110}\text{Cd}} - M_{e^-+}\right) - M_{e^-} - M_{\bar{\nu}} \\ &= \Delta_{^{110}\text{Ag}} - \Delta_{^{110}\text{Cd}} \\ &= -87.4574\text{MeV} - (-90.3503\text{MeV}) \\ &= 2.8929\text{MeV} \end{aligned} \tag{1}$$

(b) Calculate the reaction energy involved in the positron decay of ^{98}Rh

$$\begin{aligned} {}^{98}_{45}\text{Rh} &\rightarrow {}^{98}_{44}\text{Ru}^{-} + \beta^{+} + \nu + Q \\ Q &= M_{^{98}\text{Rh}} - \left(M_{^{98}\text{Ru}} + M_{e^-}\right) - M_{e^-} - M_{\nu} \\ &= \Delta_{^{98}\text{Rh}} - \Delta_{^{98}\text{Ru}} \\ &= -83.1751\text{MeV} - (-88.2248\text{MeV}) \\ &= 5.057\text{MeV} \end{aligned} \tag{2}$$

(c) Calculate the reaction energy involved in the electron-capture decay of ^{111}Sn

$$\begin{aligned} {}^{110}_{50}\text{Sn} + e^{-} &\rightarrow {}^{110}_{49}\text{In} + \bar{\nu} \\ Q &= M_{^{110}\text{Sn}} - \left(M_{^{110}\text{In}} + M_{e^-}\right) - M_{e^-} - M_{\nu} \\ &= \Delta_{^{110}\text{Sn}} - \Delta_{^{110}\text{In}} \\ &= -85.9414\text{MeV} - (-88.3832\text{MeV}) \\ &= 2.451\text{MeV} \end{aligned} \tag{3}$$

(d) Calculate the reaction energy involved in the alpha decay of ^{148}Gd

$$\begin{aligned} {}^{148}_{64}\text{Gd} &\rightarrow {}^{144}_{62}\text{Sm}^{2+} + \alpha^{2-} \\ Q &= M_{^{148}\text{Gd}} - \left(M_{^{114}\text{Sm}} + 2m_{e^-}\right) - \left(M_{^{4}\text{He}} - 2m_{e^-}\right) \\ &= \Delta_{^{148}\text{Gd}} - \Delta_{^{114}\text{Sm}} - \Delta_{^{4}\text{He}} \\ &= -76.2692\text{MeV} - (-81.9657\text{MeV} + 2.4249\text{MeV}) \\ &= 3.2712\text{MeV} \end{aligned} \tag{4}$$

(e) Calculate the reaction energy involved in the gamma decay of ^{107m}Ag

The reaction energy involved in the decay of a meta-stable isotope (such as ^{107m}Ag) cannot be calculated from a mass difference as masses are only listed for stable states. However,the Q-value for this reaction is 931 keV.

Advanced Topic: Usage of nuclear isomers in Nuclear Batteries

Generally nuclear batteries are thought as radiosotope thermolelectir generator (RTG) in which the radioactive decay of an isotope (mostly ^{238}Pu and ^{90}Sr) provides the energy for the device. The kinetic energy of the daugher reaction products is transfered into heat as the reaction products slow down, which is then converted into energy by thermocouples. These devices are liminitted in their use to the large amount of activity needed to power them and the inefficency of the thermocouples (ussually around 10 %). Metastable nuclear isomers are proposed as a possible replacement technology in which the isomers are excited into the metastable state and a controlled de-excitation is used to extract power from the battery. As metastable iosmers decay via gamma emission the thermal energy to electrical energy is not pratical due to the interaction mechanisms of photons. Instead, it is proposed to use these generators in conjuntion with a p-n semiconductor so the ionizing radiation creates electron-hole pairs from which current could be drawn. The majority of the current research has then focused on the ability to control the excitation of the metastable isotopes, as evidanced in the attached papers.

Sources:

- Wiki - `http://en.wikipedia.org/wiki/Radioisotope_thermoelectric_generator`
- Wiki - `http://en.wikipedia.org/wiki/Nuclear_isomer`