FYS3520 - Problem set 11

Spring term 2017

The exercises on PGAA and fission neutrons are under development. Please give me a feed-back on how you find them and how difficult they are. I would also appreciate if you could in the end send me the code you write for this (or on the way in case you should struggle).

Problem 1 – in class

a) Discussion of common misconceptions in the Midterm exam (specific questions can be asked eg. at the end of the class)

b) Discussion on nuclear reactions and cross-sections

c) (Presentation on physics and context of NW)

Problem 2 Isotope production reaction (Krane 11.14)

The radioactive isotope ^{15}O, which has important medical applications, can be produced in the nuclear reaction $^{12}\mathrm{C}(\alpha, \mathrm{n})$.

a) The cross section reaches a peak when the laboratory energy of the incident α particle is 14.6 MeV. What is the excitation energy of the compound nuclear state?

b) The reaction cross section at the above incident energy is 25 mb. Assuming a carbon target of 0.10 mg/cm^2 and a current of 20 nA of the $^4\mathrm{He}^{2+}$ ions (= α) particles), compute the ^{15}O activity that results after 4 minutes of irradiation.
Hint: You may also check Krane Chapter 6.3

Problem 3 PGAA

Prompt gamma-ray activation analysis is a measurement technique for nondestructive elemental analysis. Samples are irradiated by a beam of neutrons inducing elemental nuclei to capture neutrons and emit characteristic prompt gamma rays upon de-excitation. When these gamma rays are measured using a high resolution germanium detector, the energies the gamma rays energies identify the neutron-capturing elements, while the intensities of the peaks at these energies reveal their concentrations. The amount of analyte element is given by the ratio of count rate of the characteristic peak in the sample to the rate in a known mass of the appropriate elemental standard irradiated under the same conditions.

PGAA is a widely applicable technique for determining the presence and amount of many elements simultaneously in samples ranging in size from micrograms to many grams. It is a non-destructive method, and the chemical form and shape of the sample are relatively unimportant. Typical measurements take from a few minutes to several hours per sample. Typically, the sample will not acquire significant long-lived radioactivity, and the sample may be removed from the facility and used for other purposes. [Source: NIST] A schematic setup can be seen in Figure 1.

a) Estimate the spectrum emitted by a thin sample containing 10% ^{13}C and 90% ^{12}C. You analyze a thin sample disk with a 3 cm radius, an (area) density of 500 μg/cm^2 and 1 mm thickness. The neutron beam at the FRMII in Munich has a thermal equivalent neutron flux (= E_n can be assumed to be n_{thermal}) $\phi = 2.7 \times 10^{10}$ /s/cm^2 and you may assume that the beam is homogeneously spread over a circle with the radius of 1 cm.

   Hint: Cross-sections may be found with ENDF. Retrieve the energies and intensities of the prompt capture γ-rays using the CapGam database: `http://www.nndc.bnl.gov/capgam/index.html`. ”The nuclide given is the target nucleus in the capture reaction. The gamma energies given are in keV. The gamma intensities given are relative to 100 for the strongest transition.

% Iγ (per 100 n-captures) for the strongest transition is given, where known." (See 2nd line of the data files, starting "Strongest transition".)

b) Could you, based on your estimations, find the ratio between the two isotopes?

c) What would you need to pay attention to when simulating the spectrum observed with the detector? How could you do so?

d) What are additional challenges if you were to asses the enrichment of a uranium probe? How can this be explained by nuclear structure?

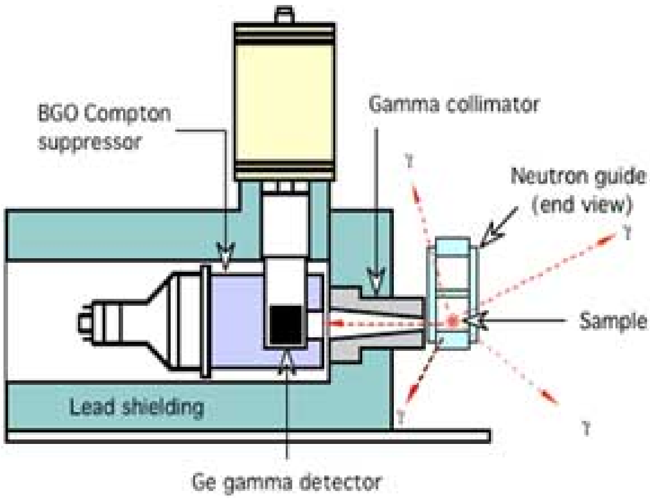

Figure 1: Sample is irradiated by cold neutron beam. Nuclei capture neutrons, emit characteristic prompt gamma rays upon de-excitation. Measurement of gamma rays gives determination of elements in the sample. Source: `https://www.nist.gov/laboratories/tools-instruments/prompt-gamma-ray-activation-analysis-pgaa`

Problem 4 A very simple model for a nuclear reactor?

Assume you have ^{235}U fission neutron point source of with a source intensity of 1000 fissions/s. Let it be surrounded by a spherical shell of 20% enriched uranium of thickness x = 1 mm with a radius r = 5 cm.

a) How many neutrons will be emitted by the source and what is their energy distribution? We will call them the 1st generation.

b) How many neutrons will be emitted from the uranium shell, assuming first that the 2nd generation neutrons do not interact with their environment? Write a program that will take an arbitrary source spectrum and fold it with the (energy dependent) cross sections. Hint: a) You may need to take into account more then only the (n,f) cross-sections. Cross-sections can be found from ENDF /JANIS

c) Why does the majority of reactors today use moderator? Simulate the effect of a perfect moderator.

d) Could you include further neutron generations – what information would you need for this?

e) What is origin of the resonance region in the cross-sections? How do you deal with it and what may be problems related to this?