Physics with neutrons 1

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Exercise sheet 5
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EXERCISE 5.1

The Maxwell-Boltzmann distribution is given in units of Energy E and particle velocity v. Express the Maxwell-Boltzmann distribution

$$f(v) = \frac{4}{\sqrt{\pi}} \left(\frac{m_n}{2k_bT}\right)^{3/2} v^2 \exp\left(-\frac{\frac{1}{2}m_n v^2}{k_bT}\right)$$

in terms of the particle wavelength λ. Determine $\langle\lambda\rangle, \langle\lambda^2\rangle$ and λ_{max} (i.e. the λ where $f(\lambda)$ is maximal). On the lecture website you will find the data file `hfir_spectrum.xls`. It contains a neutron wavelength spectrum (1st column: wavelength in Å, 2nd column: intensity in arbitrary units) measured at the cold source of the HFIR reactor in Oak Ridge, USA. Use a fitting tool to fit the Maxwell-Boltzmann flux distribution to this data and extract the moderator temperature. Remember that the flux distribution is given by

$$\Psi(v) = v \cdot f(v)$$

EXERCISE 5.2

Neutron Transmutation Doping (NTD) of semiconductors is a well established technology where industry takes advantage of neutron sources such as FRM-II. The aim is to produce homogeneously doped semiconductors through neutron absorption and subsequent transmutation into atoms with differing atomic number leading to p-type or n-type materials. With 15 tons/year of doped Silicon wafers FRM-II meets 20% of the worldwide demand. The rapid increase of green energy technology like wind mills and electric cars leads to rising need of NTD semiconductors for high power applications.
Natural silicon is composed of three isotopes, ^{28}Si, ^{29}Si and ^{30}Si. ^{28}Si and ^{29}Si are changed into other stable silicon atoms when they absorb a thermal neutron. In contrast, ^{30}Si capturing a thermal neutron becomes ^{31}Si which is unstable and decays into ^{31}P via the process:

$$^{30}\mathrm{Si} + \mathrm{n} \rightarrow ^{31}\mathrm{Si} \rightarrow ^{31}P + \mathrm{e}^- + \nu_e \tag{1}$$

As ^{31}P has five electrons in the outermost shell, n-type doping of silicon is achieved through this process.

1. Calculate the mean free path of neutrons in natural silicon, i.e. the average length a neutron travels before interacting. How often does a neutron scatter on average before it is absorbed?

2. Given that the average scattering angle between a neutron and an atom with mass number A is given by $\overline{\cos\psi} = \frac{2}{3A}$, calculate the mean distance a neutron travels within silicon before it is absorbed and the mean penetration depth. Assume a constant neutron density at the silicon surface. Hint: The process can be described as a Markov chain. Neutron cross sections for silicon are given at `http://www.ncnr.nist.gov/resources/n-lengths/`.

3. Where are the limits of this technique?