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# Introduction to neutron-induced reactions and the R-matrix formalism

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Neutron-nucleus reactions are important in a number of research fields ranging from stellar nucleosynthesis to application in nuclear technology. In the interaction between neutrons and nuclei, the kinetic energy of the neutron or the reduced de Broglie wavelength is determining the nature of the interaction.

In the energy range between roughly 1 meV and 10 MeV, depending on the nucleus, the wavelength is in the same order of magnitude as the size of the nucleus. Since the electrically neutral neutron has no Coulomb barrier to overcome, and has a negligible interaction with the electrons in matter, it can directly penetrate the atomic nucleus and interact with it.

For these energies, reactions can often be understood in the compound nucleus model introduced by Niels Bohr to explain the observed resonances in neutron-nucleus reactions. In this picture, the neutron binding energy which becomes available to the compound nucleus, is rearranged among all nucle zns, and gives rise to a complex configuration corresponding to a well defined nuclear state with an energy, spin and parity. Within Fermi's description of nuclear excitations as particle-hole configurations, such a state would correspond to an extremely complicated configuration of a many particle, many hole state. The nucleus in this regime above the neutron threshold has a statistical behaviour which can be observed by properties like the spacing between levels and the decay widths of the compound nuclear state. Typical life times for these states are in the order of $10^{-15}$ s.

An important energy region is the resolved resonance region, which covers energies from thermal up to the keV region or higher, depending on the nucleus. The R-matrix formalism is usually used to describe cross sections in the resolved resonance region. This formalism is an important tool which links the properties of the nuclear levels to cross sections.

A different approach is to describe the cross sections with an appropriate optical model. The nucleus is then seen as an optical potential in which an incoming plane neutron wave undergoes alteration. The change in wave functions describing the cross sections is usually expressed by making use of transmission coefficients. Total cross sections for higher energy neutrons can be described using an optical model. With additional modelization on the decay probabilities, the partial reaction cross sections can be derived.

In direct reactions, as the opposite reaction mechanism to compound nucleus reactions, the incident neutron interacts directly with one or a few nucleons without forming a compound nucleus. The time scale of direct reactions is in the order of $\$10^{-22}$ s, much shorter than compound-nucleus resonance reactions. Direct reactions become important for the heavier nuclei at neutron energies higher than about 10 MeV, where the De Broglie wavelength of the neutron becomes comparable to the size of nucleons, but also at lower neutron energies, mainly for light mass or closed shell nuclei.