Coulomb excitation for the investigation of nuclear shapes and more

Coulomb excitation is the electro-magnetic excitation process occurring when a nucleus is passing at close distance by another nucleus and thus experiencing a time-dependent electro-magnetic field. Coulomb excitation is a very powerful tool to excite “collective” degrees of freedom of the nucleus (rotational or vibrational states). In the case of pure Coulomb excitation, i.e. without the influence of any nuclear interaction, the excitation probability can be exactly calculated in a semi-classical approach [win75]. This allows extracting the electro-magnetic transition probabilities between different states and their static moments and thus to measure the susceptibility of the nucleus for different multipole excitation modes (quadrupole, octupole etc.). By measuring these multipole moments also the “nuclear shape”, defined as the deviation from a spherical charge distribution, can be determined. In the first part of this lecture the basic properties of the Coulomb excitation process will be introduced.

In order to assure a pure Coulomb excitation process it is important to avoid any nuclear interaction between the two nuclei, i.e. keeping them outside the range of the nuclear force. This can be achieved by either a centre-of-mass energy that is sufficiently low to assure a distance of closest approach between the two nuclei which exceeds the sum of the radii plus a certain safety margin of ~5 fm (low energy or safe Coulomb excitation) or by selecting an impact parameter, which fulfils the same criterion (high-energy Coulomb excitation). Both approaches have different advantages and deficiencies and will be discussed in the lectures.

Until very recently Coulomb excitation was limited to the use of stable beam-target combinations. In this case the (isotopically enriched) target is the nucleus of interest, while the projectile is usually “inert” against the excitation process, thus simplifying the theoretical description of the Coulomb excitation process. The choice of the projectile will depend on the exact physics case; often semi-magic or doubly-magic nuclei of either light ion (^{12}C,^{16}O, ^{32}S) or heavy ion beam (^{90}Zr, ^{208}Pb) are being used.

Due to the availability of radioactive ion beams both from low-energy (ISOL) and high-energy fragmentation facilities it became possibly to apply Coulomb excitation also to unstable nuclei. Compared to the classical approach the role of the projectile and the target nucleus are exchanged, i.e. the properties of the (short-lived) beam are being studied. The experimental considerations, which are needed in order to account for these changes as well as the different experimental approaches for low- and high-energy Coulomb excitation, will be also discussed in the lecture.

Coulomb excitation has become in recent years a major tool for the study of exotic nuclei, far from the valley of stability, which gave crucial information on the evolution of nuclear shapes, coexistence of different shapes in the same nucleus, but also the erosion of the “classical” shell structure observed in nuclei closer to the valley of stability. Example for these different topics located in different regions of the nuclear chart will be presented and discussed.

[Win75] K. Alder and A. Winther, “Electromagnetic excitation ; Theory of Coulomb excitation with heavy ions”, North Holland Publishing Company, Amsterdam (1975)