

A Brief Introduction to Statistical Mechanics

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Commentary

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DESCRIPTION

The effective absolute limit of the range of the nuclear force (also known as residual strong force) is represented by halo nuclei such as lithium-11 or boron-14, in which dineutrons, or other collections of neutrons, orbit at distances of about 10 fm (roughly similar to the 8 fm radius of the nucleus of uranium-238). These nuclei are not maximally dense. Halo nuclei form at the extreme edges of the chart of the nuclides—the neutron drip line and proton drip line and are all unstable with short half-lives, measured in milliseconds; for example, lithium-11 has a half-life of 8.8 ms.

Halos in effect represent an excited state with nucleons in an outer quantum shell which has unfilled energy levels "below" it (both in terms of radius and energy). The halo may be made of either neutrons [NN, NNN] or protons [PP, PPP]. Nuclei which have a single neutron halo include ^{11}Be and ^{19}C . A two-neutron halo is exhibited by ^6He , ^{11}Li , ^{17}B , ^{19}B and ^{22}C . Two-neutron halo nuclei break into three fragments, never two, and are called Borromean nuclei because of this behaviour (referring to a system of three interlocked rings in which breaking any ring frees both of the others). ^8He and ^{14}Be both exhibit a four-neutron halo. Nuclei which have a proton halo include ^8B and ^{26}P . A two-proton halo is exhibited by ^{17}Ne and ^{27}S . Proton halos are expected to be more rare and unstable than the neutron examples, because of the repulsive electromagnetic forces of the excess proton(s).

Nuclear models

Although the standard model of physics is widely believed to completely describe the composition and behaviour of the nucleus, generating predictions from theory is much more difficult than for most other areas of particle physics. In principle, the physics within a nucleus can be derived entirely from quantum chromodynamics (QCD). In practice however, current computational and mathematical approaches for solving QCD in low-energy systems such as the nuclei are extremely limited. This is due to the phase transition that occurs between high-energy quark matter and low-energy hadronic matter, which renders perturbative techniques unusable, making it difficult to construct an accurate QCD-derived model of the forces between nucleons. Current approaches are limited to either phenomenological models such as the Argonne v18 potential or chiral effective field theory.

Even if the nuclear force is well constrained, a significant amount of computational power is required to accurately compute the properties of nuclei ab initio. Developments in many-body theory have made this possible for many low mass and relatively stable nuclei, but further improvements in both computational power and mathematical approaches are required before heavy nuclei or highly unstable nuclei can be tackled.

Historically, experiments have been compared to relatively crude models that are necessarily imperfect. None of these models can completely explain experimental data on nuclear structure.

The nuclear radius (R) is considered to be one of the basic quantities that any model must predict. For stable nuclei (not halo nuclei or other unstable distorted nuclei) the nuclear radius is roughly proportional to the cube root of the mass number (A) of the nucleus, and particularly in nuclei containing many nucleons, as they arrange in more

Liquid drop model

Early models of the nucleus viewed the nucleus as a rotating liquid drop. In this model, the trade-off of long-range electromagnetic forces and relatively short-range nuclear forces, together cause behaviour which resembled surface tension forces in liquid drops of different sizes. This formula is successful at explaining many important phenomena of nuclei, such as their changing amounts of binding energy as their size and composition changes (see semi-empirical mass formula), but it does not explain the special stability which occurs when nuclei have special "magic numbers" of protons or neutrons.