Major step forward in theoretical description of two key properties of hot nuclei

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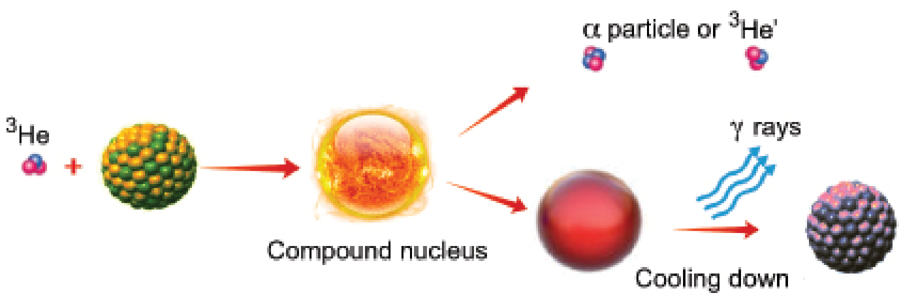

In reactions using the Oslo method the light particles (e.g. ^{3}He) fuse with a heavy target creating a compound nucleus at a certain temperature (hot nucleus), which subsequently cools down by emitting light particles (e.g. alpha-particles in transfer reactions or ^{3}He' in inelastic scattering reactions) and gamma rays. Credit: RIKEN

In work published in *Physical Review Letters*, researchers from the RIKEN Nishina Center for Accelerator-Based Science and two universities in Vietnam—Duy Tan University and University of Khanh Hoa—have made a major breakthrough by proposing, for the first time, a unified and consistent microscopic approach capable of describing simultaneously two important quantities for understanding the statistical properties of nuclei—the nuclear level density and the emission probability of gamma-rays from hot nuclei—which play essential roles in stellar nucleosynthesis.

In accordance with the rules of quantum mechanics, the atomic nucleus has discrete energy levels. As the excitation energy increases, the spacing between the levels decreases rapidly, making them densely crowded. In this condition, dealing with individual nuclear levels becomes impractical. Instead, it is more convenient to consider the average properties of nuclear excitations in terms of two quantities—known as the nuclear level density (NLD) and radiative strength function (RSF). The former, introduced by Hans Bethe 80 years ago, is the number of excited levels per unit of excitation energy. The latter, proposed by Blatt and Weisskopf 64 years ago, describes the probability that a high-energy photon (gamma ray) will be emitted.

These two quantities are indispensable for understanding astrophysical nucleosynthesis, including the calculations of reaction rates in the cosmos and the production of elements, as well as in technology such as nuclear energy production and the transmutation of nuclear waste. Therefore, the study of these quantities has become a key topic in nuclear physics. This area has gained impetus in 2000 after experimentalists at Oslo University proposed a method to simultaneously extract the two from the primary gamma-decay spectrum obtained in a single experiment. This method, however, suffers from uncertainties related to the process of normalization. Given the importance of these two quantities, it is imperative to have a consistent theoretical basis for understanding them. Nonetheless, a unified theory capable of simultaneously and microscopically describing both the NLD and RSF has been absent so far.

Now, employing the mean fields of independent nucleons (protons and neutrons), the authors solved the nucleon superfluid-pairing problem exactly. These exact solutions are employed to construct the partition function for calculating the NLD. To calculate the RSF, the exact neutron and proton pairing gaps as well as the related quantities obtained from the same partition function are input into the microscopic Phonon

Damping Model proposed in 1998 by one of the authors, Nguyen Dinh Dang of the RIKEN Nishina Center for Accelerator-Based Science, in collaboration with Akito Arima to describe the behavior of giant dipole resonance (GDR) in highly excited nuclei.

"The good agreement between the predictions of the present approach and experimental data indicates that the use of exact solutions for pairing is indeed very important for the consistent description of both NLD and RSF at low and intermediate excitation and gamma-ray energies," says Nguyen Quang Hung of Duy Tan University, the corresponding author of the paper.

Commenting on this work, Nguyen Dinh Dang says: "Our approach shows that the temperature dependence of the GDR shape in hot nuclei is crucial for the correct description of the gamma-ray emission probability at low gamma-ray energies. The next goal is to develop a fully self-consistent approach based on exact pairing and the microscopic structure of the vibrational states to study nuclear collective excitations."

More information: N. Quang Hung, N. Dinh Dang, L.T. Quynh Huong, Simultaneous Microscopic Description of Nuclear Level Density and Radiative Strength Function, *Phys. Rev. Lett.* 118 (2017) 022502

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