Eur. Phys. J. A (2014) **50**: 26
DOI 10.1140/epja/i2014-14026-9

THE EUROPEAN PHYSICAL JOURNAL A

Regular Article – Theoretical Physics

Symmetry energy from the nuclear collective motion: constraints from dipole, quadrupole, monopole and spin-dipole resonances*

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Received: 5 September 2013 / Revised: 6 December 2013
Published online: 26 February 2014 –
Communicated by A. Ramos

Abstract. The experimental and theoretical studies of Giant Resonances, or more generally of the nuclear collective vibrations, are a well-established domain in which sophisticated techniques have been introduced and firm conclusions reached after an effort of several decades. From it, information on the nuclear equation of state can be extracted, albeit not far from usual nuclear densities. In this contribution, which complements other contributions appearing in this topical issue, we survey some of the constraints that have been extracted recently concerning the parameters of the nuclear symmetry energy. Isovector modes, in which neutrons and protons are in opposite phase, are a natural source of information and we illustrate the values of symmetry energy around saturation deduced from isovector dipole and isovector quadrupole states. The isotopic dependence of the isoscalar monopole energy has also been suggested to provide a connection to the symmetry energy: relevant theoretical arguments and experimental results are thoroughly discussed. Finally, we consider the case of the charge-exchange spin-dipole excitations in which the sum rule associated with the total strength gives in principle access to the neutron skin and thus, indirectly, to the symmetry energy.

1 Introduction

As is testified by the variety of contributions in this topical issue, complementarity of the sources of information is a vital component of our understanding of the symmetry energy. In our contribution, we review several attempts to use the nuclear collective excitations as a tool to infer the properties of the symmetry energy. We stress that in most of these cases, although we can only access densities that are relatively close to the usual nuclear density, the information can be considered as quite accurate due both to well-established experimental techniques and to the availability of microscopic methods that have been tested against many other observables. This is at variance with other situations (astrophysical observations and, to some extent, heavy-ion collisions) in which one is potentially able to explore a broader range of densities, but at the expense of facing with more global and specific uncertainties.

We start by reviewing the basic equations related to symmetry energy. For any nuclear system the total energy must depend both on neutron and proton densities ρ_n and ρ_p,

$$E = \int \mathrm{d}^3 r \ \mathcal{E}(\rho_n(\boldsymbol{r}), \rho_p(\boldsymbol{r})), \qquad (1)$$

where $\mathcal{E}$ is the energy density and we have assumed locality, for the sake of simplicity. In the following, we will use q as a generic label for neutrons and protons. In finite systems the energy can actually depend not only on the spatial densities, but also on their gradients $\nabla\rho_q$, on the kinetic energy densities τ_q, as well as on other generalised densities like the spin-orbit densities J_q; however, in infinite matter, one has a simple expression in terms of the spatial densities only (cf., *e.g.*, ref. [1]).

Instead of ρ_n and ρ_p, one can use the total density ρ and the *local* neutron-proton asymmetry,

$$\beta \equiv \frac{\rho_n - \rho_p}{\rho}\,. \qquad (2)$$

* Contribution to the Topical Issue "Nuclear Symmetry Energy" edited by Bao-An Li, Àngels Ramos, Giuseppe Verde, Isaac Vidaña.

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