Available online at www.sciencedirect.com
SCIENCE DIRECT®
Nuclear Physics A 751 (2005) 209c–225c
NUCLEAR PHYSICS A

The contribution of precision mass measurements to nuclear physics

C. Scheidenberger[a]

[a]GSI, Planckstraße 1, D-64291 Darmstadt, Germany

From its beginning, precision mass measurements have played a key role in nuclear physics. This article reviews their present role in nuclear-structure physics, in nuclear astrophysics, in testing some fundamentals of the standard model, and in applied fields.

1. Introduction

To date, five pioneers of mass spectrometry have received the Nobel Prize in recognition of their work: the discoverer of the electron J. J. Thomson (Nobel Prize in physics, 1906, for the investigation on the conduction of electricity by gases), F. W. Aston (Nobel Prize for chemistry, 1922, for the discovery of isotopes by using his high-resolution mass spectrographs and for finding deviations from the "whole-number rule"), W. Paul (physics, 1989, for the development of ion traps), and J. B. Fenn together with K. Tanaka (chemistry, 2002, for the development of desorption and ionization methods and the mass spectrometric analysis of biological macromolecules). While the two latter scientists received the prize for applications in biology, the names of the other three are intimately connected with developments and discoveries in particle and nuclear physics. Their search was triggered by the enthusiasm in finding the building blocks of matter and the fundamental forces in nature. Still today, mass spectrometry and the accurate knowledge of atomic masses yields contributions to our understanding of the structure of nuclei and to one of the key issues in nuclear physics, the understanding of the strong force. The progress in understanding is closely related to the progress of experimental techniques. Measurements with highest precision and the study of radioactive nuclei give answers to a variety of questions, allow new insights into nature, and yield new applications. This will be described in this paper and is illustrated in figure 1, which shows in an exemplary way how the precision of mass measurements increased over the years and how this allows more and more detailed insights.

2. What can one learn from the atomic mass of nuclei?

The atomic nucleus is a particularly interesting many-body system and its understanding is intellectually challenging since all known forces take effect in it. This chapter surveys the directions in physics where atomic masses contribute.

2.1. Nuclear astrophysics

In the interdisciplinary field of nuclear astrophysics, at the borderline of particle physics, nuclear physics, astrophysics and cosmology, one of the prime goals is to understand the

0375-9474/$ – see front matter
doi:10.1016/j.nuclphysa.2005.02.006

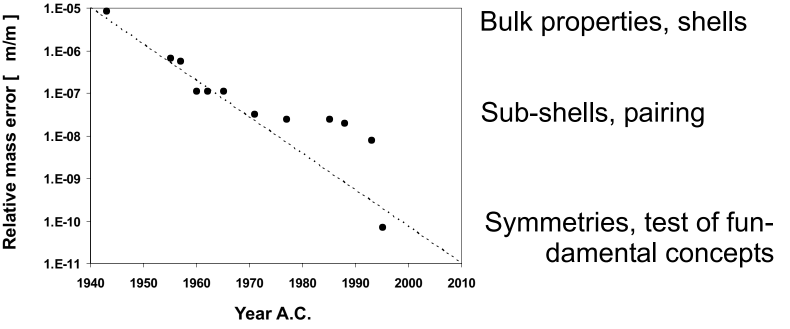

Figure 1. The graph shows for the exemplary case of ^{28}Si how the relative mass uncertainty decreased over the years due to the continuous improvement of existing and the advent of new experimental techniques. The data have been kindly provided by G. Audi.

origin and the formation of chemical elements, in particular to explain qualitatively and quantitatively the observed elemental and isotopical abundances. Three major categories of processes are distinguished: the primordial nucleosynthesis, spallation reactions, and the nucleosynthesis in stars. As far as the nucleosynthesis ins stars is concerned, the progress of the field is governed by the data collection and analysis of astronomical observations, the modelling of stars (in particular dynamical models taking into account the time-dependence of entropy, density, etc.), and refined network calculations with detailed and reliable nuclear physics input data. For the explosive scenarios such as the r- or the rp-process the presently used input data are widely based on calculation and/or extrapolations imposing a large uncertainty on the results. In most cases mass values with errors of the order of 100 keV can already lead to a significant improvement. New data in the vicinity of the r-process path have been recently obtained with isochronous mass spectrometry at FRS-ESR (see below), as seen in figure 2. More precise data are desirable for waiting-point nuclei, as for instance for ^{68}Se, where the proton capture stalls until the β-decay, which is "slow" as compared to the typical time spent until the next capture event occurs. This nuclide has attracted much attention in recent years and mass determinations of the ^{68}Se have been performed at several laboratories employing a variety of experimental approaches: at Argonne National Laboratory by direct measurements using CPT [1] and by β-endpoint measurements [2], and also with two different methods at GANIL using the spectrometer SPEG [3] and the coupled cyclotrons CSS1 and CSS2 [4,5]. The stellar effective half-live depends critically on the Q-value and varies up to more than three orders of magnitude per MeV change in Q-value, as can be seen e. g. in fig. 1 of ref. [1] or fig. 2 of ref. [2]. With new and reliable data it will be possible to further constrain and to determine in an iterative manner the astrophysical conditions and possible sites where and how rp-nucleosynthesis takes place.