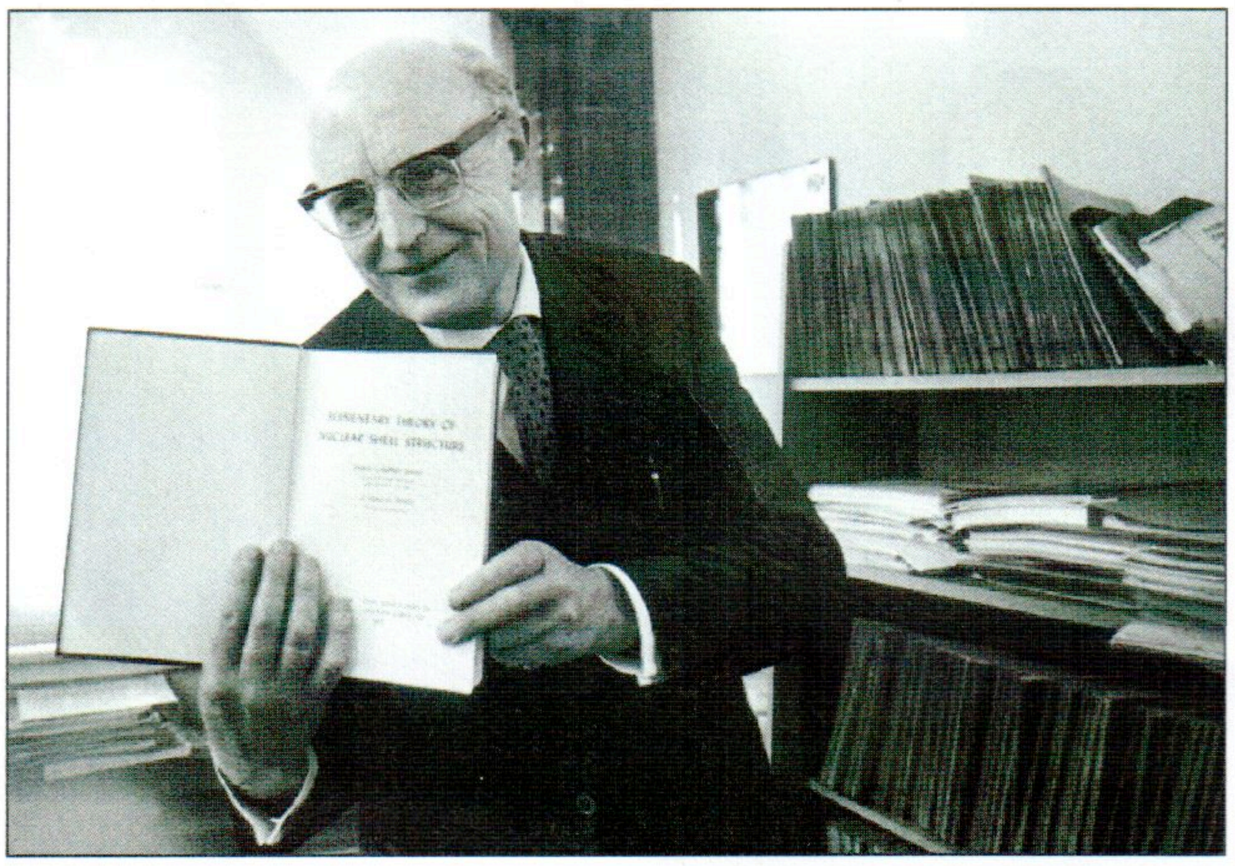
Father of the shell model

Heidelberg University held a symposium on fundamental physics and the shell model this summer to celebrate the 100th anniversary of the birth of Hans Jensen, the German who created the nuclear shell model with Maria Goeppert-Mayer of Argonne.

Hans Jensen (1907–1973) is the only theorist among the three winners from Heidelberg University of the Nobel Prize for Physics. He shared the award with Maria Goeppert-Mayer in 1963 for the development of the nuclear shell model, which they published independently in 1949. The model offered the first coherent explanation for the variety of properties and structures of atomic nuclei. In particular, the "magic numbers" of protons and neutrons, which had been determined experimentally from the stability properties and observed abundances of chemical elements, found a natural explanation in terms of the spin-orbit coupling of the nucleons. These numbers play a decisive role in the synthesis of the elements in stars, as well as in the artificial synthesis of the heaviest elements at the borderline of the periodic table of elements.

Hans Jensen was born in Hamburg on 25 June 1907. He studied physics, mathematics, chemistry and philosophy in Hamburg and Freiburg, obtaining his PhD in 1932. After a short period in the German army's weather service, he became professor of theoretical physics in Hannover in 1940. Jensen then accepted a new chair for theoretical physics in Heidelberg in 1949 on the initiative of Walther Bothe, who received the Nobel prize in 1954 for the development of the coincidence method. Apart from his work in nuclear and particle physics, Jensen became the driving force behind the rebuilding of physics research in Heidelberg after the Second World War. The Institute for Theoretical Physics obtained new chairs, particularly in theoretical particle physics. Together with Bothe, he expanded the experimental-physics department and convinced well-known experimentalists to come to Heidelberg, including his collaborator in the development of the shell model, Otto Haxel, in 1950 and Hans Kopfermann, a specialist on nuclear moments and hyperfine interactions, three years later.



Hans Jensen in his study at 16 Philosophenweg, Heidelberg in 1963. (Courtesy Bettmann/UPI/Corbis.)

The shell model past and present

To celebrate the centenary of Jensen's birth, the Heidelberg Physics Faculty and the Institute for Theoretical Physics organized a symposium on Fundamental Physics and the Shell Model. A series of talks looked at Jensen's life plus the role of the shell model in astrophysics and nuclear physics today. In keeping with Jensen's interest in music, performances by the Heidelberg Canonical Ensemble complemented the talks. In the introductory talk on The Shell Model: Past and Present, former director at the Heidelberg Max Planck Institute, Hans Weidenmüller, gave an overall view of Jensen's Nobel-prizewinning contribution to nuclear physics. The paper on the shell model by Haxel, Jensen and Hans Suess appeared in the same 1949 edition of *Physical Review* as Goeppert-Mayer's work (Haxel, Jensen and Suess 1949 and Goeppert-Mayer 1949). It proved to be a surprising solution to the problem of nuclear-energy levels. Based on the picture of independent particle motion of protons and neutrons with strong spin-orbit coupling, the model yields the correct sequence of energy levels and explains the magic numbers in terms of energy gaps above full levels.

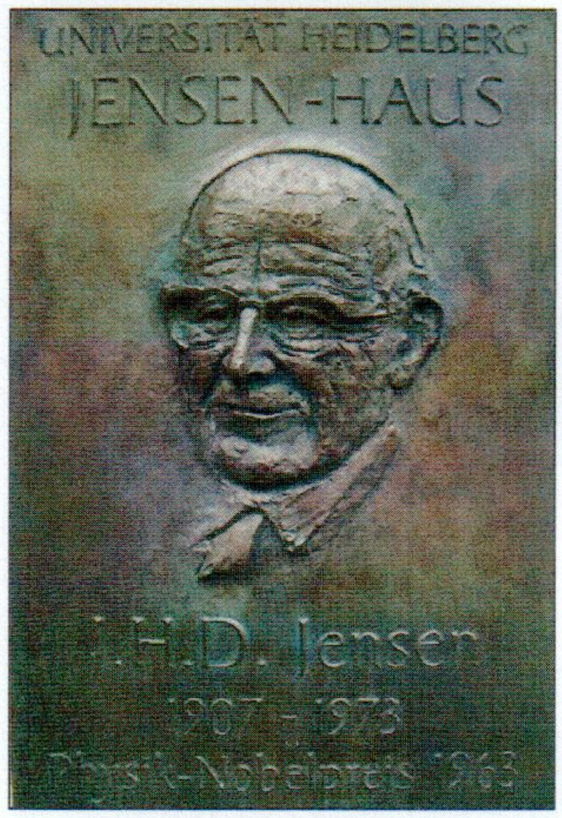
The apparent contradictions with the collective properties of nucleons in nuclei (evident from the rotational spectra) as well as with the chaotic properties of nuclei (evident in Niels Bohr's compound nucleus picture) only found their explanations much later. Today, shell-model calculations in large configuration spaces can indeed explain rotational spectra, and within individual shells consistency with the random nuclear properties appears once the residual interaction is considered. However, a derivation of the shell model from the basic nuclear interaction is still missing.

Berthold Stech, Jensen's former colleague and long-time director of the Heidelberg theory institute, presented his recollections of Jensen with photographs and anecdotes. As a student representative after the war, Stech contributed to Jensen's move to Heidelberg by writing a letter to the publisher of the local newspaper, who then went to the state government to ensure that the offer was made to Jensen. He talked about Jensen's vital contributions to making Heidelberg a famous physics centre. With private rooms in the institute, Jensen often invited students and colleagues for discussions and to listen to music. Stech also quoted from a recent letter by Aage Bohr and Ben Mottelson, who emphasized Jensen's inspiring personality.

Wolfgang Hillebrandt, director at the Max Planck Institute ▷

The theory institute at Philosophenweg

As part of his effort to convince Hans Kopfermann to move to Heidelberg University, Jensen supported the acquisition of a house at 16 Philosophenweg by the German state of Baden-Württemberg. The villa had been built in 1912 for the biologist Hugo Merton, who was deprived of his professorship at Heidelberg in 1935 by the Nazi racial decrees and was deported to the Dachau concentration camp in November 1938. Merton was able to emigrate – but not before being forced to sell his house – to Scotland, where he died in 1940. After the war, the house was given back to the Merton family. As they did not want to return to Germany, they sold the house to the university. Jensen and the Kopfermann family lived there from 1953, and at the same time, Jensen built up Heidelberg's Institute for Theoretical Physics. As part of the celebrations for the centenary of his birth, the villa was renamed "Jensen Haus", and a bronze plaque with his portrait was unveiled, created by the Darmstadt artist Thomas Duttenhoefer.



A bronze plaque at the "Jensen Haus" in Heidelberg. (Courtesy G Wolschin.)

for Astrophysics in Munich-Garching, spoke about supernovae and the shell model. This active field of research represents a synthesis of astrophysics and nuclear physics. In Type Ia supernovae there is a high and almost identical fraction of nickel-56. Even though this is a doubly magic nucleus, it is not stable (its half-life is six days) and its decay through cobalt-56 to iron-56 is what makes these supernovae shine. Hence, the brightness of the supernova is proportional to the produced mass of nickel-56. For progenitor stars that are similar, this allows for very precise determination of distances, which since 1998 have been used to infer the accelerated expansion of the universe. Many physicists consider this to be the consequence of dark energy. Its origins are currently under investigation in many institutes, for example, at the Bonn–Heidelberg–Munich research centre "The Dark Universe".

Core-collapse supernovae (Type II), such as SN1987A in the Large Magellanic Cloud, where a blue supergiant exploded in several seconds, allow the direct test of ideas about the synthesis of heavy elements. For example, the observation of the characteristic gamma-rays indicate the presence in the progenitor star of the corresponding isotopes synthesized during the explosion. Elements beyond iron are, in particular, produced in a sequence of rapid neutron captures known as the r-process. It turns out that the element abundances are mainly determined by nuclear structure, and hence, by the shell model; the subtleties of the astrophysical processes prove to be comparatively unimportant.

In the final talk of the symposium, Peter Armbruster of the GSI in Darmstadt explained the synthesis of the heaviest elements using cold fusion (only one neutron emitted) up to and beyond roentgenium, symbol Rg and atomic number Z = 111. The relative stability of these elements, with mean lifetimes in the order of milliseconds to seconds, is a consequence of the Goeppert–Jensen shell effects. Without these they would not exist. The element Z = 112, synthesized at GSI in 1996, is still unnamed. Meanwhile, Yuri Oganessian's group at the Flerov Laboratory at JINR, Dubna, used radioactive targets in hot-fusion reactions with the emission of up to five neutrons, to create synthetically the elements 114, 116 and 118. Kosuke Morita and co-workers at RIKEN in Japan made element 113 in 2004.

Relativistic mean-field calculations indicate that the closed shell should occur at Z = 120 (the number of protons), with the magic neutron number of 184, as had appeared in the book of Jensen and Goeppert-Mayer about the shell model (Goeppert-Mayer and Jensen 1955). This means that this doubly magic superheavy nucleus should have 304 nucleons. It will, however, be extremely difficult to synthesize since its low density of energy levels above the ground-state favours fission over neutron emission, as Armbruster emphasized. This would lead to a drastic reduction of the survival probability.

As a lasting tribute to Jensen, starting next year, the Jensen Guest Professorship will be created with the financial support of the Klaus Tschira Foundation, Heidelberg. During a five-year period, internationally renowned physicists will visit the Institute for Theoretical Physics in Heidelberg to conduct research, give seminars and one public lecture a year.

Further reading

H G Dosch and B Stech 1986 *"Johannes Daniel Jensen" Semper Apertus, 600 Jahre* Ruprecht-Karls-Universität Heidelberg Band **3** 417.

M Goeppert-Mayer and J H D Jensen 1955 *Elementary theory of nuclear shell structure* (Wiley, New York).

M Goeppert-Mayer 1949 *Phys. Rev.* **75** 1969.

O Haxel, J H D Jensen and H E Suess 1949 *Phys. Rev.* **75** 1766.

Résumé

Colloque en l'honneur de Hans Jensen

Cet été, à l'occasion du centième anniversaire de la naissance de Hans Jensen, à qui l'on doit, avec Maria Goeppert-Mayer, d'Argonne, le modèle en couches, l'Université de Heidelberg organisait un colloque sur le thème: physique fondamentale et modèle en couches. Les deux physiciens ont partagé en 1963 un prix Nobel pour ces travaux, publiés indépendamment en 1949. Le modèle constitue la première explication cohérente des diverses propriétés et structures des noyaux atomiques, en particulier, les "nombres magiques" de protons et de neutrons. Ceux-ci jouent un rôle important dans la synthèse des éléments dans les étoiles et dans la synthèse artificielle des éléments les plus lourds – sujets qui sont à la pointe de la recherche moderne en physique nucléaire.Résumé

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