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Concluding remarks of the ENAM'04 Conference

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Abstract. In this talk a summary of the program and scientific highlights of the ENAM2004 conference will be presented.

1 Introduction

To start, I would like to congratulate Witek Nazarewicz, Carl Gross, and the team from Oak Ridge for putting together and running this magnificent conference. Of course they could not have done this without the active role of participants in the conference, who are to be thanked as well. The conference program has been really outstanding and extremely interesting, and has demonstrated the scientific impact of the field in an important way. I am in this situation because it has been a tradition of the ENAM conferences that the chairman of the previous conference delivers the summary talk. I am sure Witek Nazarewicz is looking forward to this honorable duty in four years time in Poland when our colleagues will be organizing the next conference. There also seems to be another tradition not decided by us, namely the stormy weather during one of the days of the conference. I remember, last time in Finland, we also had a major thunderstorm during the last session of the conference, and this tradition seems to be following us everywhere.

The progress in our field since the last ENAM conference has been fast and noticeable. I think that this progress is speeding up with these conferences. One way to observe the progress is simply to look at the numbers and the statistics of this conference. We had 280 participants, 84 oral talks, 43 oral poster talks, and 162 posters. The oral poster presentations, a new feature of ENAM, was a very good idea indeed. The presentations were very informative and provided an opportunity for many more participants to actually present their work. The presentations have been of very high quality. Electronic presentations really provide an extremly efficient tool for bringing the information to the audience. Also, the posters have been of a very high quality, and I have seen that the discussions have been very lively in the poster sessions. In particular, the younger participants have been able to communicate their results and interact with the rest of the conference participants.

The conference covered basically all of its traditional areas. I could not help noticing that the community working in nuclear spectroscopy, especially in in-beam spectroscopy, has been directing its interests toward nuclei far from stability and contributing in an important way to this conference. I estimated that about 30% of the conference contributions have come from the field of in-beam spectroscopy, providing a nice complementary addition to the field.

The development in the field has been driven by a number of advances, but not least by the new facilities that are being planned and constructed and taken into operation. In particular in this conference, the MSU Cyclotron Laboratory and RIKEN have shown up in a very strong way without forgetting other facilities like HRIBF, REX-ISOLDE, TRIUMF, and many others. One typical feature in this field is that much of the research we do, is done in large collaborations and this also, I think, is an important factor. Collaborations are spread across the seas and we seem to have the ability to do our research today in a nearly optimal way with regard to our the resources and infrastructure.

In the following, I will discuss the conference content itself. As mentioned, we had close to 250 presentations, and therefore it will be impossible to give a comprehensive summary in a short time. What I am reviewing here is a summary which is, of course, strongly biased, being based on my personal impressions and taste, as well as on my knowledge of different areas of this field. I did attend all sessions; I learned a lot, and, in fact, you will see throughout this presentation that I will try to bring up some of the highlights of this conference which struck me the most. The progress has been very strong and powered by the constant development of the equipment and computing power. Several of the new methods that were discussed at the previous ENAM conference are now in full use to produce physics.

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2 Masses

The conference started traditionally with the session on atomic masses. We are now in a fortunate situation that the new atomic mass tables were introduced just prior to this conference, representing a collection of the best atomic mass values. There are two components in the tables, stable and radioactive atomic masses, as discussed by Aaldert Wapstra. As compared to the old table, the new table has a large amount of new information.

David Lunney gave a beautiful presentation on the masses, emphasizing the fast progress in this field over the last couple of years. There are many new developments in experimental techniques that have led to this. For example, the ion traps with a new feature, *e.g.*, to introduce the ions into a trap in an efficient and fast way has opened up a possibility to develop a major new tool in mass measurements for radioactive isotopes. Relative precision can typically reach the lower end of the 10^{-8} range for nuclides with half-lives less than 100 ms. Several examples, such as ^{22}Mg, ^{22,33,34}Ar, ^{68}Se, ^{72}Kr, and ^{74}Rb, mainly from the ISOLTRAP group but also from the Canadian Penning Trap group at Argonne, were presented and discussed at this conference. Also, a new Penning trap at Jyväskylä has started to work, and the very first results on masses of refractory fission products were presented at this conference by Ari Jokinen. There was a remarkable result reported by Cyril Bachelet concerning the mass of ^{11}Li, a very exotic short-lived nucleus, whose mass was measured by the MISTRAL spectrometer to a precision of 5 keV. The actual mass-measurement factory, one could say, is the experimental storage ring of GSI, which has recently produced a large number of new masses for neutron-rich nuclei. By its nature, this technique is universal and will, in the future, be a very important technology for mass measurements of very exotic nuclei. We also heard from GANIL, where a large number of new masses near the neutron drip line at $N \sim 20$ were reported by Herve Savajols. Many other techniques were reported and discussed. One of them applied accelerated radioactive ions and the household appliances at HRIBF to measure masses of exotic copper and germanium isotopes close to doubly magic ^{78}Ni.

In theory, the development of mean-field theories, providing a global approach to connect masses to effective interactions, has provided important tools for mass predictions, for example, in astrophysics. In the future, there is also a need to address the local structure effects in binding energies to understand the physics behind the fine structures. Stephane Goriely presented his overview talk giving a very nice description of the current situation on the different theories for the mass calculations. As he stated, the future challenge lies in a unified description of masses and other nuclear properties. One example discussed was the evolution of the $N = 82$ shell-gap as a function of the proton number. It was shown that different models deviate significantly from each other. It is of significant interest to extend the experimental measurements down towards the lighter elements, as reported by a recent experiment at ISOLDE where the mass of ^{130}Ag had been deduced from a beta end-point measurement.

Because mass measurement techniques have advanced in a major way in recent years, one may ask the question: why and where do we need these new accurate masses? In fact, there are many requirements for high precision. At this conference we have heard about testing the validity of the Standard Model in various ways. In experiments on superallowed Fermi-decays, a very accurate measurement of mass differences or decay energies, *e.g.* much better than one keV, is required. I think John Hardy was asking for a 100 electron volt or better precision. This is, of course, a very challenging, but not an impossible task, for example, for Penning traps. Typically, in some cases in astrophysics, especially when resonant capture reactions are studied, the accuracies have to be well below 10 keV. Nuclear structure studies require an accuracy somewhere around 100 keV or better. If one looks globally over the distant wings of the nuclidic mass surface, something like a half of a MeV is still acceptable and useful.

3 Moments and radii

From masses we move on to moments and radii. Spin-polarized radioactive beams at high and low energy, as reported by ISOLDE and GANIL, have become important tools in structure studies of nuclei close to $N = 8, 20$, and 28, as described in the presentations of Gerda Neyens and Magdalena Kowalska. Many important studies close to the magic neutron numbers far from stability on the neutron-rich side have been made by these groups. There has been major progress in studies of moments and radii of refractory neutron-rich nuclei. They have become available, as reported by Jon Billowes, for collinear laser spectroscopy, mainly thanks to the recently developed cooling and bunching techniques for short-lived radioactive ions. There is also resonant laser ion source spectroscopy that has been applied to study the coexistence of shapes in lead nuclei at ISOLDE. Two outstanding results were reported at this conference, namely the accurate measurements of the charge radii of ^{6}He and ^{9}Li by Peter Mueller and Wilfried Nörtershäuser, respectively. These experiments will eventually lead the way for future measurements in the same quantities for two important halo nuclei, ^{8}He and ^{11}Li. There were, in addition, several experimental results on studies of matter radii and matter distributions of exotic nuclei done by various experimental setups at RIKEN, GSI, GANIL, and MSU. Also, we heard about the g-factor measurements with neutron-rich radioactive beams as reported, for example, by the Oak Ridge and Munich groups. It is clear that in the future we need systematic studies over a broad range in proton and neutron numbers. In particular, I would like to express a wish to get radii in the island of inversion region near $N = 20$. There are measurements by the ISOLDE group on the neutron-rich magnesium isotopes up to ^{28}Mg; but now the challenge is to go further.

One of the outstanding results presented at this conference was the measurement of the quadrupole moment of ^{11}Li. The accuracy for the experimental ratio of the

^{11}Li to ^{9}Li quadrupole moment has been improved significantly over the years. The quadrupole moment of ^{11}Li is 10% higher than the one of ^{9}Li, which indicates that halo neutrons must partially be in the $d_{5/2}$ orbital, a result that confirms the recent reaction experiment at GSI.

4 Radioactivity

Hubert Grawe gave a nice overview of the nuclear structure changes along the $N = 50$ neutron shell, starting from the ^{78}Ni region up to ^{100}Sn. He pointed out the importance of $l = 2$ core polarization as a mechanism leading to isomerism and, in general, the important role of the monopole interaction in the structures of these nuclei.

Radioactivity studies continue to be a rich source of information on single-particle states near the magic numbers far from stability. For example, Paul Mantica's overview talk discussed a number of experiments that have been done on the beta decays of aluminum and sodium nuclei, mapping the levels and spins on both sides of the $N = 20$ magic neutron number. Another presentation related to these nuclei, more specifically to the lifetime measurements of their excited states, was given by Henryk Mach.

Isomeric decays, as discussed by Robert Grzywacz, were demonstrated as an important spectroscopic tool at the previous ENAM2001 conference. They have been effectively used to probe nuclear structures and states of medium and high spin very far from stability. At this conference, Ivan Mukha reported the discovery of the highest spin beta-decaying isomer discovered so far, ^{94}Ag. The story is just beginning, and it seems to me that this one isomer will, in the future, provide us a rich laboratory of nuclear structure and radioactive decay studies.

Experimental activity in the proton decay studies has somewhat diminished due to the natural reason that there are fewer and fewer new cases to be studied. It was satisfying to observe that the theory effort in the field of proton and two-proton decay is substantial and extremely important, as reported by Cary Davids, Alexander Volya, and Jimmy Rotureau and co-workers. For experiments, there are new techniques which provide a complementary approach to get additional information on the excited states preceding the proton decay, as discussed by Andrew Robinson. Two-proton radioactivity was reviewed by Marek Pfutzner. In fact, a few weeks after the previous ENAM conference the first evidence for two-proton radioactivity of ^{45}Fe was observed at GANIL and at GSI. It seems that there are other interesting candidates for true diproton (or ^{2}He) radioactivity which still remain to be uncovered. In this connection, we have already heard about a new two-proton emitter, ^{54}Zn, presented by Bertram Blank. To unravel the decay mechanism, one really needs new detection systems for energy and angular correlation measurements.

When the experiments advance very far from stability, it remains important to obtain information on gross decay properties, but as a second step, we will have to aim at high-resolution, high-sensitivity experiments to uncover the increasing complexity of radioactive decays.

5 Clusters and drip line

There were two interesting sessions on drip-line nuclei, especially on the role of clusters in nuclear structure that was reviewed very nicely by Y. Kanada-En'yo. She showed convincingly that clustering really plays an essential role in structures of unstable light nuclei as well as in some stable nuclei. In fact, even ^{12}C, in the framework of cluster physics, stays in the news both from a theoretical as well as from an experimental point of view. Recently, there has been plenty of new information reported at the conference on the states of ^{12}C at about 10 MeV excitation energy. This new information will also have an impact on the triple-alpha process leading to the formation of carbon in stars.

The clusters and the mean field do coexist and both need to be considered at the same time to understand the structures observed in light nuclei. A specific problem concerning the concept of a tetra neutron was discussed both in the experimental talk of Miguel Marques and the theoretical presentation of Steven Pieper. It seems that some more work is needed since our current rational understanding of nuclear force and nuclear interaction does not allow a bound tetra neutron.

It was interesting to hear from Michael Thoennessen that there are still about 200 nuclei to be discovered near the proton drip line. Two of these were presented by Andreas Stolz, who presented evidence of new nuclei ^{62}Ge and ^{64}Se. There has been a considerable amount of work done at Jyväskylä on alpha decays near the proton drip line, as reported by Juha Uusitalo.

6 Nuclear structure and spectroscopy

The main general subject of the conference, nuclear structure and spectroscopy, covered about 30% of the program. It included several interesting presentations. The main theme currently is the study of neutron-rich nuclei at and near the classical closed neutron shells, but far from stability. There are several different experimental approaches that were presented; the accelerated radioactive ion beam experiments were reported mainly by teams from REX-ISOLDE at CERN and the HRIBF at Oak Ridge. In both, Coulomb excitation and transfer reactions have been employed in experiments near $N = 20, 50$, and 82. There were also a number of experimental results reported from RIKEN and MSU using the fragmentation technique. Since fragmentation is a universal production method, it allows studies of many exotic nuclei simultaneously and with high sensitivity, but it lacks the high accuracy of in-beam spectroscopy. A continuing important role of the network of stable beam facilities was demonstrated by several contributions from Argonne, Legnaro, Jyväskylä, and elsewhere. The successful future of this field calls for a constant development of tracking methods for gamma rays and charged particles.

I will briefly highlight some examples of studies presented at the conference. The first results employing

Coulomb excitation of n-rich Mg isotopes from REX-ISOLDE were reported by Heiko Scheit. The $B(E2)$ value observed for ^{30}Mg was found to be in some discrepancy with the values derived earlier from the high-energy experiments at GANIL and MSU. The newest data, presented by Robert Varner and David Radford, yielded $B(E2)$ values for Sn and Te isotopes. The experimental values for Sn at $N = 80, 82$, and 84 are reproduced rather nicely by the theory. Also, we heard about an interesting experiment at RIKEN on ^{30}Ne, which had been done with a beam intensity of only 0.3 ions/s. It detected, for the first time, the first 2^+ excited state at 790 keV in ^{30}Ne, which is very similar to ^{32}Mg. It seems to have, if based on the energy argument alone, a similar collectivity as that of ^{32}Mg. Level lifetime measurements employing the recoil shadow technique, reported by Hiro Sakurai, also from RIKEN, was very interesting. The anomalously small $B(E2)$ value for ^{16}C suggests a strong contribution of neutron matter to this excitation. This was also discussed by James Vary, who presented theoretical calculations based on the no-core shell model that reproduced the experimental value very nicely.

There was an interesting presentation by Janne Pakarinen, which concerned the probing of the famous 0^+ state structures in ^{186}Pb studied at Jyväskylä using the recoil decay tagging. The group had identified a new rotational band based on one of the excited 0^+ states. More work is needed here to clarify the picture, but there has been a lot of progress in this area.

We heard of several new results from Legnaro, as reported by Andres Gadea. The PRISMA spectrometer, coupled with the CLARA Ge-array, is now in full operation and is going to provide us with a large amount of spectroscopic information on neutron-rich nuclei via transfer reactions in the coming years. Frank Becker reported on a larger number of results from the GSI RISING setup. For example, they have measured the first $B(E2)$ values for neutron-rich $^{54-58}$Cr nuclei.

This conference has convincingly shown that we have made many significant developments in nuclear structure theory. Several of these were discussed in review talks, such as the *ab initio* no-core shell model overview talk of James Vary. No-core shell-model calculations employing realistic two- and three-body interactions were also discussed by Peter Navratil. Coupled-cluster calculations were extensively reviewed by Piotr Piecuch, and microscopic models for exotic nuclei were treated in an extensive way by Michael Bender. Wojtek Satula discussed a special treatment of the isospin degree of freedom in nuclear structure calculations. It seems that any given theory framework is becoming increasingly tested against many observables at the same time, including binding energies, excited states, as well as nuclear bulk properties. It is obvious that the predictive power of theories has been significantly improved, which will eventually lead the way to new and better formulated physics searches far from stability.

7 Heavy elements

At the time of the ENAM2001 conference, the heaviest element observed was the one with $Z = 112$, and then we had this mysterious $Z = 118$ result. Since those days, the community has become extremely active, and heavy element research has gained new momentum in many ways. For example, during the last year or two, two new elements were named, $Z = 110$ as darmstadtium, and $Z = 111$ as roentgenium. Several new results were discussed by Dieter Ackermann, Vladimir Utyonkov, and Paul Greenlees. The Berkeley activity in this field is back on track, and the LISE spectrometer at GANIL has entered the field as another new player. There were some really exciting new results from RIKEN, namely the discovery of a new element ^{278}113 by Kosuke Morita and his team. This result was reported by Dieter Ackermann. It was a pity that there was no Japanese presentation of this beautiful result. In-beam spectroscopy studies of transfermium elements have been pushed to more new nuclei around ^{252}No at Jyväskylä and Argonne.

We had an interesting presentation by Heinz Gaeggeler on the chemistry of the superheavy elements. He presented exciting results on the chemistry of the element 112 done at GSI and on the chemistry of Dubnium, which was produced as a decay product in the decay chain of element 115 observed in Dubna. It is important that chemists participate in the research, because they will be very helpful in assigning the Z of the new elements.

If we look at the upper corner of the nuclear chart, it has many interesting new features. There is the so-called nobelium region which is actively researched by the Jyväskylä and Argonne groups for excited and microscopic structures. We have several new elements and isotopes produced in cold fusion reactions at GSI and at RIKEN and, finally, more than 30 new isotopes, all produced at Dubna in hot fusion reactions. The decay chains of the latter nuclides end up in unknown isotopes. Connecting these chains to the known upper part of the nuclear chart will be a challenge for future studies in this field.

8 Reactions

Reactions were discussed in penetrating ways. The field is developing very rapidly, although difficulties related to the beam quality, the energy, and angular resolution need constant attention. There were several reports on low-energy radioactive ion beam experiments concerning the fusion reactions of neutron-rich nuclei. The proof for the expected enhancement of fusion was shown by Walter Loveland for the $^{132}\mathrm{Sn} + {}^{64}\mathrm{Ni}$ reaction at sub-barrier energies. The first spectroscopy results by transfer reactions at the new VAMOS facility at SPIRAL were presented by Wilton Catford. Several high-energy experiments were described. Knock-out reactions used for extracting spectroscopy factors along the isotones were described by Alexandra Gade of MSU with an intriguing difference in valence neutron orbital occupation observed between ^{22}O and ^{32}Ar. Deeply bound states in ^{32}Ar possess a very small reduction factor compared to loosely bound ^{22}O.

Also, scattering experiments used to extract radii and halos of drip-line nuclei were presented by Wolfgang Mittig and several other contributions. A special technique relying on scattering of radioactive beams from a polarized hydrogen target was introduced by Hide Sakai who demonstrated the sensitivity of the reaction in probing the radial extension of the spin-orbit part of the nuclear potential.

9 Nuclear astrophysics

Nuclear astrophysics was presented in a very lively presentation by Art Champagne. We often discuss the importance of nuclear physics in astrophysics, and I just want to agree with the statement of Hendrik Schatz that the role of nuclear physics should not be underestimated in astrophysics. Several key reaction rates continue to be of interest in this field, and some of them mentioned at the conference were ^{7}Be(p,γ), ^{14}N(p,γ), ^{18}F(p,α), ^{22}Na(p,γ), and so on. Also, many new important results concerning the masses of the rp-process waiting-point nuclei were presented. The masses of ^{68}Se and ^{72}Kr have been measured accurately at the Canadian Penning Trap and ISOLTRAP, as reported by Jason Clark and Frank Herfurth, respectively. Also, very detailed reviews on the r-process, both for experimental and theoretical aspects, were provided by Hendrik Schatz, Karl-Ludwig Kratz, as well as by Stephane Goriely and Gabriel Martinez-Pinedo.

10 Fundamental symmetries

Klaus Jungmann provided us with a highly interesting tour through the different possibilities we have concerning studies of fundamental symmetries and interactions at the current nuclear physics facilities and accelerators. A few of these subjects were specifically presented at the conference: T and CP violation was discussed by Jonathan Engel, correlations in beta decays by John Behr, and the unitarity of the CKM matrix by John Hardy. These experiments are all very difficult and not many of us are involved. However, they are important experiments and definitely should be very strongly supported at our facilities.

11 Radioactive ion beams and applications

Production methods and technologies for radioactive ion beams have advanced tremendously, leading to the success of many of the experiments presented at this conference. This subject was not reviewed at this conference. However, a few important new developments were presented. Piet Van Duppen, from Leuven, reviewed the current status and future developments of laser ion source technology for the production of radioactive beams. While in the past only the ISOLDE at CERN and Louvain la Neuve in Belgium were utilizing this technique, it is now becoming more common and several laboratories are adapting to it. Another important general development related to radioactive ion beam manipulation was presented by Guy Savard from Argonne. Applications, in small scale, were presented as well, but although they are important, they are normally not discussed in detail at this conference. In this connection, we enjoyed a presentation by Jose Benlliure on nuclear cross section measurements for transmutaion of nuclear waste.

12 Conclusion

In summary, this conference has shown that our field is indeed in good shape, and we have a very enthusiastic community. I would like to underline that theoretical efforts have been significant, and they are able to offer challenges for the experiments which I think are particularly important. We are living in exciting times, during which new facilities are developing throughout the whole world. There is great promise for an excellent ENAM 2008 conference in Poland.

Thank you.