THE 26TH MAZURIAN LAKES SCHOOL OF NUCLEAR PHYSICS: SUMMARY

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(Received January 20, 2000)

The Mazurian Lakes School of Nuclear Physics has over 30 years of tradition, and a well-earned reputation for excellence. As usual, its efficient organization, warm hospitality, interesting subjects, and outstanding speakers, accompanied by beautiful lakes and forests, sailing, wild mushrooms, and good weather, attracted participants from many different countries.

Unfortunately, this year the spirit of the School could hardly be the same, due to the sudden and unexpected death of Zdzisław Szymański.

The principal subjects at the 26$^{\mathrm{th}}$ School were:

- nuclear (nucleonic) matter at medium and high energies;
- the properties of hot nuclei;
- the structure of nuclei far from the stability line.

All three topics are relevant for astrophysics, while at the same time they are included in the set of problems which to date have not been adequately solved by nuclear physics. The exciting possibilities offered by cooperation between nuclear physics and astrophysics were demonstrated by interesting lectures on stellar processes, neutrino astronomy, and cosmic radiation.

Well aware of the Biblical injunction to "render unto Caesar the things which are Caesar's, and unto God the things which are God's," the organizers devoted the first two days to applications of nuclear physics in medicine, geology, archeology, and transmutation of elements. New experimental techniques in nuclear physics were also presented.

Problems and new solutions in nuclear cancer therapy were discussed in lectures delivered by Uli Weber, Fuminori Soga, and Per Hoff.

The history of X-ray and gamma ray therapy can be traced back to the end of the 19^{th} and beginning of the 20^{th} century, respectively. The first attempt at nuclear beam cancer therapy was mentioned (unofficially) in connection with Lawrence's mother's illness and his Berkeley cyclotron.

The basic problem for nuclear cancer therapy is to kill the tumor cells without unacceptable damage to normal tissue. For X-rays and gamma rays, the best solution seems to be rotation of the radiation source around the tumor location (the patient's bed). Neutron therapy, characterized by much larger linear energy transfer, presents similar problems in terms of damage to normal tissue.

For protons and heavy ions, the energy loss curves have a flat plateau in the high velocity region and a sharp peak near the end of the range, which opens up the possibility that the radiation damage can be in some sense "focused" at the tumor location. The "focal length" of the beam can be adjusted by varying the beam energy. A rotary gantry can also be used here, increasing the biological efficiency of the radiation.

One major problem is the cost of such treatment. In some scientific institutions, a certain portion of the accelerator time is made available for cancer therapy. In this situation the argument can be made that radiotherapy costs less than chemotherapy. In Japan, a specially dedicated heavy ion machine at the National Institute of Radiological Sciences works exclusively for medicine — which is, of course, the best solution, though it is also the most expensive.

As an alternative to nuclear beam therapy, tumors can be destroyed by targeting them with special α-active or β-active compounds. This promising — and far less expensive — therapy, which has been shown to be very effective in cases of diffuse cancer or brain tumors (such as glioma), is still mostly in the testing stage.

It should be mentioned in this context that in Japan, for example, cancer has been listed as the leading cause of death since 1981. The reason for this may lie in the rising level of environmental pollution, or in an inappropriate diet, but it is certainly also due to the great achievements made in other branches of medicine, especially cardiology, so that the mortality rate in specialties other than oncology has diminished considerably.

Different applications of nuclear physics were presented by two other speakers.

Wolfgang Kretschmer discussed new accelerator mass spectroscopy methods of ^{14}C dating and their applications in geology, environmental research, and archeology. Accelerator mass spectroscopy makes it possible to perform ^{14}C dating with greater accuracy, in a shorter time, and using much smaller quantities of material.

Wacław Gudowski explained the principles of modern alchemy. The transmutation of isotopes can today be performed efficiently by capturing spallation neutrons. The main goals here are deactivation of nuclear waste and the nuclear energy production of thorium. Both of these are matters of major importance for the future of the human race, since sooner or later energy production will necessarily have to turn to nuclear sources. Aleksander Polański presented the Monte Carlo simulations performed in that regard.

The achievements of nuclear technology are closely related to new methods of nuclear detection, particle accelerator techniques, and nuclear electronics. Maciej Kapusta discussed new scintillators. Anna Wysocka presented a 6 MeV liniac constructed for X-ray surgery, and Wojtek Skulski advertised the motto "digitize early!", which is a vital principle in the electronics of γ and particle spectroscopy.

This first, application-oriented part of the School's program was realized under the NATO umbrella (the NATO workshop), and was closed by a round table discussion led by Ludwik Dobrzyński and Jerzy Jastrzębski. The leading question was how to erase the syndromes associated with nuclear weapons and Chernobyl, and convince the general public that nuclear physics does not kill, but rather saves lives. Gudowski pointed out, for example, that in order to mollify anxious patients the word "nuclear" is frequently omitted in medical contexts. Nuclear magnetic resonance is called "MRI," or "Magnetic Resonance Imaging", and when the possibility of nuclear medicine is suggested the conversation often turns to palliative medicine instead.

Another round table discussion was devoted to new instrumentation and experimental methods for basic research. Great progress can be noted here: suffice it to mention, among many others:

- GREAT, the electron and recoil decay spectrometer for exotic and heavy nuclei (Peter Butler);
- FOPI, the multipurpose from-fragment-to-strangeness detector (Brunon Sikora);
- detection of the neutron skin and halo, and measurement of the deformation parameters in reverse kinematics with the (p,p') reaction on radioactive nuclei (Yorick Blumenfeld);
- the CELSIUS/WASA facility for high precision studies of rare processes in intermediate energy light-ion reactions (A. Turowiecki).

Dominique Durand, William Lynch, and Kazimierz Grotowski discussed the problems of medium energy (no subnucleonic degrees of freedom), heavy ion collisions, and the reaction mechanism and properties of the hot nuclei produced in this way. Such collisions are studied today with multidetector

4π systems. Although dominated by deep inelastic collisions, these reactions also reveal the existence of an intermediate velocity source (neck structure), which evolves into a highly excited participant region at higher collision energies. Considerable nuclear density variations (compression-decompression) are observed with sufficiently energetic and more central collisions. All decay modes, from evaporation to vaporization, have been observed in the deexcitation of the hot nuclear systems created here. The data reveal competition between the static and dynamic aspects, and accordingly pose a difficult challenge for theoretical description. Studying the properties of the hot nuclei produced in heavy ion collisions is the only test ground — though unfortunately an imperfect one — for nuclear thermodynamics. Although it appears that we are observing the nuclear liquid-gas transition here (spinodal decomposition?), the nature of the caloric (maximum temperature?) curve remains a problem, as do the critical phenomena observed in the region of the caloric curve, which lies very far off the expected critical point. Since some neutron enrichment of the gas phase has been observed, the significance of the isotopic spin degree of freedom in the equation of state remains an important question here.

The phases of nucleonic matter and the nucleonic equation of state (EOS) were explained by Jean-Paul Blaizot, who pointed out certain analogies: cold nuclear matter $\rightarrow$ Fermi liquid; pairing correlations $\rightarrow$ transition to superfluidity; hot matter $\rightarrow$ gas; and so forth. With increasing pressure and temperature, hadronic degrees of freedom emerge, and the picture becomes very complicated, though it becomes simpler again at $T \approx 200$ MeV (free quarks in the quark–gluon plasma). The nucleon–nucleon interaction, which is very important for the shape of the EOS, becomes no more than a correction in the neutron star, where gravitation dominates.

The very instructive and deceptively simple lecture delivered by Blaizot was balanced by the talk given by Wolfgang Cassing, who discussed the details of the EOS and its application in describing the nucleus–nucleus collisions in the extended Relativistic Boltzmann–Uehling–Uhlenbeck model (RBUU), which reproduces the experimentally-observed sideward flow data, as well as the rapidity and transverse mass distributions at AGS energies. This also suggests a transition from hadronic to string matter (dissolution of hadrons), given increasing energy.

One of the more important measurable parameters restricting the EOS is the compressibility of nuclear matter. Umesh Garg explained its relation to the isoscalar giant dipole resonances.

The emission of pions and kaons in the high (SIS) heavy ion energy range was described by Helmut Oeschler. Due to the high interaction cross section with nuclear matter, pions are continuously absorbed by forming the baryonic resonances, which subsequently decay again into pions. Thus pions emitted anywhere from the early stage until the very late stage of the collision can be used to time the heavy ion reaction. It can be demonstrated that high-energy pions are emitted during the early collision phase, carrying information on the reaction dynamics, while lower-energy pions are mainly emitted later, over a long time interval, and their energy spectrum has a slope that depends on the system's apparent temperature. This scenario is reminiscent of the prompt thermal emission of light particles in low-energy nuclear reactions.

Helena Białkowska discussed strangeness production in high-energy nucleus–nucleus collisions and the signature of quark gluon plasma. It is the ambitious goal of the modern high-energy physics planned for the Brookhaven RHIC machine to discover this signature. The lecture helped us to realize how difficult — though presumably not impossible — this task will be.

The internal structure of nucleons and mesons is determined by the strong interaction between confined quarks. Nucleon–nucleon forces originate in the tails of that interaction leaking out of the nucleons, via exchange of mesons. The internal structure of nucleons (baryon resonances) plays an important role as an intermediate state in nuclear interactions. An example of such influence was presented by Madeleine Soyeur, who described the contribution of the Roper resonance, N*(1440), in three-nucleon interaction and particle production in relativistic heavy ion collisions. She also pointed out how poorly we understand this resonance.

The coupling between the nucleon structure and nucleon–nucleon interaction may also work in the opposite direction. It was amazing to learn from Volker Metag how great an influence the presence of nuclear matter can exert on the internal structure of nucleons and mesons. Due to the *in medium* effects, there are changes in the widths and position of the mesons and nucleon resonances. The magnitude of these *in medium* effects is a function of the nuclear matter density, and has consequences for astrophysics (K condensation in neutron stars at $\rho \geq \rho_0$, for example, or the maximum possible mass of a neutron star). Quantitative investigation of the *in medium* effects has been rendered possible by the development of theory, and by improvements in experimental tools (such as the TAPS or HADES multidetector systems).

Karl Heinz Langanke presented stellar processes, most of them nuclear. We learned that although the standard nucleo-synthesis picture typically contains fusion reactions below Fe, and — for heavier isotopes — the sn, rn, and rp processes activated by a supernova explosion as well, it demands major modifications, due to improvements in star models and new astronomical observations. Under typical conditions, the rn-process path is located about 15–20 units away from the valley of stability, and demands detailed knowledge of the nuclear structure in that region of nuclei. The same is true for the *rp*-process. The weak stellar reaction rates are important in the pre-supernova collapse, and require large-scale shell model calculations. The "hot neutrino bubble" above a newly-formed neutron star in a Type II supernova is under consideration as a possible site for the nuclear *r*-process. The neutrino-induced reactions seem to be important both during and after the *r*-process. The Type Ia supernova, a thermonuclear explosion on a white dwarf in a binary system, also contributes to the nucleo-synthesis. Both the convection of matter and turbulence are important, especially in massive stars. The asymmetries observed recently in some supernova explosions suggest that models with axial symmetry (spherical symmetry) are not sufficient.

New ideas in stellar models require new information from nuclear physics. Some of this information could be obtained from the following lectures:

- Marek Płoszajczak, "Radiative capture reactions of astrophysical relevance"
- Krzysztof Rykaszewski, "Nuclear properties far off stability (near the proton drip line) and the *r*-*p* process"
- Wiktor Nazarewicz, "The physics of weakly bound nuclei"
- Pier Francesco Bortignon, "A description of nuclear excitations beyond the mean field"
- Wojciech Satuła and Stanisław Szpikowski, "Pairing in nuclei"
- Yorick Blumenfeld, "Inelastic proton scattering on radioactive nuclei".

In order to be successful, the new stellar models require the input of sufficiently accurate experimental data. This provided the topic of Gilles Bogaert's talk, dealing with the importance of nuclear reaction cross sections for understanding and interpreting nucleo-synthesis processes in static and explosive stellar scenarios. In the MEGAJOUL Project, focused laser beams will create a tiny amount of hot, dense plasma, simulating the conditions of the stellar environment, *e.g.* inside a red giant. This will enable measurements to be made of the reaction rates in a plasma at keV temperatures, and will take into account the screening effects of plasma electrons.

The enormous installations used today for astrophysical research were presented by Heinigard Rebel and Iliana Brancus (cosmic rays, the KASKADE project), and by Yuen-dat Chan (the Sudbury neutrino observatory).

As the summary such as this should not be to long, I would like to apologize for not mentioning many other excellent talks presented during the evening sessions, or the interesting poster contributions.

In the opening lecture delivered at the beginning of the School's first session, Andrzej Kajetan Wróblewski described the situation in physics as it stood at the beginning of the 20$^{\mathrm{th}}$ century. This proved to be the proper point of reference. The instruments available in the laboratories of Marie and Pierre Curie, or Ernest Rutherford, may look slightly ridiculous when compared to the gigantic installations required in contemporary nuclear physics. Yet these same instruments were very sophisticated in their time, especially when compared to the instruments used by Archimedes to study hydrostatics. The number of brilliant physicists and brilliant ideas is not necessarily proportional, however, to the sheer number of scientists working, or to the volume of the apparatus.

What are the prospects for the future, then? There is no easy answer to that question. When we look at a map of the Mazurian Lake District, however, and pinpoint the consecutive locations of the Mazurian Lakes School, we can clearly see that the chaotic trajectory of these various locations will finally find its attractor at Jaśkowo, on the estate of the School's Chairman, Professor Ziemek Sujkowski.