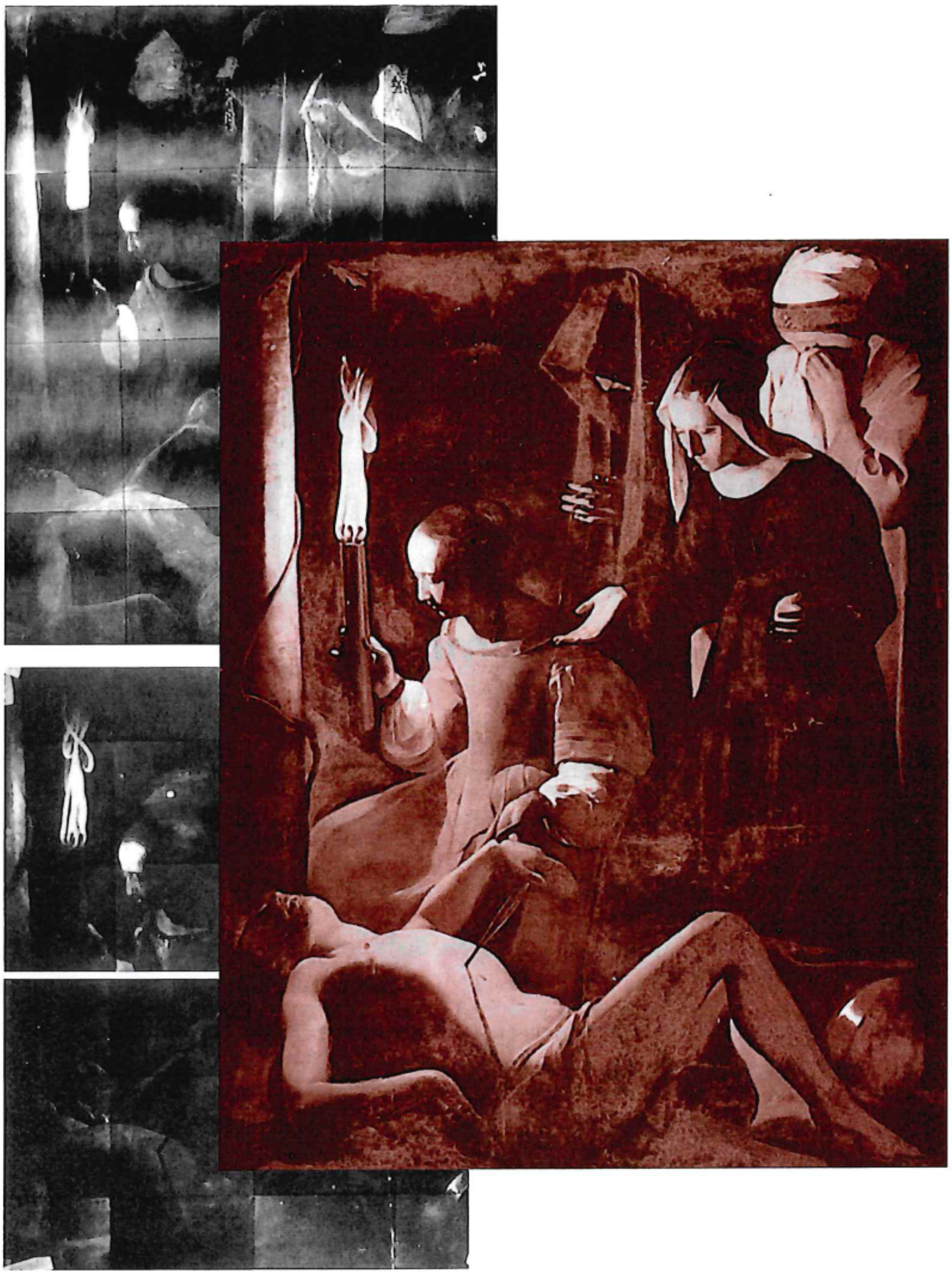

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From Exotic Nuclei and Phase Transitions in Hadronic Matter to Cancer Therapy

Heavy-Ion Research at GSI Darmstadt

K.D. Gross and H.J. Specht
(GSI, Darmstadt, RFA)

The Gesellschaft für Schwerionenforschung (GSI) in Darmstadt is the German National Laboratory for heavy-ion research, funded by the Federal Government and the State of Hessen. The research centre has about 700 employees including 300 scientists and engineers. GSI operates a large accelerator complex consisting of the linear accelerator UNILAC, the medium energy synchrotron SIS, and the storage cooler ring ESR (*Figure 1*). Heavy-ion beams of all elements up to U with energies from the Coulomb barrier up to 2 GeV/u can be provided. In addition, cooled stable and radioactive beams as well as highly charged ions up to bare U are available. The accelerators are complemented by several large spectrometers and advanced detector systems that offer unique opportunities for basic research in nuclear and atomic physics, and also for application-oriented studies in the fields of plasma physics, materials research, biophysics and radio therapy.

GSI is a user facility with primarily external users. The laboratory at Darmstadt has thus become a focal point where scientists from both domestic and foreign universities and other research institutions collaborate. There is, in particular, a vigorous German-French exchange programme ongoing between researchers from GSI and the institutes of IN2P3 and CEA. On an international level, cooperation also exists with CERN and other leading heavy-ion laboratories in Europe, the US, the CIS, and Japan. Within the EC programme "Training and Mobility of Researchers" (TMR), GSI was accepted as a large scale facility for nuclear research which has further enhanced the European participation in research projects at GSI. Altogether, there are more than 1000 scientists from over 150 institutes in 25 countries participating in the research and development work conducted in Darmstadt.

The central focus of the GSI research programme is on nuclear physics, comprising more than half of all investigations. This programme can again be divided into two branches: the investigation of nuclear structure far off stability on the one hand, and the study of hadronic matter on the other.

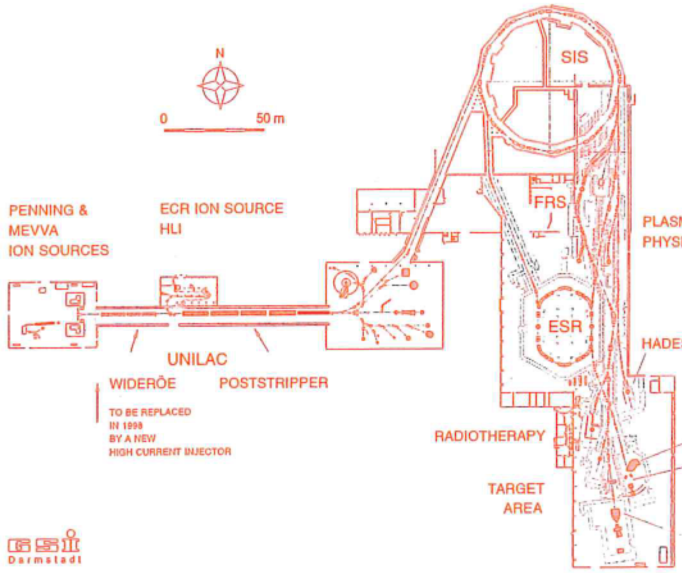

Figure 1 : Plan view of the GSI accelerator and experimental facility. The UNILAC delivers beams of any ion species up to U with energies reaching up to 15 MeV/u. Using two ion-sources, two different beams can be provided in a time-sharing mode, one of which is used for the low energy programme in the adjoining experiment hall, and the other of which is injected into the synchrotron SIS for further acceleration. In the SIS, the ions reach energies of 1-2 GeV/u, before being directed to experiments at the Fragment Separator FRS, the storage cooler ring ESR, or the various experimental areas.

Extremes of Nuclear Structure

In the area of nuclear physics, investigations into extremes of nuclear structure play a major role in the GSI programme. The most prominent example from this research is probably the search for super heavy elements. Indeed, with the synthesis and the discovery of the six heaviest elements up to the element 112 — the latter raised public attention at the beginning of 1996 — GSI is at the forefront of experimental efforts to expand the periodic system and nuclear chart upwards [1]. The discovery of element 112, however, not only marked a new record, but also, by the details of its decay chain, gave new experimental insight into the nuclear structure of these very heavy nuclei (*see Fig. 2 in the article of P. Armbruster in this issue*). Theoretical models predict an increased stability of deformed nuclei with neutron number N = 162 and proton number Z = 108. This was confirmed by the decay chain for element 112 which reflects decreased alpha energies and a drastic increase of the lifetimes below element 110. The results confirmed the optimistic expectation for further progress in the realm of the heavy elements. Thus the year 1997 will witness strong efforts to synthesize and detect still heavier elements. Some 30 years after first speculations on the existence of shell stabilized nuclei around the element 114, their discovery would be a great triumph of nuclear structure physics.

Besides super-heavy elements, i.e. nuclei with extremely high Z values, the production and investigation of isotopes with extreme values of the isospin, i.e. with unusual ratios of the neutron to proton number N/Z, represents the other central topic of the nuclear structure research at GSI. The motivation for studying such exotic nuclei is twofold. First, the existing models on the properties of nuclei can only be refined by looking beyond the range of stable isotopes and taking into account the largest possible spectrum of nuclei present in the universe. Second, it is known that the synthesis of all elements, especially the heavier ones, occurs via complex processes in the interior of stars involving exotic nuclei as intermediate products. These nuclei decay — in most cases by β-decay - until the stable isotopes known to us on earth are left. Thus the formation of chemical elements and their abundance are essentially determined by the properties of these exotic nuclei.

The SIS accelerator in combination with the Fragment Separator and the storage cooler ring ESR offer unique opportunities for this kind of research. Using the methods of nuclear fragmentation and Coulomb dissociation, exotic nuclei of all elements throughout the periodic table are being created and then separated by the Fragment Separator according to nuclear charge and mass. To date, apart from the six heaviest elements, some 200 new isotopes have been discovered at GSI. Amongst them are the long-searched doubly magic nuclei ^{100}Sn identified in spring 1994[(2)] (almost simultaneously with an experiment at GANIL) and ^{78}Ni discovered in 1995[(3)]. These doubly magic nuclei far off stability provide a critical testing ground for the validity of existing nuclear models. For ^{78}Ni, there is in addition a strong astrophysical relevance, since this nucleus plays a crucial role in the nucleosynthesis of the elements heavier than Fe.

Of particular interest are also isotopes at the proton — and neutron - drip lines, i.e. with such an excess of protons or neutrons that spontaneous proton or neutron emission occurs. On the proton-rich side this line could for the first time be reached in 1982, when proton-radioactivity in ^{151}Lu was discovered at GSI. Again on this proton-rich side, a new record was established at GSI at the beginning of 1996. With the discovery of ^{45}Fe and ^{49}Ni, isotopes with an isospin $T_z = -7/2$, i.e. a neutron to proton excess of $Z - N = -7$ were produced for the first time[(4)]. According to theoretical predictions, these nuclei should decay by two-proton emission, which, however, remains to be demonstrated experimentally. The discovery of ^{49}Ni also raises the exciting question whether even ^{48}Ni with the doubly magic configuration $Z=28$, $N=20$ and $T_z=-4$ can be reached.

To study the properties of these exotic nuclei, the beams of unstable particles can either be directly used for experiments or transferred to the ESR for storage and further manipulation of their beam properties. By electron cooling, it is in particular possible to drastically reduce their initially large momentum spread. This is a prerequisit for using the ESR as a sensitive mass spectrometer. Besides decay studies, mass measurements provide the most direct information on the stability of the nuclei under investigation. Using the

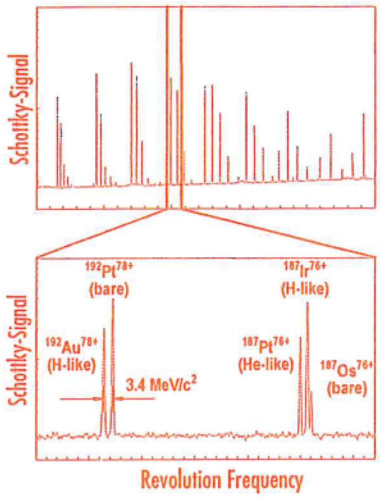

Figure 2 : Upper part: Schottky signals as a function of the mass-over-charge (m/q) difference for cooled fragments from a ^{197}Au primary beam. Lower part: The marked area was recorded with a smaller band width, thus allowing to resolve finer structures, which result from Au, Os, Pt, and Ir isotopes at different charge states.

so-called Schottky frequency spectroscopy, this can be achieved with high accuracy at the storage ring. The unstable nuclei stored and cooled in the ESR circulate at exactly the same velocity. However, in as far as their masses differ, they travel along different paths and have different periods of revolution. The mass of a certain nucleus can thus be determined directly from its revolution frequency.

The Schottky analysis is an extremely efficient and sensitive method for mass determination. For more than 280 nuclides covering a wide region of the chart of nuclei, the masses could be measured in only two experimental runs using primary ^{179}Au and ^{209}Bi beams, respectively (*Figure 2*). For 90 of those nuclides the masses were determined for the first time [(5)]. The precision of the method is of the order $\Delta m/m \approx 10^{-6}$, and for very low intensities, it can be improved towards the 10^{-7} region. This is another advantage of the Schottky technique that, in particular for high Z ions, extremely few particles down to a single ion can be detected. So far only isotopes with lifetimes $\gtrsim 20$ s were investigated due to the characteristic cooling times of about 20 s for electron cooling of hot fragments. To overcome this difficulty, a stochastic cooling device is presently being installed at the ESR which should allow to approach the lifetime region of a few seconds. Employing an alternative time-of-flight technique for mass measurement, it will even become possible to go much below this value towards lifetimes of the order of milliseconds and below.

These few examples already elucidate the richness of the nuclear structure investigations at GSI. A further boost will be given to this programme by the ongoing intensitiy upgrade, which includes the installation of a SIS electron cooler and the replacement of the Wideroe section of the UNILAC by a new high current injector. Thereby, the intensities can be increased for all ions up to the SIS space charge limit, which for U corresponds to about 10^{10} particles/s.

Hot and Dense Hadronic Matter

The study of nuclear or more precisely of hadronic matter under extreme conditions is the other major topic of nuclear research at GSI. Expanding on the work done at the Bevalac, a strong programme is ongoing at the SIS accelerator to investigate the properties of compressed and hot hadronic matter by heavy-ion collisions up to 2 GeV/u. Ultimately, these studies aim at an investigation of the equation of state for nuclear matter which beyond nuclear physics is also of astrophysical relevance, e.g. for an understanding of the properties of neutron stars or the dynamic evolution of supernova explosions.

Particular focus has been directed to the production and investigation of hot nuclei. Already two decades ago, the van der Waals behaviour of the nucleon-nucleon force inspired the idea of a liquid-gas-phase transition of nuclear matter. Despite enormous efforts, the experimental search for clear hints from this phase transition has, however, turned out to be extremely difficult. It was only last year that major progress was achieved from a systematic study of intermediate fragment formation in relativistic heavy-ion collisions.

The experiments were performed at the forward spectrometer ALADIN, exploiting peripheral collisions in inverse kinematics[(6)]. As a first important result, it was shown that heavy projectiles, such as Au or U, which were directed with energies of up to 1 GeV/u on various light and heavy targets, are so strongly heated in the course of the peripherial reactions that they disintegrate into different medium sized — so-called intermediate mass — fragments. Even more important, it could be demonstrated that this intermediate fragment formation does not depend on the details of the entrance channel, but is mainly governed by the energy transfer to the projectile remnant. This provides a strong argument that the observed multifragmentation arises from an intermediate state which is close to equilibrium, and for which the definition of a temperature is a reasonable concept. Finally, it has proved possible to simultaneously measure the energy content of the projectile remnant before disintegration and the temperature at the time of fragment formation. The energy content was deduced from the sum of the kinetic energy of the fragments and the binding energy that was required for the desintegration into these fragments. The temperature was determined from the isotopic composition, comparing the relative abundances of ^{3}He/^{4}He and ^{6}Li/^{7}Li isotopes.

By plotting the values thus deduced for the temperature versus excitation energy, a s-shaped curve reminiscent of the phase diagram of macroscopic fluids was obtained (*Figure 3*). The increase in temperature when the nuclei are heated is followed by a region of constant temperature at around 5 MeV — despite increasing energy content. Along this plateau, any energy added to the system is taken up in fragment formation. While the plateau was already well known from previous experiments performed by several groups, the ALADIN data showed for the first time that the temperature increases again at energy contents exceeding 8-10 MeV/nucleon, as would be expected in the case of a transition from the co-existence region to the gas phase.

The results obtained by the ALADIN collaboration are indicative of a first order phase transition — similar to the liquid-gas-phase transition of water. The discussion of the new data is, however, still far from being completed. In particular, the validity of the temperature measurement — as compared to alternative methods of temperature determination — is still a matter of controversial discussion. Further studies are needed, with alternative hadronic thermometers on the one hand and with larger system sizes on the other, to allow final conclusions on the existence of the long searched phase transition of hot nuclei.

The formation of still much hotter and compressed hadronic matter is investigated in central nucleus-nucleus collisions at energies up to 2 GeV/u. The space time evolution of such a head-on collision can be summarized as follows: For a time interval of a few 10^{-23} s the nuclear medium in the overlap zone is compressed to about 2 to 3 times its normal density. The system subsequently explodes in a collective expansion due to the repulsive nucleon-nucleon interaction at small distances. Besides temperature and compression, the initial energy of the colliding nuclei can also be partly converted into the excitation of individual nucleons in the collision zone. Being composite systems of quarks and gluons, the nucleons can be excited to shortly lived resonance states which subsequently decay by the emission of mesons or other radiation, such as γ-rays or electron-positron pairs.

Both, the dynamics of the exploding collision zone — the so called fireball region — and the production of mesons are being studied at SIS. The FOPI detector, which allows a complete momentum analysis of nearly all charged particles emitted during the reaction, is especially well suited for studying the dynamics of the expansion phase. A major result obtained by the FOPI collaboration was the first observation of the so called nuclear blast, i.e. the explosion of the fireball region[7]. These studies revealed that more than half of the energy of the colliding nuclei turns up again in collective expansion following the compression phase (*Figure 4*). Only

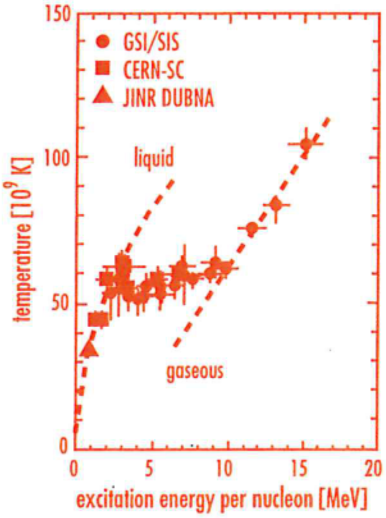

Figure 3 : Caloric curve of hot nuclei as deduced by the ALADIN collaboration. The s-shaped structure is suggestive of a first order phase transition of hot nuclear matter, reminiscent of the liquid-gas-phase transition of macroscopic fluids.

the remaining fraction of less than 50 % is available for heating or exciting the nucleons into resonant states.

Further insight came from studies of the meson production in central nucleus-nucleus collisions. At SIS energies, it is mainly the Δ resonance which is populated and which decays by the emission of π mesons. Measurements at the FOPI detector, the photon spectrometer TAPS and the magnetic spectrometer KAOS have shown that up to one third of the nucleons in the compression zone are excited to resonances for time intervals of several times the Δ half-life. Since at the same time the nucleon density is raised by a factor of 2-3, one can estimate that the Δ density in the fireball region comes close to that of normal nucleon density. The results are consistent with the formation of resonance matter, with strong interactions among the nucleons and resonances leading to several cycles of resonance

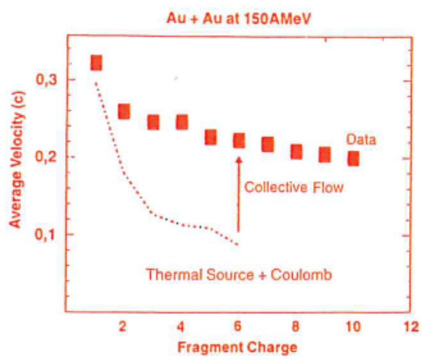

Figure 4 : Explosion-like expansion of nuclear fragments from a central collision of Au nuclei at 150 MeV/u. The nearly constant average velocity for all fragment charges (sizes) clearly deviates from prediction of a thermal model calculation and suggests a collective expansion of the fireball region, the so-called nuclear blast.

excitations and subsequent decays in the reaction zone.

The experiments performed so far have provided detailed information on the density, temperature and composition of hadronic matter formed in relativistic heavy-ion reactions. Such reactions are also regarded as an unique tool to study basic features of Quantum-Chromodynamics (QCD), the theory of strong interactions. According to theoretical predictions, a partial restoration of chiral symmetry — a fundamental symmetry of QCD which is broken under normal conditions — is expected at elevated nucleon densities and temperatures. Experimental signatures of such chiral effects include possible mass shifts of the vector mesons ρ and ω in the dense reaction zone. Vector mesons, especially ρ-mesons, are sufficiently short-lived to decay within the transient hot and compressed collision zone produced in a relativistic nucleus-nucleus reaction. Moreover, they can decay via lepton pairs which escape from the fireball region undisturbed by final state interactions. These features make the ρ and ω meson ideal candidates to investigate chiral effects in relativistic heavy-ion collisions. Studies of this kind have started at the CERN/SPS with the CERES-detector and will become a central part of the forthcoming nuclear physics programme at GSI. To this end, a high acceptance dilepton spectrometer named HADES is presently being set up at GSI by a large European collaboration. First experiments with this novel detector system are scheduled for 1998/99.

Precursor phenomena for chiral symmetry restoration, i.e. shifts of vector meson masses, are predicted to occur already at normal nuclear matter density. For normal nuclear matter, the effects are smaller, but can be calculated more reliably. Thus, experiments have been proposed to measure the ω meson in nuclei via its recoilless production in a π induced reaction. In contrast to heavy-ion reactions with its rapidly exploding collision zone, the ω meson produced recoil free via the p (π^-, ω) n reaction on a bound proton will experience the nuclear medium with constant normal nuclear density throughout its full lifetime. These studies are also part of the HADES programme, and will make use of the the π beam facility which is presently being installed at SIS.

In ultra-relativistic heavy-ion collisions, a transition from hadronic to a new phase of matter, the quark-gluon-plasma, including full restoration of chiral symmetry, is predicted. These investigations are of tremendous cosmological interest, since it is expected that such a phase transition occured in the opposite direction in the early universe some 10^{-5} sec after the big bang. In order to participate in this research, GSI has been one of the main promoters of the heavy-ion programme at CERN since its very beginning in 1983. As a pre-requisite of this programme, it took over the responsibility for the construction of the ion-injector, which for the first time allowed O and S beams to be injected into the CERN/SPS for acceleration up to 200 GeV/u. In the following experiment phase, GSI had a leading role in two larger experiments, NA35 and WA 80 (WA93). In 1990, a further essential step forward was made for the field. Together with other European laboratories, GSI developed a new injector for Pb beams, which allowed the heavy-ion programme at the CERN SPS to be extended to collisions of very heavy nuclei with energies up to 160 MeV/u. The Pb-beam programme started in fall 1994, and GSI again participates in two major experiments, NA49 and WA89.

With the ALICE project at CERN LHC, a fascinating perspective is opened up for this field. There, heavy-ion collisions will be investigated at centre-of-mass energies of up to 6 TeV/u. Being a member of the ALICE Collaboration, GSI is prepared to make a significant contribution to this ultimate experiment which will see first beams from LHC around 2005.

Precision Tests of QED with Highly Charged Heavy-Ions

In addition to nuclear physics studies, a strong atomic physics programme is going on, making use of cooled, highly-ionized beams up to bare U^{92+}. Particular focus is directed to precision tests of Quantum-Electrodynamics (QED) via measurements of the 1s Lamb-shift in hydrogen-like heavy atoms. The 1s Lamb-shift scales with a high power of Z, leading to a large value of 459 eV for U^{91+} as compared to 3.2 x 10^{-5} eV for the hydrogen atom. From recent experiments performed with U^{91+} ions stored in the ESR, this quantity was determined to be 470$\pm$16 eV (*Figure 5*)[8]. Although this result constitutes an experimental progress in accuracy of more than one order of magnitude compared to older Bevalac data, it is still not sufficient for a critical test of the theoretical prediction 459 $\pm$ 1 eV for which an ultimate accuracy of $\leq$ 1 eV will be needed. To reach this goal, a new detector system, composed of a crystal spectrometer and a bolometric detector device will be installed at the ESR. First experiments with this high precision spectrometer are envisaged for 1998.

In another experiment, also performed at the ESR, the ground state hyperfine transition of hydrogen-like $^{209}Bi^{82}$ — the analogue of the famous 21 cm line in atomic hydrogen — was investigated[9]. Probing especially magnetic terms, these studies provide a complementary test of QED in strong fields. The analysis of these data is, however, much more complicated, since QED and nuclear effects have to be disentangled with high accuracy. In order to achieve this, further measurements of the hyperfine splitting of nuclides adjacent to ^{209}Bi are being prepared.

As a future project for this kind of investigations, a trap for highly charged recoil

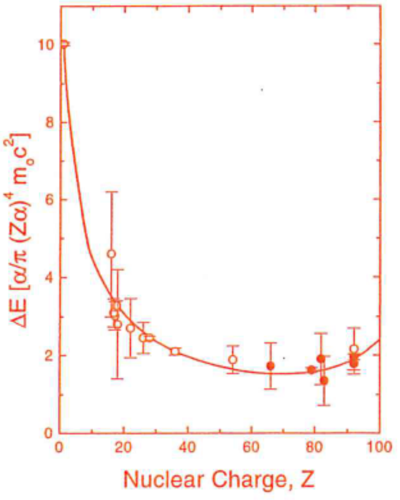

Figure 5 : Comparison of the 1s ground-state Lamb-shift measured for hydrogen-like ions with QED-theory. The full circles are new data from the ESR. With the high precision-spectrometer presently under construction, the experimental accuracy will be improved by another order of magnitude, allowing then a critical test of QED in strong fields.

ions has been proposed. Using such a device, it will then become possible to measure with high precision the g-factor of the 1s electron in hydrogenlike heavy atoms, which provides a further independent test of QED in strong fields.

Application Oriented Research

In addition to basic research, there is a strong application oriented programme ongoing, including the investigation of ion-induced dense plasmas, the modification and structuring of materials by heavy-ions, and biophysical and biological research on the effect of heavy-ions on cells and tissue including a project of cancer therapy with heavy-ions[10].

By focusing intense heavy-ion beams onto a solid target, very high energy densities can be created along the paths of the beam particles. This provides a unique tool for the production and study of hot

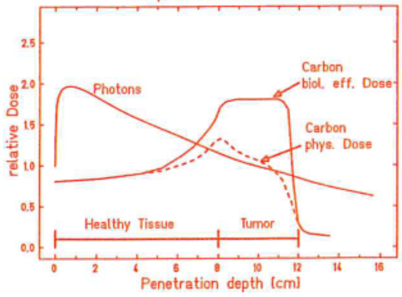

Figure 6 : Physical and biological dose distribution of a C beam as a function of penetration depth as compared to photon - irradiation. The enhanced dose towards the end of their range make heavy ions an ideal tool for the treatment of deep lying tumors.

dense plasma volumes. A recent highlight from investigations in this field is the observation of hydrodynamic expansion of a Kr-crystal bombarded with intense Ne beams. This programme will also considerably profit from the ongoing intensity upgrade at SIS, which allows an increase in the power densities generated, from presently 0.1 TW/g to values around 10 TW/g. Temperatures of $\approx$10 eV will thus be attainable. In conjunction with the high pressures of several Mbars and the large volumes of the generated plasmas, larger than those attainable by laser heating, this will open the door to yet unexplored areas of plasma physics. Besides basic research, these studies also include pre-explorations in pursuit of the long-term technological goal of heavy-ion induced inertial confinement fusion. In this connection, GSI, together with other leading laboratories in accelerator and plasma physics research, has established a European study group to assess the feasibility of such a heavy-ion ignition facility and to develop a coherent set of parameters for its realization.

The materials research programme is mainly devoted to a better understanding of the mechanism(s) of track formation caused by heavy ions penetrating into solids. There is, however, also a number of technical applications, such as the creation of microstructures by galvanic replication of etched tracks, the production of optical wave-guides, and the increase of the critical current densities of high T_c superconductors through heavy-ion bombardement.

The biophysical studies concentrate on a deeper understanding of the radiobiological damage caused by heavy-ion irradiation on a microscopic level, i.e. on the level of chromosome aberrations. The use of heavy-ions (and also of protons) for tumor therapy has principal advantages compared to conventional therapy with photons. Heavy charged particles show a sharp Bragg maximum in the energy loss towards the end of their range, which allows a much more favorable dose distribution (*Figure 6*). For heavy-ions, there is in addition an increased biological efficiency in the Bragg peak. Based on these features and on the development of novel irradiation techniques for a precise tumor-conform treatment, a major project in radio therapy was started together with the Radiologische Universitätsklinik Heidelberg, the Deutsche Krebsforschungszentrum (DKFZ) and the Forschungszentrum Rossendorf.

Within this project, a heavy-ion therapy unit has been installed at the SIS accelerator during the last three years. The central part of this therapy unit is the so-called rasterscan, which allows a three-dimensional control of the beam and of the applied dose. Laterally, the beam is steered by crossed magnetic fields. For a control of the penetration depths, the energy of the synchrotron and the following beam transport system can be adjusted from pulse to pulse, without changing the position and size of the beam spot within an accuracy of 1 mm. Starting next summer, about 70 patients per year will be treated at GSI to demonstrate the superiority of heavy-ions for selected medical indications.

Long Term Plans of GSI

In the last two and a half decades GSI has developed into an internationally recognized heavy-ion centre with a broad spectrum of activities ranging from nuclear physics studies to specific applications in radio therapy.

The ongoing programme, including the new projects — the intensity upgrade, the HADES experiment and heavy-ion therapy — will allow GSI to keep a leading role in the field of heavy-ion research well beyond the year 2000. How about the long-term perspectives beyond the next 10 years? To address this question, a major discussion process was initiated in the beginning of 1996. Several working groups with international membership have been established to investigate two major directions, on one hand an energy increase for the proton/heavy-ion beam in combination with an electron beam, on the other a further intensity increase by several orders of magnitude.

The first option, a proton-ion electron collider, would aim at a dedicated facility for studying QCD in the non-perturbative regime, e.g. the structure of hadrons, parton correlations, confinement phenomena, and the transition to the perturbative regime. Such a facility would offer a joint perspective for the research groups presently working in this field at hadron and electron facilities. The other option would aim at the production of extremely high proton/ion currents for a next generation radioactive beam facility. Beyond a further boost for the nuclear structure and nuclear astrophysics programme, such a facility should also open new perspectives for the investigation of dense plasmas, including conceptual prestudies for inertial confinement fusion. The working groups will present their results in a GSI workshop in January 1997. Their reports will form the basis for a decision which option should be pursued further towards a proposal for a new project. It is clear that in any case such a proposal should be unique on a world-wide scale and should also find unanimous European support ■

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Cinquième congrès "Plasmas" de la SFP

Le 5[e] congrès "Plasmas"' organisé par le Bureau de la section Plasmas de la SFP aura lieu à Autrans (Isère) les 5-7 février prochain. Le Bureau souhaite répondre à deux préoccupations essentielles :

- provoquer la rencontre et la communication entre chercheurs universitaires ou industriels exerçant leur activité dans un quelconque domaine de la physique des plasmas ou de ses applications ;
- faire participer à cette manifestation le maximum de jeunes chercheurs.

Pour tout renseignement concernant le programme du congrès et les modalités d'inscription, écrire à Jacques Derouard, 5[e] Congrès Plasmas de la SFP, Laboratoire de Spectroscopie Physique, Université Joseph Fourier (Grenoble I), BP 87, 38402 Saint-Martin-d'Hères Cedex.

XXIII International Conference on Phenomena in Ionized Gases (ICPIG)

La XXIII[e] édition de la conférence internationale sur les phénomènes se produisant dans les gaz ionisés se tiendra à Toulouse, du 17 au 22 juillet 1997. Le programme scientifique couvrira la plupart des sujets d'étude en physique des plasmas, avec une orientation plus spécialement marquée vers les plasmas de faible et moyenne température. Un workshop sur les applications industrielles de la physique des plasmas est également prévu le 19 juillet. Les participants sont invités à soumettre une contribution (2 pages maximum) avant le 30 janvier 1997. Le format à adopter pour l'écriture de cette contribution a été publié dans la seconde annonce de la conférence. Pour tout renseignement : M.C. Bordage, Secrétaire XXIII ICIPIG, CPAT, 118 route de Narbonne, 31062 Toulouse Cedex 4.
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