sions must be taken into account in order to explain the observed features. Further, radiative absorption and hydrodynamic effects may contribute to the observed deviations from the equilibrium populations. As these effects are of a general nature, they will be covered in a talk entitled *Rate Equations for Dense Plasmas and Their Applications.*

Highly-ionized species emit lines in the region of weak X-rays. Population inversion would therefore lead to light amplification in this wavelength region, which would provide an alternative to the free-electron laser for which a synchrotron is needed. Recent studies in this field will also be reviewed.

In laser-compressed plasmas, electron densities of the order of 10^{24}cm^{-3} have been obtained. The spectral lines of high-Z impurities (added for reasons of diagnostics) are broadened by the Stark effect, and a line shift occurs depending on the ion charge state and the electron density. A measurement of the shift and width or, if possible, the whole profile allows in principle the determination of the electron density. In addition to the electric microfields there can exist self-generated magnetic fields of the order of 10^2 to 10^3 T which also influence the line profiles. And finally the line profiles may be influenced by collective plasma oscillations. Reliable theoretical calculations of the profiles are necessary for diagnostic applications. This new field of application of line broadening will be reviewed and we shall hear how Stark and Zeeman effects may also influence other relevant plasma data such as dielectronic recombination coefficients and opacities.

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Atomic and Molecular Collision Physics

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For many decades, spectroscopic methods dominated research in atomic and molecular physics, quite overshadowing scattering experiments which, in contrast, held the stage in nuclear and particle physics. As a result, our knowledge of bound atomic and molecular systems developed much faster than that of unbound systems and important questions such as those relating to interatomic potentials or molecular reaction mechanisms remained without a final or proper physical answer. Only in the mid sixties did experimentalists learn how to master the severe problems inherent in low energy scattering phenomena, while the theoreticians, in their turn, developed the physical concepts necessary for understanding and computing the physical processes involved. The word "collision" — frequently used in this domain instead of "scattering" — underlines the complex character of these many body encounters. Since then, the field of atomic and molecular collisions has grown and spread at a prodigious rate.

In the following we pick out three characteristic topics around which discussions at Istanbul will revolve:

i) collisions of heavy atoms at very high energies
ii) lasers involved in low energy collisions
iii) the role of theory in atomic and molecular collision physics.

Collisions of Heavy Atoms at High Energies

This field was born when heavy ions could be accelerated to energies of several MeV per nucleon. At these energies, not only the colliding nuclei exhibit quite new and interesting features but also the electron clouds. Many of them may be understood in the picture of a quasi-molecule transforming into a quasi-atom by (more or less adiabatic) merging of the two electron shells around a common centre of charge $Z_1 + Z_2$ for some 10^{-20} s. *Europhysics News* reported on these new phenomena in an article by F.W. Saris and Yu. S. Gordeev (vol. 11 (1980) N° 1/2). We shall confine ourselves to those related to the very highest charges and energies.

When we enlarge in a gedanken experiment the central charge of an atom beyond $Z = 137$, strange things happen to the innermost electrons according to Dirac's theory: their spatial wave function shrinks tremendously with a corresponding increase in the high momentum components; the binding energy equals the electron rest mass around $Z \approx 150$ and reaches even the fermi niveau of the negative energy continuum at $Z \approx 173$ (calculated for a charge of nuclear dimensions rather than a point charge). Neither the electron self energy nor the vacuum polarisation are expected to prevent this "diving". Obviously, such atoms would be most desirable objects for investigating fundamental effects of quantum electrodynamics. Although they do not exist in nature, one may create them in a heavy ion collision for the short lifetime of a quasi-atom. At the present time, the experimental work on such quasi-atoms is focused on the following topics:

(1) Search for the so-called "spontaneous" positrons as a clear signature of the predicted diving process. Such positrons should be produced together with an electron when filling a vacancy of the united atom K-shell.

(2) Measurement of the vacancy production probability as a function of the internuclear distance in the collision, and additionally, a measurement of the emitted high energy electrons (δ-electrons). These should reflect both form factors and binding energies of the innermost electronic states.

(3) Investigation of the X-rays stemming from transitions into empty quasi-molecular orbitals; this X-ray continuum produced in very heavy ion-atom encounters reaches energies of many hundred keV.

Meanwhile, experiments have undoubtedly answered some questions, notably:

(a) The innermost electrons in quasi-atoms with $\alpha Z \geq 1$ can be excited at very small internuclear distances ($R < 100$ fm) with a probability falling off exponentially with distance.

(b) δ-electrons are emitted with measurable cross sections up to energies of several MeV.

Both findings, the small excitation region as well as the high momenta of the ejected electrons, confirm the idea of an extremely localized and deeply bound K-state in the quasi-atomic system. Thus, based on excitation probabilities and δ-electron energies, some kind of "spectroscopy" of such superheavy quasi-atoms could be established, although a precise determination of binding energies in the usual sense is obviously impossible.

Still the majority of questions remain without an answer: e.g. a clear "fingerprint" of the spontaneous positrons – and thus, of the diving – has not been obtained yet. One reason is the severe problem of disentangling the positrons that are undoubtedly observed, from others originating in different processes, especially those induced by the strong transient Coulomb field itself.

Recent results of several groups, however, show an unexpected energy distribution of the emitted positrons. A satisfactory explanation for this is not yet given.

Quasi-atoms formed in heavy ion encounters are presently the only objects allowing a glance into the hidden territory beyond $\alpha Z = 1$. They can be used to study the largest electric and magnetic fields ever produced, over regions of atomic dimensions. Thus, this field of research will remain a stimulating one in the future – at least so long as these "shadows" are not substituted by their counterparts, the stable superheavy atoms.

Lasers Involved in Low Energy Collisions

Tunable dye lasers have not only revolutionized optical spectroscopy, but also collision experiments which have profitted very much from their unique properties, leading to a fruitful merger of the two experimental fields. Over the past decade, lasers have been widely used for analytical purposes, that is to detect molecules in specific quantum states after a collision. The majority of this type of experiment have been done in the field of reactive scattering where one is interested in the internal level population of product molecules. More recently, lasers have been employed to prepare atoms or molecules in excited states before collision, to select single rovibronic states out of thermally populated closely spaced levels, and even to open up new channels via absorption of photons during the atomic or molecular encounter. As will be illustrated with a few examples, these experiments have led to a significant improvement in our understanding of important processes such as electronic to vibrational energy transfer, and the exchange of rotational energy.

The collisional transfer of electronic excitation energy to vibrational modes of a molecule has been studied in bulk gases for more than a decade. A comprehensive description of the transfer mechanisms had to await, however, the successful completion of molecular beam experiments. In these experiments, sodium atoms were excited in the crossing region of an atomic and molecular beam (e.g. N_2) with a dye laser to the 3p level. By measuring post collision velocity spectra of the Na atoms, the experiments proved that the E → V transfer was in general not a resonance process for the systems studied. The electronic energy was shared by all three degrees of freedom: vibrational, rotational and translational. Only for large molecules with many accessible states was the electronic energy transferred largely to internal degrees of freedom.

Another fundamental energy transfer process which lasers have helped to clear up is the exchange of rotational energy. A typical experiment is the following: using a quadrupole field to select a beam of LiH molecules in the rotational level $j = 1$, integral cross sections for various Δj transitions have been measured by monitoring with a laser the level population after passage of the molecules through a scattering cell. Characteristic differences were found in scattering from polar and non polar molecules. Differential state to state cross secion $d\sigma / d\Omega$ have been investigated in scattering Na_2 molecules from rare gas atoms. This time, lasers were used to prepare (in fact deplete) the initial state by optical pumping as well as to analyse the final state by fluorescence. Characteristic structures of $d\sigma / d\Omega$ such as rotational rainbows could be verified and thus the collision dynamics clarified; determination of anisotropic interaction potentials directly from such scattering data should be possible soon.

In a different type of experiment, lasers have been used to open up new channels that would be inaccessible without the presence of the laser field. A typical example is the laser induced switching of electronic excitation energy from Eu to Sr, or the collisional-aided ionisation of Cs by sequential absorption of two non-resonant photons in the course of collisions with Sr atoms. Another opening has also been observed in reactive scattering of K and $HgBr_2$. The important implication of these experiments is the prospect of controlling the outcome of an inelastic or reactive scattering process in a very specific predetermined way.

Now, that a number of key experiments have successfully introduced lasers into collision physics their increasing role in this field is easily predicted, as well as an expansion into the UV and IR.

Role of Theory in Atomic and Molecular Collision Physics

The past ten years have witnessed a tremendous growth in those areas of atomic and molecular physics which involve the study of collision phenomena as starting points for quite numerous and diverse fundamental processes. Cross-fertilisation between physics and other natural sciences has been particularly fruitful, molecular dynamics and chemical kinetics being the branches of chemistry which have most heavily borrowed the techniques of collision physics, while providing also a new wealth of problems.

The analysis of detailed pathways which provide channels for energy storing and energy partitioning in molecules undergoing reactive and subreactive scattering, to quote a prime example, has thus come a long way, moving from being a qualitative art, mainly "sensed" from indirect evidence collected by experiments in bulk, to a precise science that pinpoints several stages of the energy redistribution.

This particular "quantification" of our knowledge has also been greatly helped by the corresponding increased attention paid to the formulation of theoretical models and to the implementation of their use in numerical experiments. Theory has played a key role in low-energy (i.e. near-thermal) collision physics. The now numerous laboratories, in Europe and around the world, that carry out quite sophisticated and accurate experiments and which involve molecules and atoms colliding with ions, electrons, photons and neutral projectiles, all under special conditions of reagent state selection or final product analysis, are relying on the theoreticians who elaborate the relevant formal or computational treatments. Trends of behaviour in series of atoms or molecules are today very effectively used by theorists to uncover, among the unsuspected variety of measured phenomena, what one might call primitive patterns of understanding which afford the scientific community with a much more detailed and meaningful knowledge of atomic and molecular forces at play in chemical reactions, energy losses in surface scattering, astrophysical processes, plasma chemistry and other apparently quite unrelated areas.

The Symposium on Atomic and Molecular Collision Physics will highlight the crucial developments in that growing and diversified field.

Neutron Stars

C.J. Cesarsky, Saclay

The existence of neutron stars had been predicted as early as 1934 by Baade and Zwicky when astronomy was restricted to observations in the optical range. At present, the combination of advanced technology and of space exploration has enabled the astronomers to explore the sky over (almost) the whole electromagnetic spectrum, and neutron stars have actually been observed at a number of frequencies.

Neutron stars are formed in the centre of massive stars ($M_{\odot} > 5\text{-}7$ solar masses) at the end of their evolution. One possible scenario is as follows: as the star is steadily burning its nuclear fuel, a core of pure iron, of mass 1.3 to 2.2 solar masses, is formed in the centre. The core is so much denser than its surroundings that it is completely decoupled from them, and strongly resembles a degenerate star (white dwarf). It steadily contracts at a slow rate and eventually, when the density is $\sim 10^7$ g/cm^3, the Fermi energy of the degenerate electrons becomes so high, iron is no more the most favoured energy state. The nuclei start capturing electrons, so decreasing the degeneracy pressure of the electrons, at the same time undergoing endothermic photo-dissociation reactions, so lessening the ion pressure. The core then yields under the effect of its own weight, and in tenths of a second collapses. On bouncing back to its initial radius, the reflection sets up a shock wave which propagates outwards and blows up the stellar envelope: the star becomes a supernova, and the core a neutron star (see R.I. Epstein and C.J. Pethick, *Europhysics News,* **11** (1980), 12, p. 7).

For a typical mass of 1.4 solar masses (1 solar mass = 2×10^{33} g), a neutron star has a radius of only 7 to 20 km; its average density is of the order of, or higher than, the density of nuclear matter, $\rho_o = 0.17$ nuc.fm^{-3} = 2.8×10^{14} g cm^{-3}. A steep density gradient is required to maintain hydrostatic equilibrium. The outer layers form a crust, where the nuclei are arranged in a lattice, surrounded by free electrons, or, in the inner layers, by free neutrons. The inner boundary of the crust is at a density $\rho_c = 2.4 \times 10^{14}$ g cm^{-3}; beyond that point, the nuclei dissolve into a neutron soup, spiced with some electrons and protons.

The equation of state of very dense matter is, at present, quite uncertain. Depending on the short range behaviour of the nucleon-nucleon interaction, one can obtain stars made of "soft" matter or of "stiff" matter. At a given density, the interior pressure is higher in the "stiff" case, so that for a given mass the radius is larger. It has been conjectured that exotic phases of matter exist in neutron star interiors, one possibility being that, at densities higher than ρ_o, the pi meson field ceases to fluctuate around nucleons, and instead develops a non zero expectation value. This is the "pion-condensation" hypothesis, which leads to a soft equation of state, an enhanced cooling rate for the star, and possibly even to crystallization of the interior. Another possibility is to consider that, in highly compressed matter, the quarks are no longer confined in the nucleons, so that we go from a neutron to a quark soup.

Radiation Emission

When the neutron star is first formed, it is fantastically hot: its temperature may attain 3.10^{11} K. However, it cools down to $T \sim 10^9$ K in only a few hours, by emitting large amounts of neutrinos. After that, the cooling proceeds more slowly: standard nuclear theories predict that a surface temperature of 2-3 MK will be maintained for 10^4-10^5 years (depending on the stiffness of the equation of state). If the interior contains pion condensates or is made of quarks, the surface temperature remains at $\sim$ 1 MK for $< 10^4$ years. These results assume that the stellar matter undergoes no further heating whereas in practice, as the crust and the interior of the star are rotating at different rates, there will be some heating associated with the dynamical friction between the two components. In addition, the polar caps of the star may be heated by the bombardment of fast particles accelerated in the magnetosphere.

The hot surfaces of neutron stars emit thermal photons in the UV and the X-range and it is interesting to compare the luminosities predicted by various theories with observations of neutron stars of known age. At present, the most powerful instrument available in the relevant energy range is the X-ray imaging telescope aboard the Einstein Observatory (HEAO-2). This instrument has only detected steady emission from two neutron stars, and established an upper limit for a third. (It has also given upper limits for several as yet undetected neutron stars which may exist in young supernova remnants; but we are not sure that all supernova explosions leave neutron stars behind). The present results are compatible with the predictions of any of the cooling scenarios, but the next generation of instruments — the Space Telescope in the UV, AXAF in X-rays, and others — may be able to collect more information on the surface of neutron stars.

Pulsars

If the sun contracted to the radius of a neutron star while conserving its angular momentum, and the magnetic flux through one hemisphere, it would rotate with a period in the range of 10^{-3}s and have a surface magnetic field of $\sim 10^{12}$ gauss. When Hewish and his collaborators, in 1968, first