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

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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 ($M_{\odot} > 5$-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 ~ 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 observed pulsating radio-sources with a very short and steady period, they interpreted it as emission of beamed radiation from a rotating neutron star — a "pulsar". Since then, about 300 pulsars have been discovered, with periods ranging from 33 ms to 5 s. The rotation period increases with time at the rate predicted by Pacini (1967) who assumed that the star has a dipolar magnetic field, of strength $\sim 10^{12}$ gauss at the surface of the star, and that it is shedding angular momentum by steadily emitting magnetic-dipole electromagnetic radiation. His calculation assumed that the star is surrounded by vacuum but we now know that it has a magnetosphere. Nevertheless, the decelerating torque on the star, though due to other processes, is of the same magnitude as given by the vacuum dipole formula.

The problem of the structure of the pulsar magnetosphere is also very complex, and has not yet been satisfactorily solved — except in perhaps the least exciting case, that of inactive pulsars. Active pulsars, which emit incredibly coherent radio radiation, and in some cases also optical light, X-rays and γ-rays, must be accelerating particles to relativistic energies. In present models, the acceleration occurs in "gaps" which are empty regions close to the polar cap of the star, or along the magnetic field lines connected to the poles, where DC electric fields, parallel to the magnetic field, can be maintained for more or less long times. The voltage drop across such a gap can attain 10^{13} V. Electrons, accelerated by the electric field along the curved field lines, emit γ-rays of curvature radiation (just like relativistic electrons spiralling around field lines emit synchrotron radiation). The γ-rays in the strong magnetic field produce electron-positron pairs, increasing the supply of particles to be accelerated. It is possible that the fast electrons streaming along field lines tend to "gather in bunches" which emit coherent radio-radiation. Other models assume that the high energy radiation is emitted at the light cylinder, i.e. at the distance from the star axis at which the rigid body rotation velocity becomes equal to the velocity of light.

Binary Systems

Neutron stars have now been observed in another context notably when they are part of a binary system. Matter from the stellar companion keeps falling on the surface of the neutron star and, as it hits the surface, its considerable kinetic energy is transformed into heat, giving rise to the emission of large fluxes of X-rays. Because the infalling matter has so much angular momentum, it forms a disk in the orbital plane, and slowly spirals in. Of the 100 strong galactic X-ray sources known, 16 at least involve a neutron star in a binary system. The rotation period of the neutron stars, in this case, decreases with time, as the neutron star is spun up by the infalling matter.

In the spectrum of one of these systems, Her XI, a line is clearly visible at 58 keV. It is attributed to cyclotron resonance and has led to the first measurement of the surface magnetic field of a neutron star; the value obtained is in excellent agreement with the early predictions. Recently, a similar line has been observed in another type of system; namely in the spectrum of transient sources, called "gamma-ray burst sources", which only shine for a few seconds. Such γ-ray burst sources are probably also neutron stars, which are accreting matter — but, it could be mentioned, only from the interstellar medium. Other, softer, transient sources, the "X-ray bursters", are also believed to be associated with neutron stars; the accreted matter can attain such high temperatures and densities that thermonuclear reactions take place on the star surface.

Finally, we should mention the famous "binary pulsar", where a pulsar is separated from its companion (probably another neutron star) by only $\sim$ 1 solar radius. After several years of careful observation of this system with the Arecibo telescope, Taylor and his collaborators have found that the orbital period of the system (7.75 h) increases at a rate of 10^{-4} s/an: this result is exactly as predicted by the theory of general relativity. Thus, neutron stars have led to the first (though indirect) detection of gravitational radiation, and have become a powerful tool for the testing of post-newtonian gravitation theories.

These are just some of the topics which will be discussed at the Symposium on Neutron Stars, at the Istanbul Conference.

Heavy Ion Collisions

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One of the most active domains of nuclear physics is that of heavy ion physics, where a large amount of new information has been obtained in the recent past and more can be expected as new and powerful accelerators come into operation. From the experimental data already available, simple and general trends characterizing heavy ion collisions, can be extracted. These suggest new fundamental concepts and help in the construction of models through which phenomena can be studied. The field of heavy ion physics is rich indeed, and provides us with the means for producing new nuclei with large numbers of neutrons, nuclear matter of very high density or very high angular momentum, new reactions such as deep inelastic processes, etc...

The study of a system comprising two heavy ions in collision involves the treatment of a finite, strongly interacting fermion system which is far from equilibrium. It is clear that such a complex system is not large enough to be described entirely by classical statistical mechanical methods, and yet is too far from equilibrium to be covered by the usual microscopic methods of many body theory which are very successful at, or near, equilibrium. However, it can be hoped that both concepts will be helpful in understanding the main features of ion-ion systems as they can exhibit some properties which are typical of a classical infinite system, and others more relevant to a quantal finite system.

Theoretical Treatment

As the microscopic one body mean field picture (Hartree-Fock) of a nucleus at equilibrium, and the small amplitude vibrations picture (RPA) of collective nuclear states near equilibrium, have been so successful in describing many nuclear properties, it is natural to attempt a description of ion-ion collisions by extending these pictures. This is achieved by the time-dependent Hartree-Fock (TDHF) method, which describes the system as a "one body system" in which each independent nucleon interacts with a time-dependent mean field. The solutions of the static Hartree-Fock equations, which describe so well the nuclei at equilibrium, are special solutions of the TDHF equations. On the other hand the RPA picture of collective vibrations around equilibrium, can be derived as the small amplitude limit of the TDHF approach, which provides us with a microscopic description of heavy ion collisions. This relates the complex phenomena to the nuclear ground state and near equilibrium properties.

Once the TDHF problem has been solved, information on the collision: energy loss, mass and angular momentum transfer etc... are extracted, which can be compared to experimental data. The results should help us to derive or justify, macroscopic models of ion-ion collisions which are more tractable as they retain the mean field aspect of the collision but contain only