a re-write rule acting on a 4-letter alphabet, the Rudin–Shapiro sequence. He also wondered if the well-known phenomenon of Shape Memory Effect (SME) observed in the Ni–Ti alloy, the Nitinol marmem, where a large-scale plastic deformation (phenotype) gets encoded into its microstructure (genotype), suggests a kind of allelogenetic regulation – Lamarck's ghost!

The discussion meeting concluded with holding a general-body meeting of members of the Indian Complex Systems Society.

N. Kumar, Raman Research Institute, Bangalore 560 080, India

Bose condensation and the atom laser

R. Srinivasan

The fundamental constituents of matter have an intrinsic quantum mechanical property called the spin. The elementary particles, proton, neutron and electron each have a spin angular momentum of 1/2 in units of $h/2\pi$, where h is the Planck's constant. An atom consists of a nucleus and some extra-nuclear electrons. The nucleus will have a spin depending on the total number of protons and neutrons in the nucleus. Some of the protons will have a spin pointing in one direction (i.e. +1/2) while others will have a spin pointing in the opposite direction (–1/2). The same holds for neutrons and extra-nuclear electrons. The sum total of the spins of all the particles in an atom will have some value which will be integral or half integral. Since isotopes contain different number of neutrons, but the same number of electrons and protons, the total spin of two different isotopes of the same element can be different.

In a gas, a liquid or a solid, many identical atoms are put together. In a gas the interaction between the atoms is weak as the inter-atomic separation is large. In a non-interacting gas, one may consider the total quantum mechanical state of the gas to be made up of a product of individual one-particle states. The behaviour of the many body quantum mechanical state when two of the indistinguishable atoms are interchanged will depend on the total spin of the atom. If the total spin is zero or an integer multiple of $h/2\pi$, then the many body wave function will not change when two atoms are interchanged. One consequence of this property is that any given single particle quantum state can be occupied by any number of particles in the system. Such a system is described by Bose statistics, first postulated by S. N. Bose. On the other hand if the atom has half integral spin then the many body quantum mechanical wave function will change sign when two atoms are interchanged. In such a case a given quantum mechanical one particle state can only be occupied by zero or one particle in the system. Such a system obeys the Fermi–Dirac statistics. At very high temperatures the two statistics approach in behaviour classical statistics proposed by Boltzmann. However at low temperatures the two different quantum statistics predict different behaviour. In Fermi–Dirac statistics, at absolute zero all quantum states with an energy lower than a certain value E_F are occupied, each by one particle. All states with energy greater than E_F are unoccupied. On the other hand in Bose statistics as the temperature is reduced, more and more particles can get into the one-particle ground state. This becomes an avalanche below a certain temperature T_c called the condensation temperature. Below T_c a macroscopic fraction of the number of particles occupies the ground state and this fraction increases as the temperature is lowered below T_c. This is a phase transition and is accompanied by a change in the specific heat at T_c. This transition is similar to condensation in real space, though the condensation in the Bose gas occurs in phase space consisting of the position coordinates and the momentum components of all the atoms. This distinctive feature of Bose statistics was pointed out by Einstein.

Experimental attempts to see Bose condensation in a gas failed because at the densities prevalent under normal pressure, there is an attractive interaction between molecules of a gas. This attraction is strong enough to cause a vapour-to-liquid-phase transition to occur before the Bose condensation temperature is reached. In a dense liquid in which intermolecular interactions are strong, the theory of Bose condensation between the quasi-particles is considerably modified. The superfluid transition seen in liquid ^{4}He at 2.17 K is believed to be due to Bose condensation, though no satisfactory quantitative theory has yet been worked out to account for the properties of superfluid ^{4}He.

To observe Bose condensation in a weakly interacting gas, one uses atomic vapours. In atomic vapours, two conditions are required: namely that (i) the density of the vapours be low (10^{11} to 10^{14} atoms/cc) to reduce considerably the interatomic interactions, and (ii) the vapours be cooled to temperatures below T_c which, at the above mentioned densities, is usually below 1 μK. Obviously such vapours have to be produced in ultra-high vacuum (pressure $\approx 10^{-9}$ to 10^{-10} mbars). To cool these atoms, one uses lasers. When the atoms are placed in a region in which appropriately tuned counter-propagating laser beams in three orthogonal directions meet, absorption and re-emission of the photons cause the atoms to lose their kinetic energy and to cool to a temperature of the order of 50 μK. Such an arrangement is called the optical molasses. To trap the atoms for a sufficiently long time and to cool them to the above temperature, one uses a magneto-optical trap. In this trap a small mag-

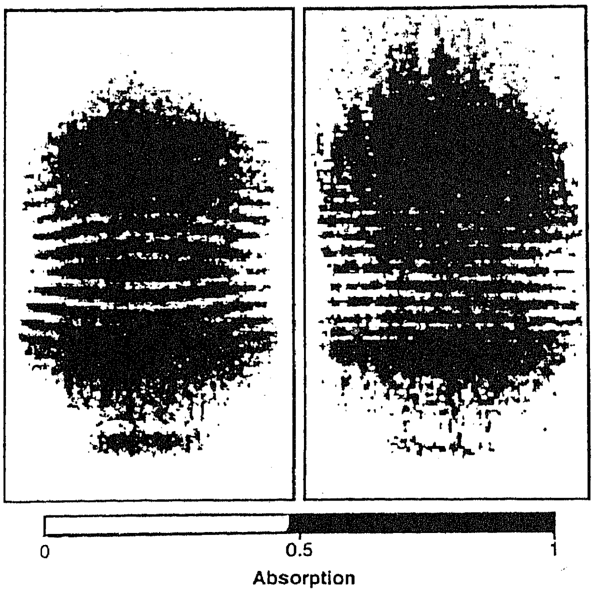

Figure 1. Interference pattern for two expanding condensates observed after 40 ms time of flight for two different initial separations of the condensates. The fringe widths are 20 and 15 μm (Reproduced from *Science*, 1997, **275**, 639).

netic field gradient is combined with laser beams of suitable circular polarization in the optical molasses configuration. The magnetic field gradient produces a differential absorption of photons from the counter-propagating beams and this results in a force confining the neutral atoms at the centre of the trap.

A temperature of ≈50 μK is still too high to observe Bose condensation. After switching off the laser beams, the atoms in the appropriate magnetic ground state are trapped in a magnetic field gradient. A suitable RF frequency is applied to switch the atoms to a different magnetic ground state which cannot be trapped by the magnetic field gradient. The value of the frequency will depend on the magnetic field. Starting with a high frequency and ramping down the frequency, atoms having a large kinetic energy are assisted by the RF to escape from the trap. The remaining atoms achieve a redistribution of their kinetic energy by interatomic collisions and reach a lower temperature. When the temperature falls below T_c appropriate to the number density and mass of the atoms, a large fraction of the atoms goes into the ground state. The ground state corresponds to that in an anisotropic potential and hence the atoms in the condensate should have an ellipsoidal spread. This Bose condensation has been seen by imaging the atoms by absorption of resonant fluorescent radiation. The first definite evidence for Bose condensation was obtained in the isotope ^{87}Rb by Anderson and co-workers[1] in 1995 using a time orbiting potential (TOP) trap. They had a maximum of 2000 atoms in the condensate when it was cooled much below the T_c of 170 nK.

Since then there has been considerable improvement in the techniques of magneto-optical trapping and magnetic confinement. It is now possible to produce Bose–Einstein condensates with 10^6 atoms. The magnetic trap used in the MIT, Cambridge, USA experiments is an Ioffe–Pritchard trap[2]. It is more anisotropic than the TOP trap. The trapped condensate looks cigar shaped in such a trap. By focussing an intense blue detuned laser beam from an argon ion laser at the centre of the trap, one can create two potential wells in which separate condensates can be formed. The separation between the condensates can be controlled by the power of the focussed beam. By removing the argon-ion laser beam and the confining magnetic field, the two condensates can be allowed to expand towards each other. This enables one to investigate the interaction between the condensates when they are allowed to overlap.

Coherence of the Bose condensate and an atom laser

It is believed that the Bose condensate will be coherent, i.e. the wave functions of all the atoms will have the same phase. But it is not clear if it will be so when the number of atoms in the trap is fixed. There were speculations that phase coherence will be lost due to inter-atomic collisions. The only way to find out if the condensate is coherent or not is to perform an interference experiment.

Consider two independent light sources. Since the photons are emitted at random by spontaneous emission in each light source, there is no coherence of the photons from such a source. When the light waves from the two sources overlap, there is no interference. The total intensity at any point is the sum of the intensities from the two light sources. In a laser, on the other hand, the atomic transitions are stimulated by the photons present. In stimulated emission the photons are in step. So the light beam from each laser is coherent though the phase of the light beam may be different in the two identical lasers. Similarly, the phase of the condensate will be different in the two condensates. However, if the two condensates move with a relative velocity v, then the deBroglie wavelength of atoms in one condensate relative to the atoms in the other condensate will be $\lambda = h/mv$. Because of this, in the region of overlap between the two condensates, the phase difference will vary with position. Where the two condensates are in phase, the total amplitude of the wave function will add. Where the two condensates are out of phase, the wave amplitudes of the condensates will annul each other. Since the density of atoms at any point is proportional to the square of the amplitude, one should have periodic variations in the density of atoms, with a spatial period given by $\lambda = h/mv$. The group at MIT did such an experiment[3]. They produced two cigar-shaped condensates of sodium atoms and allowed them to expand towards each other for 40 milliseconds after removing the trapping magnetic field. Using a probe laser beam tuned to the resonant transition of the atoms, they imaged the overlapping region in absorption. Locations where the atomic density was large were imaged as darker regions and locations where the density was low were imaged as lighter regions. They observed such interference patterns. The spatial period of the interference pattern was 20 μm when the two condensates were 32 μm apart. By varying the distance d between the condensates, they could change the velocity ($v = d/t$) and prove that the spatial period of the interference pattern corresponded to the deBroglie wavelength λ. This is a clear demonstration that the Bose condensate has a definite phase and that the phase is robust.

In a photon laser there is a cavity resonator in which stimulated emission takes place and the photons are in phase. However for applications as a laser, it is necessary to bring out a fraction of the coherent photons out. In a laser, the mirror at one end of the cavity achieves this by partially transmitting the coherent beam of photons. If we want to build an atom 'laser' (i.e. a source of coherent atomic beams) we must devise a technique to couple out from the trap part of the coherent atoms in the condensate. The MIT group achieved this by using a suitable RF pulse[4]. The RF pulse couples the atoms in the magnetically trapped state of the condensate to other magnetic states which are not trapped. These atoms, originally derived from the coherent condensate, leave the trapped region. By an interference experiment, it was shown that a beam of such atoms coupled out of the trap is coherent. Thus the Bose condensate with a suitable output coupler has successfully resulted in an atom laser, albeit a primitive one.

With such an atom laser, one will be able to study phase coherence and superfluid behaviour over a range of particle densities not accessible with liquid ^{4}He. However for such applications one will have to increase the flux and simplify the design. The applications of such atomic beams will most probably be in precision measurements of fundamental constants, atomic clocks, etc.

1. Anderson, M. H., Ensher, J. R., Mathews, M. R., Wieman, C. E. and Cornell, E. A., *Science*, 1995, **269**, 198–201.
2. Mewes, M. O., Andrews, M. R., van Druten, N. J., Kurn, D. M., Durfee, D. S. and Ketterle, W., *Phys. Rev. Lett.*, 1996, **77**, 416–419.
3. Andrews, M. R., Townsend, C. G., Miesner, H. J., Durfee, D. S., Kurn, D. M. and Ketterle, W., *Science*, 1997, **275**, 637–641.
4. Mewes, M. O., Andrews, M. R., Kurn, D. M., Durfee, D. S., Townsend, C. G. and Ketterle, W., *Phys. Rev. Lett.*, 1997, **78**, 582–585.

R. Srinivasan is in the Raman Research Institute, Bangalore 560 080, India.

SCIENTIFIC CORRESPONDENCE

Glutathione-s-transferases activity in *Macrobrachium lamarrei lamarrei* during embryonic and larval development

Glutathione-s-transferases (GST, EC 2.5.1.18) are a group of multifunctional enzymes considered to play a vital role in the protection of cells against oxidizing metabolites. They enhance the nucleophilic attack of glutathione on the electrophilic centre of a wide array of lipophilic molecules[1,2] and are involved in the reduction of organic hydroperoxides (selenium-independent glutathione peroxidase activity)[3]. The GST activity is well documented in vertebrate species[4], amphibians[5] and fishes[6]. A limited number of studies have been made on the activity of GST in invertebrates[7,8]. The principle activity of this enzyme, in particular, during embryonic development remains uncertain. Since the young ones are fragile and extremely susceptible to any small change, they should have some intrinsic mechanism to overcome this change. Such a protective mechanism may include the expression of GST. Thus the detoxifying enzyme is quantified to understand how the aquatic animals develop to defend themselves against environmental evils right from the embryonic stage.

Many works are available on these detoxifying enzymes in hepatic and extra hepatic tissues of different animals including man, during foetal and postnatal development[9–12], but little is known about the level of this enzyme during embryo development and their possible changes occurring in the transition from embryonic to adult life[13–15]. The present investigation, therefore, was made to understand the specific activity of GST in the passage from embryonic to adult. In this regard the cytosolic fraction prepared from different stages of development such as egg, embryo, larvae and adult tissues of freshwater prawn *Macrobrachium lamarrei lamarrei* was studied.

The adult freshwater prawn *M. lamarrei lamarrei* was collected from Gundoor pond near Tiruchirappalli, India. The ovarian development and spawning were allowed to take place in the laboratory. The spawned mother incubated the eggs in their brood chamber. The developing eggs of *M. lamarrei lamarrei* were grouped into five different stages following the colour variations[16]. Cytosol preparation of developing eggs, embryo and freshly hatched larvae, adult hepatopancreas, gill and muscle were obtained from the homogenization of 1 g sample of each type of tissue. Six replicate samples from each tissue were suspended in 5 ml of 0.1 M sodium phosphate buffer at pH 7.0 and homogenized. The homogenates were centrifuged for 60 min at 105,000 g. The