Experimental Devlopment of Dilute atomic Bose-Einstin Conduration

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Introduction

In 1925, Albert Einstein showrd theoretically that a phase transition occurs below a critical temperature for a system of identical, non-interacting particles. Usuallythe temperature of a sample corresponds to the average velocity of its atoms 02 modecules. However, there is always a distribution of particles moving faster or slower. In a Bose-Einstein condenste (BCE) this characterstic, distribution vanishes. Instead, a large number of atoms in the sample are narly at rest. They constitute the BCE. The sample remains in gaseous state. Hence, it is not a usual phase transition from gas to liquid or a solid.

Einstein's result can be explained in terms of wave nature of matter i.e. each atom can be regarded as wavepacket with a size determined by its temperature. During cooling process, the atomic wavepackets grow & start to overlap at a certain temperature. At tihs point, the statistics of particles that can occupy the same quantum state, the so-called bosons, predicts that atoms accumulate in the lowest energy state of the system. They form a BEC. In this State, the ware nature of all particles becomes identical. Hence, all atoms have a distinct phase Relationship, a property often called coherence.

Einstein made his predictions based on work by S.Bose (1924), who had developed the statistics of bosons in 1924. It took physicists 1995 to produce BCE in dilute atomic gases (Anderson et at. 1995; Bradely et at 1995; Davis et at. 1995; Fried et at. 1998; Robert et at. 2001; santos et at. 2001)

Bose-Einstein condensates in dilute atomic gases, which were first realise exprimetally in 1995 for Rubidium, sodium & lithium provide unique opportunites for exploring quantum phemomena on a macroscopic scale. These systems differ from ordinary gass liquids & solids in a member of Respect; The particle density at the centre of a Bose-Einstein condensed atomic cloud is typically 10^{13}-10^{15} cm^{-3}. By contrast, the density of mokcules in air at room temperature & atmospheric pressure is about 10^{19} cm^{-3}. In liquids & solids, the density of atoms is of 10^{22} cm^{-3}, while the density of nucleans in atomic nuclei is about 10^{38} cm^{-3}. To obseruquantums phenomena in such low-density systems, the temperature must be of order10^{-5k} or less. This may be contrasted with the temperature at which quantum phenomena occuer in solids & liquids. In solids, quantum effects become strong for electrons in metals below the Fermi temperature, which is typically 10^4-10^5 K and for phonons below the Debye ttemperature, which is typically of order 10K. For the helium liquids, the temperatures required for observing quantum phenomena are of order 1K. Due to the much higher particle density in atomic maclei, the corresponding degeneracy temperature is about 10^{11}K.

The path that led in 1995 to the first realization of Bose-Einstin condensation in dilute gases exploited the powerful methods developed over the past quanter of century for cooling alkali metal atoms by issuing lesers. Since laser cooling alone cannot produce sufficiently high densities & low temperatures for condensation, it is followed by an evaporatine stagte, in which the more energetic atomsare removed from the trap, therby cooling the Remaining atoms.

Experimental Development

Now, we present a brief Review of experimental development within BEC field.

The first experiment after the realiration of BEC in the alkali gases focussed on the macrosacopic properties of the sample. There include the growth of condensate fraction as the temperature of the sample is lowered (Ensher et al. 1996) and the propagation of sound (Andrews et. Al. 1997). There experiments led to a better thieoretical understanding of the interaction between the condensate of the thermal cloud (Hutchinsan et al. 1998). Later experiments started to explore the quantum mechanical water of the condensate. The existence of will difined phase was demoustrated by intrfiring two condensates (Andriur et al. 1976) and prompted much debate about the nature of the condensate wavefunction (Castin and Dalibard 1997). The analogy between the coherence of BEC & laser light sparked on intrest in producing cowerent atomic beams (Mewrs et al. 1997), but later experiments produced coherence of BEC & laser light sparked on intrest in producing coherent atomic beams (Mewes et al. 1997), but later experiments produced continuous dreams of unlimited duration (hagley et al. 1999; Bloch et al. 1999), beautifully intrastating the concept of an atom leser. The challenge of repopulating the BEC to produce a sustained atomic beaur still has to me met. By loading a BEC into a dipole trap (Stamper-Kurh et al. 1998), it was demonstrated that laser-cooling techniques can be used to manipulate BECs. Populating an optical lattice (Anderson and Kaseuich 1998) with and Kasevich 1998) with a BEC has led to the observation of Josphsantype junctions between neighbouring lattice sites. The manipulation of BEC with laser light promises huge possibilities and has resulted in a number of recent publications (Deng et al. 1999; stamper-kurh et al. 1999). More recently, the field has foursed on the superfluid nature of bose condensates and the formation of wortices (Mathews et al. 1999; Madison et al. 2000; Abo Shaler et al. 2001). Recently more atomic species and isotopes have been condensed. Two experiments have succeeded in condensing metastable helium (Robert et al. 2001; Santos et al. 2001). The large quternal energy of the coherent atomic ensemble is of particular intrest for lithographic applications. The rubidium isotope^{85} Rb has been condensed (Comish et al. 2000) by exploiting a Feshbach sesohance at particular magnetic fields. In this system, the futeraction strength between atoms can be controlled accurately, allowing for a few livied of experiments of quartum degenerate gases (Roberts et al. 2000).

Bose-Einstein condensation in atomic clouds

Bosons are particlues eith integer spin. The ware function for a system of identical bosons is symmetric under intercharge of any teo particles. An order of magnitude estimate of the transition temperature to the Bose-Einstein condeused state may be made from dimensional arguements. For a uniform gos of free particles, the relevant quantities are the particle mass 'm', the member density 'n',and the plank constant 'h'=2IIh. The only evergy the can be formed t, n, and m is $t^2 n^{2/3}/m$. By dividing this energy by the Baltzmann constant k we obtain an estimate of the condusation Temperature 'Tc'.

$$Tc = \frac{t_h^2 n^{2/3}}{mk} \qquad (1.1)$$

Here C is a memerical factor. When (1.1) is evaluated for the mass and density appropriate to liquid use at saturated vapour pressure one detains a transition temperature of approximately 3.13k which is close to the temperature below which super fluid phemomena are observed, the so-called lambda point (T_h = 2.17k at saturated vapour pressure). An equivalent way of relating the transition temperature to the particle density is to compare the thermal de Broglie wavelugth at with the mean interparticle spacing wich is of order $n^{-1/3}$. The thermal de Broglie waerlenghth is conveintionally defined by-

$$yT = \left\{\frac{2IIt_h^2}{mkT}\right\}^{1/2} \qquad (1.2)$$

At hight temperatures, it is small and the gas behaver classically. Bose – Enstcin condensation in an ideal gassets in when the temperature is so low that it yT is comparalde to $n^{-1/3}$. For alkatiatoms, the densities achievedrange from 10^{13} cm^{-3} to 10^{14}-10^{15} cm^{-3} in early to recent experiments, with transition temperatures in the range from100hk to a few MK. In experiments, gases are non-uniform, since they are contained in a trap, which tyupically provides a Harmonic oscillator potential. If the member particles are N, the density of gas in the cloud is of order N/R^3, where the size R of a thermal gas cloud is of order $(KT/mw.^2)^{1/2}$, wobeing the angular frequency of single particle motion in the harmonic-oscillator potential. Substituting the valuep of the density n-N/R^3 at T = Tc into equation (1.1), the transition temperature is given by-

$$kTc = Ghw_0N^{1/3}$$

Where G is a mumerical constant which are hall later show to be approximately 0.94. The frequencies for traps used in experiments are typically of order 10^2 H_2, corresponding to W_0 – 10^3 s^{-1}, and therefore temperatures lie in the range quated above. Estimates of the transition temperature based on results for a uniform Bose gas me therefore consistent with those for a trapped gas.

References:-

1. B.DeMarco and D.S Jin, Science 285, 1703 (1999); B. DeMarco, S.B. Papp and D. S Jin, Phy. Rev. Let. 86, 5409 (2001)
2. D. A Butts and D.S. Rokhsar, Phy. Rev. A55, 4346 (1997)
3. L. Vichi and S. Stringari, Phy. Rev. A60, 4734 (1999)
4. J. Bardem, L.N. Cooper and J.R. Schrieffer, Phy. Rev. 108, 4175 (1957)
5. V.A Khodel, V.V. Khodel and J.W. Clark, Nucl. Phy. A598, 390 (1996)
6. T. Papenbrok and G.F. Bertsch, Phy. Rev. C59, 2052 (1999)
7. G.M. Brmin and C.W. Clark, Phy. Lett. 83, 5413 (1999)
8. M.A. Baranovand D.S. Petrov, Phy. Rev. A62, 041601 (2000)
9. Andersan MH, Ensher JR, Mathess MR, wiemann CE, cornell EA (1995), Observation of Bose Einstin condusation in a dilute atomic Vapour. Science 269:198-201
10. Andrew MR, Townsend CG, Miesher H-J, Durfee DS, Kurn DM, Ketterla W (1997.b) observation of interference between two Bose-Einstein condusates. Science 215:637-691.
11. Einstein A (1925) Quantentheorie des eintomigen Idealen Gases: Zwwie Abhandding. Sitzungsber K Preuss Akad wiss Phys. Math 3.
12. Bose S (1924) Plancks Gesetz and lichtquantenhypothese Z Phys 26:178-181
13. Browh G.E, in Bose – Einstein condensation, edited by griffin A, Snoke D.W. and stringris (combridge University Press, 1995) Chap. 18, pp. 438-451.
14. Ranninger J, in Bose-Einstein condensation edited by Griffin A., Shoke D.W and stringaris (Cambridge University 1995), Chap. 16, pp. 393-417
15. R. Combescat. Phys. Rev. Lett. 83, 3766 (1999).