Condensates on crest of a wave

The ability to tune the interactions between atoms in a Bose–Einstein condensate has led to atomic wave packets that can propagate without dispersion and other novel quantum states.

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One of the remarkable things about low-temperature physics is that it offers a place where the hidden world of quantum mechanics can be revealed, often giving rise to spectacular effects. In 1995 the Nobel-prize-winning observation of Bose–Einstein condensation showed that a dilute gas of atoms cooled to sufficiently low temperatures could “condense” into an intriguing state in which all the atoms can be described by the same quantum wavefunction.

Bose–Einstein condensation is actually a phase transition – just like the formation of ice in a vessel of water when it is cooled below freezing – but it occurs as a direct result of the underlying rules of quantum mechanics. For decades undergraduates have studied this phenomenon as a textbook problem in statistical physics.

So why is Bose–Einstein condensation in gases still the subject of intense research? If the atoms were truly non-interacting, like the textbook problem usually assumes, interest would likely have died out long ago. Without interactions it would not have been possible to demonstrate superfluidity in these systems, including the recent beautiful observations of large numbers of vortices arranged in well ordered lattices (see Physics World May 2001 pp21–22). The atoms do interact, but in such a way as to allow a detailed theoretical understanding from first principles.

The interactions can even be dynamically controlled, allowing one to prescribe whether the atoms interact strongly or weakly and to change the force between the atoms from an attractive interaction to a repulsive one. This developing theme of control is one reason why breakthroughs in the field continue to emerge at a remarkable rate – such as the recent demonstration of bright solitons in a Bose–Einstein condensate.

Out of the shadows

Solitons, and their close relatives solitary waves, occur throughout physics. The term solitary wave refers to a localized disturbance in a continuous medium that can propagate over long distances without any change to its shape or amplitude. Such disturbances were noted as long ago as 1834 by the Scottish scientist John Scott Russell for a shallow canal. He noticed that water waves could propagate for many miles without attenuation or dispersion.

Solitons are essentially the same as solitary waves but they have the additional feature that their amplitude and spatial profile do not change even when multiple solitons collide. Optical solitons are particularly important in fibre-optic communications because the information they carry remains intact as the light pulses travel through the glass fibres.

Now two groups – Randall Hulet’s group at Rice University in the US, and Christophe Salomon and co-workers at the École Normale Supérieure in Paris – have announced the successful generation of bright solitons in Bose–Einstein condensates. This latest work follows several previous experimental efforts to study “dark solitons” in condensates. These objects correspond to regions inside the condensate that ideally contain no atoms, and they occur in systems where the interactions between the atoms are repulsive. Obviously this kind of disturbance can only exist within the confines of a medium. Bright solitons, on the other hand, are completely self-determined condensate bunches that bind together and can propagate through free space. They only occur in systems where the attractive interactions exactly compensate for any dispersion of the wave packet.

Although there are important differences in detail, the two experiments are remarkably similar in spirit. They both used the same isotope of lithium, namely lithium-7, to form the gas. The first step was to create a Bose–Einstein condensate using the now standard techniques of laser cooling and evaporative cooling (see Physics World August 1999 pp37–42). Next the atoms were transferred from a trap created by magnetic-field gradients to a simple 3D trap formed by strong laser fields in order to allow the interactions to be controlled.

The Paris group generated a bright soliton by tuning the interactions between the atoms to be slightly attractive (L Khaykovich et al 2002 Science 296 1290). The researchers observed that most of the condensate atoms were lost, probably due to the fact that an attractive interaction in a gas can lead to the onset of mechanical instability and collapse. However, they also saw a condensate remnant containing some 6000 atoms form a stable bright soliton that could then be studied. Salomon and co-workers guided the atoms in one dimension for a distance of approximately 1 mm and established that there was no discernible spreading of the wave packet and no decay of the amplitude – a clear signature for a soliton. And when they repeated the experiment without interactions between the atoms, they saw obvious evidence for spreading of the wave packet.

The Rice group used a different configuration of laser trap that also restricted the atoms to move in one dimension. In this case, the researchers showed that multiple
Can noise actually boost brain power?

The human brain is the latest biological system to show signs of stochastic resonance

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Random noise may improve the human brain's ability to process information, according to recent research by two physicists in Japan. Toshio Mori and Shoichi Kai of Kyushu University have shown that the visual-processing region of the human cortex responds better to an external periodic stimulus when external noise is also applied. The findings represent yet another example of the seemingly ubiquitous phenomenon of stochastic resonance — and is one of the most interesting biological examples to date (2002 Phys. Rev. Lett. 88 218101).

The notion of stochastic resonance was originally introduced in relation to the Earth's ice-age cycle, in an attempt to explain how a tiny periodic variation in the amount of radiation reaching the surface of the planet could trigger the huge climatic changes that have been discovered. In stochastic resonance, a weak periodic signal in a noisy system can be enhanced by adding extra noise. This astonishing effect was identified about 20 years ago by Roberto Benzi and colleagues at the University of Rome Tor Vergata and, independently, by Katy Nicolis, then at the Belgian Institute for Space Aeronomy in Brussels. Even more remarkably, there are many cases where the signal-to-noise ratio, as well as the signal, is enhanced by the addition of noise.

Stochastic resonance demystified

Although stochastic resonance seemed mysterious at first — and there were even suggestions that it violated the second law of thermodynamics — it was explained in 1990 by Mark Dykman, then at the Ukrainian Academy of Sciences in Kiev. He used classical linear-response theory to point out that stochastic resonance can occur in any noisy system in which the susceptibility is strongly dependent on noise.

In practice there are many such systems, one of the most common being the class of two-state systems or oscillators in which there are two potential wells. In the latter case, the physical origin of the stochastic resonance is intuitively obvious: in the presence of noise, a weak periodic signal can induce coherent hopping between two widely separated states, i.e. the noise produces much