so, their characterization could help to clarify many of the unresolved issues discussed above. Zebrafish genetic screens have identified many additional mutations that perturb midline mesodermal and neural differentiation (*32*), and it seems likely that the molecular analysis of some of these mutants will reveal novel components in the pathway of floor plate differentiation. The need to define the relative contributions of Hh-dependent and -independent signaling to floor plate differentiation should maintain this intriguing cell group at the center of developmental studies for some considerable time.

References and Notes

1. B. F. Kingsbury, *J. Comp. Neurol.* **50**, 177 (1930).
2. J. Ericson, J. Briscoe, P. Rashbass, V. van Heyningen, T. M. Jessell, *Cold Spring Harbor Symp. Quant. Biol.* **62**, 451 (1997).
3. E. D. Leonardo *et al.*, *ibid.*, p. 467.
4. M. Placzek, *Curr. Opin. Genet. Dev.* **5**, 499 (1995).
5. G. Vogel, *Science* **280**, 1838 (1998).
6. T. M. Jessell, P. Bovolenta, M. Placzek, M. Tessier-Lavigne, J. Dodd, *Ciba Found. Symp.* **144**, 255 (1989).
7. G. C. Schoenwolf and P. Sheard, *J. Exp. Zool.* **255**, 323 (1990).
8. M. A. Selleck and C. D. Stern, *Development* **112**, 615 (1991).
9. M. Catala, M. A. Teillet, N. M. LeDouarin, *ibid.* **122**, 2599 (1996).
10. L. Dale and J. M. Slade, *ibid.* **100**, 279 (1987).
11. H. Roelink *et al.*, *Cell* **81**, 445 (1995).
12. J. Ericson, S. Morton, A. Kawakami, H. Roelink, T. M. Jessell, *ibid.* **87**, 661 (1996).
13. C. Chiang *et al.*, *Nature* **383**, 407 (1996).
14. M. P. Matise, D. J. Epstein, H. L. Park, K. A. Platt, A. L. Joyner, *Development* **125**, 2759 (1998).
15. Q. Ding *et al.*, *ibid.*, p. 2533.
16. A. Ruiz *et al.*, *Dev. Biol.* **170**, 299 (1995).
17. V. Garcia-Martinez *et al.*, *J. Exp. Zool.* **267**, 431 (1993).
18. S. Fraser, R. Keynes, A. Lumsden, *Nature* **344**, 431 (1990).
19. M. Placzek, T. M. Jessell, J. Dodd, *Development* **117**, 205 (1993).
20. H. E. Schauerte *et al.*, *ibid.* **125**, 2983 (1998).
21. P. A. Beachy *et al.*, *Curr. Biol.* **5**, 944 (1995).
22. P. D. Currie and P. W. Ingham, *Nature* **382**, 452 (1996).
23. M. E. Halpern, R. K. Ho, C. Walker, C. B. Kimmel, *Cell* **75**, 99 (1993).
24. M. E. Halpern *et al.*, *Dev. Biol.* **187**, 154 (1997).
25. K. Hatta, C. B. Kimmel, R. K. Ho, C. Walker, *Nature* **350**, 339 (1991).
26. M. R. Rebagliati, R. Toyama, P. Haffter, I. B. Dawid, *Proc. Natl. Acad. Sci. U.S.A.* **95**, 9932 (1998).
27. K. Sampath *et al.*, *Nature* **395**, 185 (1998).
28. B. Feldman *et al.*, *ibid.*, p. 181.
29. J. Zhang, W. S. Talbot, A. F. Schier, *Cell* **92**, 241 (1998).
30. U. Strahle *et al.*, *Genes Funct.* **1**, 131 (1997).
31. A. F. Schier, S. C. Neuhauss, K. A. Helde, W. S. Talbot, W. Driever, *Development* **124**, 327 (1997).
32. A. F. Schier, *Curr. Opin. Neurobiol.* **7**, 119 (1997).
33. M.-A. Teillet, F. lapointe, and N. Le Douarin [*Proc. Natl. Acad. Sci. U.S.A.* **95**, 11773 (1998)] have recently suggested that the failure of floor plate differentiation after notochord removal results from the coincident elimination of floor plate precursors. However, in many previous studies of the consequences of notochord ablation (*4, 16*) in which notochord cells alone were removed, leaving the node and cordoneural hinge intact, floor plate differentiation still failed to occur. Thus, it is unlikely that the absence of floor plate differentiation in these previous studies is attributable to the removal of floor plate precursors.

34. We thank T. Edlund, M. Halpern, P. Ingham, A. Schier, G. Schoenwolf, C. Stern, and W. Talbot for helpful discussions in the preparation of this article and for comments on the manuscript.

PERSPECTIVES: BOSE-EINSTEIN CONDENSATION

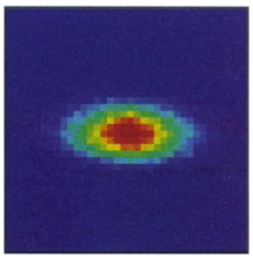
Go Forth and Multiply

Keith Burnett

In Bose-Einstein condensed systems, instead of each atom occupying its own quantum world, they have all entered a single macroscopic quantum state. Over the past several years, exploration of the remarkable properties of these gases has proceeded apace. The first Bose-Einstein condensed atomic gases were produced in 1995 at JILA by the group of Eric Cornell and Carl Wieman (*1*). In these experiments, rubidium atoms were trapped in a magnetic field and cooled to nanokelvin temperatures. Since then other scientists around the world have succeeded in producing condensates in a variety of traps and with several alkali atoms (*2*). At the Massachusetts Institute of Technology (MIT), earlier this year, a condensate has even been produced in atomic hydrogen (*3*). And now, as reported on page 1686 of this issue, Anderson and Kasevich at Yale have demonstrated the Bose-Einstein equivalent of the well-known Josephson effect in superconductivity (*4*).

Greytak and Kleppner's work with hydrogen (*3*) has attained a goal that provided the initial stimulus for the whole search for Bose condensation in the 1970s. These developments herald a new field of coherent matter wave physics that is moving into fresh areas as the range of systems and the degree of control over them steadily expand. In recent studies the macroscopic nature of the wave function of the atoms, or matter wave coherence, has been examined in detail: Why is this such an interesting issue?

Bose-Einstein condensation is one of the most intriguing phenomena one can see in physical systems. When it takes place, the wave-mechanical properties of atoms are amplified to levels at which they can be observed and manipulated directly. We know that in the microscopic world quantum mechanics rules the waves. In most circumstances, however, we can only infer the shape of the waveforms that control the motion of particles in the microscopic world. It is, however, sometimes possible to see these waveforms writ large and accompanied by phenomena such as superfluidity and superconductivity. The macroscopic nature of these quantum mechanical systems is at the heart of the phenomena. It occurs when the individual matter-waves of the constituents of a material start to overlap. If the particles are bosons (more precisely, particles with integral spin that obey Bose-Einstein statistics), they can jump into a shared waveform that we term a condensate: hence, the term Bose-Einstein condensation. In the atomic gases the individual waves get bigger as the gas is cooled and energy is removed from the particles. If the particles are cold enough the waves then overlap and condensation occurs. We can look then directly at the quantum waveform and determine its shape without destroying it. Such direct access is not usually possible because waveforms usually have just the one owner and measuring them destroys them. If, however, we can get many atoms to share the same wave function, observing it just knocks out some of the atoms without destroying the waveform. The wave is then a macroscopic thing: looking at it does not eliminate it.



Cold condensate. Spatial image of a rubidium-87 condensate just below the transition temperature. The condensate contains ~10^4 atoms and has a ~9-μm waist along the horizontal axis. The non-condensed fraction is also visible.

Bose-Einstein condensed atomic assemblies are particularly interesting and useful for the study of these macroscopic quantum effects. First, the interactions between the particles have only a very small effect on the behavior of the atoms, and nearly all of them share the same waveform. The small effect of interactions also means that it is possible to make first principle calculations of the properties and the behavior of the assembly. (For other systems where condensation occurs, such as liquid helium, the effects of interactions is very large and theory is not so straightforward.) The theory is being subjected to stringent quantitative tests, and for low temperatures the theory has emerged with flying colors. For higher temperatures the atomic Bose-Einstein

The author is in the Department of Physics, University of Oxford, Oxford OX1 3PU, UK. E-mail: k.burnett1@physics.ox.ac.uk

condensates are proving to be an excellent test-bed for theories of quantum assemblies at finite temperatures. This is a subject of importance in a wide range of systems, including nuclear collisions and phase transitions in the early universe. The other crucial feature of the ultracold atomic condensates is their sensitivity to control by very modest strength fields, including laser fields. This makes it possible to manipulate and control their shape with surgical precision as has been shown in several recent experiments. External fields can be used to change the strength of the interactions between atoms, as was first shown by Wolfgang Ketterle's group at MIT (*6*). Atoms also have internal states into which the condensates can be transferred and retrieved at will.

The macroscopic coherence of the wave function was beautifully displayed in the earlier MIT experiments. Anderson and Kasevich (*4*) have been able to observe directly one of the most interesting and important effects: macroscopic quantum oscillations in a waveform. These Josephson effects have been observed and routinely used in superconducting junctions and more recently in superfluid liquid helium (*6*). They rely on the fact that a macroscopic wave can extend over an object such as a small wall. In the case of the Yale experiments (*4*) the wave extends over many wells of a potential formed by the standing wave of a laser field: an optical lattice. This is the advantage of ultracold atoms: The force due to a laser light field is enough to form a lattice in which the atoms' motion is confined and an extraordinary range of behavior investigated. This is done by first producing a Bose condensate of rubidium atoms with the methods that are now "standard". The atoms are then captured in the laser field that holds the wave function, spread across many potential wells. When atoms fall out of this arrangement, because of gravity, they do so in a way that has to be thought of as them moving coherently from all of the wells at the same time. This coherent escape produces beautiful interference effects in the form of pulses in the waveform that moves away from the lattice (see figure). The shape of the interference pattern reflects the nature of the coherence across the lattice and, hence, the macroscopic quantum coherence that is established. Small differences in the potential energy from one well to the next, due to the presence of gravity, give rise to a varying phase of the wave across the lattice and profoundly affect the shape of the output. This response to small changes means the system is exquisitely sensitive to weak forces and may thus be the basis for new types of measurements.

References

1. M. A. Anderson, J. R. Ensher, M. R. Matthews, C. E. Wieman, E. A. Cornell, *Science* **269**, 198 (1995).
2. C. Bradley *et al.*, *Phys. Rev. Lett.* **75**, 1687 (1995); K. Davis *et al.*, *ibid.*, p. 3969; and others, see BEC homepage.
3. D. G. Fried *et al.*, *Phys. Rev. Lett.* **81**, 3811 (1998).
4. B. P. Anderson and M. A. Kasevich, *Science* **282**, 1686 (1998).
5. M.-O. Mewes *et al.*, *Phys. Rev. Lett.* **77**, 988 (1996); M. R. Andrews *et al.*, *Science* **275**, 637 (1997).
6. S. Pereverzev *et al.*, *Nature* **388**, 449 (1997); S. Backhaus, S. V. Pereverzev, A. Loshak, J. C. Davis, R. E. Packard, *Science* **278**, 1435 (1997).

PERSPECTIVES: POPULATION GENETICS

No Need to Isolate Genetics

Michael E. Soulé and L. Scott Mills

By the age of 16 every kid knows about the cultural taboos of incest—and that it is genetically contraindicated to marry your cousin, let alone a sibling. Avoidance of inbreeding is not limited to human beings, however. Many plants (*1*) and animals (*2*) evaluate relatedness (*3*) and avoid matings with close relatives. In a small isolated population, inbreeding occurs because of a limited number of mates to choose from, not from preferential mating among kin. This can lead to increased homozygosity, and, therefore, to homogeneity of the genes affecting the immune response (*4*) and to increased expression of recessive deleterious genes that reduce survival, fertility, and physiological vigor (*5*).

Enhanced online at www.sciencemag.org/cgi/content/full/282/5394/1658

Conservation geneticists have argued that in small populations the extinction probability should increase over time because these genetic effects magnify the extrinsic sources of jeopardy, including disease, inclement environmental conditions, and random demographic events. On page 1695 of this issue Westemeier *et al.* (*6*) provide one of the first extensively documented examples of these complex interactions pushing a formerly large population toward extinction.

Spring booming. Prairie chickens still thrive in a few areas of native grasslands, where courting males stomp their feet while making hollow moaning sounds.

CREDIT: S. SUTER

Westemeier *et al.* (*6*) monitored greater prairie chickens in Illinois for 35 years, noting a steep population decline as habitat was lost, as the population became isolated during the 1970s, and as the Illinois population reached a demographic low of less than 50 birds by the early 1990s. At the same time, adjacent populations in Kansas, Minnesota, Missouri, and Nebraska have remained comparatively large and widespread. Concurrent with the population decline, egg fertility and hatch success in Illinois prairie chickens also declined and was lower than in the neighboring large populations. The decline in egg hatching success in fully incubated clutches was correlated with a decrease in genetic variation, both for the Illinois birds when compared with the larger, nearby populations (*7*), and for the present population compared with historical samples collected before the demographic contraction (*8*).

Loss of genetic variation in small isolated populations is inevitable, as is an increase in the inbreeding coefficient of surviving individuals. Nevertheless, critics have pointed out that the theoretical inexorability of inbreeding in small isolated populations does not necessarily translate into inbreeding depression or an increase in the likelihood of extinction (*9*). For instance, such a small population is likely to be in dire straits already because of exposure to chance environmental events (droughts, storms, disease), or simply because of demographic accidents, including those that might skew the sex ratio. Although modeling results have demonstrat-

M. E. Soulé is with The Wildlands Project, Post Office Box 2010, Hotchkiss, CO 81419, USA. E-mail: Soule@co.tds.net. L. S. Mills is in the Wildlife Biology Program, School of Forestry, University of Montana, Missoula, MT 59812, USA. E-mail: smills@forestry.umt.edu