NEWSLETTER

ONTARIO ASSOCIATION OF PHYSICS TEACHERS
(An Affiliate of the American Association of Physics Teachers)
December, 2003

# Bose-Einstein Condensation - Cooling Atoms Into Matter Waves

By Ana Jofre

Perhaps one of the most fascinating and mind-boggling phenomena in quantum physics is the idea of wave-particle duality, and it is most exciting to visually observe such abstract effects. The relatively new field of atom-optics investigates wave-like behaviour in atoms. The key condition to making atoms behave this way is to cool them to near-absolute-zero temperatures. If one cools the atoms far enough, a phase transition is reached, whereupon the atoms are then said to be in a Bose-Einstein Condensate (BEC). Drawing on the analogy of light, which is also both a particle and a wave, one can think of cold atoms as ordinary light, and of atoms in a BEC as the matter equivalent of laser-light. Atoms in a BEC and photons (light particles) in a laser both possess the property of coherence, which is to say that these particles are all completely identical and they move in step with one another.

The idea that particles are also waves came from DeBroglie's theory, which postulated that particles have a wavelength of $\lambda=h/p$, where h is Plank's constant, and p is the particle's momentum. Since momentum (p) is the product of the particle's mass and velocity, then it follows that the slower the particle moves, the longer its wavelength. As the DeBroglie wavelength becomes longer, the quantum-mechanical properties of the particle become more apparent.

The typical velocity of an atom or molecule at room temperature is about 300m/s. In most atom optics experiments that study quantum effects, atoms are slowed down to a few centimeters per second. Since temperature is a measure of the kinetic energy of the atoms, such slow velocities imply a temperature of a millionth of a degree above absolute-zero.

The method by which a vapour cloud of atoms is cooled to such temperatures doesn't require the use of any refrigeration or cryogenics. Instead, lasers are used to cool them. This may seem counter-intuitive since most people associate lasers with heating. However, in this scenario, lasers slow atoms down with the radiation force they exert on them. This radiation force arises because light is composed of many tiny particles called photons, and as with any other particle, there is a momentum exchange that occurs when a photon collides with an atom. One can imagine that the atom is a freely rolling car, while the laser-light is a continuous stream of ping-pong balls being thrown at the car. The car, as with the atom, will eventually slow down as a result of all these collisions. Techniques for laser-cooling atoms were developed by C. Cohen-Tannoudji, W.D. Phillips, and S. Chu , for which they were awarded the Nobel Prize in 1997.

Laser-cooling is only the first step required to reach BEC, and other methods are used to cool the atoms further. Reaching the temperatures necessary for Bose-Einstein condensation earned E.A. Cornell, W. Ketterle, and C.E. Wieman the Nobel Prize in 2001.

Once the atoms are laser-cooled, they are trapped into a localized region with magnetic fields, and the atoms are then cooled further by selectively expelling the hottest atoms from the trap. This method is known as evaporative cooling, the physics of which is similar to the cooling of a cup of coffee, where the hottest molecules escape through the steam.

In 1925, Albert Einstein made a striking prediction that if a group of particles, such as atoms, are cooled down sufficiently, they will all fall into the lowest energy state (the ground state). This prediction applies only to particles that are called bosons, these being particles whose total spin is an integer number. Particles of the other type are called fermions, whose total spin is a half-integer number. The difference between bosons and fermions is that fermions never occupy the same state, whereas bosons do. A Bose-Einstein condensate is formed when atoms, that are bosons, are cooled until they all fall into the ground state.

The effects of having all atoms in the ground state are striking. Since the atoms are indistinguishable and they all occupy the same state, they no longer behave as a cluster of atoms, but as a single entity. It is because atoms occupying this state are indistinguishable that a BEC is the matter equivalent of a laser and gives it the property of coherence. It is this coherence that makes the dynamics of atoms in a BEC particularly interesting, as there are very clear analogies with lasers. For example, if one were to overlap two laser beams, an interference pattern of bright and dark fringes would form in the region of overlap. It is the same with atoms in a BEC. In an experiment done at MIT in 1995, it was shown that two over-lapping BECs produce an interference pattern that is exactly analogous to that of two overlapping laser beams. There are currently no practical applications for atoms in a BEC, for the most part because it is an extremely fragile state that is currently very difficult to produce. However, that doesn't mean they won't someday be useful. Remember, no one even dreamed of any applications for lasers until 20 years after their discovery!

*Ana Jofre is a PhD candidate in the Dept. of Physics at the University of Toronto. Her current area of research is Bose-Einstein Condensation, and her email address is jofre@physics.utoronto.ca.*

## The University of Ontario Institute of Technology, Canada's Newest University

By William Smith

The University of Ontario Institute of Technology (UOIT) is pleased to host the 2004 OAPT annual conference next May. UOIT, the first brand-new university in Ontario in 40 years, was established by an Act of the provincial legislature on June 27, 2002, and opened to more than 900 students in September 2003. At Ontario's first fully laptop-based university, students enjoy networked, state-of-the-art classrooms and wireless learning spaces. UOIT offers a variety of innovative undergraduate programs, with additional new programs planned for the 2004-05 academic year. UOIT is on a path to become a full research-oriented university with graduate-level programs under development. Located in the beautiful northeastern reaches of Oshawa directly across from Windfields Farm, the university is less than an hours drive east of Toronto. A spectacular, student-focused campus is being built, including a new research library, state-of-the-art academic buildings and a new residence village, all surrounded by beautiful outdoor spaces. Designed by one of Canada's leading architectural firms, the campus is modeled on the concept of an academic village with outdoor quadrangles, connected interior and exterior walkways and a reflecting pond which can be used for skating in winter. The construction site at UOIT is the second largest in the province, exceeded only by that at the Toronto Airport!

UOIT's primary orientation is science and technology, and it has seven Schools: Science, Business and Information Technology, Education, Energy Engineering and Nuclear Science, Health Science, Criminology and Justice, and Manufacturing Engineering. Liberal studies electives for students are offered by Trent University on the UOIT campus. UOIT shares much of its infrastructure with Durham College, including its main physical campus and IT, registrarial, library, and student services, providing an innovative example of college-university cooperation. Joint programs involving the College and the University are a special feature of this cooperative venture, and are under active development.

The UOIT School of Science offers undergraduate programs in Physical Science and in Biological Science, currently encompassing biology (with streams in pharmaceutical biotechnology and environmental toxicology), chemistry, mathematics, and physics. A Concurrent Education program will begin in Fall 2004, through which students may acquire combined BSc and BEd degrees. New programs in Energy and Environment Science and in Computing Science are in the advanced planning stages. A secondary specialization area of study in Computational Science is available in combination with any of the primary areas. Computational Science is a "third way of doing science", in addition to the traditional methods of theory and experiment. It seeks to gain insight through the development and implementation of mathematical models of phenomena by means of their computer simulation. Computer visualization of the results of such simulations is a key ingredient of the methodology.

There are no Departments in the School of Science, and interdisciplinary teaching and research are emphasized, according to Dean William Smith, who joined UOIT from his former position at the University of Guelph, where he held appointments in Mathematics and Statistics, Engineering, and the Guelph-Waterloo Physics Institute. All teaching faculty in Science use Tablet computers in the classrooms and tutorials, a technology at the forefront of current practice (eg., write original lecture notes or annotate previously prepared material directly on the Tablet computer screen connected to the classroom data projector, and subsequently save the entire lecture for posting on the course web site). A key feature of the student laptop program entails the installation of several thousand dollars worth of sophisticated scientific software on all student computers (dual-boot Windows /Linux machines), which is integrated into the pedagogy of all science courses, right from the first year of the programs. The software includes: Maple, MATLAB, SigmaPlot, LaTeX, and many other packages.

The UOIT Science faculty currently numbers 13, and expects to grow to a complement of about 40 in four years. Faculty currently have over $300,000 in research funding, and several Postdoctoral Fellows and Visiting Professors will be in residence from January, 2004. Current research areas include analytical chemistry, aquatic toxicology, computational science, materials science, mathematical finance, mathematical biology, neutraceutical and functional foods, and photonics. Computational Science is a major focus, and UOIT is a member of SHARCNET (Shared Hierarchichal Academic Research Computing Network), a consortium of 14 universities, colleges, and research institutes in southern Ontario. SHARCNET is a geographically distributed computer network consisting of state-of-the art equipment at the host institutions.

For more information about the University of Ontario Institute of Technology in general, see http://www.uoit.ca, and for the School of Science, see http://www.uoit.ca/schoolofscience

*William Smith is the Dean of UOIT, and can be reached at William.smith@uoit.ca.*

## The Demonstration Corner: Seeing the Speed of Sound

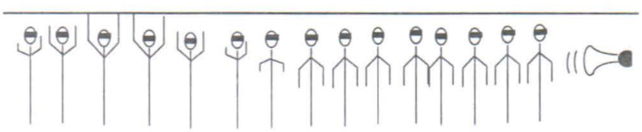
by Diana Hall

This demonstration allows students to get an idea for how slow sound actually travels. I take students outside and have them line up about 1 m apart. They should have their eyes closed. A bicycle horn is sounded at one end of the line. When each student hears the sound, he/she should raise their arms and then drop them again. A video camera can capture the motion of the sound wave down the line of students so that they can view it back in the classroom.

*Diana Hall is a teacher at Bell High School in Nepean, ON.*

**Column Editor:** Ernie McFarland, Physics Department, University of Guelph, Guelph, Ontario, N1G 2W1
Email: elm@physics.uoguelph.ca

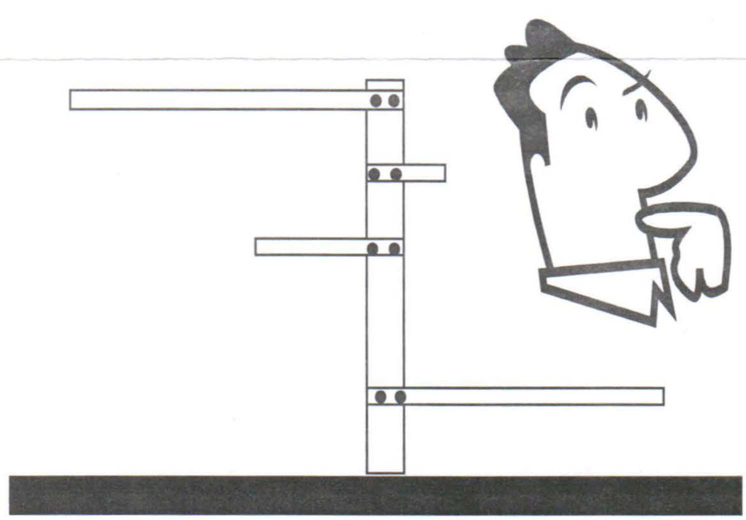
*Submissions describing demonstrations will be gladly received by the column editor.*



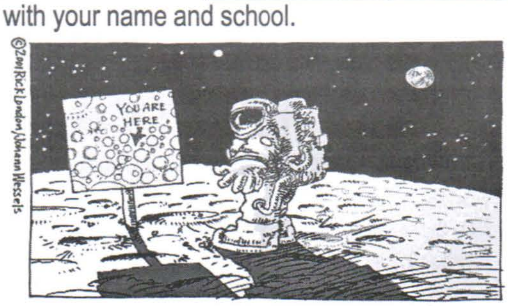
## Mind Games!

By Paul Passafiume

Here's a little mind boggler I cooked up while playing with IP2000, the physics simulation software package. The idea is to place each of four masses (of size 2 kg, 100 kg, 20 kg, static equilibrium. The beams are made of different material so that each has a mass of 0.5 kg. Have fun! For the solution, turn to page 4.



If you have an idea for a *Mind Game*, please submit it to the editor, Paul Passafiume (paulpassafiume@hotmail.com), along with your name and school.



## Annual OAPT Conference May 27-29, 2004: Call for Papers!

This year's conference will be hosted by the *University of Ontario Institute of Technology (UOIT)*, in Oshawa. The conference theme has yet to be determined; however, we're looking for individuals who would like to share their ideas with colleagues.

All physics educators are invited to contribute a presentation at the conference. Possible ideas include: demonstrations, teaching tips, reports on advances in physics and related fields, or useful information pertaining to physics education.

Interested participants please e-mail the following to **Elzbieta Muir** (emuir@sympatico.ca)

a) an abstract (please include your name and school/university/institution),
b) the approximate presentation length (10, 15, 20, or 30 minutes), and
c) audio-visual requirements

by **January 2004**, if possible. The deadline for submissions is **April 30, 2004**. Conference details are available at http://www.uoit.ca/schoolofscience/OAPT2004.

## Let's Play: Quotable Quotes!

Here's the deal. Identify the famous scientist who said the quote below. Be the first person to email your response (c/w mailing address) to the editor, Paul Passafiume, at paulpassafiume@hotmail.com and you'll win a prize! It's that easy. Here we go!

"What we observe is not nature itself, but nature exposed to our method of questioning"

Last issue's winner: David Sutherland, from Guelph. Congratulations David!

## Do you want to give back to your profession? Participate in the OAPT!

This wonderful organization needs volunteer help in the following capacities:

- Guest presenters
- Conference organizers, and facilitators
- Members of the executive committee
- Article, and classroom idea contributors for the Newsletter


New articles, ideas, or other information items may be sent to Glen Wagner (glenn.wagner@ugdsb.on.ca) or Paul Passafiume (paulpassafiume@hotmail.com). Ideas for demos may be sent to Ernie McFarland (elm@physics.uoguelph.ca).

## Membership Matters!

Join the Ontario Association of Physics Teachers! Members receive a Newsletter and reduced registration rates at the annual conference.

As well, from time to time, the Association makes available special resources. Examples have included reprints of **"Demonstration Corner"** articles from the **Newsletter**, and the videotape, **"The Physics of Dance,"** from a presentation at one of the annual conferences.

To become a member of the OAPT, send a cheque for $8 (or a multiple thereof) payable to OAPT to:

**Ernie McFarland**
**OAPT Membership Coordinator**
**Department of Physics**
**University of Guelph**
**Guelph, Ontario**
**N1G 2W1**

Solution to *Mind Games* on page 3:

- Place 50 kg mass on top beam
- Place 100 kg mass on beam second from top
- Place 2 kg mass on beam third from top
- Place 20 kg mass on bottom beam