Nobel prizes honour atom-trappers . . .

[LONDON] For their development of methods to cool and trap atoms with laser light, this year's Nobel prize for physics has been awarded to Steven Chu of Stanford University, Claude Cohen-Tannoudji of the Collège de France and Ecole Normale Supérieure, Paris, and William Phillips of the National Institute of Standards and Technology (NIST) in Maryland.

"These three are absolutely the world leaders," says Peter Knight of Imperial College, London, adding that he is "hugely delighted" with the announcement.

Cooling and trapping atoms with light are distinct but related processes. Because optical traps for neutral atoms are generally shallow, the atoms must be cooled to below one kelvin before trapping can be contemplated.

Ions are easier because they interact more strongly with electromagnetic fields. "For a single ion in its much deeper [electromagnetic] trap, the attainment of ultra-low temperatures loses its importance," explains Hans Dehmelt of the University of Washington.

Transfer of momentum

Laser cooling of an atomic gas was proposed in 1975 by Theodor Hänsch and Arthur Schawlow of Stanford University. In the same year, David Wineland and Dehmelt suggested a similar scheme for cooling ions. Dehmelt's work on ions earned him and Wolfgang Paul of the University of Bonn a half-share in the 1989 Nobel prize; Norman Ramsey of Harvard University received the other half.

The principle behind the laser cooling of atoms is the transfer of momentum from a photon to an atom that can absorb it. The atom is given a kick in the direction in which the photon was travelling. Subsequent re-emission of a photon by the excited atom delivers a recoil impulse to conserve momentum. But if the emission is spontaneous rather than stimulated, the direction of the emitted photon is random.

A series of sequential absorption and emission events transfers momentum to the atom in the direction of the light beam, whereas the recoil force from emission averages to zero. The result is that an atom propagating counter to the light beam is slowed down, like a cyclist riding into the wind.

In the 1980s, Phillips and co-workers at NIST (then the National Bureau of Standards) used this idea to slow and cool beams of sodium atoms. The frequency of the cooling laser beam is tuned to just below that needed to induce an optical transition — the Doppler shift experienced by the counter-propagating atoms boosts the frequency to make absorption possible.

In 1985, Phillips and colleagues developed a method for trapping a cooled beam of sodium atoms magnetically, using a graduated magnetic field to shift the absorption frequency via the Zeeman effect and thus to compensate for the fact that the Doppler shift decreases as the atoms are slowed. They cooled the atom beam to less than 100 millikelvin, reducing the average velocity to almost zero.

But cooling a gas, rather than a beam, is harder, because atoms in a gas move in random directions. In 1985, Chu and co-workers, then at Bell Laboratories at Holmdel in New Jersey, used six laser beams arranged in mutually orthogonal pairs to cool a gas of about a million sodium atoms.

To cool all the atoms, each laser beam has to impart a force only to those atoms moving in the opposite direction. These atoms, however, are automatically selected because only they experience a Doppler shift sufficient to allow absorption.

The result is that the atoms experience a retarding force — a kind of viscosity — in whichever direction they move. Chu called this 'viscous' light field an 'optical molasses'.

Better ways of measuring the temperature of a gas held in optical molasses led Phillips to discover in 1988 that the gas could be cooled to 40 microkelvin — significantly lower than the predicted limit based on the Doppler effect. The finding was confirmed by other groups, including Cohen-Tannoudji's in Paris.

Cohen-Tannoudji made pivotal contributions to understanding how sub-Doppler cooling was possible. The key point is that there is a finite mean time between absorption events for each atom, during which atoms find themselves generally moving up energetic slopes in the electromagnetic field — a phenomenon called the Sisyphus effect.

Further limits to cooling

Although the Doppler limit can be overcome, it appeared at first that there was another fundamental limit to the maximum degree of cooling: atoms could not be slowed below the velocities attained by recoil when they emitted a photon. This is because even the slowest atoms are continually absorbing and emitting.

But in 1988, Cohen-Tannoudji's group demonstrated that even this limit could be surpassed. "You must prevent very cold atoms from absorbing light," he says, and to do that he uses quantum interference effects to convert these atoms to a dark, non-absorbing state.

Their initial experiments used two opposed laser beams to achieve sub-recoil cooling in one dimension; they extended this to two dimensions in 1994 and to three dimensions, using six laser beams, in 1995. In this way they cooled a gas of helium atoms, for which the recoil limit is 4 microkelvin, to less than a fifth of a microkelvin.

In the practical sphere, the possibilities of laser cooling and trapping will be felt in precision measurement. More accurate atomic clocks that exploit laser cooling are already in operation, and Phillips foresees improved gyroscopic rotation sensors for aircraft navigation.

Chu has pioneered the use of laser beams to trap neutral particles other than atoms. Arthur Ashkin at AT&T Bell Laboratories first demonstrated this kind of optical trapping in 1970, using two counter-propagating beams to trap microscopic latex particles in water. It was later realized that a single beam would suffice, and Chu, Ashkin and collaborators achieved single-beam trapping of polymer particles in 1986.

That work makes this year's physics prize rare in having made a significant impact as far afield as the life sciences, where laser trapping and manipulation is used to study the mechanics of cellular machinery.

The techniques for cooling and trapping neutral atoms were essential for the long-awaited demonstration in 1995 of Bose–Einstein condensation (BEC) of atoms by Carl Wieman and co-workers at the University of Colorado, an experiment that had been widely tipped to net this year's prize.

But "one couldn't reward that without first recognizing laser cooling," says Knight, who admits to losing a bet on the award being made for BEC.

Philip Ball



AP

Winners of the Nobel prize for physics: Chu (above), Phillips (top right) and Cohen-Tannoudji (right).