

A WEEK IN MY LIFE

AFTAAB DEWAN

When I introduce myself as a researcher, people often ask me “what do you do as a researcher?” With research being an open-ended endeavour, this is often not an easy question to answer. For example, over the last week, I have made some calculations, aligned a new laser path in the laboratory I work in, been involved in troubleshooting problems in an electronic system, and read academic papers by other researchers to keep abreast of the latest happenings in my field. However, none of these truly answer the question ‘what I do’.

Let’s take the first of those: the calculations. One part of my work involves the capture of atoms in a magnetic trap. You could think of a magnetic trap as being something like a porcelain bowl holding atoms, except that instead of porcelain, the bowl’s made of magnetic field lines. These magnetic field lines are often generated using two circular electrical coils (loops of wire) that are held apart at a fixed distance from each other. Calculating the magnetic field in any part of the bowl is a rather difficult task, but it is easier to compute in the part nearest the atoms – which is at the centre of the bowl. I made this calculation mostly to help me understand what a typical magnetic trap looks like.

The primary tools we use in our labs are lasers. These laser beams are used to trap, probe and manipulate atoms according to the requirements of our experiments. My lab’s recently acquired a new laser system, which needs to be aligned accurately to ensure that its beams hit atoms at the precise spot that we want them to. Since both the size of a laser beam and a cloud of atoms is less than a tenth of a millimetre, reaching this alignment is a delicate process. My work this week involved aligning this new laser system using two different mirrors, one to point the beam at the right spot, and the other to align the pointing of the beam.

Working with electronic systems is almost a requirement for an experimental physicist. For example, our experiments involve the use of lasers that are beamed at specific frequencies. These frequencies are stabilised using lock boxes. While we only need one lockbox to run our experiments, it’s always handy to have a couple of spare ones. Since we routinely use about six to ten laser frequencies in our lab you can see why we need a lot of lockboxes. So, when we recently acquired a couple of new lock boxes and found that they were not functioning properly, I spent some time diagnosing the problem and fixing them.

What is a laser beam?

A laser beam is a highly focused and collimated beam of light. It can travel a long distance without changing its shape.

I should probably explain what exactly I mean by ‘locking’ a laser, or in more general terms, locking a signal. Imagine you have a laser beam and you would like to use it at a particular power or frequency – for example, I may want to use the beam at a constant output of 500 mW at a particular point. The actual power of the laser beam I use in my experiment may vary for a variety of reasons, including changes in temperature or humidity, mechanical vibrations, air currents etc. And these variations can change the power of my laser beam by as much as 10-20%. How do I ensure that the laser beam remains at the exact power/frequency that I require it to be? I do this by locking the laser at that power. To do this, I measure the power of the laser signal at its intended destination. Let’s call this signal A, and compare it with the signal I want, call it signal B (=500mW in this case). What a lockbox does is that it feeds a signal (let’s call this the lock signal, or L) to a laser controller that changes the

What is a Bose-Einstein Condensate?

We are all taught about matter existing in three states: solid, liquid and gas. For most of our lived experience, knowing just three phases is sufficient. However, in physics, matter may (and indeed does) have many more states (or more properly written as phases). A Bose Einstein Condensate is one such phase of matter that occurs when particles of a particular type (i.e. bosons) get cold enough to all condense to the same quantum state. What is important to remember is that this phase is a configuration that is energetically most favourable to the condensing particles, given the environment.

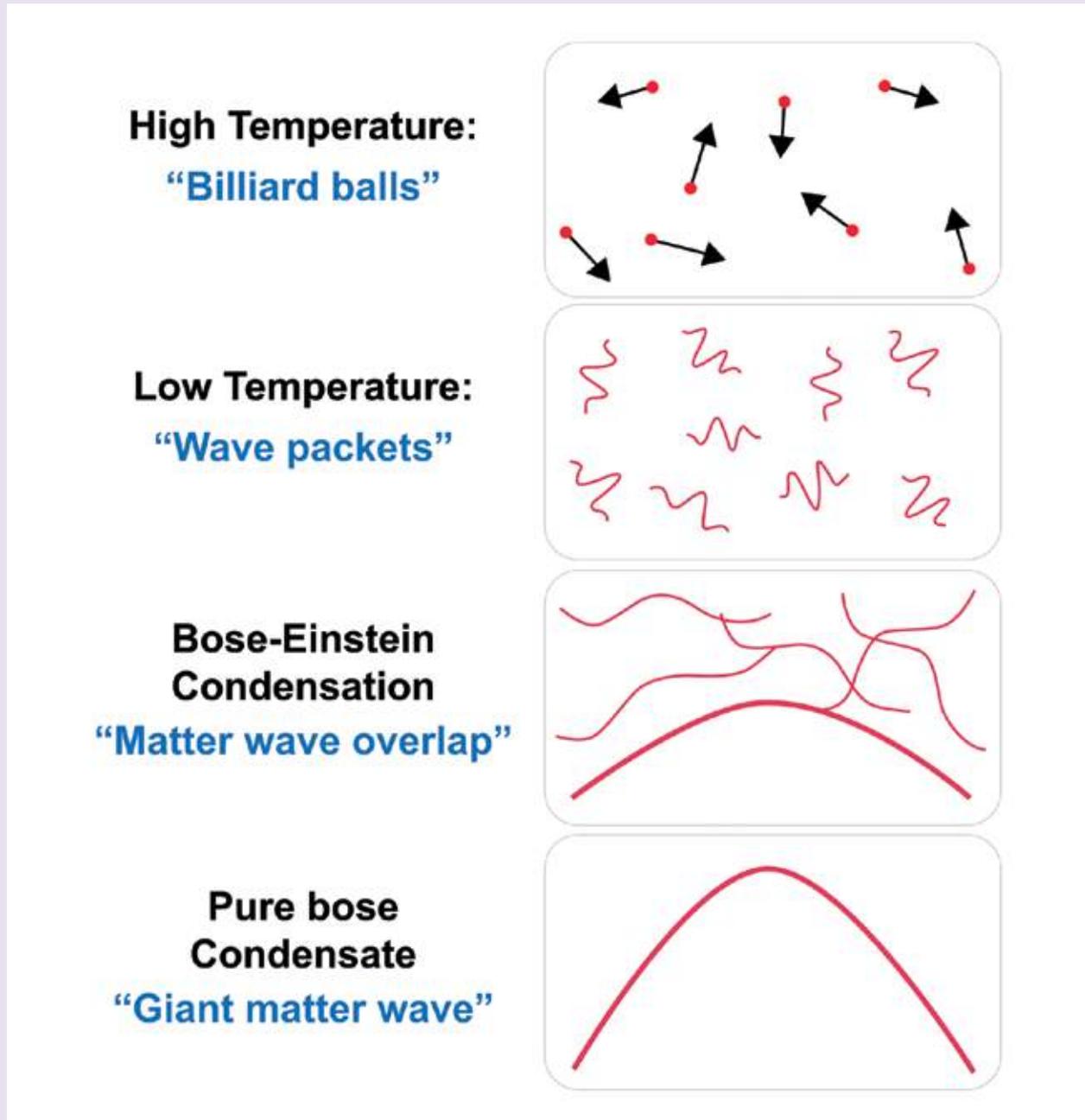


Fig.1. Recipe for a BEC. What makes a BEC particularly interesting as a phase is that it is a really good example of a macroscopic quantum state. Therefore, by manipulating a BEC, we are actually manipulating a particular macroscopic state; in ways that are specific to the nature of phenomena we are interested in investigating.

Credits: Adapted from image used in Experimental studies of Bose-Einstein condensation, by Dallin S. Durfee and Wolfgang Ketterle, in *Opt. Express* 2, 299-313 (1998).

power of the laser in real time. When we tell the lockbox to lock a signal at a particular power, it tries to make signal A as close as possible to signal B by changing signal L, and it does all of this incredibly quickly, over the course of a few microseconds. This is what keeps the laser power/frequency from changing during an experiment. More generally, this can be used to lock any signal to a particular value with a high degree of precision.

Behind all these different tasks is a larger goal, one that leads to the research project I am part of. The goal of this project is to use all the tools I have just described to cool atoms to extremely low temperatures of about -273°C or almost 0 K and explore their behaviour at these low temperatures. However, getting this near 0 K is not a small feat in itself and requires multiple steps that have to all work together in conjunction. The atoms we use are from an isotope of Rubidium, Rubidium 87. A block of this rubidium isotope is converted to its gaseous form by baking it in an oven. The gas produced contains atoms that are very hot and, therefore, move extremely fast. To capture and hold these atoms in a magnetic trap, they need to be cooled down, and the way to cool them is to make them go as slow as possible. We do this in a

series of steps. The first step is to use a laser beam propagating in the opposite direction of their travel. The collisions between the atoms and the photons that constitute the laser slow down the atoms to a velocity where they can be held in magnetic trap. This is much like trying to run headlong into the wind or a stream of water – the frictional force will slow you down. Once the atoms are in a magnetic trap, we use a magnetic field and a combination of lasers to slow them down to about 400 mK. The principle of this step is the same as the first one, with the only difference being that it brings the temperature of the atoms down to a much higher degree. Once this is completed, the atoms are transferred to an optical trap, where they are held in place by a pair of laser beams. The final step in this process involves exposing the atoms in the optical trap to evaporation which allows the higher energy atoms to leave the trap. With a lot of fine-tuning, one can eventually obtain a Bose-Einstein condensation, or a BEC for short. A BEC is a new phase of matter, where whole groups of atoms behave like a single entity. This means that in this phase, there is no way to distinguish between the 100,000 or so individual atoms that make up the condensate – they all appear the same. This happens because,

in some sense, they all occupy the same space. And since they are all atoms of the rubidium isotope, it becomes impossible to tell them apart if they are all in the same space.

The physical phenomena we are currently investigating in our lab is how a stack of these BECs behave in different scenarios. To explain this in simpler terms, imagine the BEC to be a giant watermelon that we slice vertically into many different pancakes. We then investigate what happens when we move the different pancakes apart, twist them a little bit, and bring them back together. Do they still form a watermelon? Or do they form something different?

But this is not all. After we are done with this experiment, we can do another, looking at something completely different. Over time, the cumulative results of these experiments, gradually contribute to an increase in our knowledge of the natural world and, therefore, to the greater project of human knowledge. This is what our research is about, but doing it requires wearing multiple hats. This is also why there is no easy answer to the question 'what do you do?' The answer is often – many different things!



Note: Credits for the image used in the background of the article title: Laser play, Jeff Keyzer from San Francisco, CA, USA, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Laser_play.jpg. License: CC-BY.

Aftaab Dewan is currently a Ph.D student at the University of Maryland. He can be reached at aftaab.dewan@gmail.com.