SAMPLE

Bose-Einstein Condensates

The Fifth State of Matter

Aira Astralis

Free sample: Introduction & Chapter 1

putrabooks.github.io

Buy the full book:

Carousell carousell.sg/p/bose-einstein-condensates-ebook-pdf-1467810574

ElevenReader

Ko-fi

Payhip

Contents

Introduction

Chapter 1: The Discovery of Bose-Einstein Condensates

Chapter 2: Bosons and Fermions: The Two Statistics

Chapter 3: The Anatomy of a Condensate

Chapter 4: Helium: The Condensate That Was Already There

Chapter 5: The Long Road to 1995

Chapter 6: The Coldest Place on Earth: June 1995

Chapter 7: The Instruments of Cold

Chapter 8: The Theory of the Wave

Chapter 9: Important Features of Bose-Einstein Condensates

Chapter 10: Vortices and Superfluid Motion

Chapter 11: Fermions Pair Up

Chapter 12: The Family of Condensates

Chapter 13: Low Dimensions and Small Worlds

Chapter 14: The Atom Laser

Chapter 15: The Instruments of Time

Chapter 16: The Coldest Objects Ever Made

Chapter 17: The Sky and Free Fall

Chapter 18: Uses and Visions

Chapter 19: The Man Who Counted Identically: Bose and Einstein

Chapter 20: The Fringes: From Dark Matter to the Web

Chapter 21: Fun Facts and Trivia About Bose-Einstein Condensates

Chapter 22: Conclusion: The Significance of Bose-Einstein Condensates

Conclusion

This free sample contains the Introduction and Chapter 1. The complete book contains the full contents above.

Introduction

A Bose-Einstein condensate is a state of matter made by pushing a gas of the right kind of atoms so close to absolute zero that the atoms stop behaving as a crowd of individuals and begin behaving as a single collective thing. The temperature required is not merely cold; it is cold beyond the coldest place in nature, a few billionths of a degree shy of absolute zero itself, and the result is a cloud of atoms in which a large fraction of the particles occupy one and the same quantum state. When that happens, the strange rules that normally govern only the microscopic world, wave interference above all, become visible to ordinary instruments, at ordinary magnification, in a cloud large enough to photograph.

The idea belongs to the 1920s. In 1924 the Indian physicist Satyendra Nath Bose found a new way of counting identical particles, and Albert Einstein, recognizing what the counting meant, extended it from light to atoms and drew the conclusion that a gas cooled far enough would collapse into a single shared state, a condensate. The prediction sat for seventy years, because no one could reach the temperature it demanded. In the 1930s, superfluid helium was suspected to be a cousin of the effect, but the liquid was too dense and too messy to prove it. The demonstration finally came on 5 June 1995, when Eric Cornell and Carl Wieman condensed about two thousand rubidium atoms at 170 nanokelvins, in a laboratory in Boulder, Colorado. Wolfgang Ketterle repeated the feat with sodium at MIT four months later, and the 2001 Nobel Prize in Physics crowned the three of them for it.

This book tells the story whole: the statistics, the prediction, the seventy- year hunt for the temperature, the discovery, and everything that flowed from it, from the slowest light ever measured to a condensate floating in the International Space Station. The chapters keep the physics honest without equations, because the story does not need them; the ideas can be carried in plain language, and they are.

Chapter 1: The Discovery of Bose-Einstein Condensates

The discovery was, in the beginning, a mistake that worked. In the early 1920s, Satyendra Nath Bose was lecturing at the University of Dhaka on radiation and the ultraviolet catastrophe, the failure of classical physics to describe the colors of hot objects. He wanted to show his students that the accepted theory gave results that disagreed with experiment, and in the middle of the demonstration he made an error in applying it. The error was of a familiar kind, equivalent to arguing that flipping two fair coins produces two heads a third of the time, a slip that anyone with a basic grasp of statistics would catch, and it resembled a famous earlier blunder by the eighteenth-century mathematician Jean le Rond d'Alembert. But the answer it produced matched the experiments.

Bose had the presence of mind not to discard it. If the wrong counting gave the right physics, perhaps the counting was not wrong, and the accepted way of distributing energy among particles was. He recast his argument as a short paper, deriving the law of blackbody radiation with no reference to classical physics at all, counting identical particles as genuinely identical, and sent it to a European journal, where the referee rejected it. Undaunted, he mailed the manuscript to Albert Einstein directly, asking whether he would arrange its publication in Germany. Einstein read it, at once understood that the mistake was the discovery, translated the paper into German himself, and submitted it on Bose's behalf to the Zeitschrift für Physik, where it appeared in 1924. He added his name to nothing and took no credit; he simply published a stranger's paper and then wrote two of his own extending the idea.

Einstein's extension moved the statistics from light to matter. If photons could be counted the way Bose counted them, so could atoms, and the arithmetic had a consequence that had gone unnoticed: cool a gas of such particles far enough and the mathematics forces a collapse, a large fraction of the whole population dropping into the single lowest quantum state, a new form of matter. The papers of 1924 and 1925 contain the prediction that would take seventy years to test. Einstein's own manuscript for the translation, once believed lost, resurfaced in 2005, in a library at Leiden University, a quiet relic of the moment quantum statistics was born.

The reason Bose's wrong counting gave the right answer is worth stating plainly, because it is the heart of everything this book is about. Photons are identical to one another in a way coins are not: two photons carrying the same momentum and polarization are not two distinguishable objects that happen to

look alike, but literally interchangeable occupants of the same state, and counting them as if they had identities is the error, not the correction. Bose's paper, titled on the hypothesis of light quanta, divided the radiation field into cells of the allowed size and counted only the number of photons per cell, never which photon sat where; the arithmetic of that count reproduces Planck's law exactly, with no detour through classical waves.

Einstein, translating, noticed a small refinement, replacing a factor Bose had included for two spin states with the two polarizations of light, and the paper went to press corrected in the founder's own hand. The episode has become the standard lesson in the philosophy of physics: sometimes the result that comes out right from a procedure everyone believes wrong is telling you that the procedure is right and the belief is wrong.

Einstein's two extension papers did more than translate the statistics into the language of matter; they asked what a gas of indistinguishable particles would actually do, and the answer is the reason this book exists. In the first, he applied the new counting to a gas of atoms and found the distribution of the particles among their energies; in the second, he noticed that the arithmetic had a singularity in it, a temperature below which the equations quietly stopped describing a gas of many atoms and began describing a single shared state, with a macroscopic fraction of the whole population in the ground state.

He wrote of the effect with some bemusement, describing the condensed and uncondensed fractions as two phases of one gas, thermodynamically distinct, like steam and water, and the analogy he reached for, a vapor condensing, gave the phenomenon the name it carries. The papers appeared in the same journal, back to back, in 1924 and 1925, and the physics world read them as arithmetic, not prophecy; no one imagined that the singular temperature was reachable, and the seventy-year silence that followed was not skepticism so much as the quiet of an impossible direction.

End of free sample. The full book is available at putrabooks.github.io

ABOUT THE AUTHOR

Aira Astralis is a science writer specializing in astronomy and space exploration. Her work spans the full breadth of humanity's relationship with the cosmos -- from the earliest naked-eye observations to the engineering marvels of modern space missions.

Her books are built on a foundation of primary sources: peer-reviewed research, mission archives, and direct engagement with the scientific community. She writes for readers who want to understand not just what we know about the universe, but how we came to know it.

She believes that the most important frontier is not out there but in the gap between what scientists discover and what the public understands. Her books exist to close that gap.