Bose-Einstein condensation and superfluidity

Plancks Gesetz und Lichtquantenhypothese.

Von **Bose** (Dacca-University, Indien).

(Eingegangen am 2. Juli 1924.)

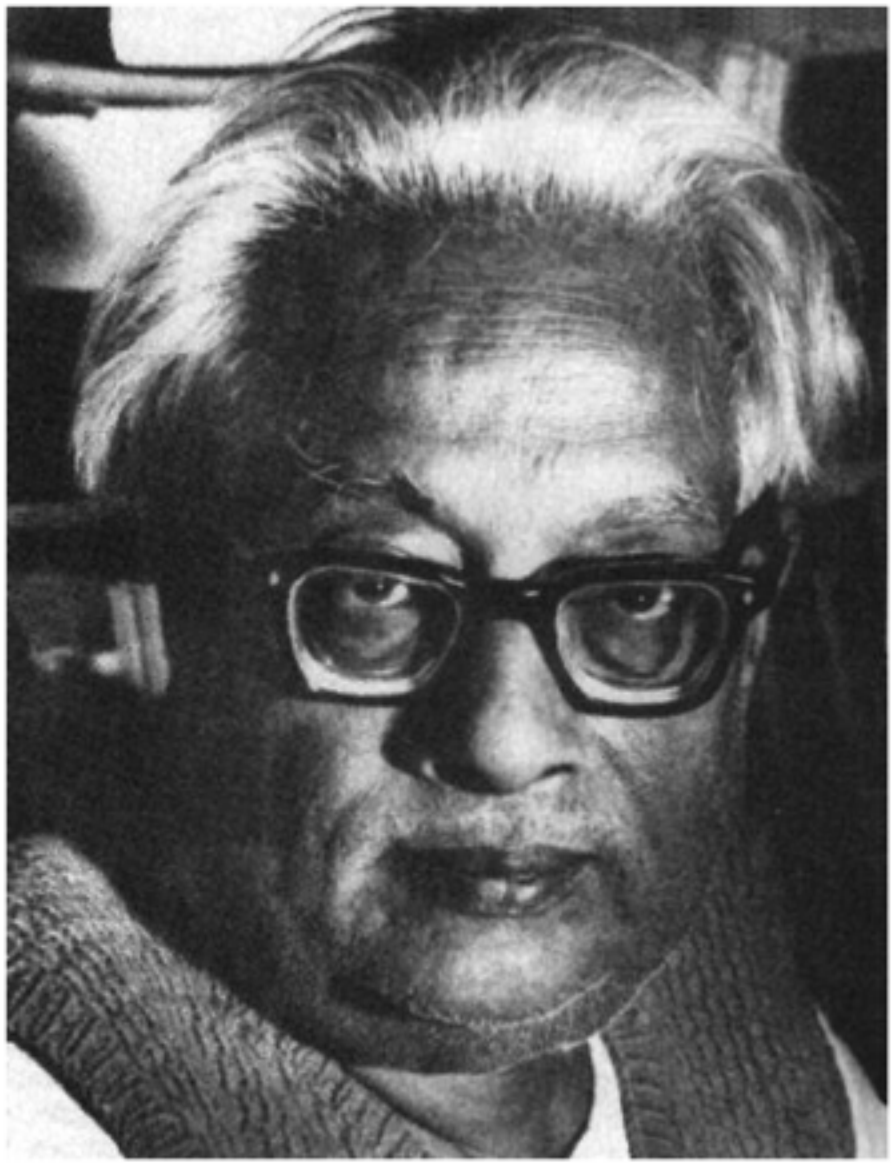
Der Phasenraum eines Lichtquants in bezug auf ein gegebenes Volumen wird in „Zellen" von der Größe h^3 aufgeteilt. Die Zahl der möglichen Verteilungen der Lichtquanten einer makroskopisch definierten Strahlung unter diese Zellen liefert die Entropie und damit alle thermodynamischen Eigenschaften der Strahlung.

Quantentheorie des einatomigen idealen Gases.

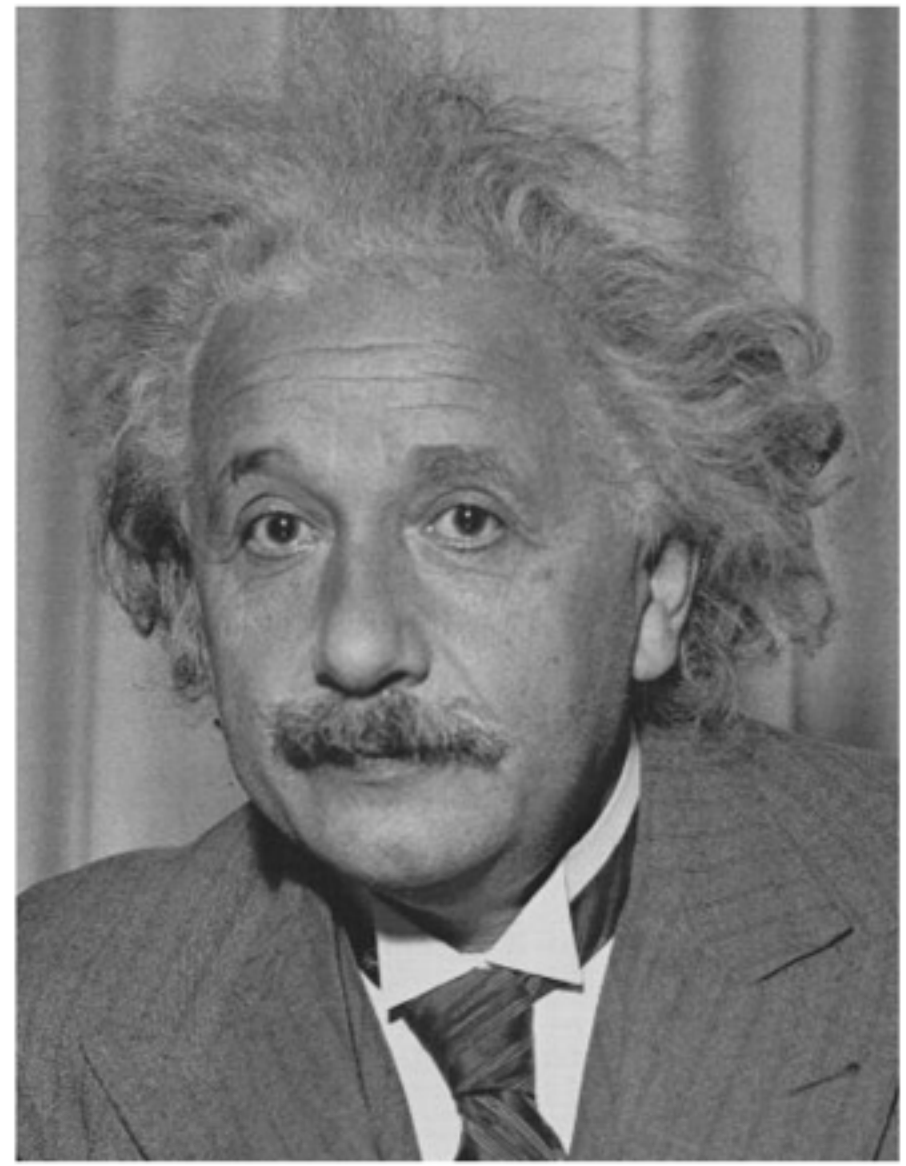
Von A. Einstein.

Eine von willkürlichen Ansätzen freie Quantentheorie des einatomigen idealen Gases existiert bis heute noch nicht. Diese Lücke soll im folgenden ausgefüllt werden auf Grund einer neuen, von Hrn. D. Bose erdachten Betrachtungsweise, auf welche dieser Autor eine höchst beachtenswerte Ableitung der Planckschen Strahlungsformel gegründet hat[1].

Bose-Einstein condensation *1924



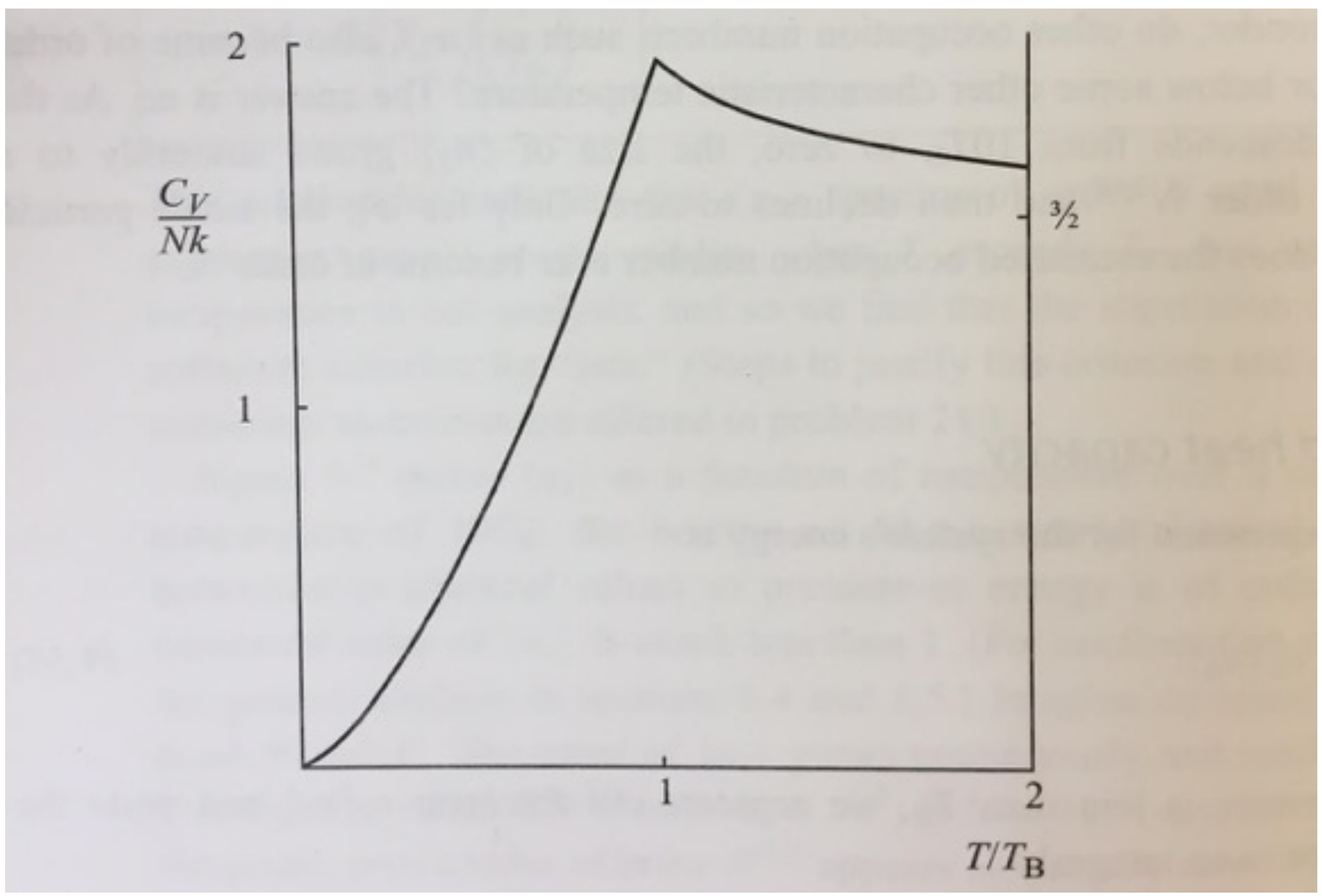
Satyendra Nath Bose



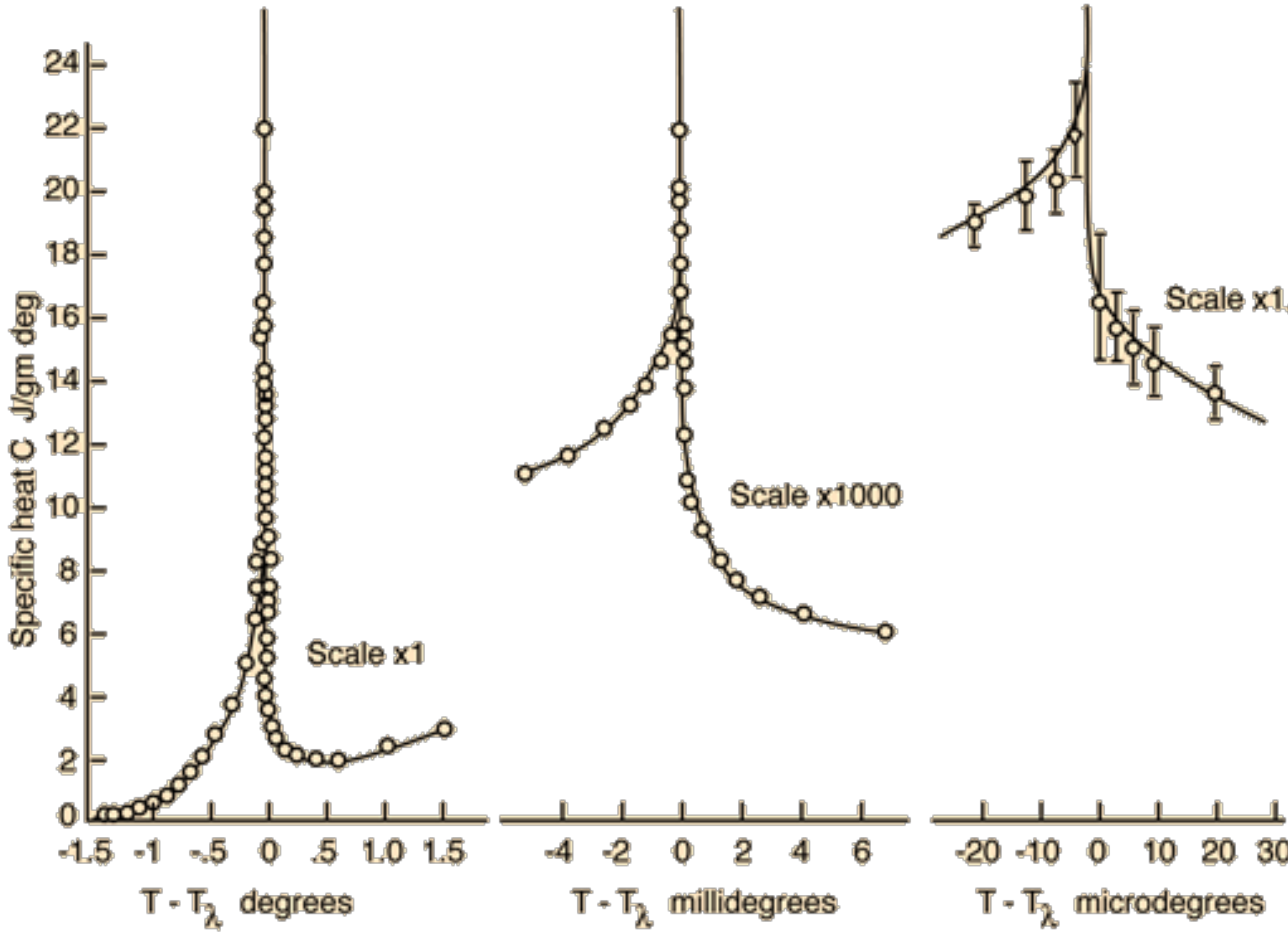
Albert Einstein

How to observe a BEC?

- London in 1938 was the first to propose that BEC was the mechanism behind superfluidity.



Lambda point of He-4



- Is a superfluid a BEC?
  - There is one fundamental difference: *superfluids have interactions.*
  - It should be possible to have a BEC even without any interactions.

$$k_B T_c = 3.3125 \frac{\hbar^2}{m} \left(\frac{N}{V} \right)^{2/3}$$

- We need a sufficiently high Tc:
  - Can use very small mass.
  - For many years people tried to use hydrogen.
    - But hydrogen is a mess to work with.
  - So maybe use He.
    - But He condenses into a superfluid.

- The solution was using magneto-optical traps.
    - Laser cooling
    - Evaporative cooling.

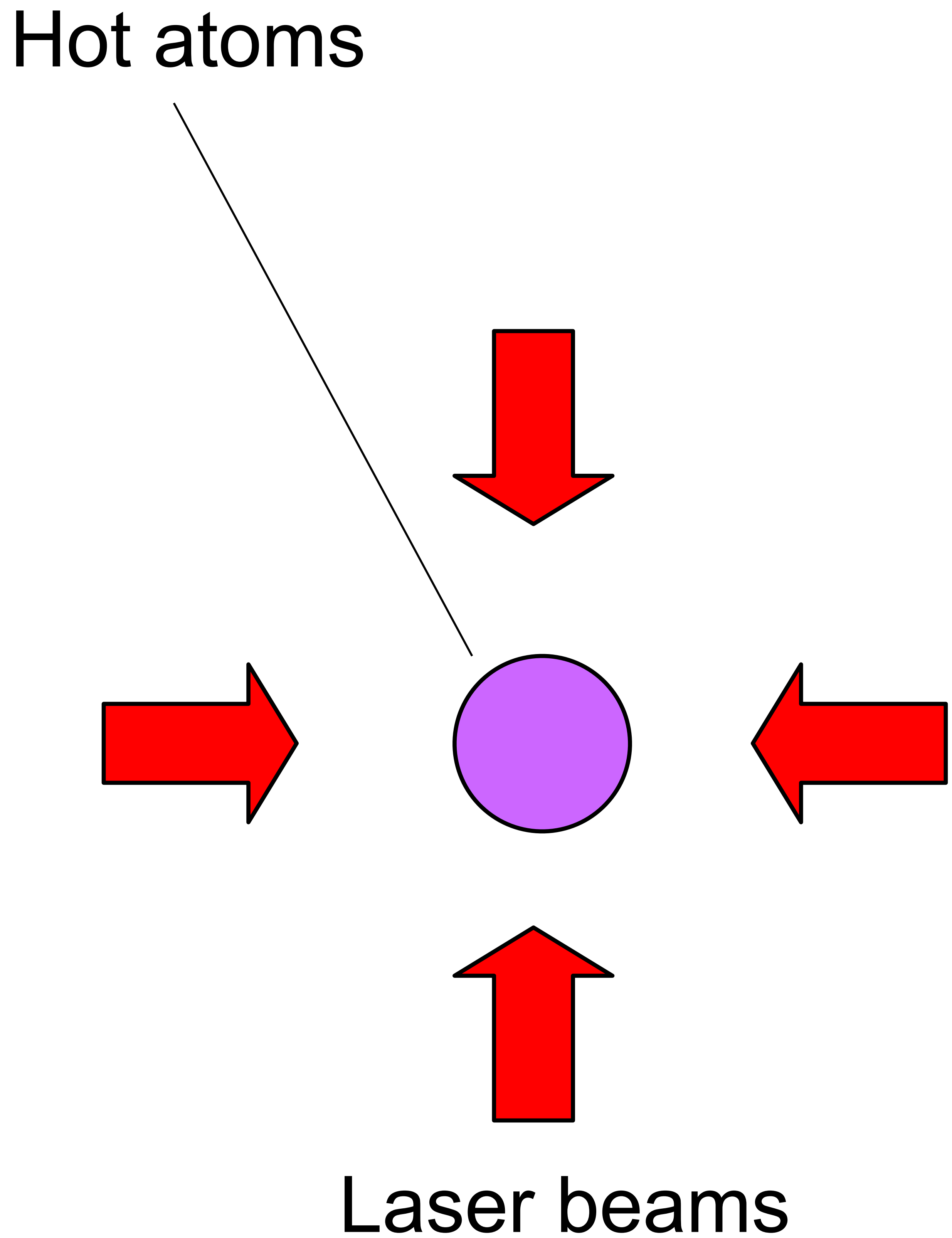
The Nobel Prize in Physics 1997

"for development of methods to cool and trap atoms with laser light"

Steven Chu

Claude Cohen-Tannoudji

William D. Phillips


Hot atoms
Laser beams

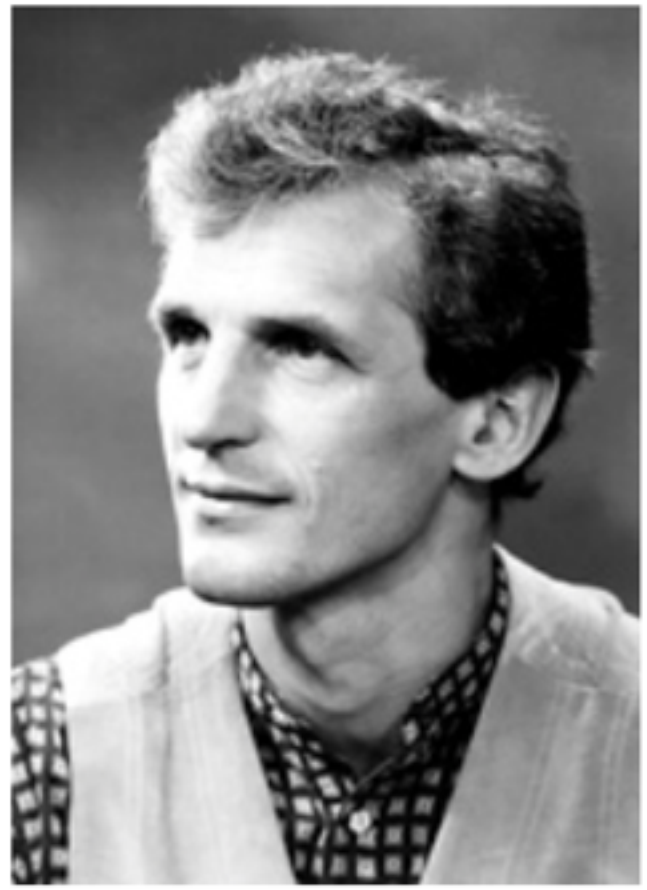
Evaporative cooling

- Coils create a magnetic trap that works just like a 3D harmonic oscillator.
- Hot atoms (tail of the Boltzmann distribution) escape the trap.
- The atoms that remain are colder.

- First BECs was produced in 1995 by Cornell and Wieman at University of Colorado at Boulder NIST–JILA lab.
    - They used Rubidium atoms cooled to 170 nK
- In the same year Ketterle at MIT did the same with Sodium atoms.

The Nobel Prize in Physics 2001

Eric A. Cornell
Prize share: 1/3



Wolfgang Ketterle
Prize share: 1/3

Carl E. Wieman
Prize share: 1/3

The Nobel Prize in Physics 2001 was awarded jointly to Eric A. Cornell, Wolfgang Ketterle and Carl E. Wieman *"for the achievement of Bose-Einstein condensation in dilute gases of alkali atoms, and for early fundamental studies of the properties of the condensates"*.

Observation of Bose-Einstein Condensation in a Dilute Atomic Vapor

M. H. Anderson, J. R. Ensher, M. R. Matthews, C. E. Wieman,*
E. A. Cornell

A Bose-Einstein condensate was produced in a vapor of rubidium-87 atoms that was confined by magnetic fields and evaporatively cooled. The condensate fraction first appeared near a temperature of 170 nanokelvin and a number density of 2.5×10^{12} per cubic centimeter and could be preserved for more than 15 seconds. Three primary signatures of Bose-Einstein condensation were seen. (i) On top of a broad thermal velocity distribution, a narrow peak appeared that was centered at zero velocity. (ii) The fraction of the atoms that were in this low-velocity peak increased abruptly as the sample temperature was lowered. (iii) The peak exhibited a nonthermal, anisotropic velocity distribution expected of the minimum-energy quantum state of the magnetic trap in contrast to the isotropic, thermal velocity distribution observed in the broad uncondensed fraction.

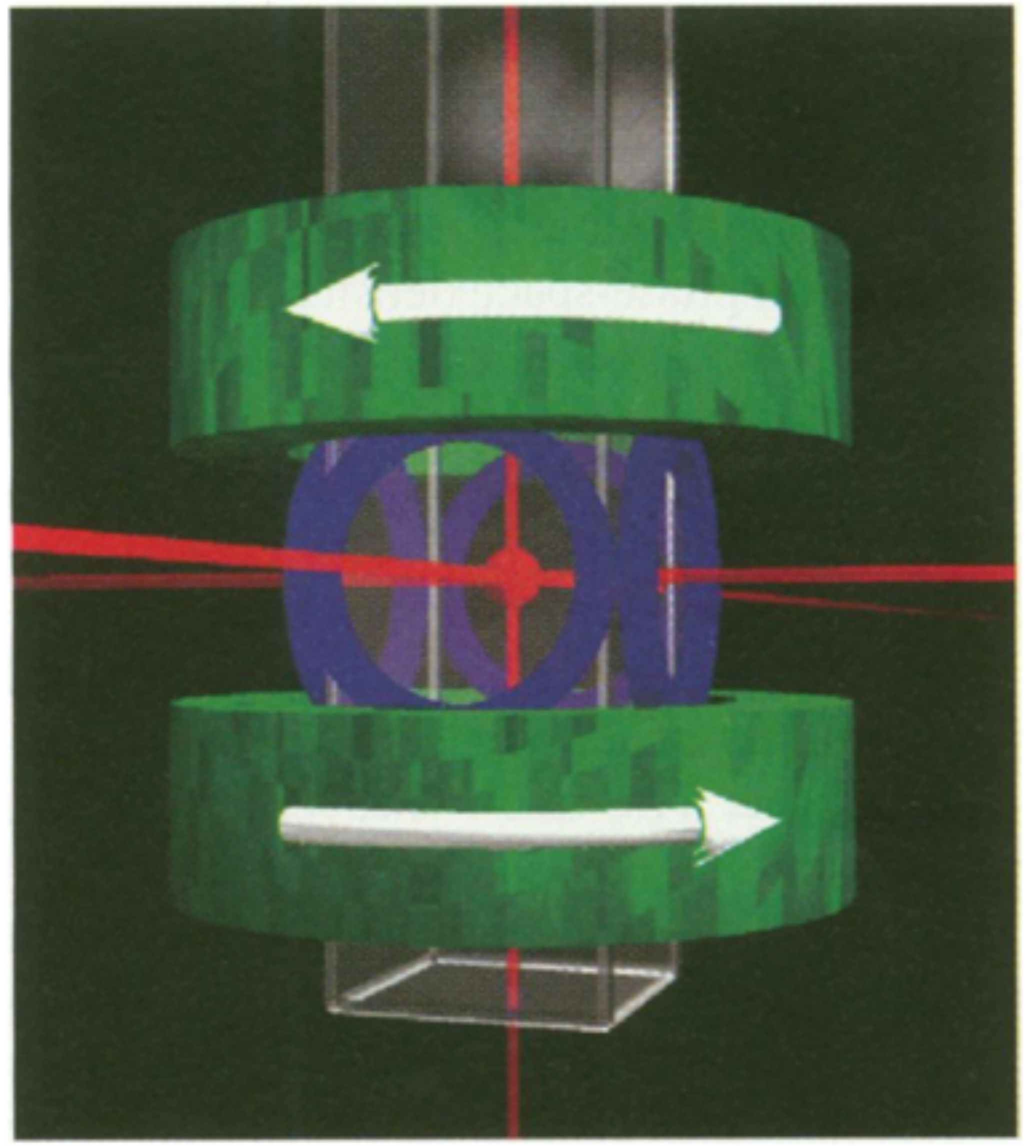
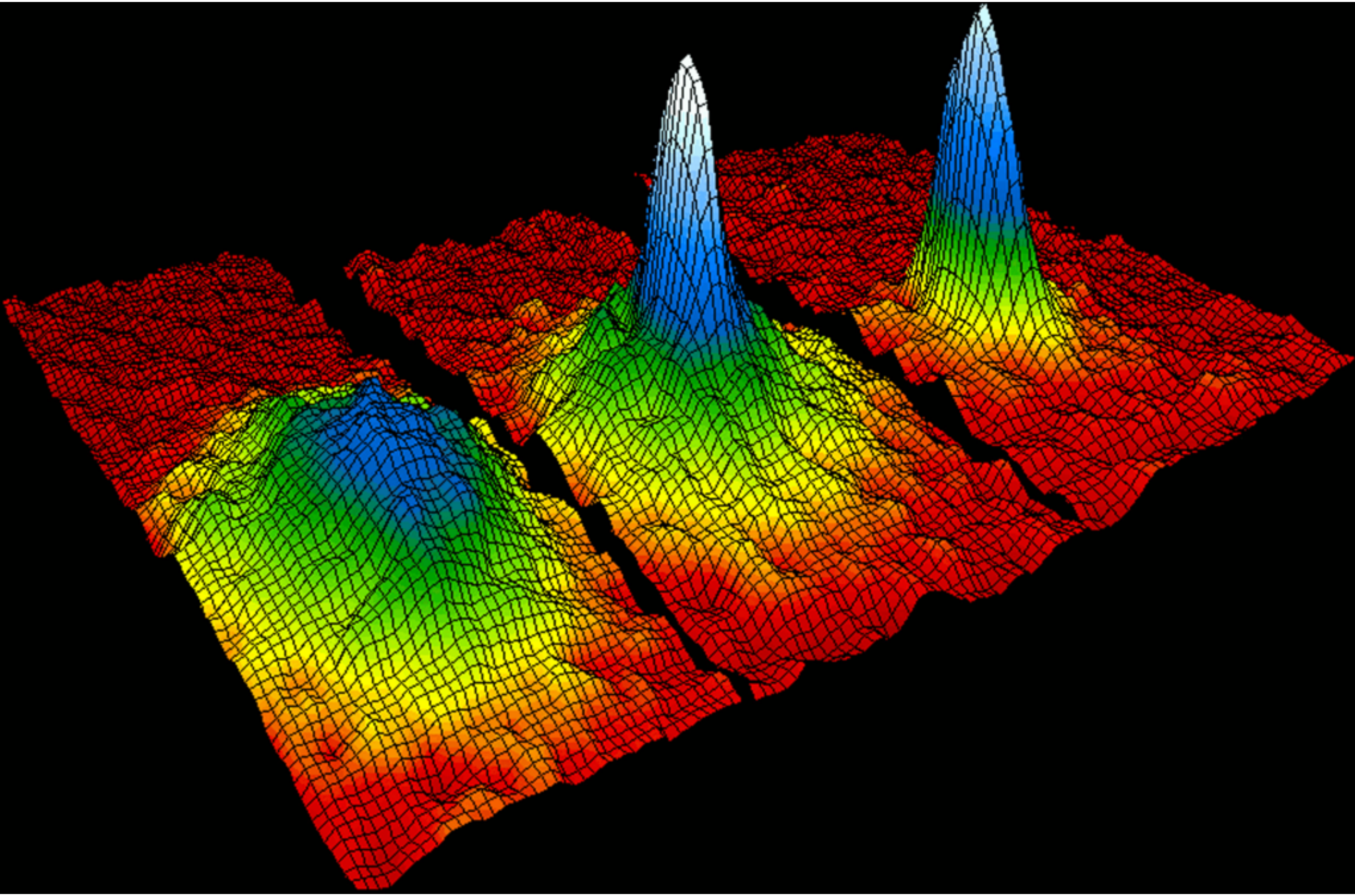
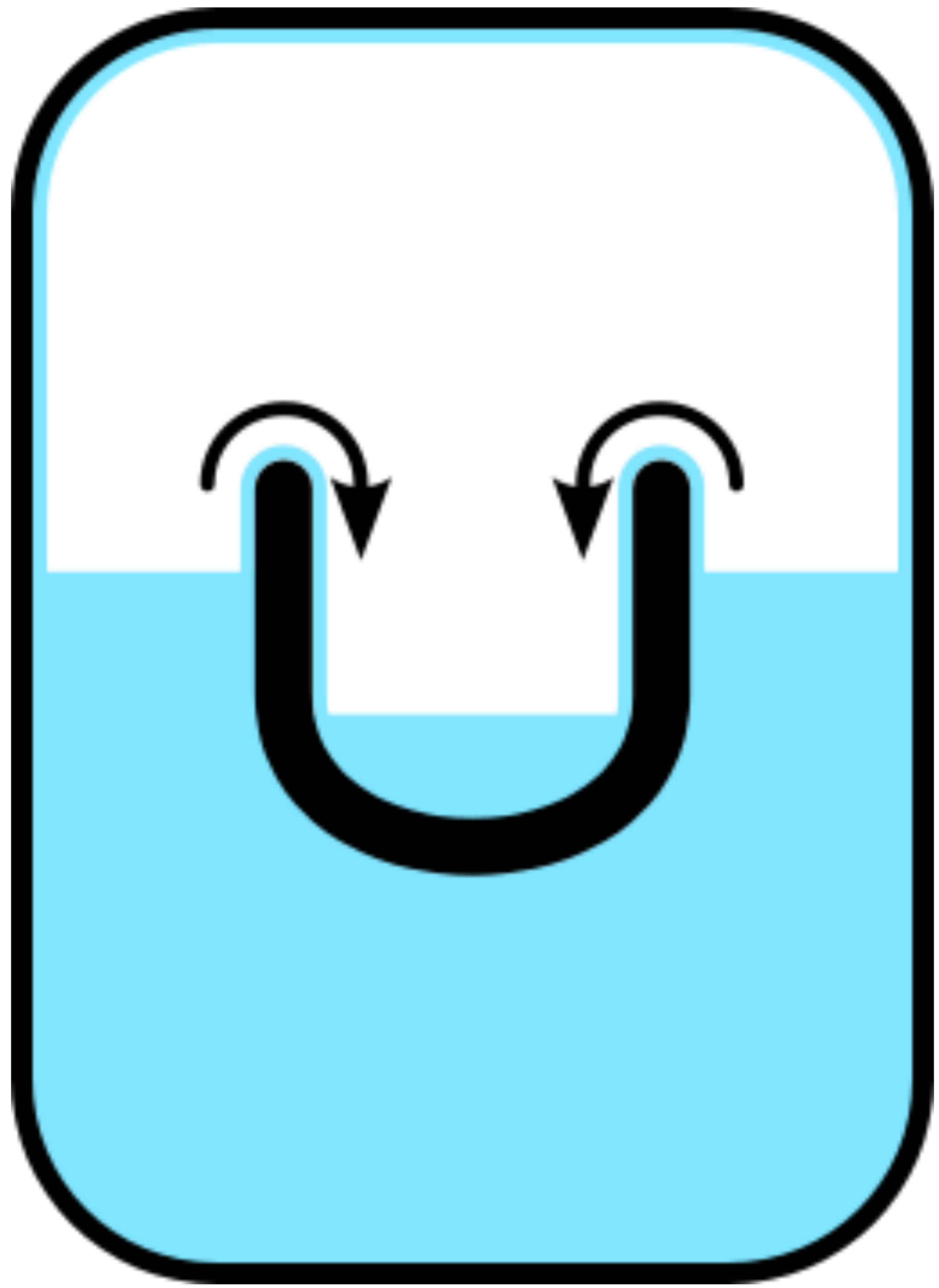
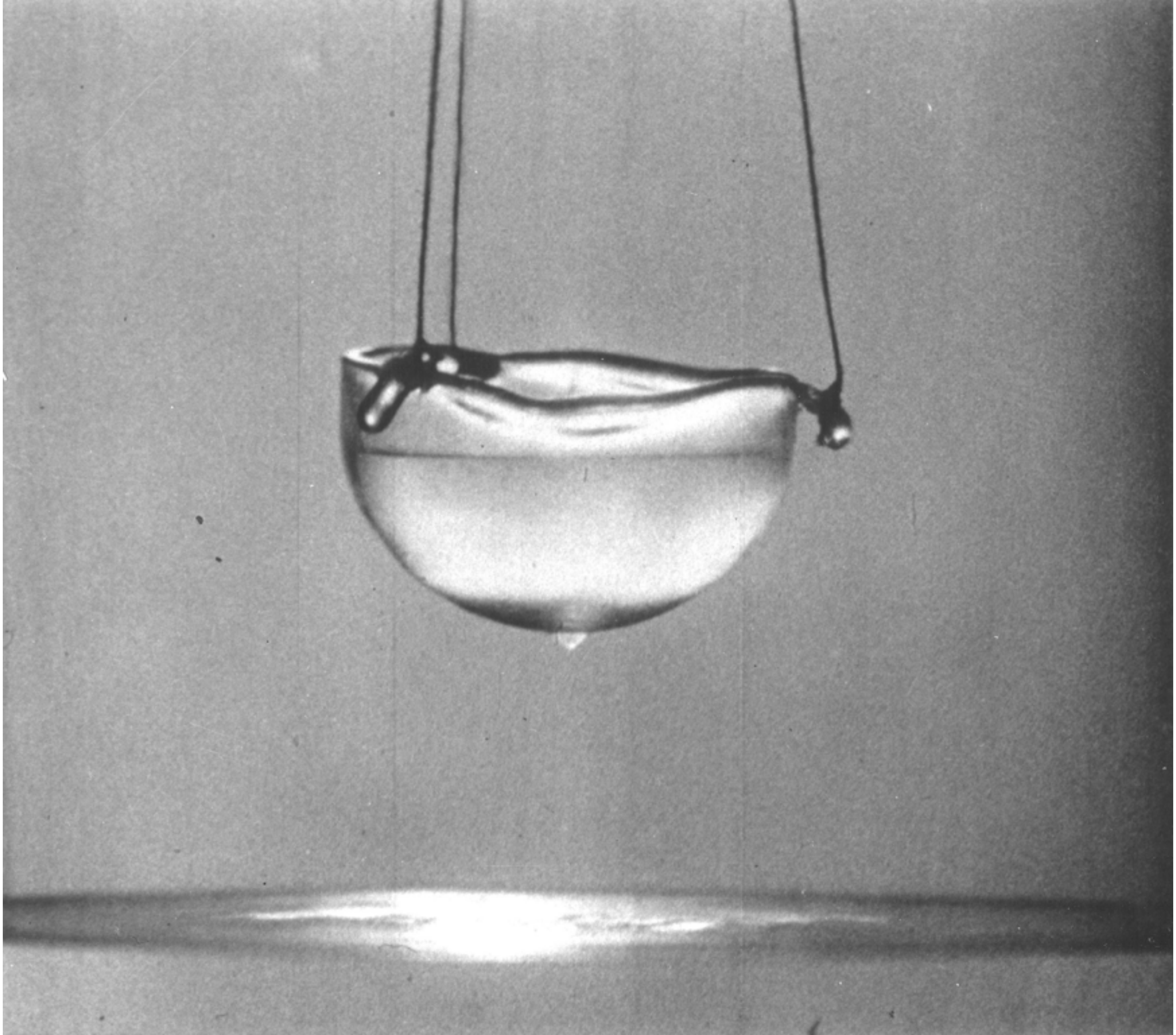


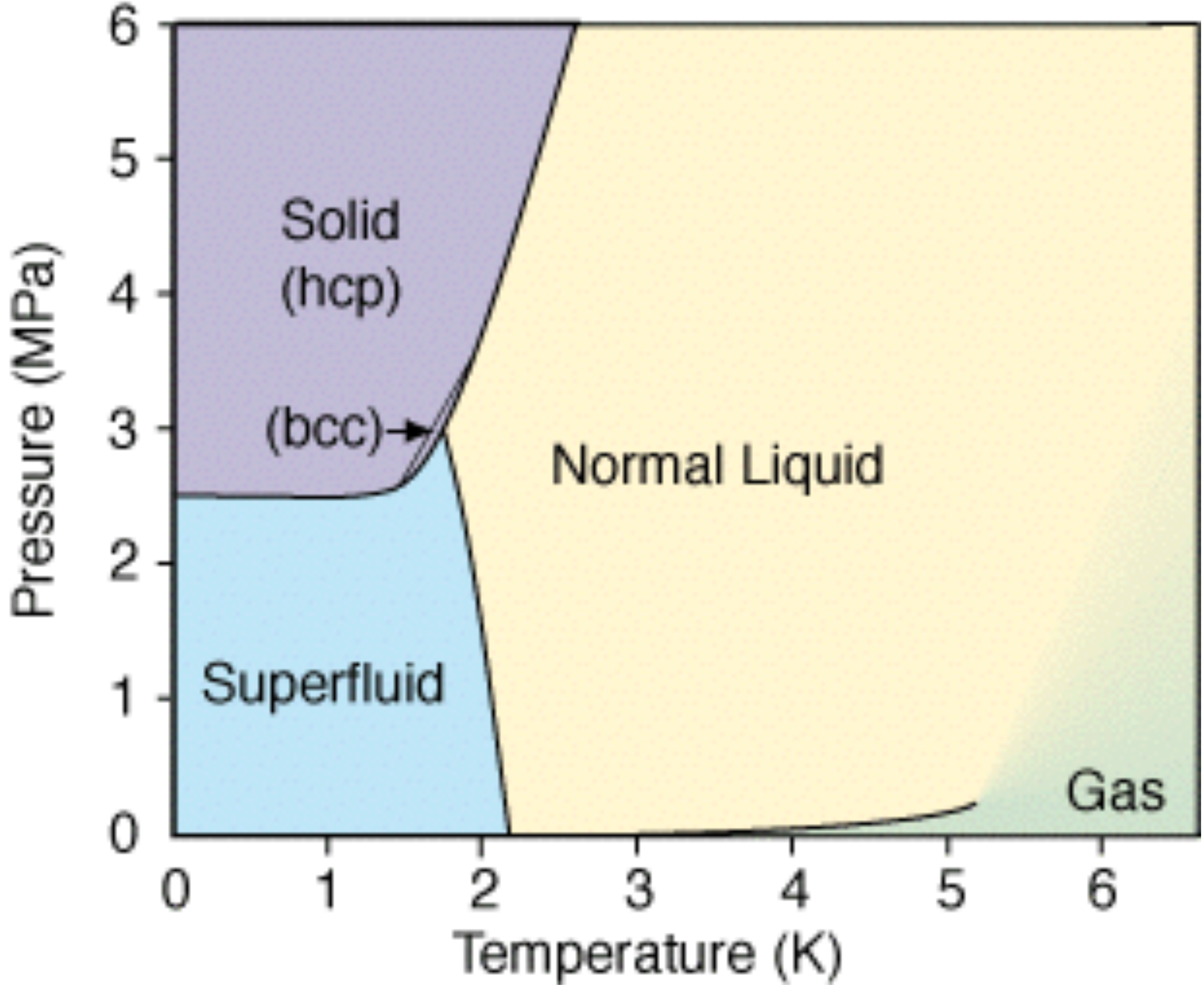
Fig. 1. Schematic of the apparatus. Six laser beams intersect in a glass cell, creating a magneto-optical trap (MOT). The cell is 2.5 cm square by 12 cm long, and the beams are 1.5 cm in diameter. The coils generating the fixed quadrupole and rotating transverse components of the TOP trap magnetic fields are shown in green and blue, respectively. The glass cell hangs down from a steel chamber (not shown) containing a vacuum pump and rubidium source. Also not shown are coils for injecting the rf magnetic field for evaporation and the additional laser beams for imaging and optically pumping the trapped atom sample.



Superfluidity






Solid
(hcp)
(bcc)
Normal Liquid
Superfluid
Gas
Pressure (MPa)
Temperature (K)
0
1
2
3
4
5
6
0
1
2
3
4
5
6

Lambda point of He-4