答案上載
http://panpearl.phys.ust.hk

卷一

1. 立竿无影: 2.4 / 5
2. 六枚飞弹: 4.2 / 5
3. 下跌中的梯子: 7.2 / 10
4. 光子气体: 2.4 / 5
5. 海面传音: 2.4 / 5
6. 空腔中的电子轨迹: 4.9 /10
7. 带电荷电流线邻近的质子运动: 3.3 / 5

总分: 26.8 / 45 (去年: 25.3 / 50)

卷二

1.玻色-爱因斯坦凝聚: 11.4 / 22

2. 游泳微生物: 10.6 / 33

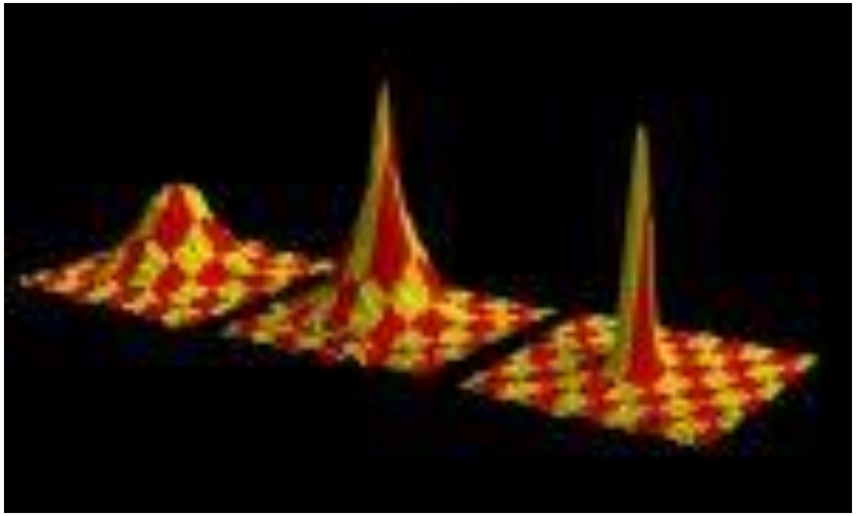
总分: 21.8 / 55 (去年: 18.5 / 50)

卷一和卷二

- 总分: 48.6 / 100 (去年: 43.8 / 100)
-
- 中位数: 51 (去年: 46.5)

The Prize

"for the achievement of Bose-Einstein condensation (玻色-愛因斯坦凝聚態) in dilute gases of alkali atoms (碱原子) , and for early fundamental studies of the properties of the condensates"



The Winners

Eric A. Cornell

康奈爾

JILA & NIST,
Boulder, Colorado.

1961-

Wolfgang Ketterle

克特勒

MIT

1957-

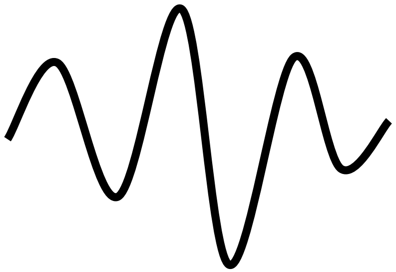
Carl E. Wieman

維曼

JILA &
University of
Colorado, Boulder.

1951-

Q1: What Is Bose-Einstein Condensation?

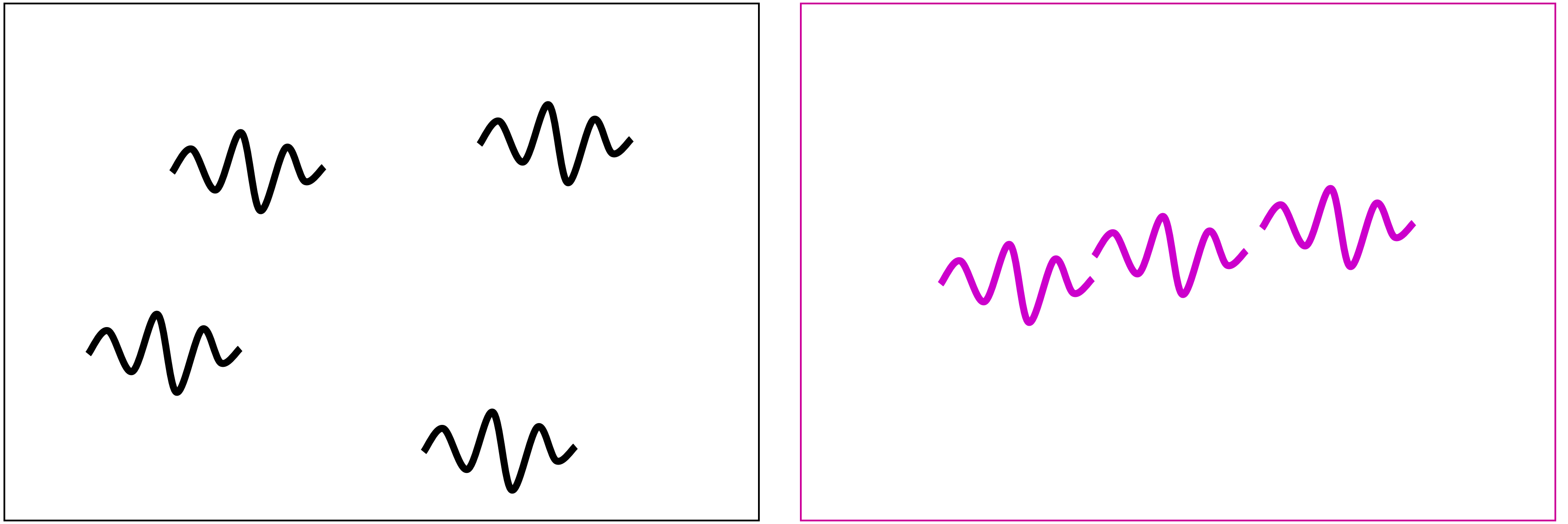


De Broglie 德布羅意 (1929 Nobel Prize winner) proposed that all matter is composed of waves. Their wavelengths are given by

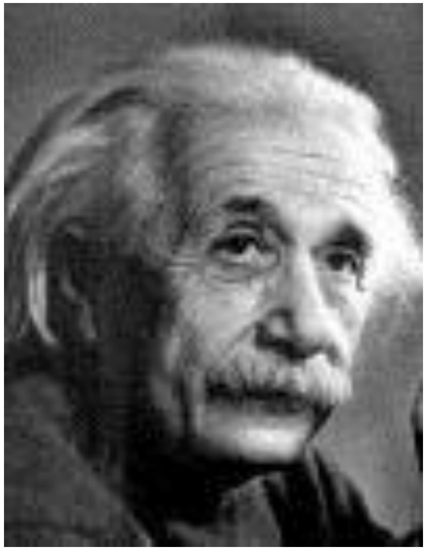
$$\lambda = \frac{h}{mv}$$

λ = de Broglie wavelength
h = Planck's constant 普朗克常數
m = mass
v = velocity

Against Our Intuition?!

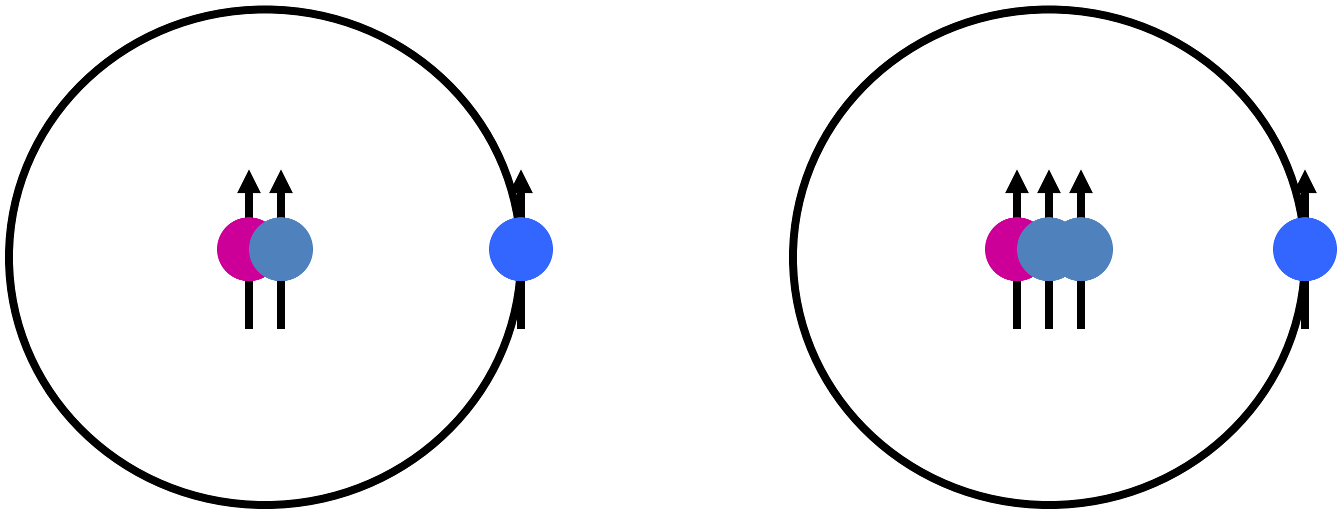


Bose and Einstein



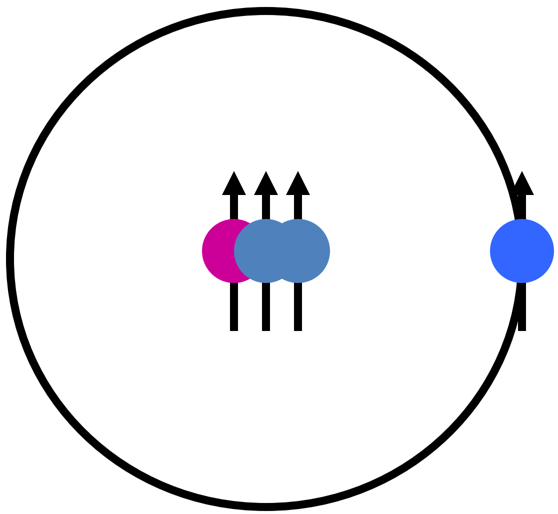
- In 1924 an Indian physicist named Bose studied the quantum behaviour of a collection of photons.
- Bose sent his work to Einstein, who realized that it was important.
- Einstein generalized the idea to atoms, considering them as quantum particles with mass.
- Einstein found that when the temperature is high, they behave like ordinary gases.
- However, when the temperature is very low, they will gather together at the lowest quantum state. This is called Bose-Einstein condensation.

Fermions (費米子) and Bosons (玻色子)



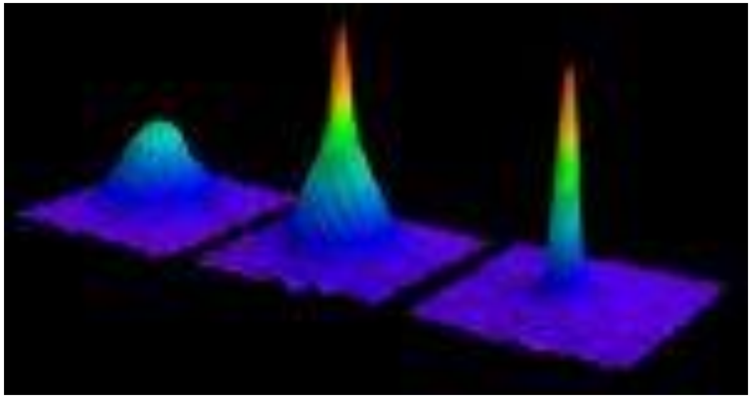
- Not all particles can have BEC. This is related to the spin of the particles.
- The spin quantum number of a particle can be an integer or a half-integer.
- Single protons, neutrons and electrons have a spin of $\frac{1}{2}$. They are called fermions. They cannot appear in the same quantum state. BEC cannot take place.
- Some atoms contain an even number of fermions. They have a total spin of whole number. They are called bosons.
- Bosons show strong "social" behaviour, and can have BEC.
- Example: A ^{23}Na atom has 11 protons, 12 neutrons and 11 electrons.

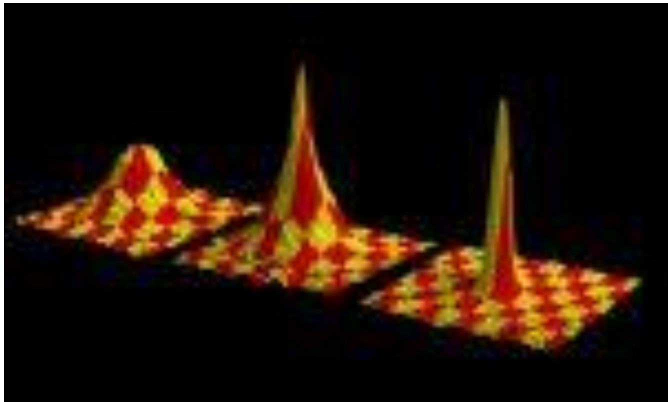
The Material For BEC



* BEC was found in alkali metals e.g. ^{87}Rb (金如), ^{23}Na (鈉), ^{7}Li (鋰) because:
    * They are bosons.
    * Each atom is a small magnetic compass, so that a cooling technique called magnetic cooling can work.
    * The atoms have a small repulsion, so that they do not liquefy or solidify down to a very low temperature.

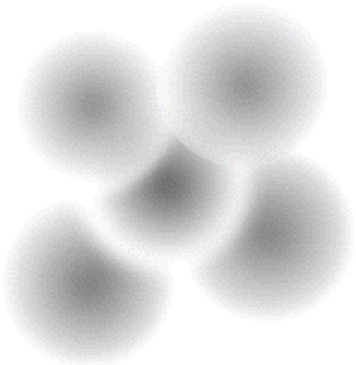
Cooling Down the Atoms



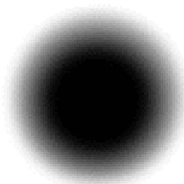


* See the animation: http://www.colorado.edu/physics/2000/bec/what_is_it.html
* When the temperature is high, the atoms have high energies on average. The energy levels are almost continuous. It is sufficient to describe the system by classical physics.
* When the temperature is low, the atoms have low energies on average. It is necessary to describe the system by quantum physics.
* When the temperature is very low, a large fraction of atoms suddenly crash into the lowest energy state. This is called Bose-Einstein condensation.

The Strange State of BEC



Some very cold atoms

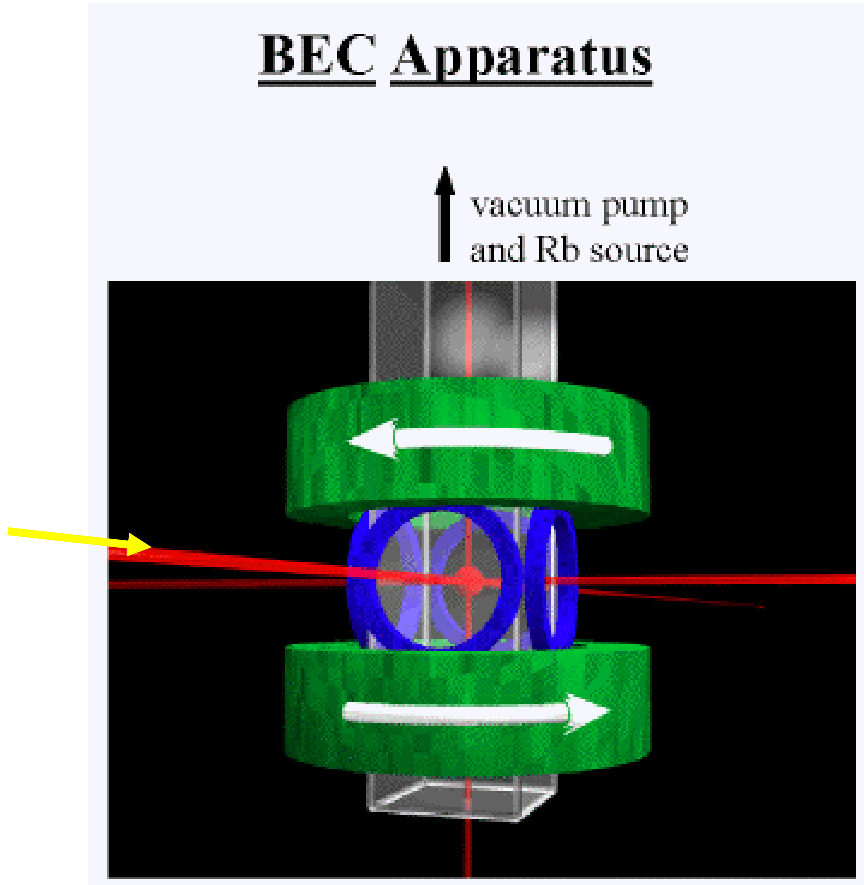


Some atoms in a BEC condensate

* When all the atoms stay in the condensate, all the atoms are absolutely identical. There is no possible measurement that can tell them apart.
* Before condensation, the atoms look like fuzzy balls.
* After consdensation, the atoms lie exactly on top of each other (a superatom).

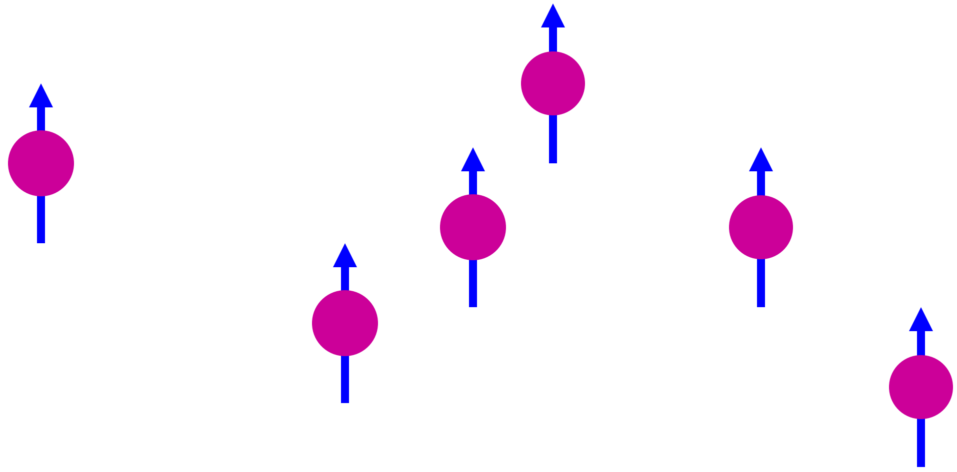
Q2: How Is BEC Made?

Laser beam



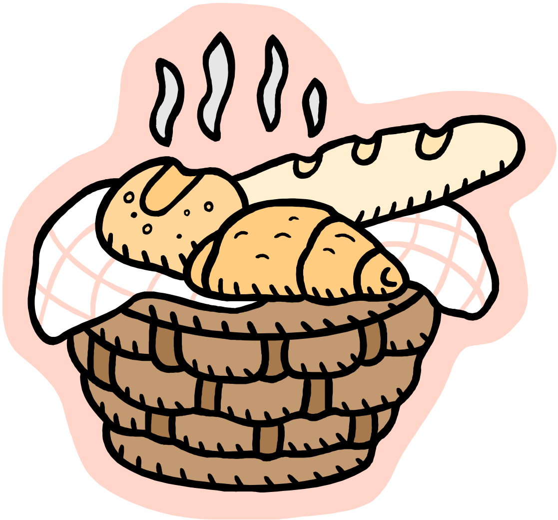
Other equipment: laser equipment, computer, electronics
Cost less than US$100,000

Magnetic Trapping (磁性陷阱)



- ∗ Problem: Laser cooling can cool the atoms down to 10μK, because atoms can spontaneously emit the absorbed photon. This is still too hot for BEC.
- ∗ Solution: <u>Evaporative cooling</u>
- ∗ The atoms behave as tiny compasses. They can be pulled by magnetic fields.
- ∗ A magnetic field can be designed to push the atoms inwards from both sides, forming a magnetic trap.

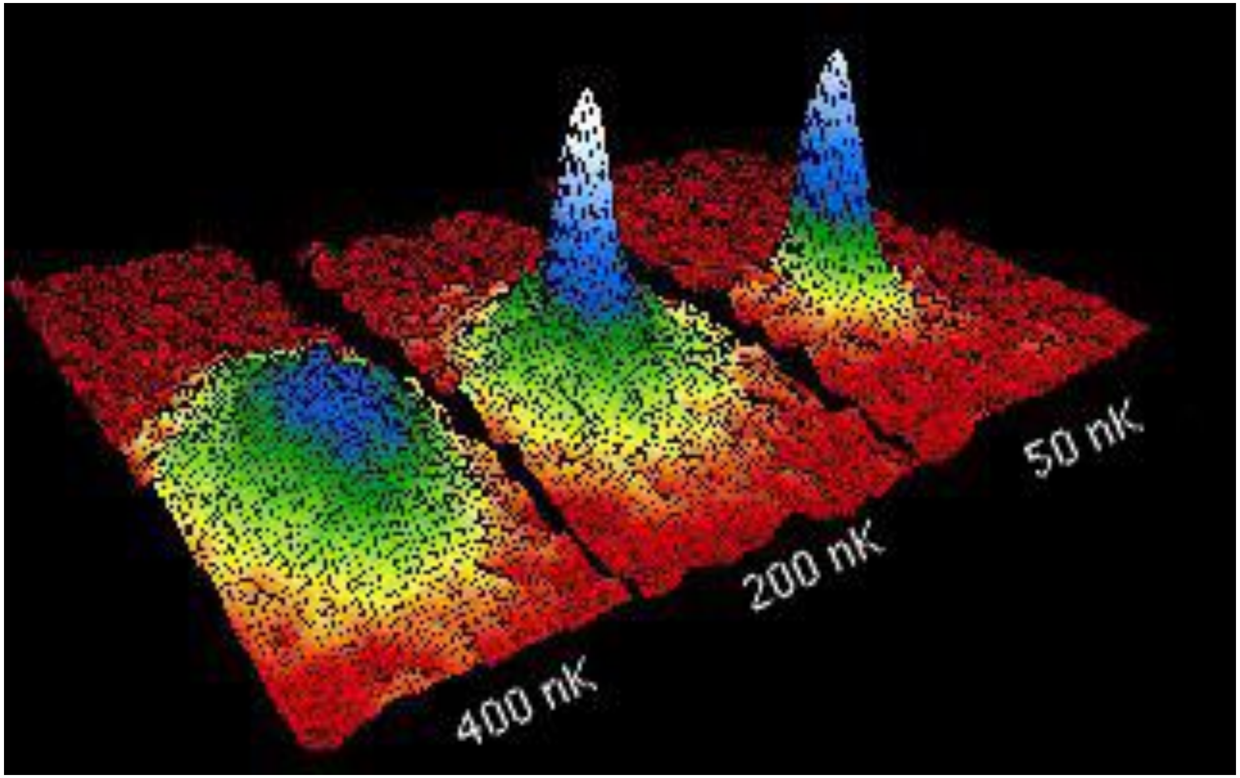
Evaporative Cooling (揮發冷卻)



- Principle: Evaporation takes heat. A cup of tea gets cool after steam escapes, because faster atoms escape from the cup, leaving behind the slower ones.
- Technique: Lower the height of the trap quickly, so that there are still enough atoms left in the trap to get involved in BEC.
- Try to trap the largest number of atoms in BEC in the animation:
- http://www.colorado.edu/physics/2000/bec/evap_cool.html

Q3: What Does a Bose-Einstein Condensate Look Like?

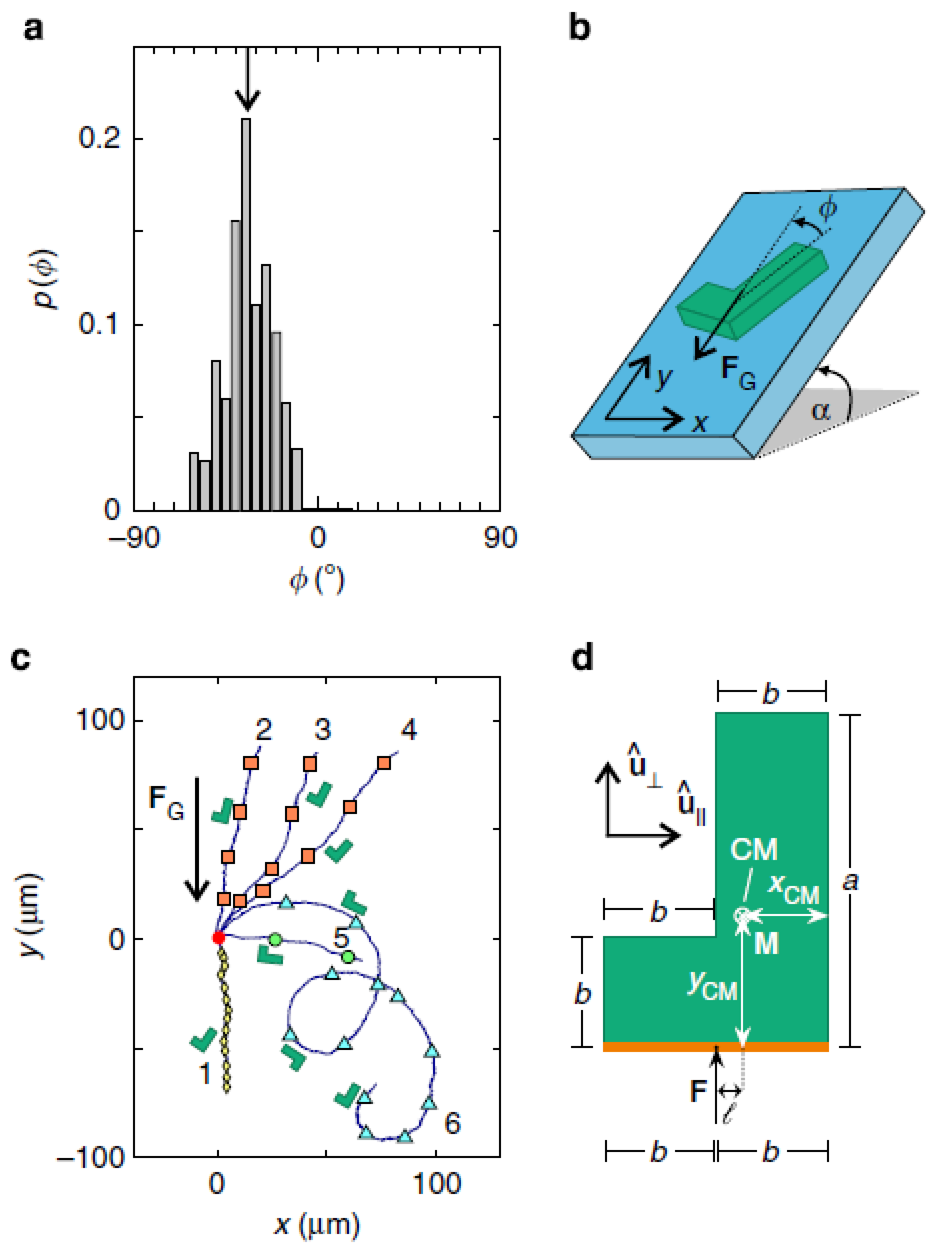
* There is a drop of condensate at the centre.
* The condensate is surrounded by uncondensed gas atoms.
* The combination looks like a cherry with a pit.
* See the movie when it cools from 400 nK to 50 nK (1 nK納開= 10^{-9}K). :
  http://www.colorado.edu/physics/2000/bec/what_it_looks_like.html



2.游泳微生物: 33分， 平均10.6分

诸如草履虫的微生物怎样按着**重力场**的影响, 控制游泳的方向?

最近, 物理学家提出他们的游泳模式和他们**不对称**的形状有关。


a
b
c
d
p(ϕ)
ϕ (°)
0.2
0.1
0
−90
0
90
ϕ
F_G
y
x
α
100
0
−100
y (µm)
x (µm)
2
3
4
1
5
6
b
a
û⊥
û∥
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x_CM
M
y_CM
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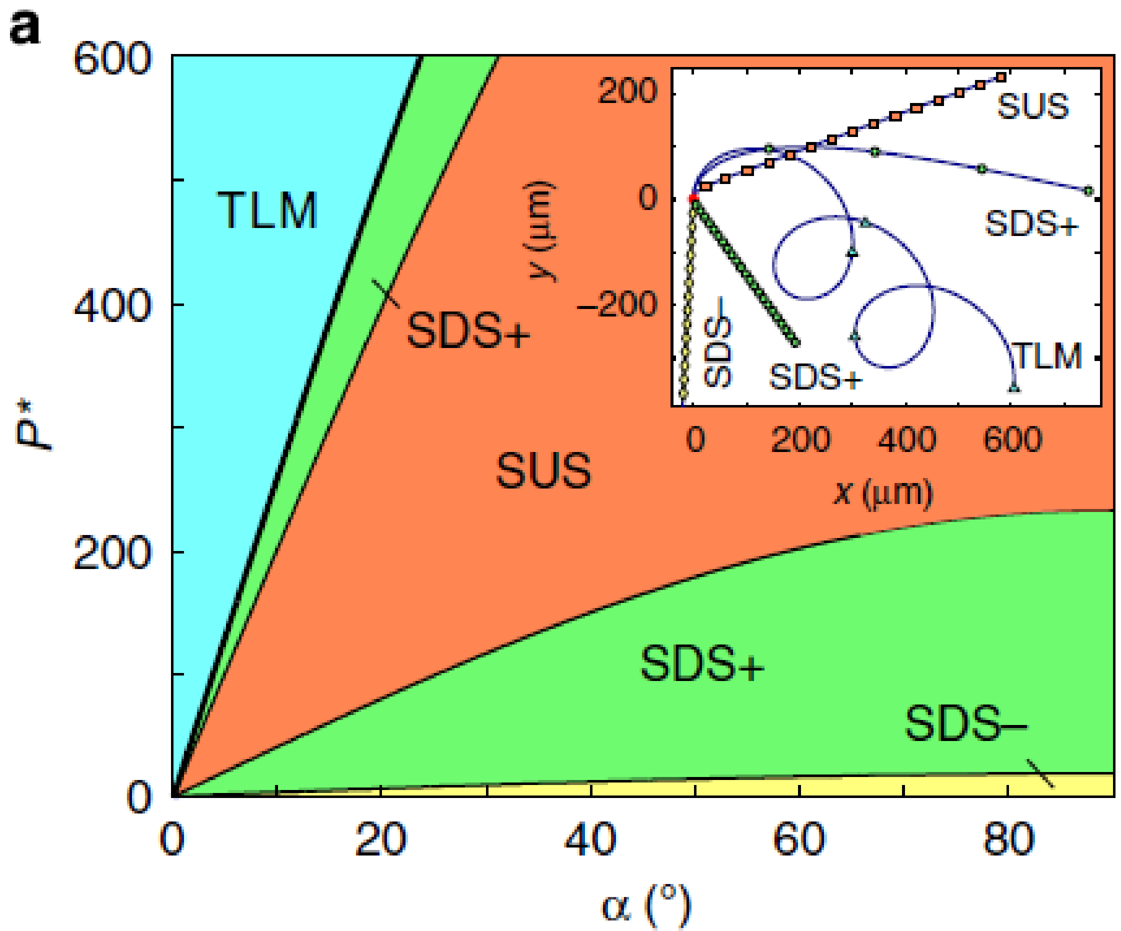


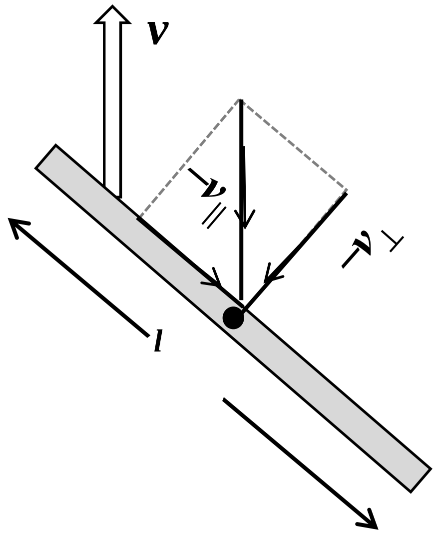
TLM = trochoid-like motion

SUS = straight upward swimming

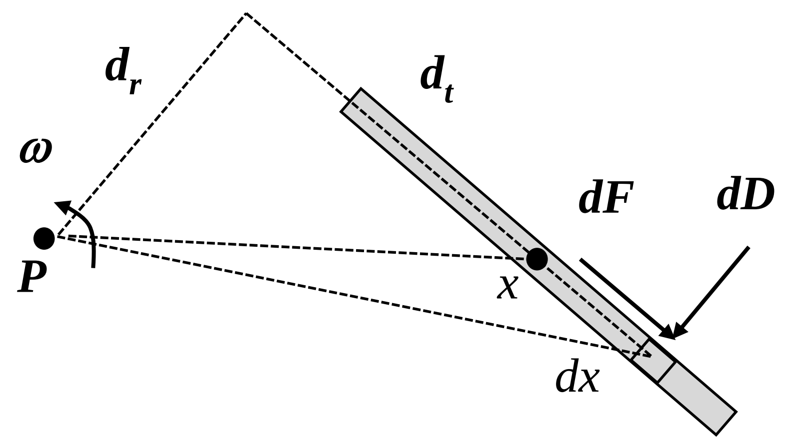
SDS+ = straight downward swimming with a positive drift

SDS- = straight downward swimming with a negative drift

(a)



(b)



$$D = \mu v_\perp l$$

$$F = \frac{1}{2}\mu v_\parallel l$$

$$D = \mu l d_t \omega \qquad F = \frac{1}{2}\mu l d_r \omega$$

$$\tau_f = \frac{1}{2}\mu l d_r^2 \omega$$

$$\tau_d = \frac{1}{12}\mu l^3 \omega + \mu l d_t^2 \omega$$