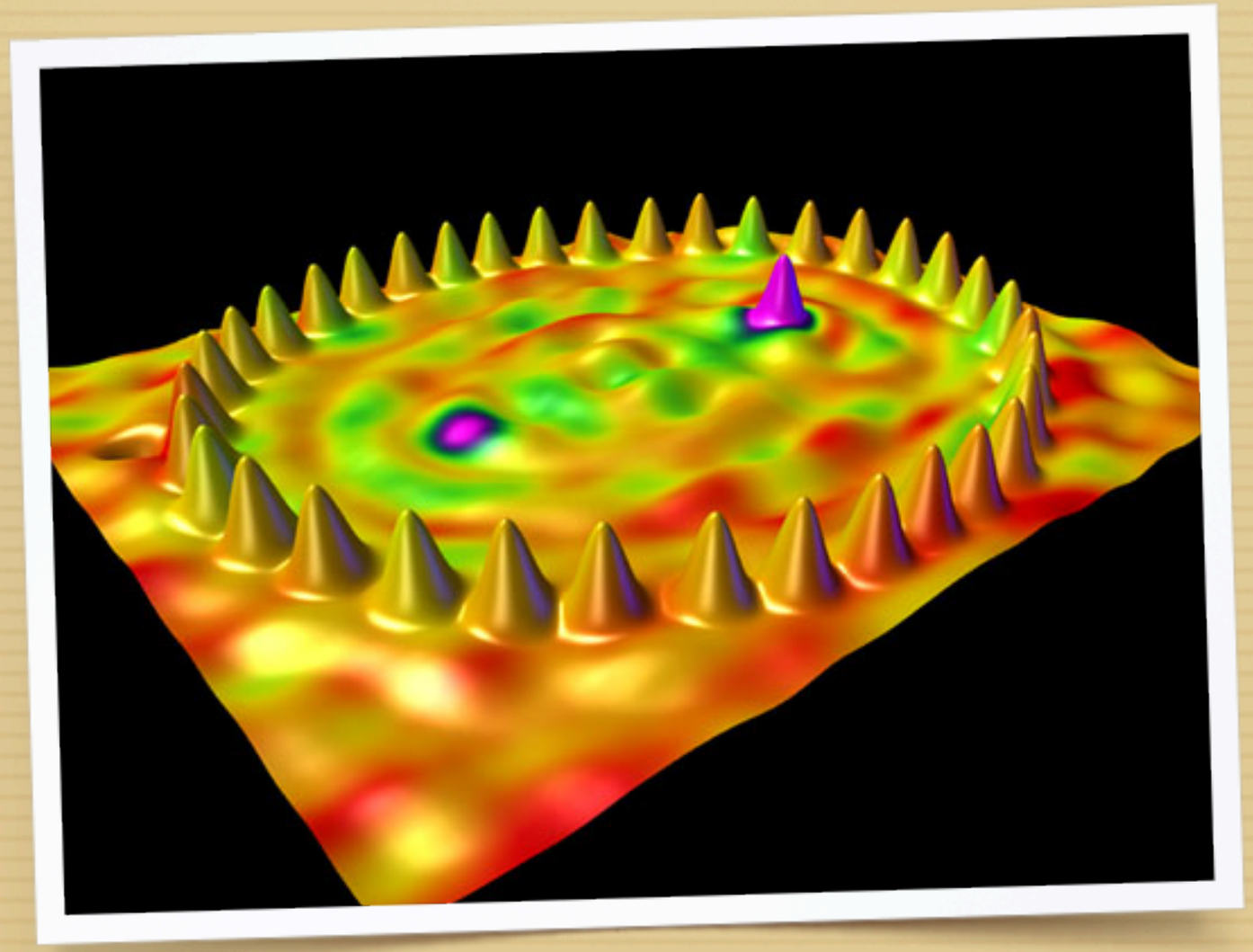
你的鉛筆會超導嗎？

林秀豪
清華大學物理系

大綱

- 什麼是凝態物理?
- 你了解自己的鉛筆嗎?
- 你了解電子的自旋嗎?
- 你了解奈米傳輸嗎?
- 結語



什麼是　凝態物理？

From Wikipedia I

Condensed matter physics is the field of physics that deals with the macroscopic physical properties of matter. In particular, it is concerned with the "condensed" phases that appear whenever the number of constituents in a system is extremely large and the interactions between the constituents are strong.

The most familiar examples of condensed phases are solids and liquids, which arise from the bonding and electromagnetic force between atoms. More exotic condensed phases include the superfluid and the Bose-Einstein condensate found in certain atomic systems at very low temperatures, the superconducting phase exhibited by conduction electrons in certain materials, and the ferromagnetic and antiferromagnetic phases of spins on atomic lattices.

From Wikipedia II

Condensed matter physics is by far the largest field of contemporary physics.A lot of progress has also been made in theoretical condensed matter physics. By one estimate, one third of all American physicists identify themselves as condensed matter physicists.

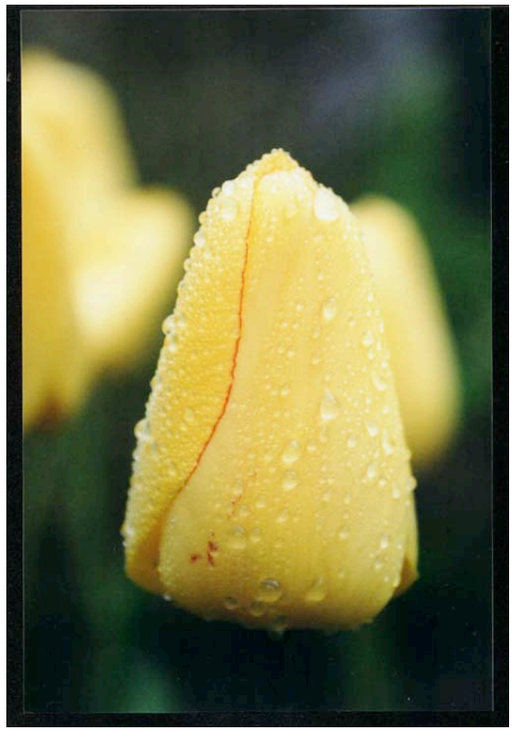
Historically, condensed matter physics grew out of solid-state physics, which is now considered one of its main subfields. The term "condensed matter physics" was apparently coined by Philip Anderson when he renamed his research group - previously "solid-state theory" - in 1967. In 1978, the Division of Solid State Physics at the American Physical Society was renamed as the Division of Condensed Matter Physics. Condensed matter physics has a large overlap with chemistry, materials science, nanotechnology and engineering.

From Wikipedia III

One of the reasons for calling the field "condensed matter physics" is that many of the concepts and techniques developed for studying solids actually apply to fluid systems. For instance, the conduction electrons in an electrical conductor form a type of quantum fluid with essentially the same properties as fluids made up of atoms. In fact, the phenomenon of superconductivity, in which the electrons condense into a new fluid phase in which they can flow without dissipation, is very closely analogous to the superfluid phase found in helium 3 at low temperatures.

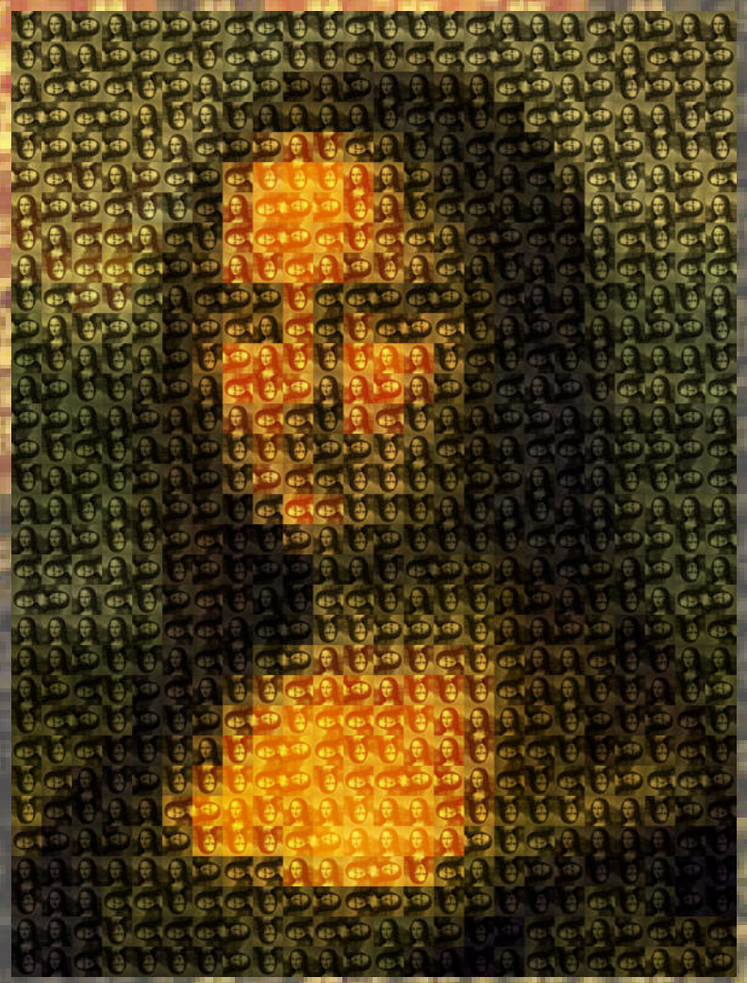
Many Means Beauty?

格物致知?
化約主義的科學家?

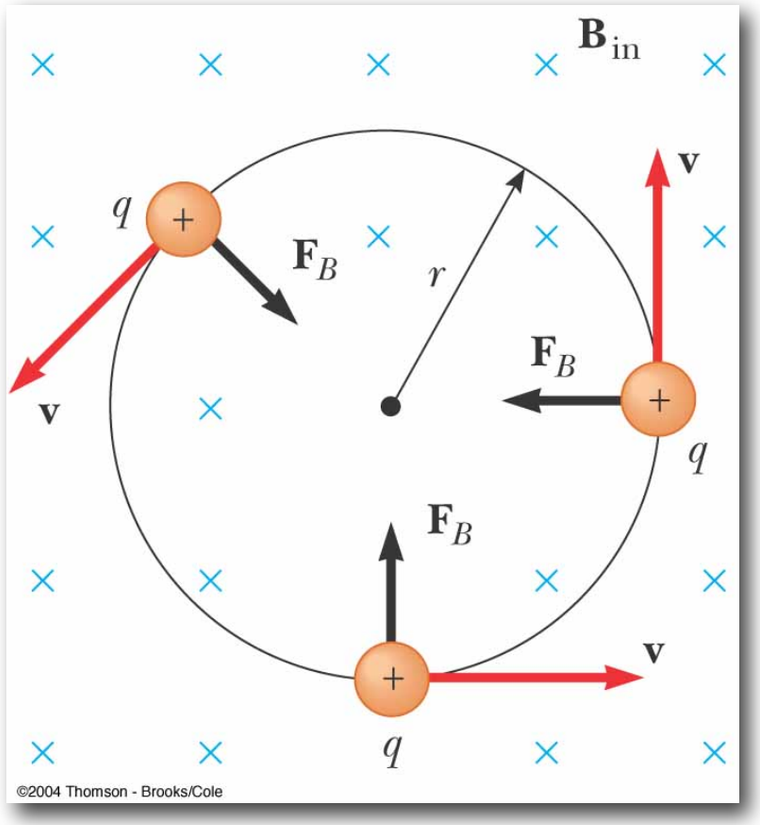


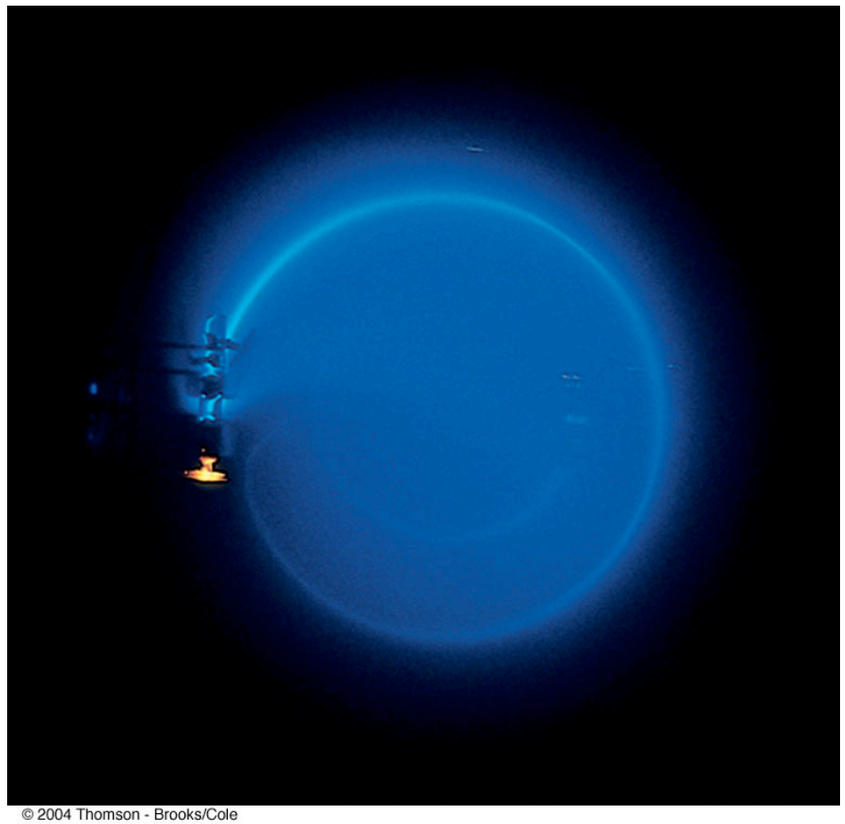
數大便是美?

Why Many?



What is Temperature?

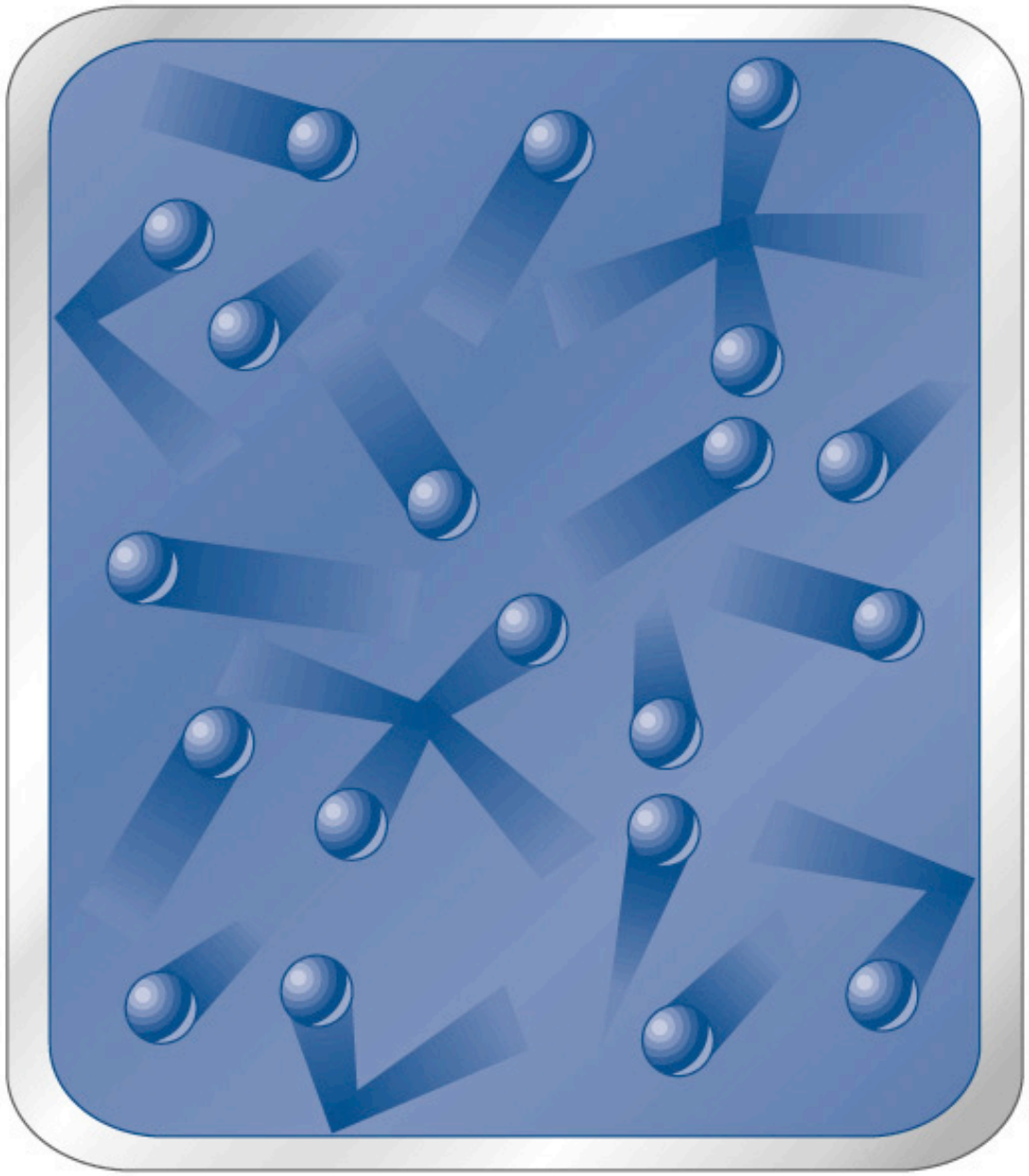


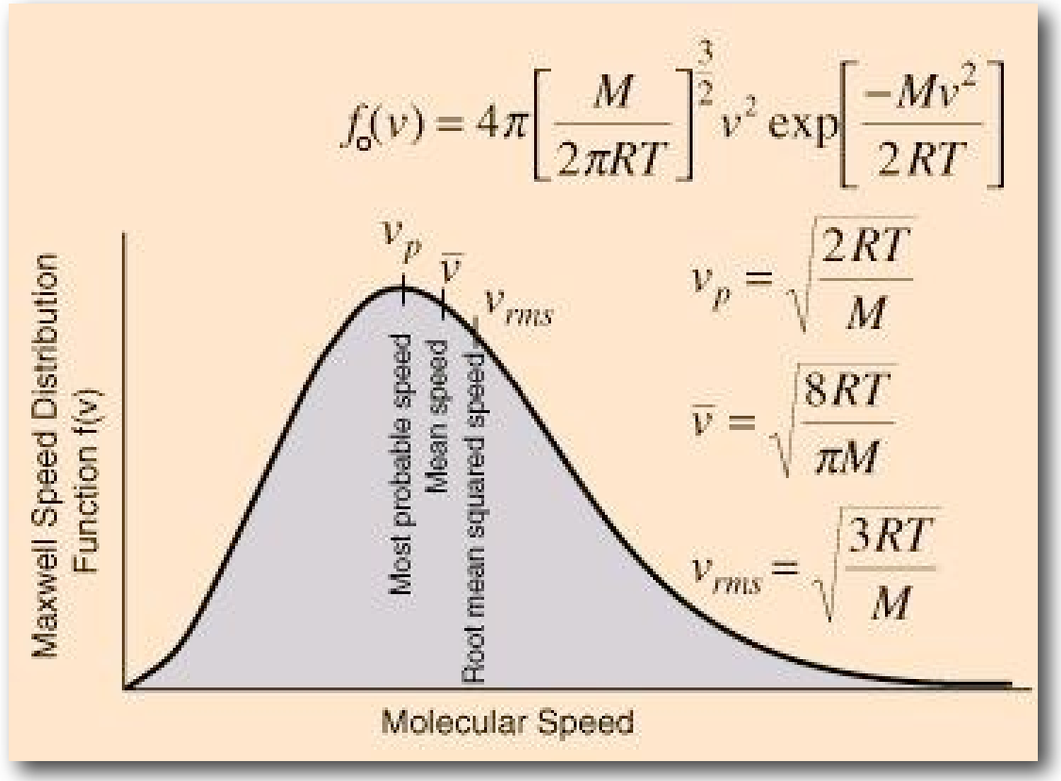

© 2004 Thomson - Brooks/Cole

請問，一顆在磁場中繞圈圈的電子，
它的溫度是多少呢?

Temperature

因為無知，所以才有溫度的概念。

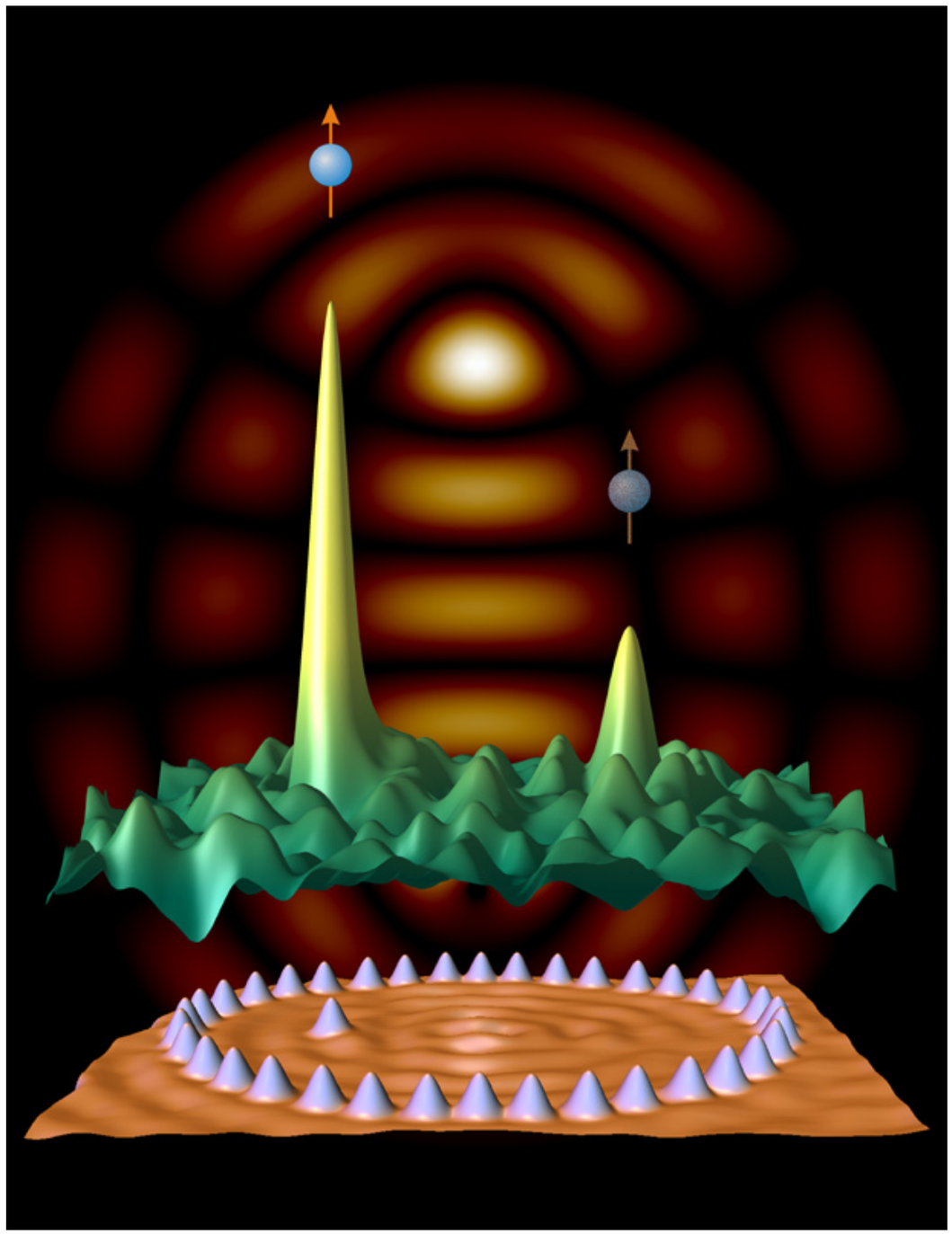




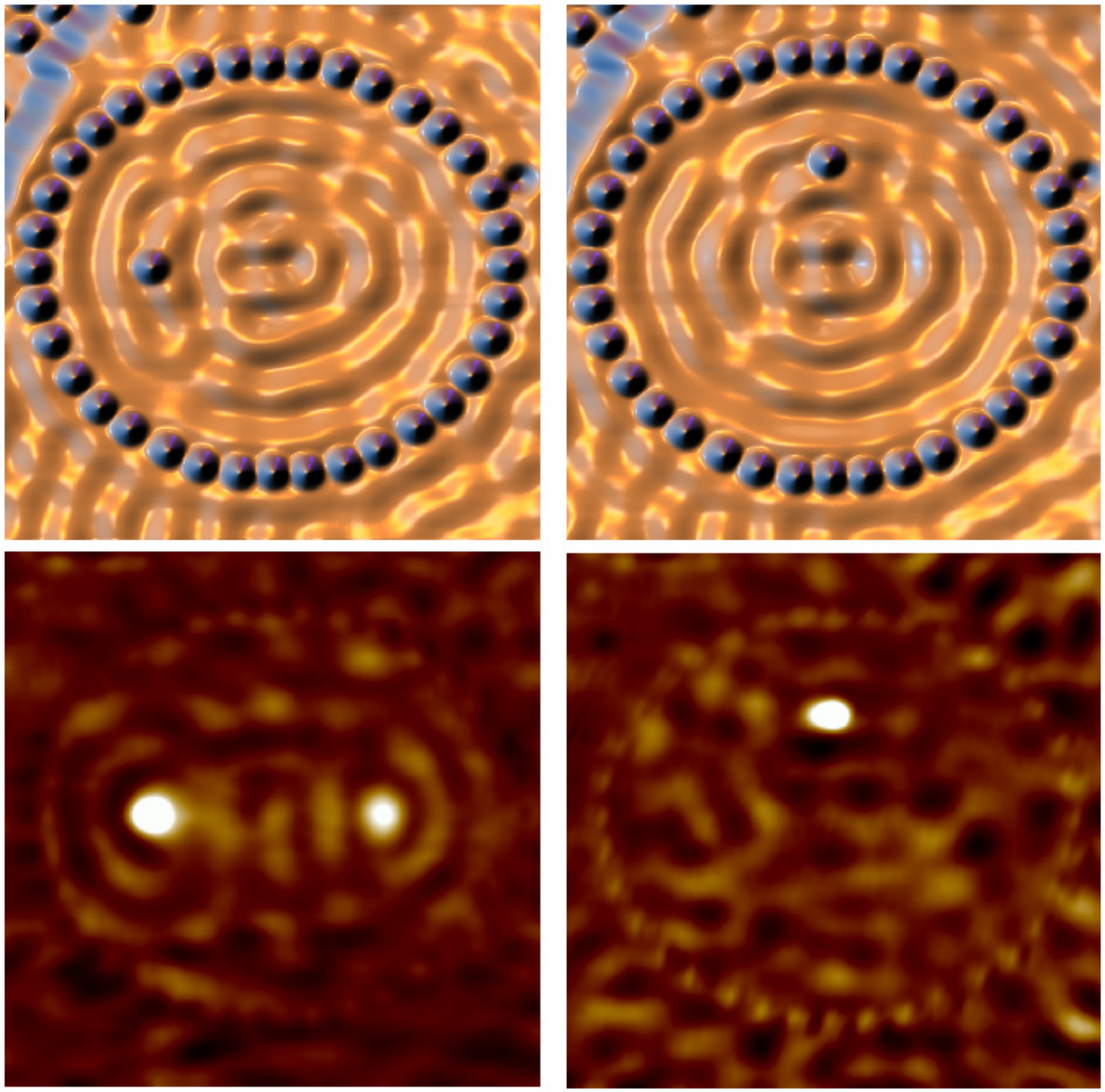
溫度是能量不守恆的產物

Some Quantum Flavor

- 量子物理讓我們對一顆粒子也可以很無知。
- 所以，數不必大，也可以很美。
- 因為無知，所以處處驚奇。



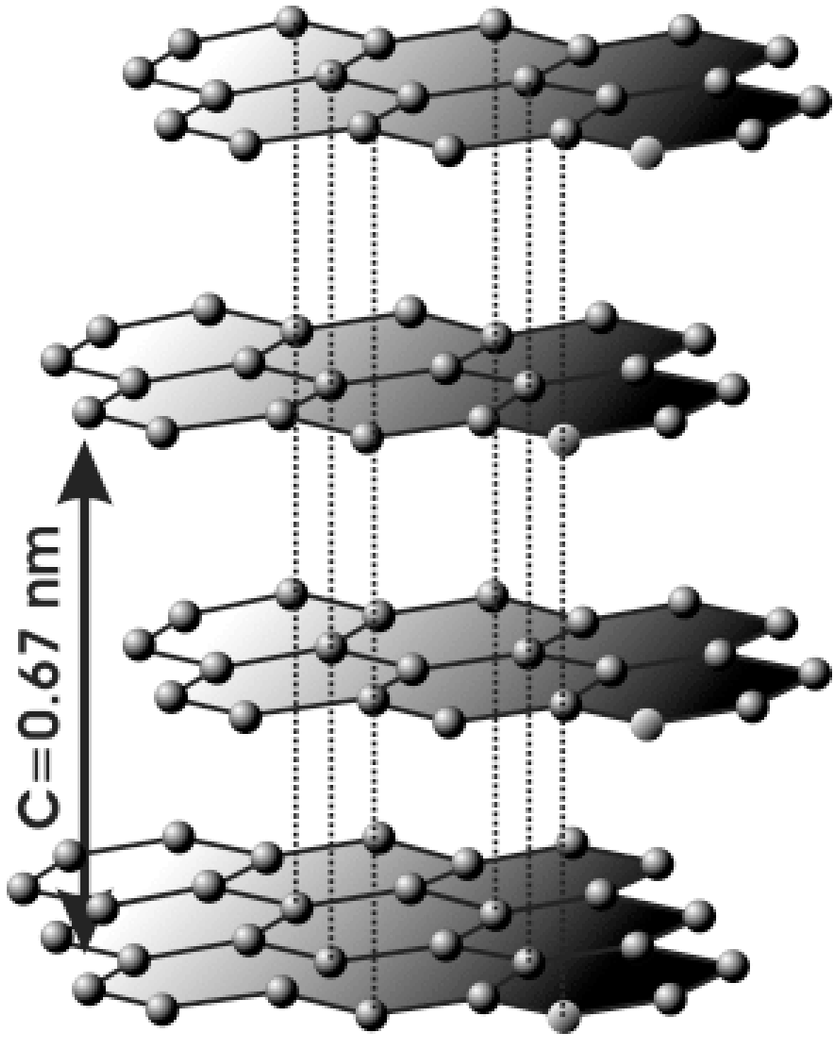
Quantum Interferences



量子分身術

你了解 自己的鉛筆嗎？

Why pencil can write?



為什麼我們可以用鉛筆寫字呢?

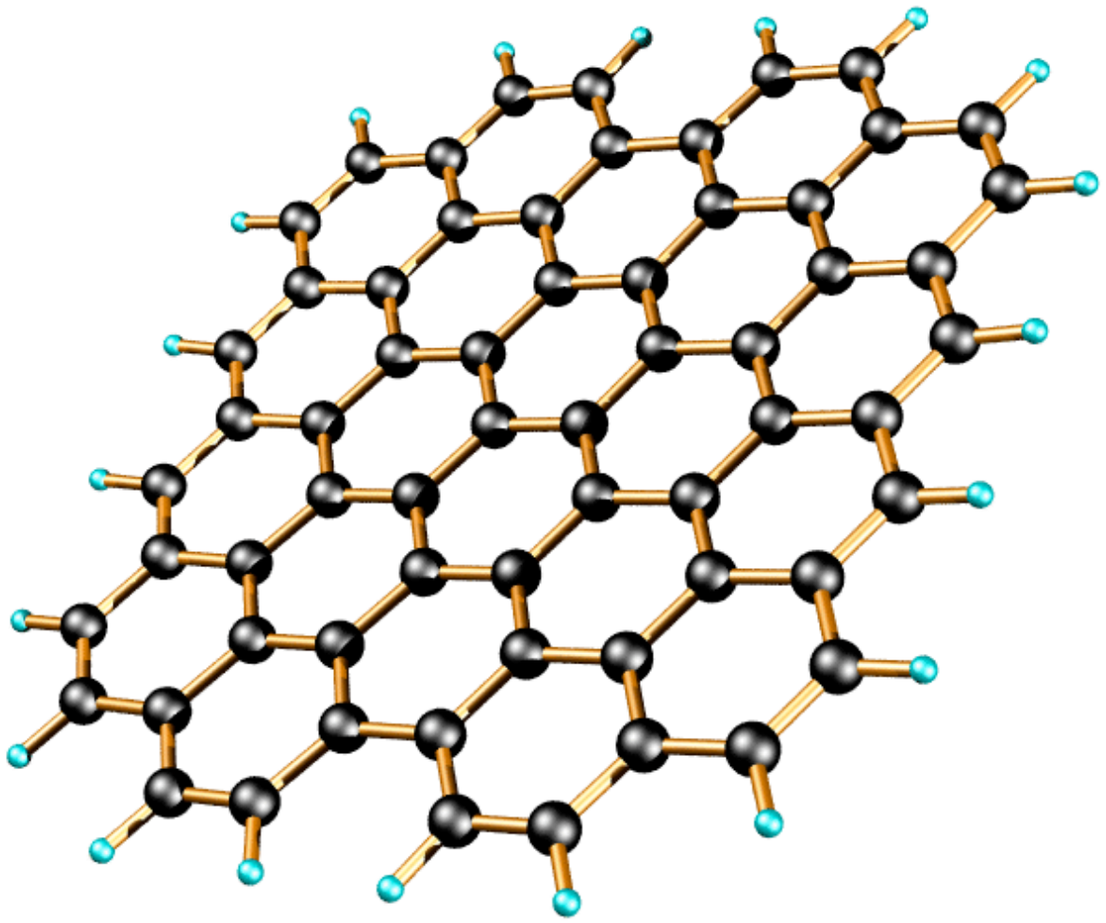
又為什麼可以用橡皮擦來擦掉呢?

Shinny Graphite?

黑金黑金的…

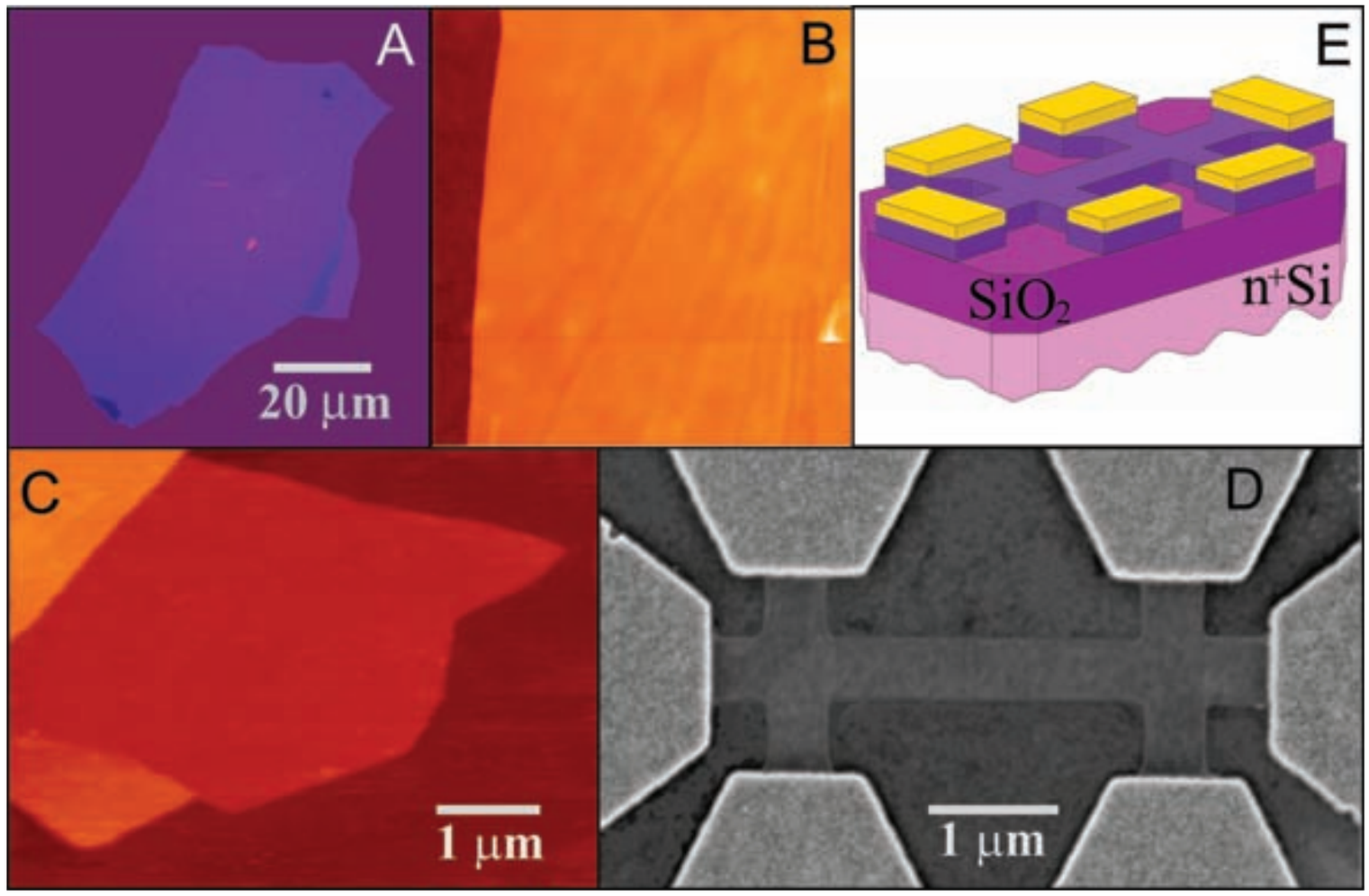
為什麼呢？早點想到可能可以拿Nobel Prize 喔！

Cheap Nanotechnology



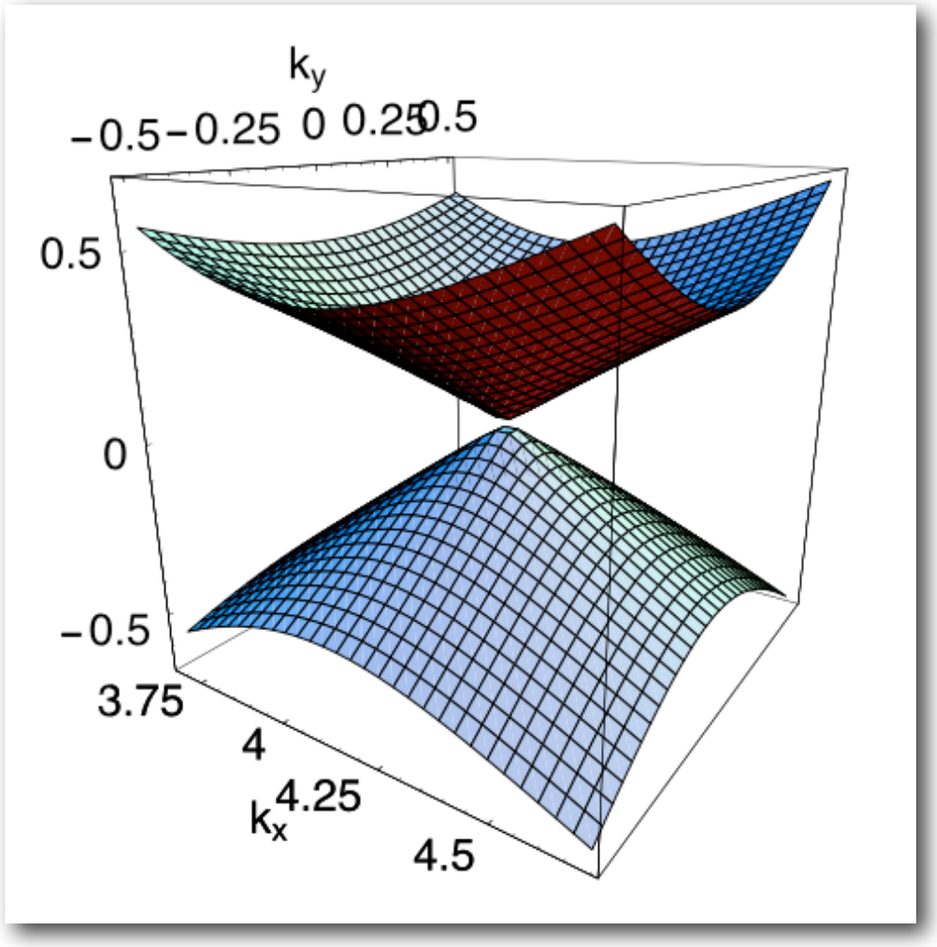
我黏，我撕，我黏
我做實驗！

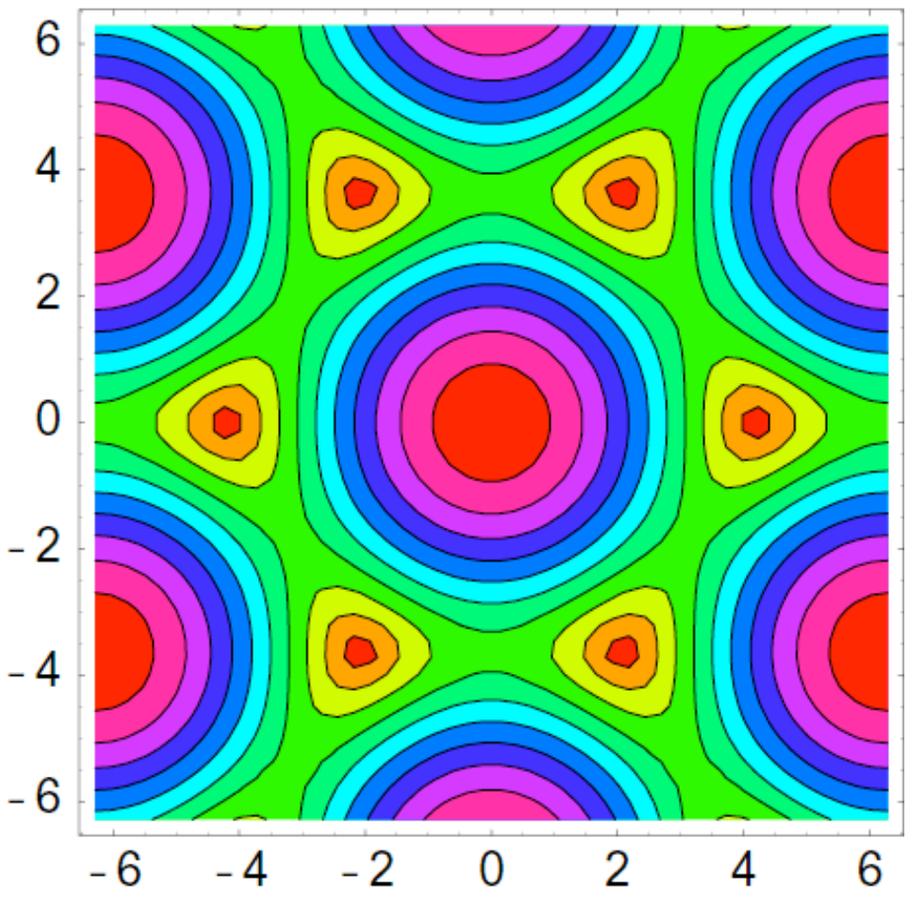
Not-so-cheap Part...



這就不太便宜了...

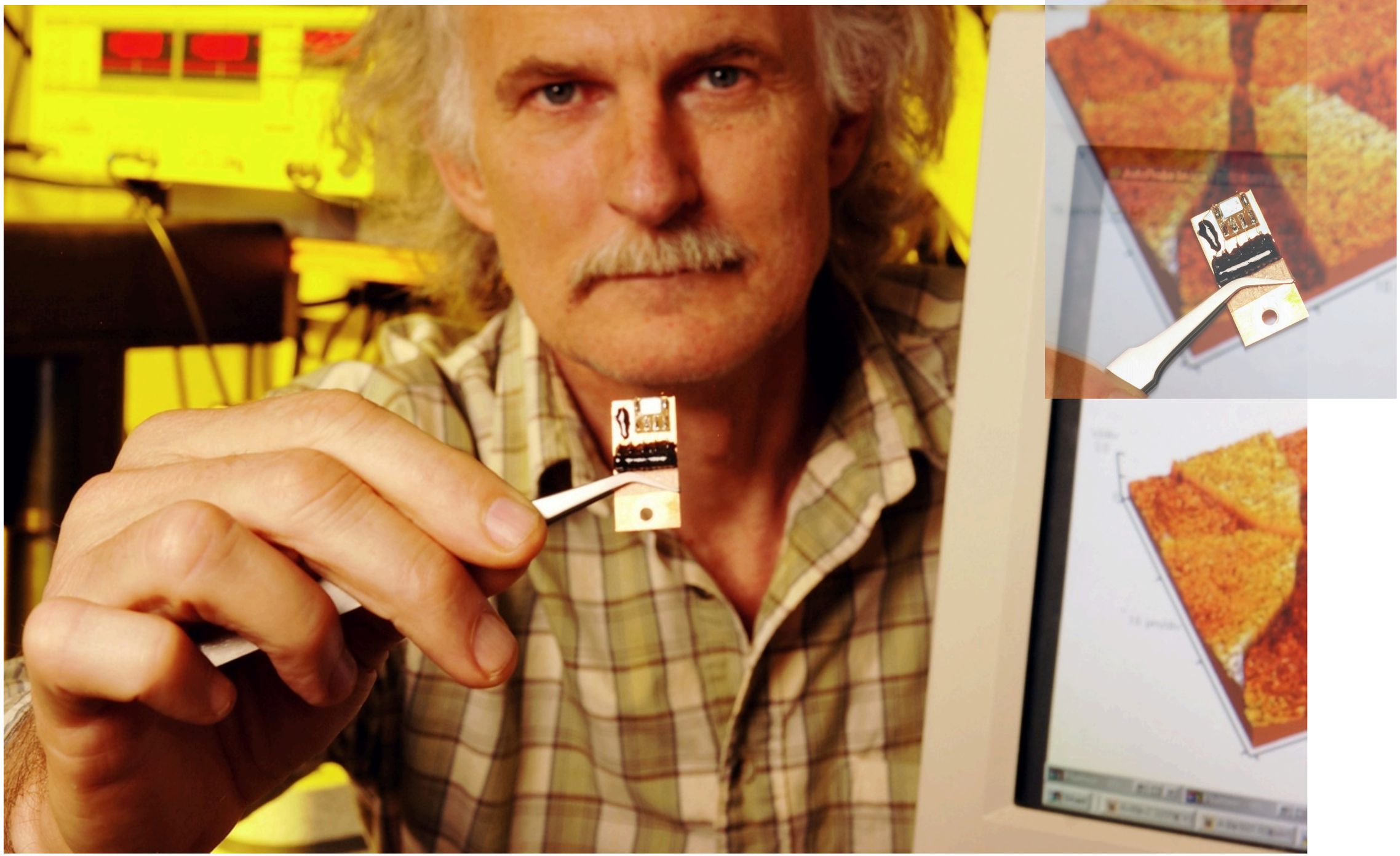
Relativity in Pencil Flakes?



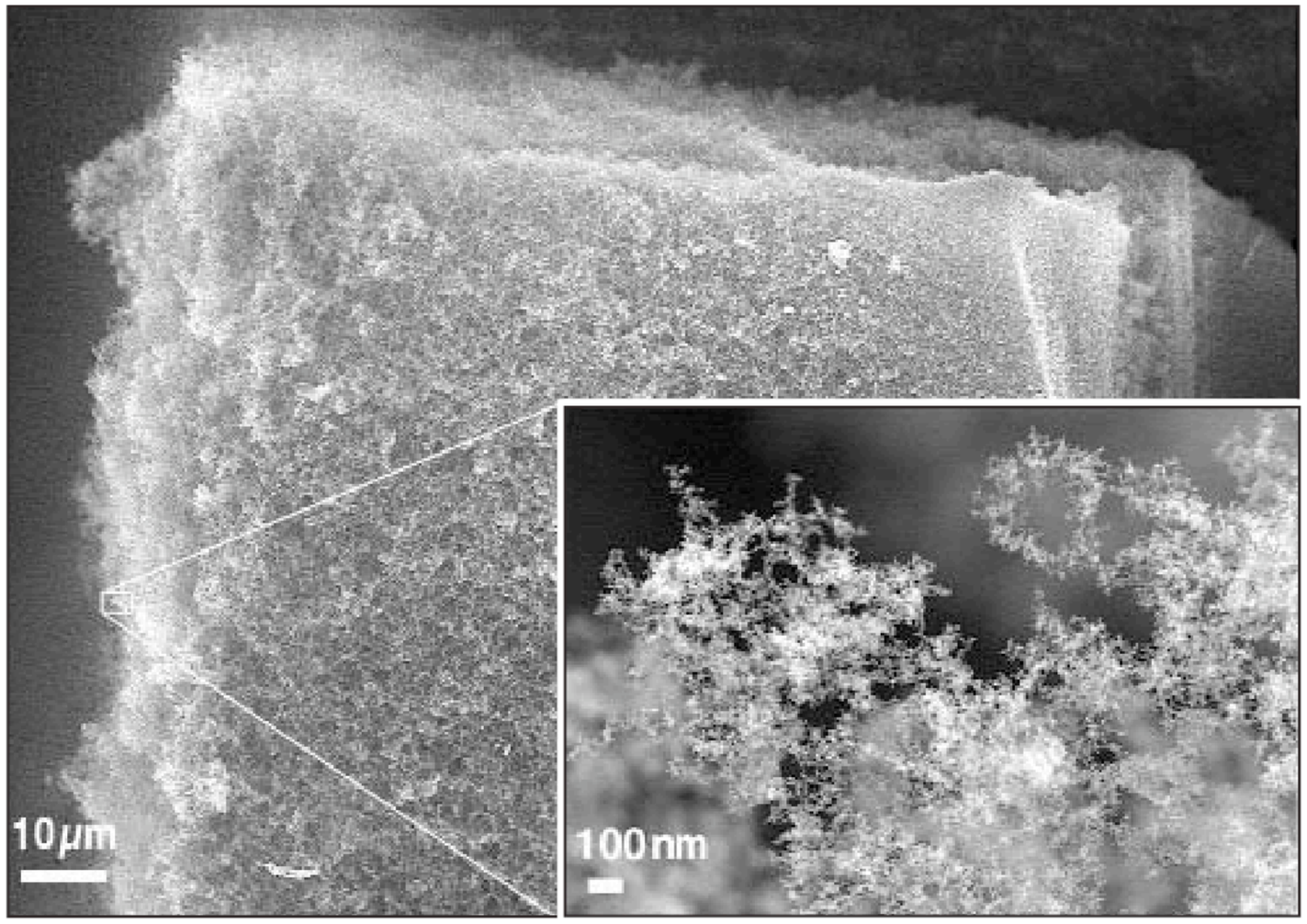


在鉛筆屑堆，找到相對論。

Birth of Carbon Era?

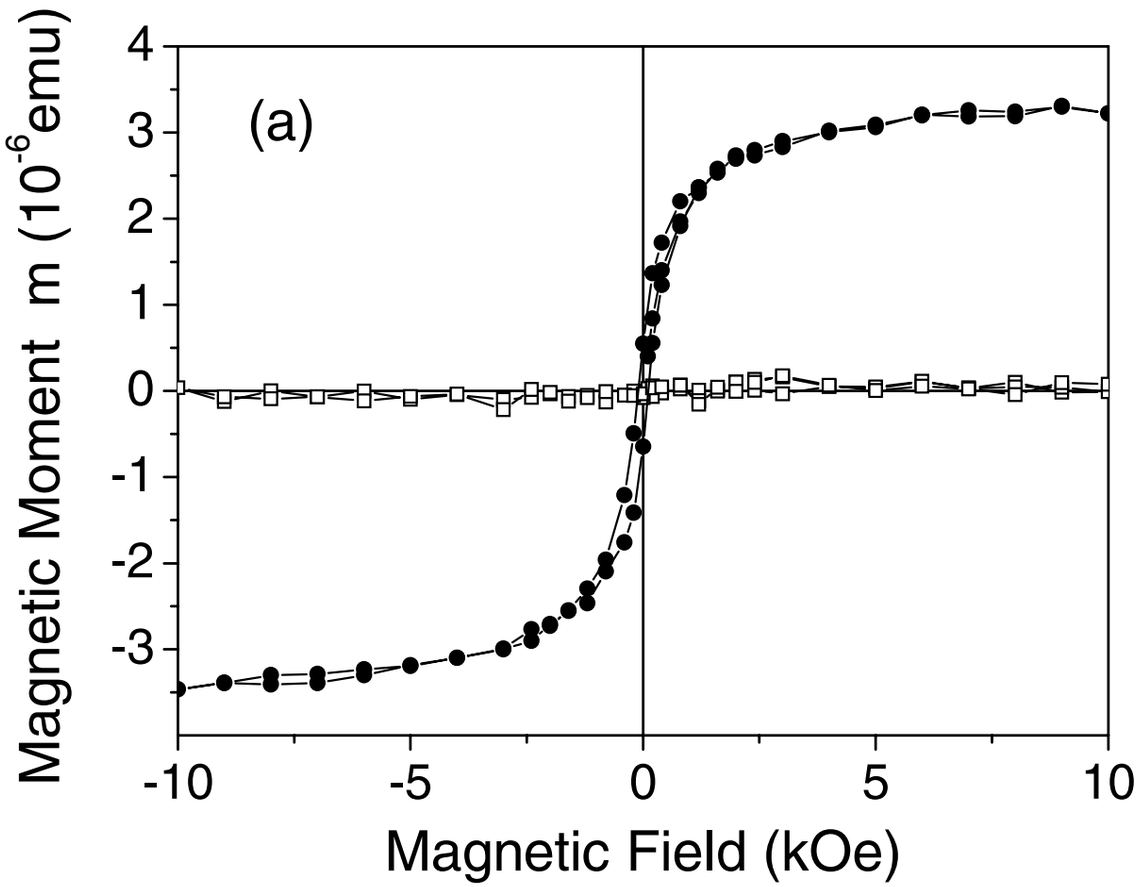


Magnetic Carbon Foam

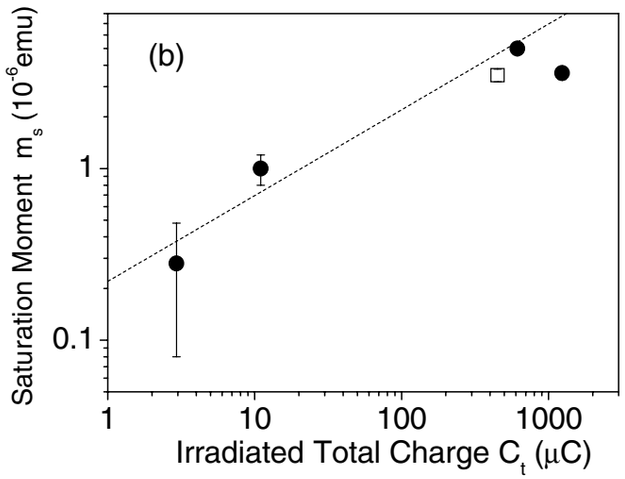


Carbon Foam Reveals a Fleeting Magnetic Personality 2 APRIL 2004 VOL 304 SCIENCE

Strange Magnet?



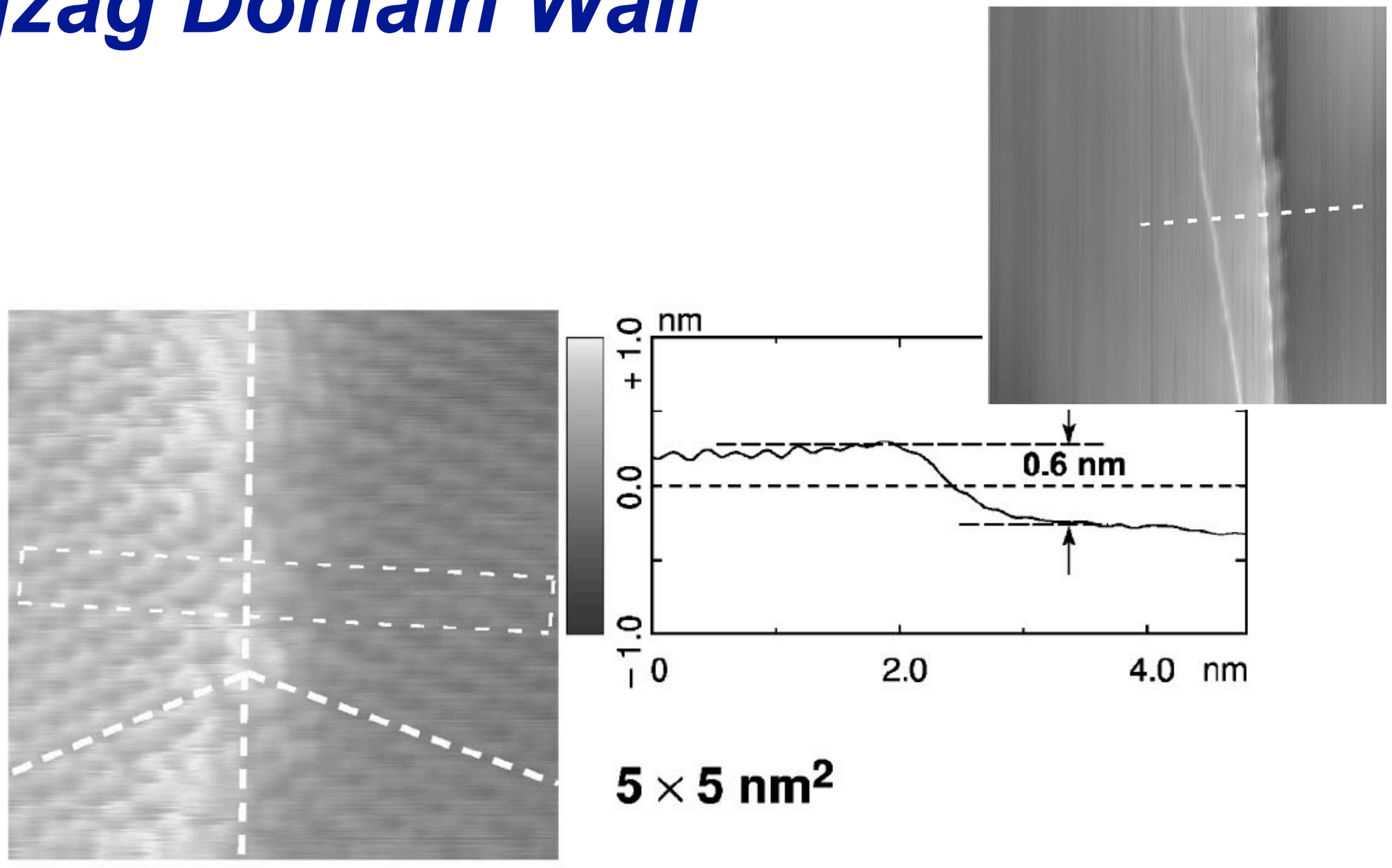
*Esquinazi et al., PRL **91**, 227101 (2003)*



猜猜看...

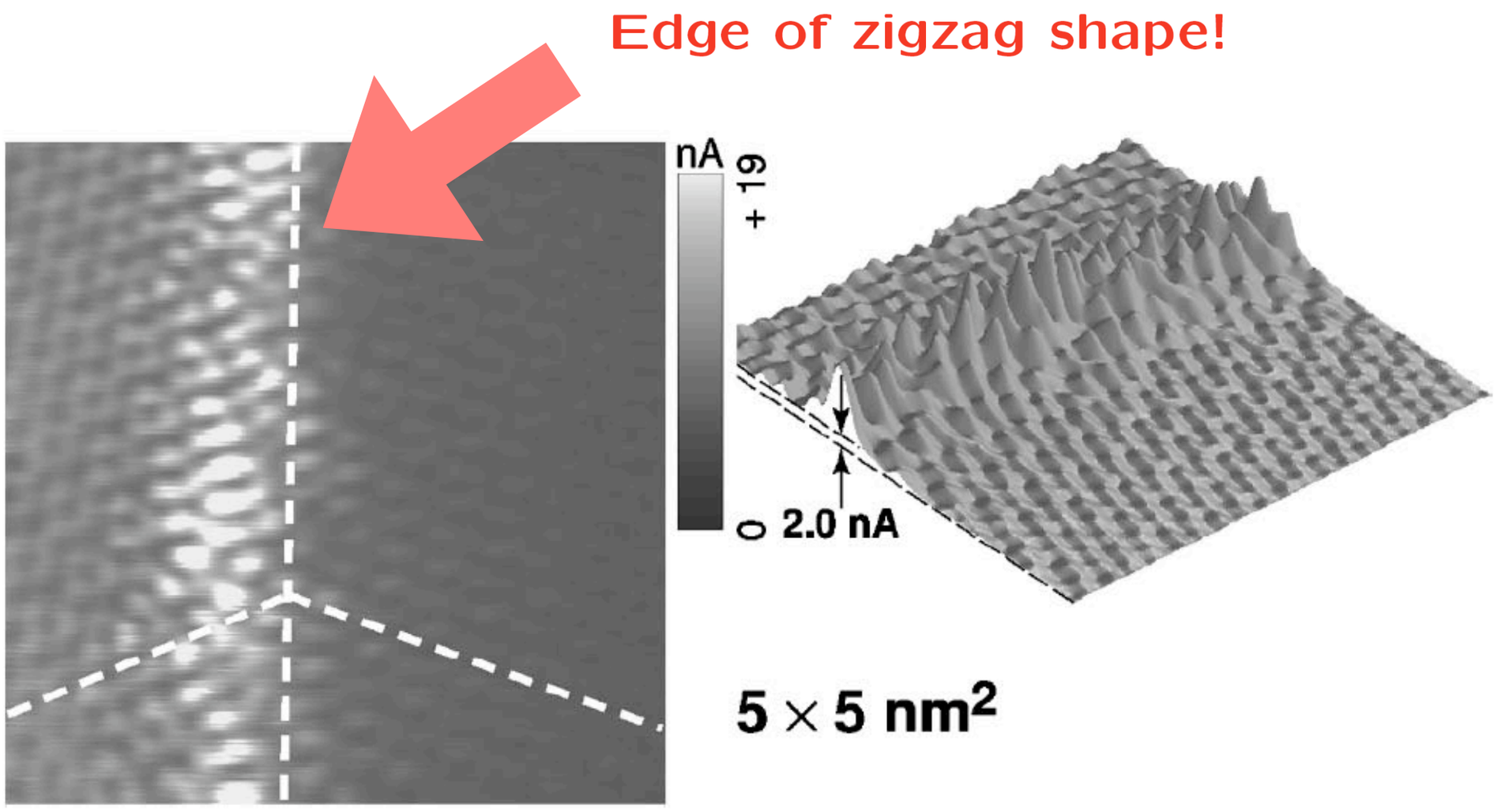
哪個是打爛前?
哪個是打爛後?

Zigzag Domain Wall



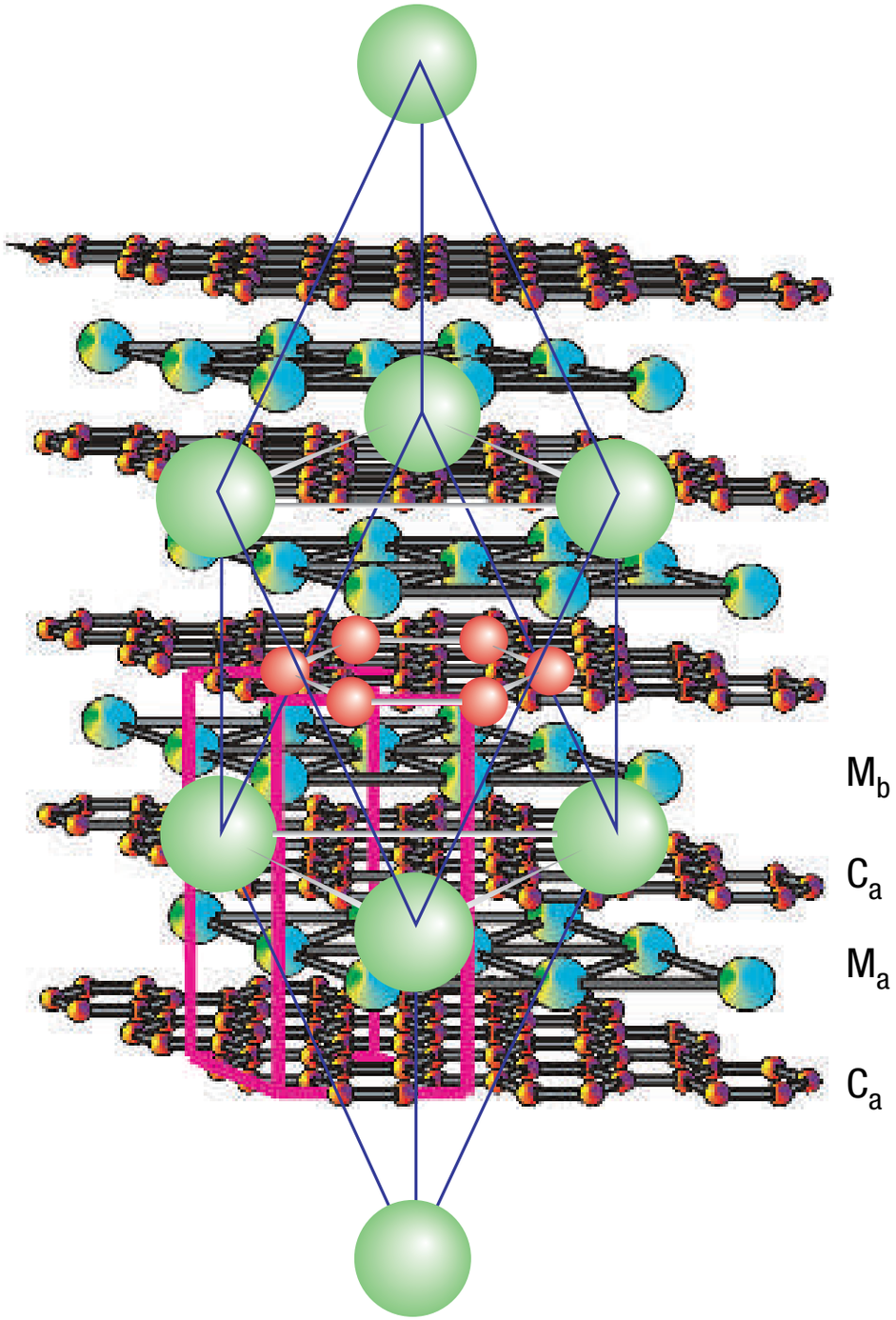
在石墨平原上的奈米懸崖

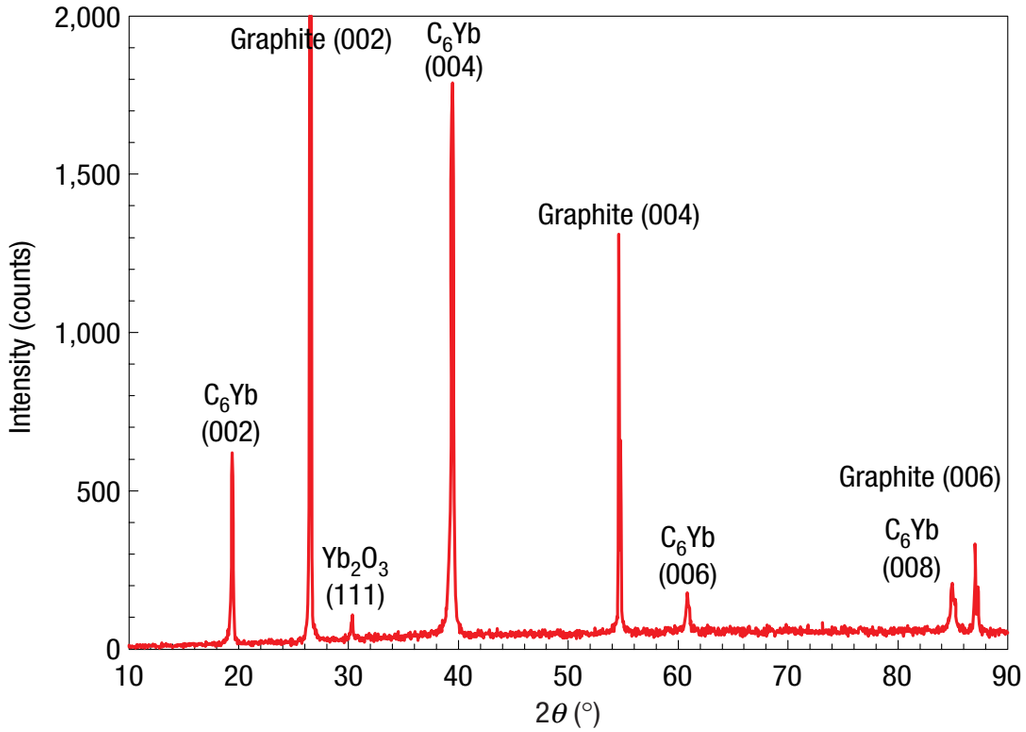
Edge State



活在奈米懸崖邊的電子們

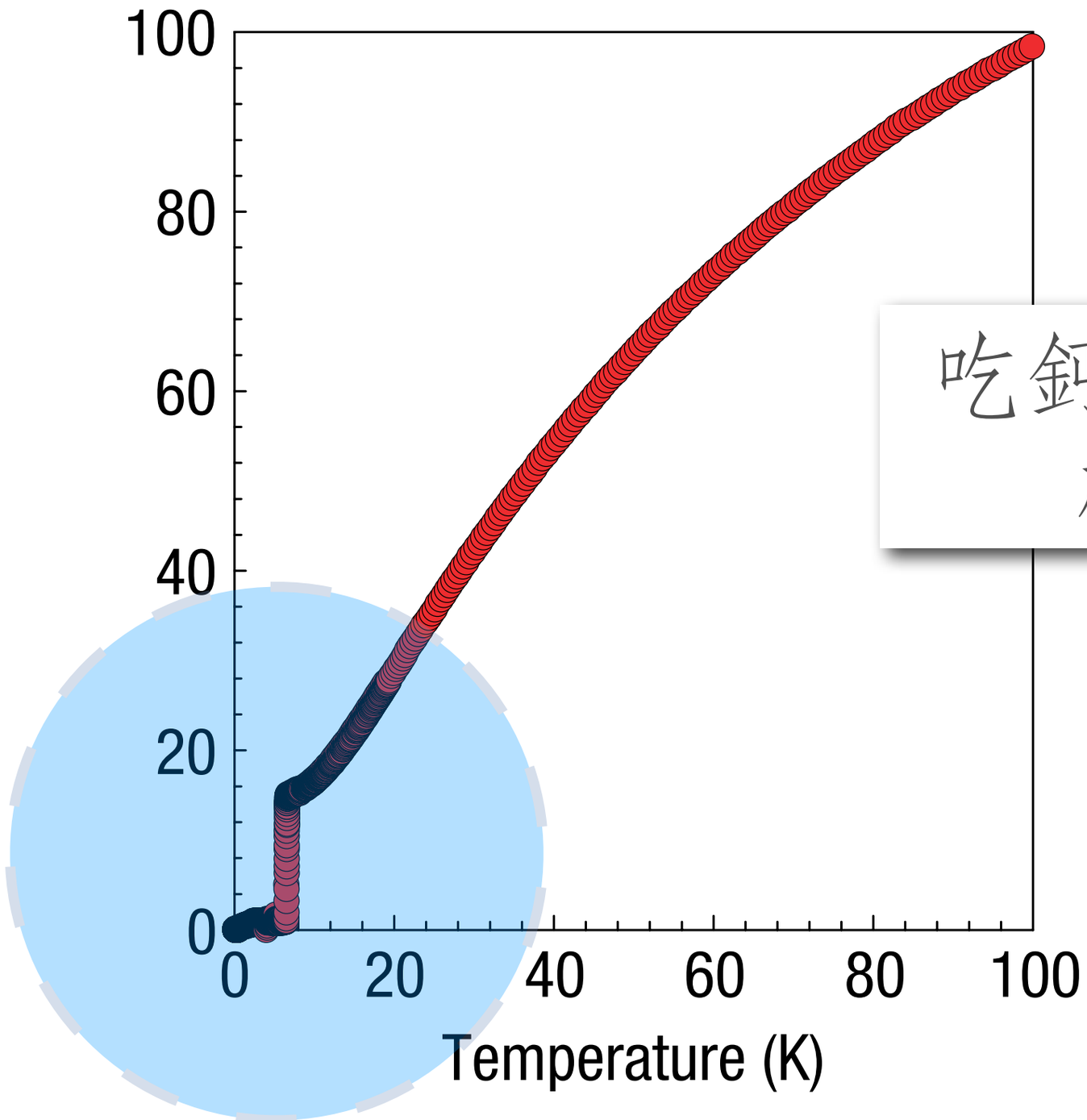
Have Some Calcium...





補充點鈣質，
有益身心健康！

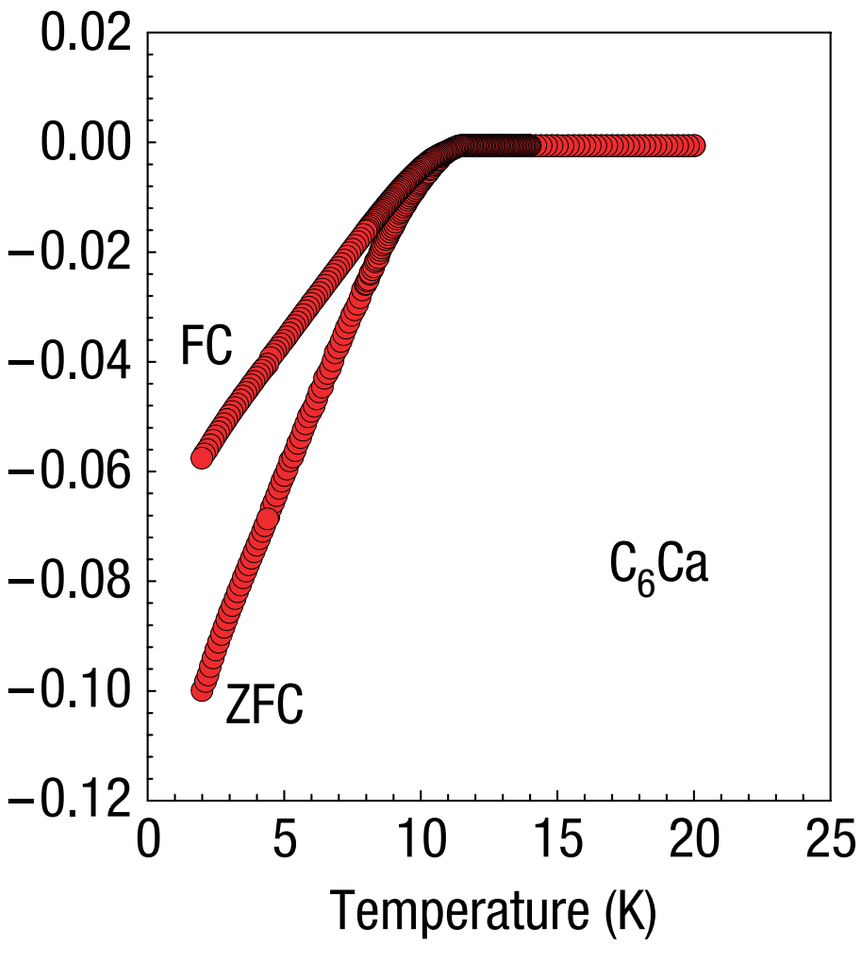
Superconducting!!

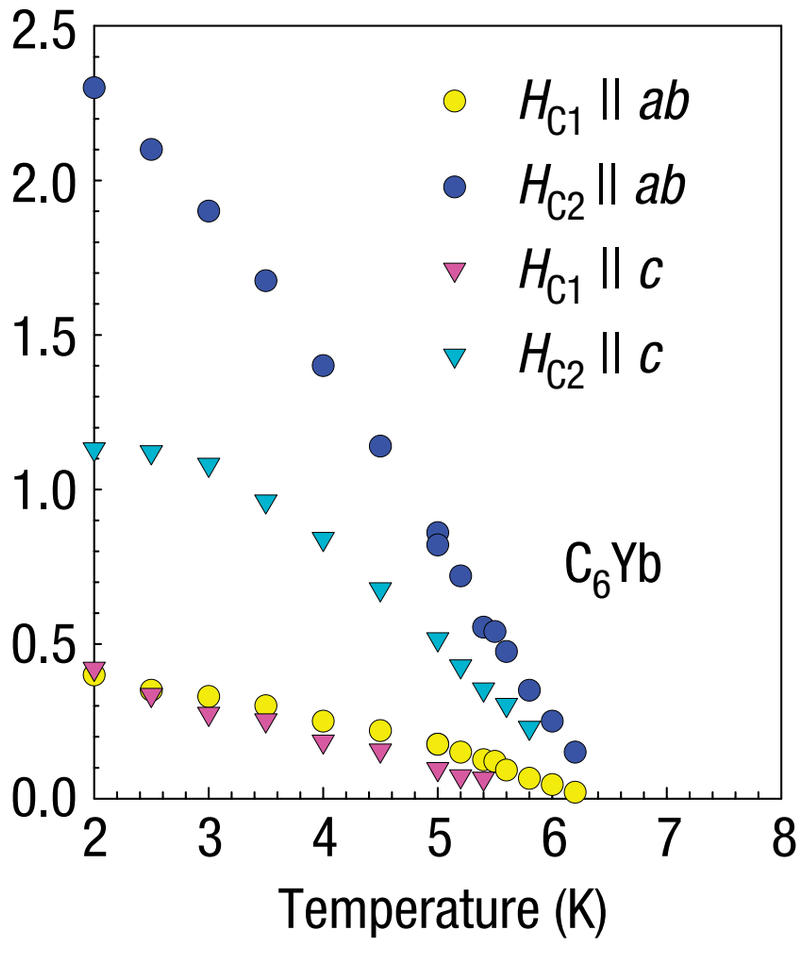


吃鈣的鉛筆，
超導！

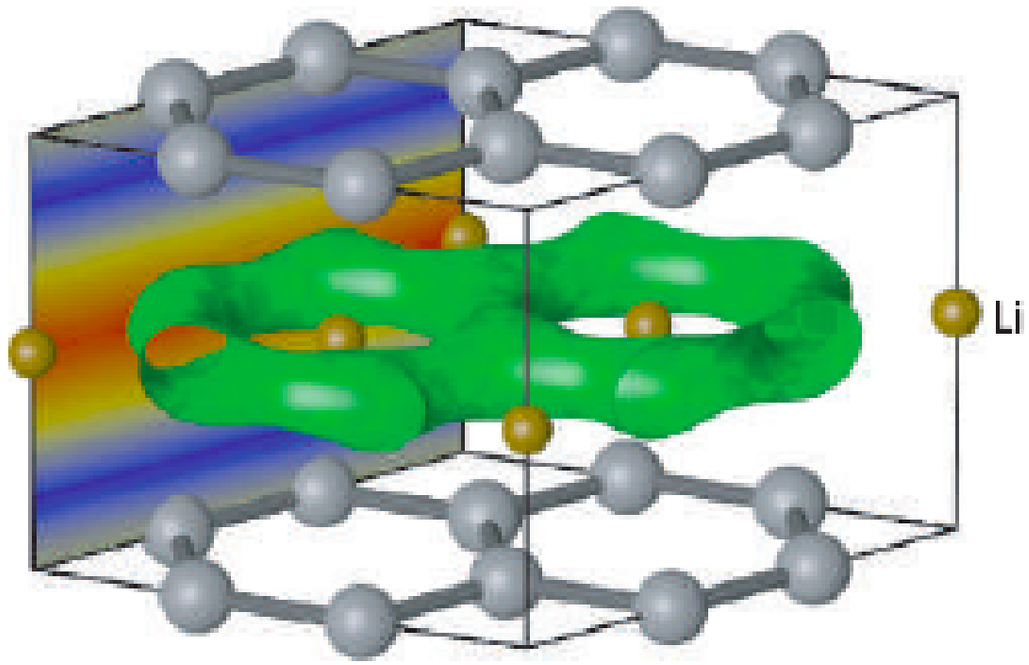
Diamagnetic Response

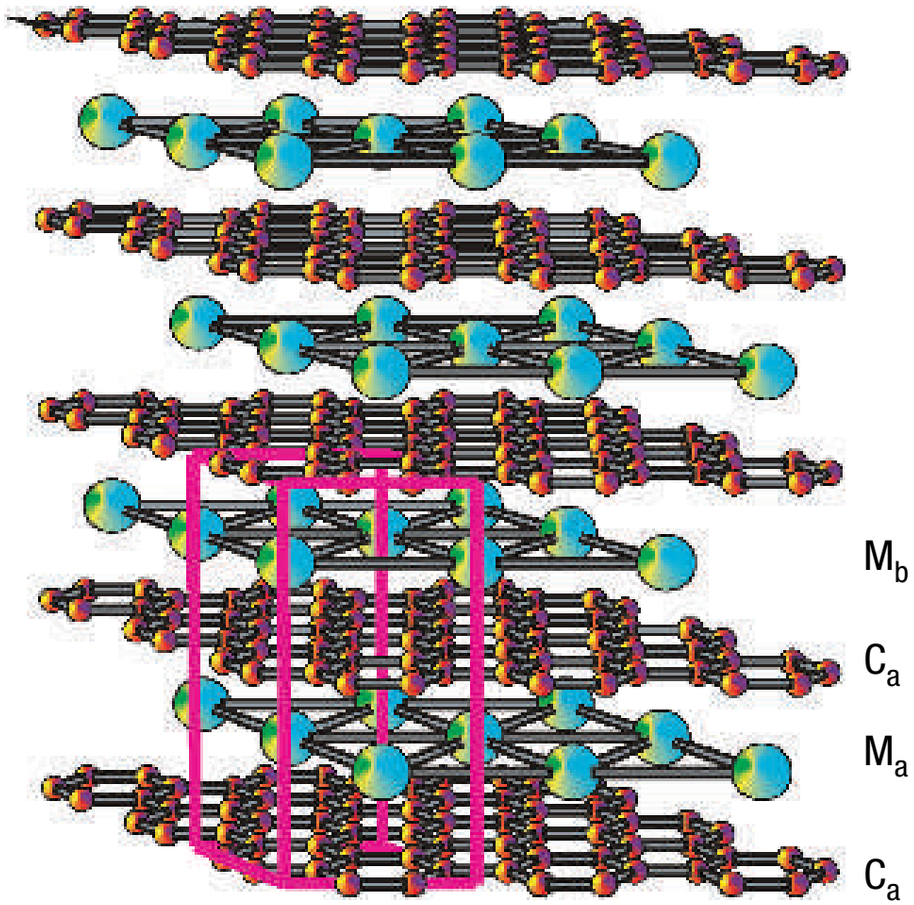
漢賊不兩立 — 不喜歡磁場的超導體





Where are the electrons?





作媒的電子雲

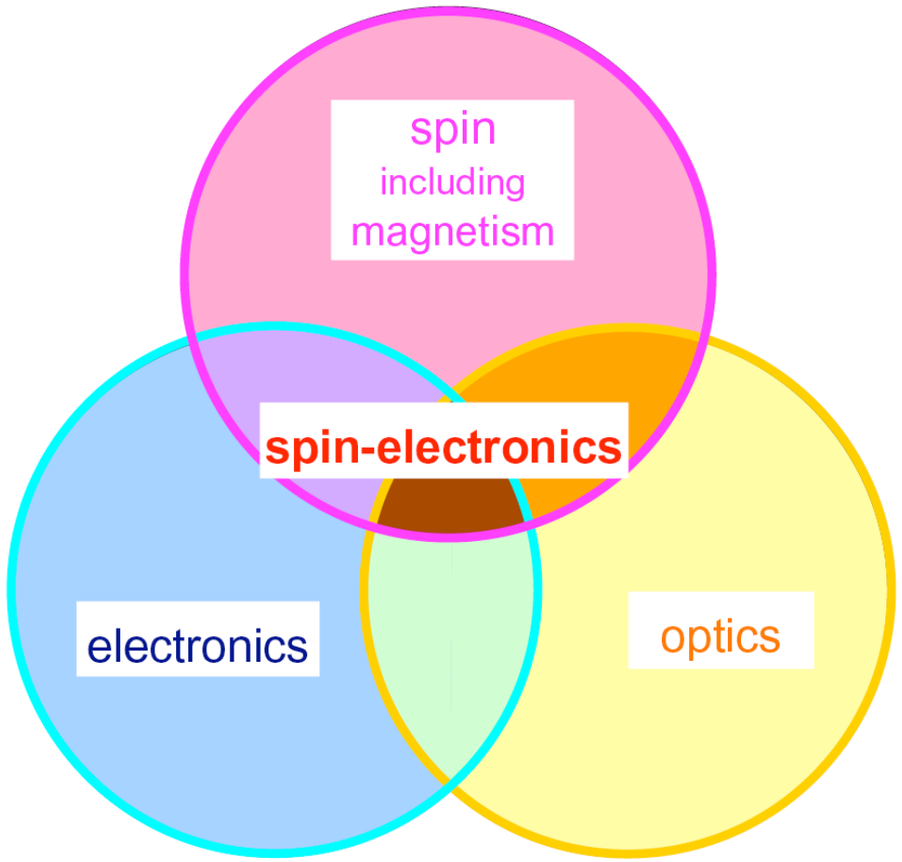
你了解 電子的自旋嗎？

Charge and Spin

電荷：運用半導體
處理資訊

自旋：運用磁性材料
儲存資訊

What is “spintronics” ?



Spintronics
= ***Spin*** **+** ***Electronics***

如何在複雜的凝態系統中，
隨心所欲地操控自旋。

Spin Valve

G. Prinz, Science 282, 1661 (1998)

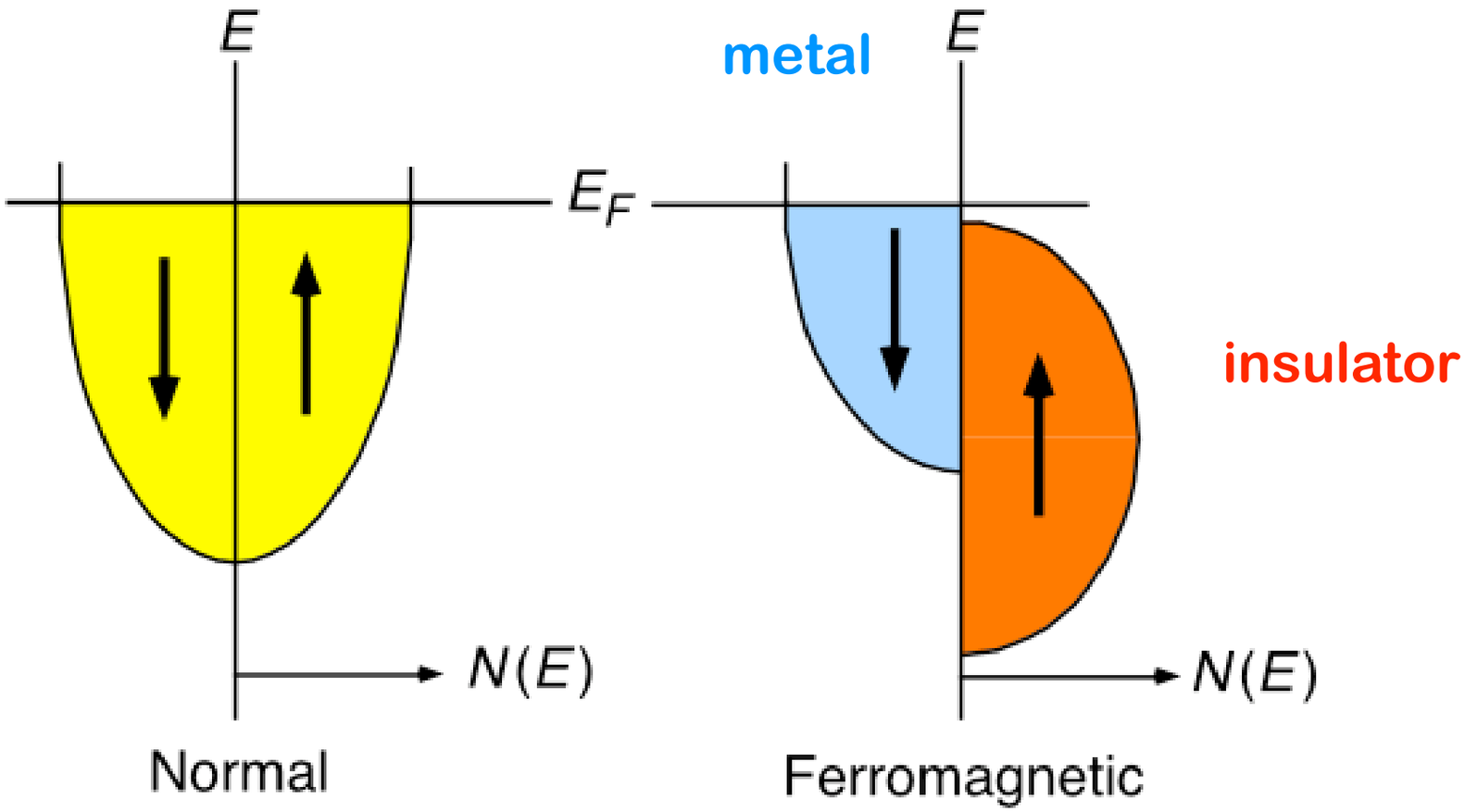
SCIENCE'S COMPASS • REVIEW

REVIEW: DEVICE PHYSICS

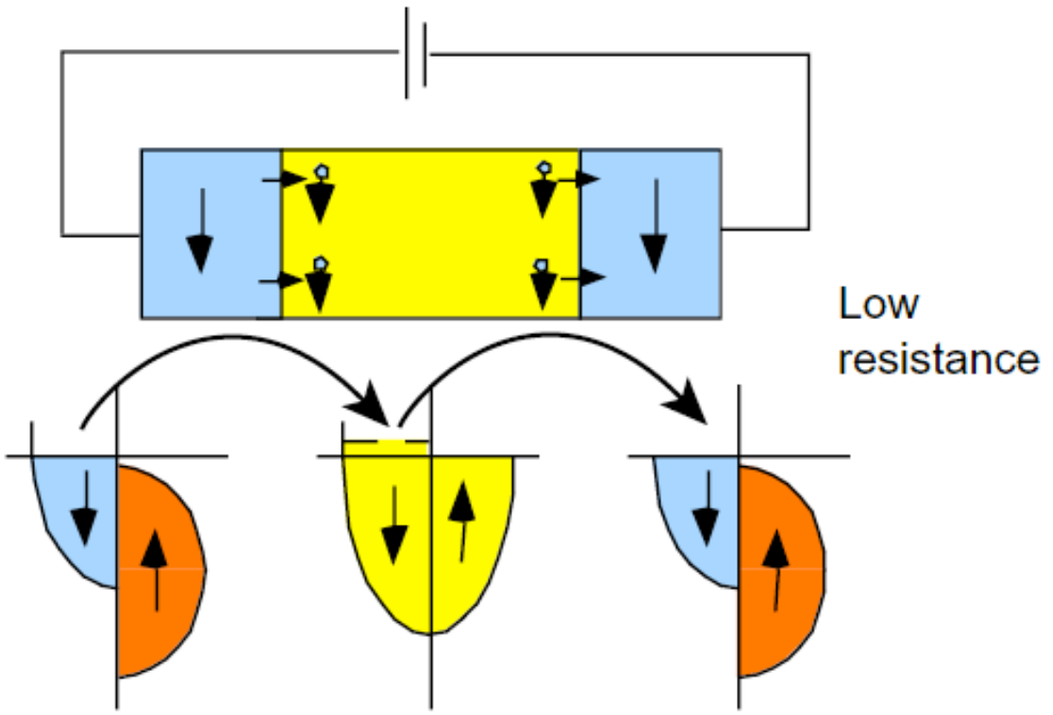
Magnetoelectronics

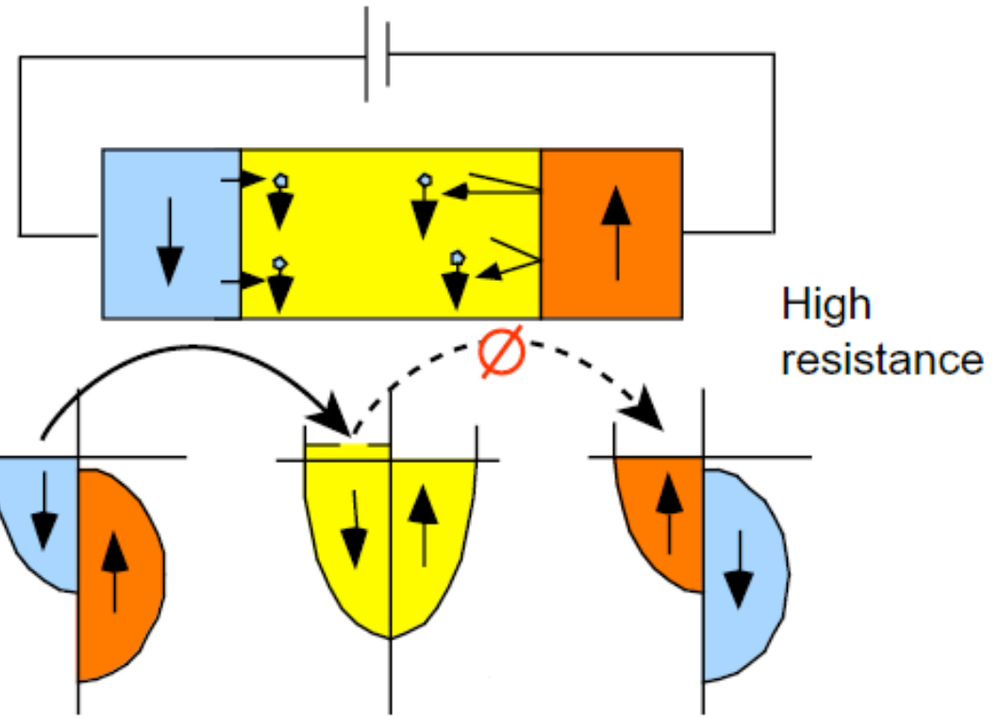
Gary A. Prinz

自旋不同，物性不同。



Spin Valve



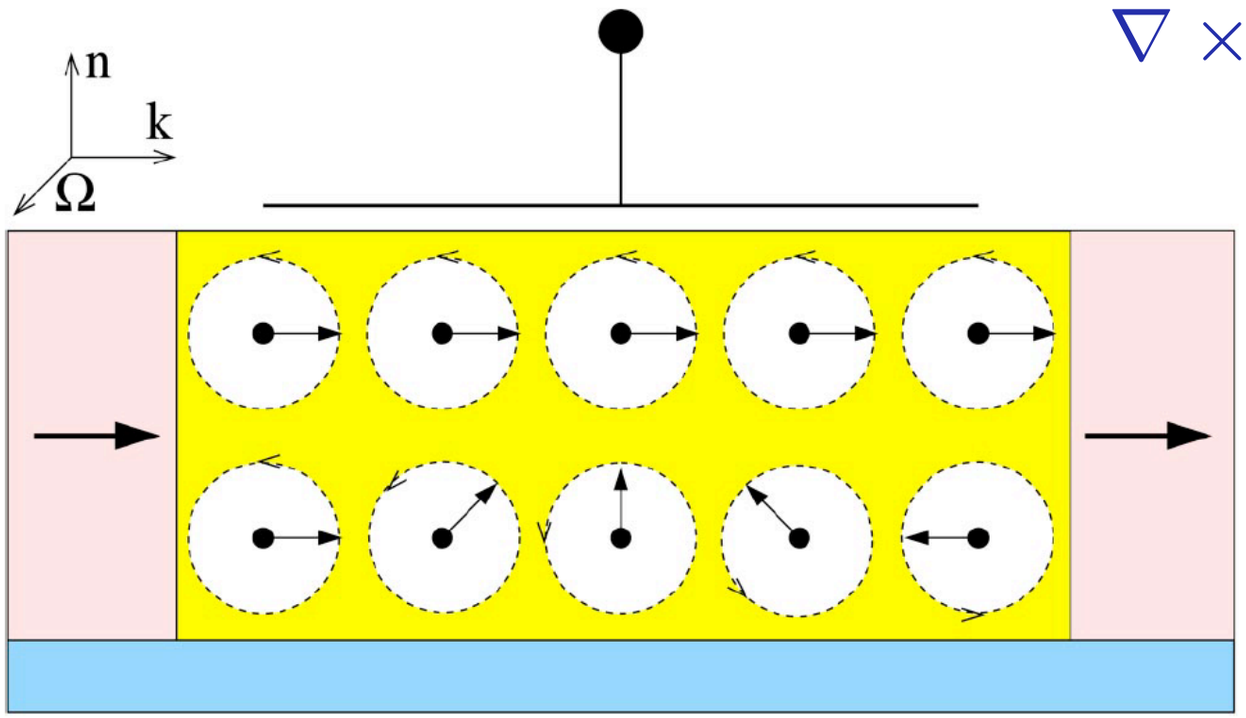


用自旋來當開關。

Moving Electric Field...

複習一下電磁學...

$$\nabla \times \boldsymbol{B} = \mu_0 \boldsymbol{J} + \frac{1}{c^2}\frac{\partial \boldsymbol{E}}{\partial t}$$

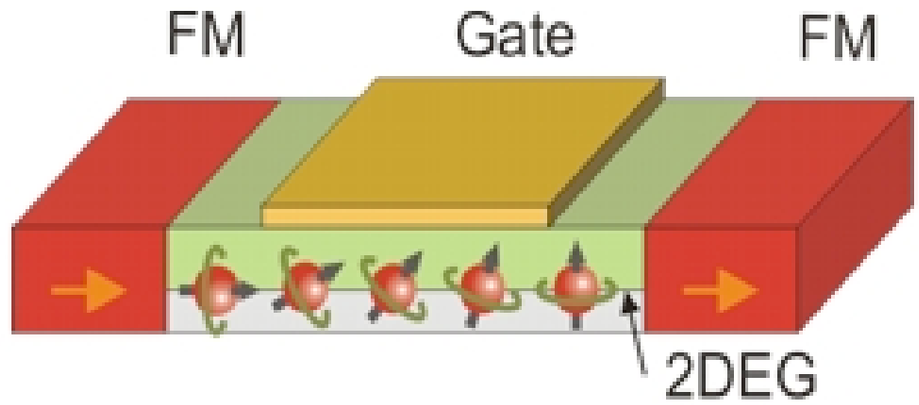


電動生磁

$$\boldsymbol{B}' = -\frac{1}{c^2}\,\boldsymbol{v} \times \boldsymbol{E}$$

Rashba Interaction

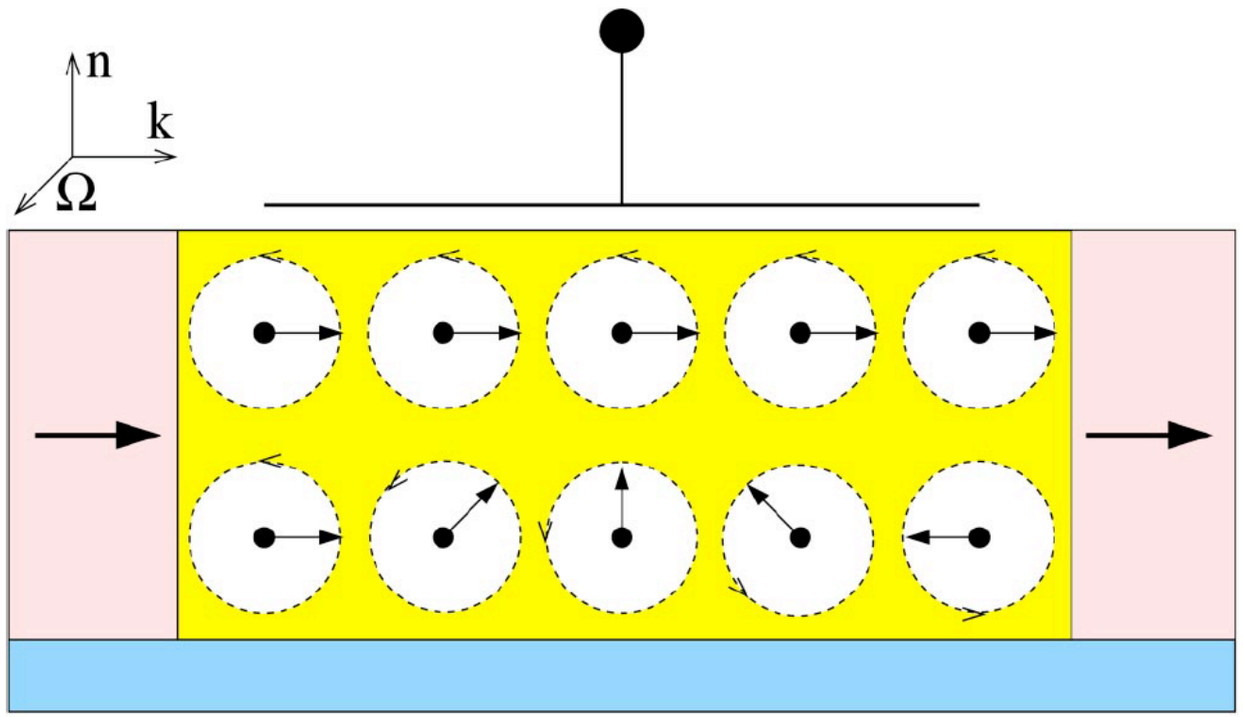
自旋－軌道
交互作用



$$H_{so} = \alpha_R \left(\boldsymbol{k} \times \hat{\boldsymbol{n}} \right) \cdot \boldsymbol{S}$$
$$= \boldsymbol{\Omega}_k \cdot \boldsymbol{S}$$

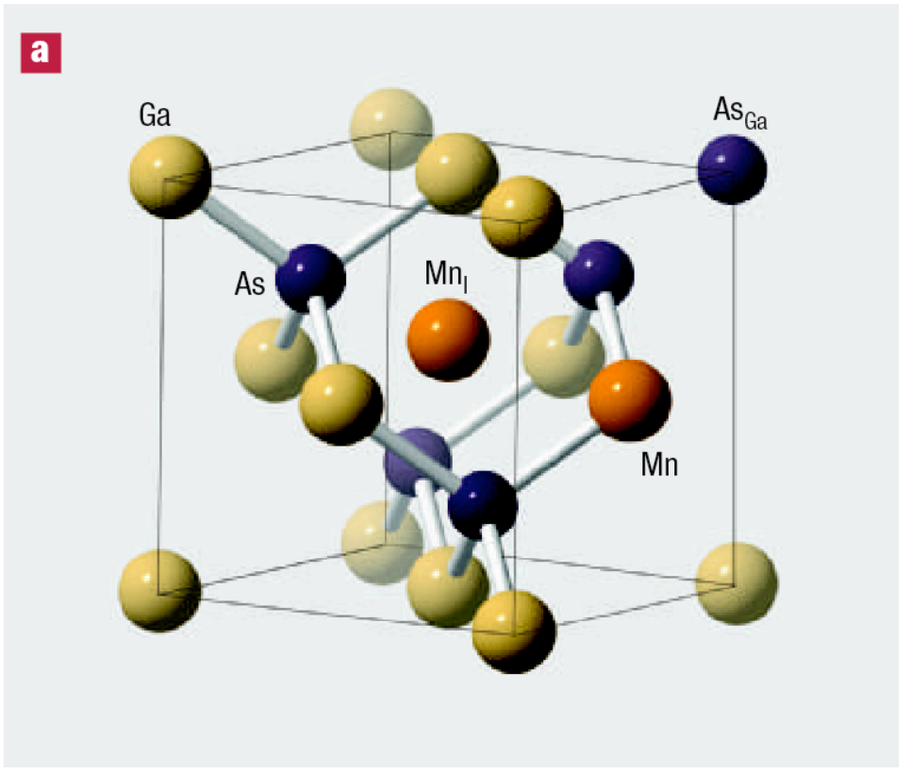
Datta-Das Transistor

用電場來控制自旋

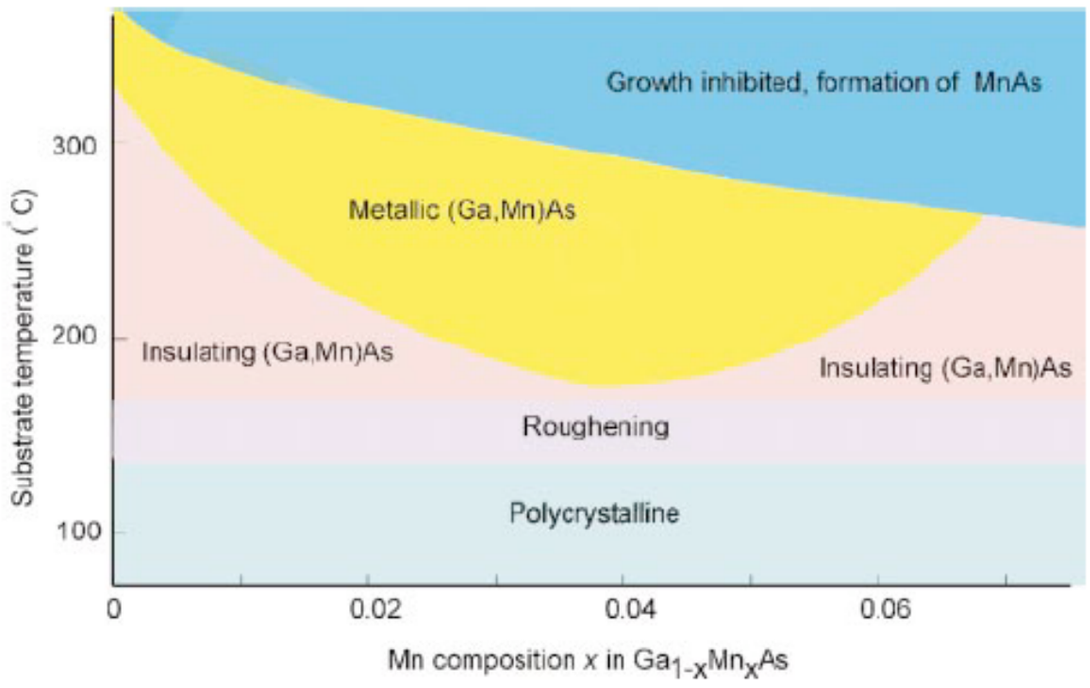


用自旋來控制電流

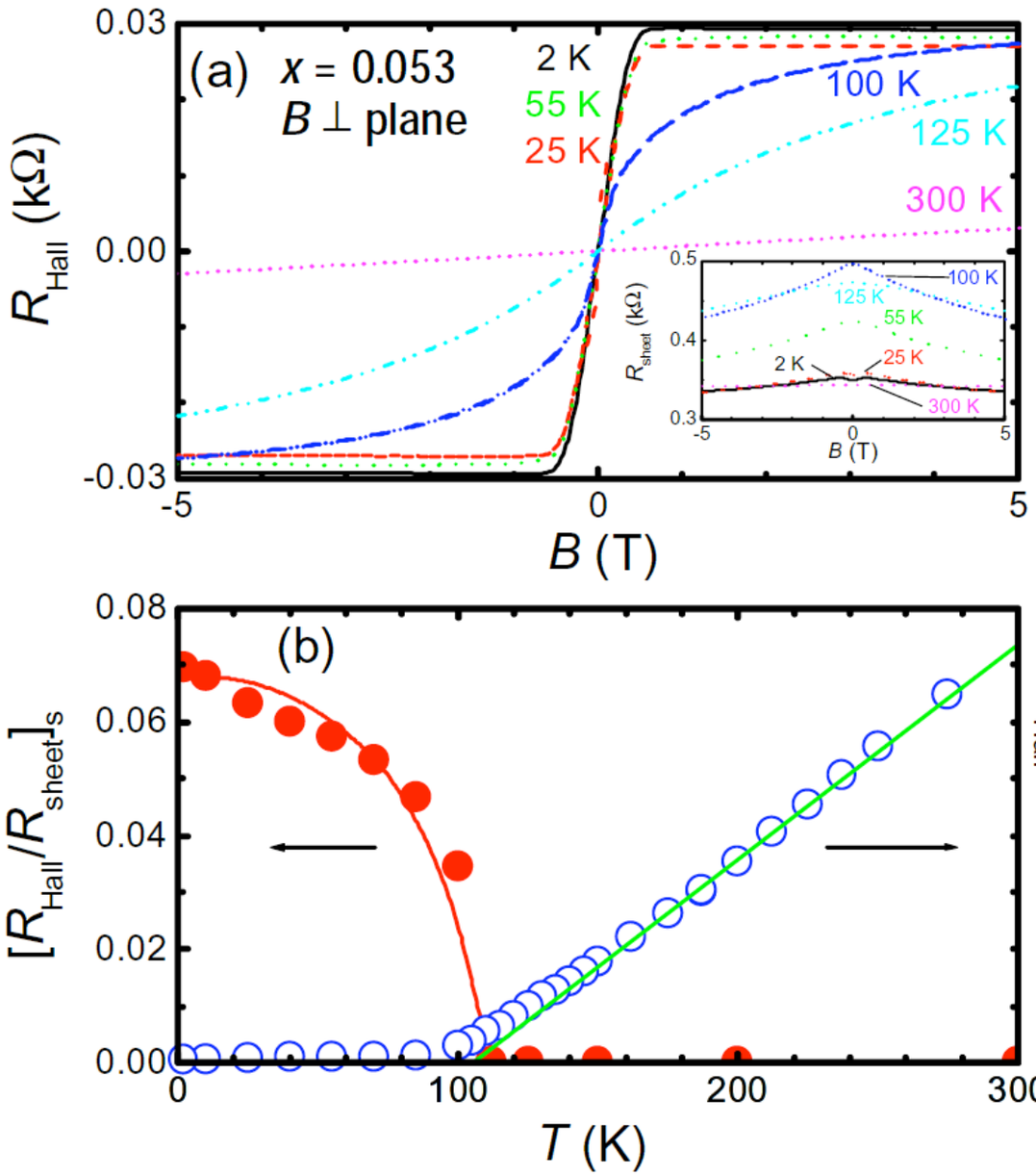
(Ga,Mn) As



半導體摻點磁性雜質，如何?

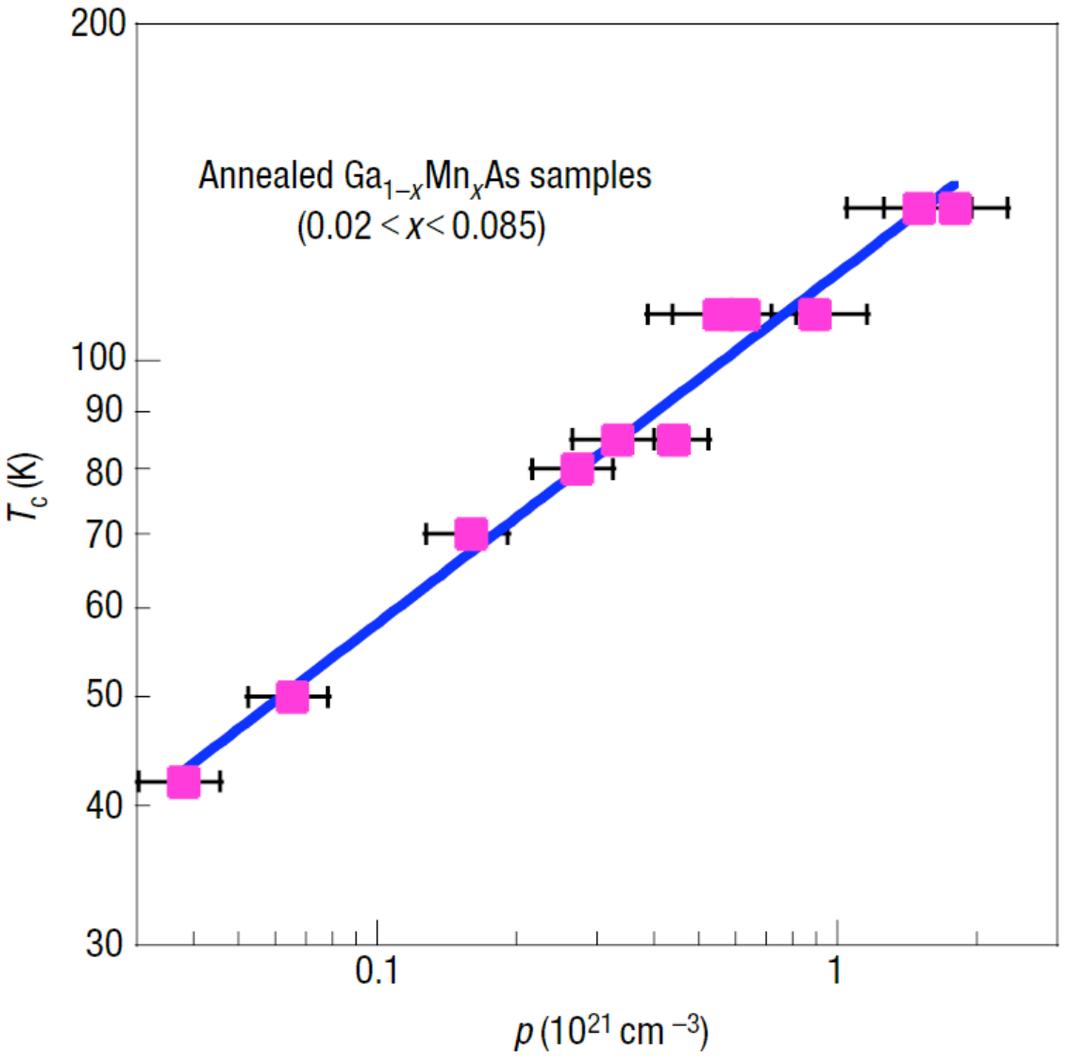


Ferromagnetic Semiconductor



於是，磁性半導體就誕生了。

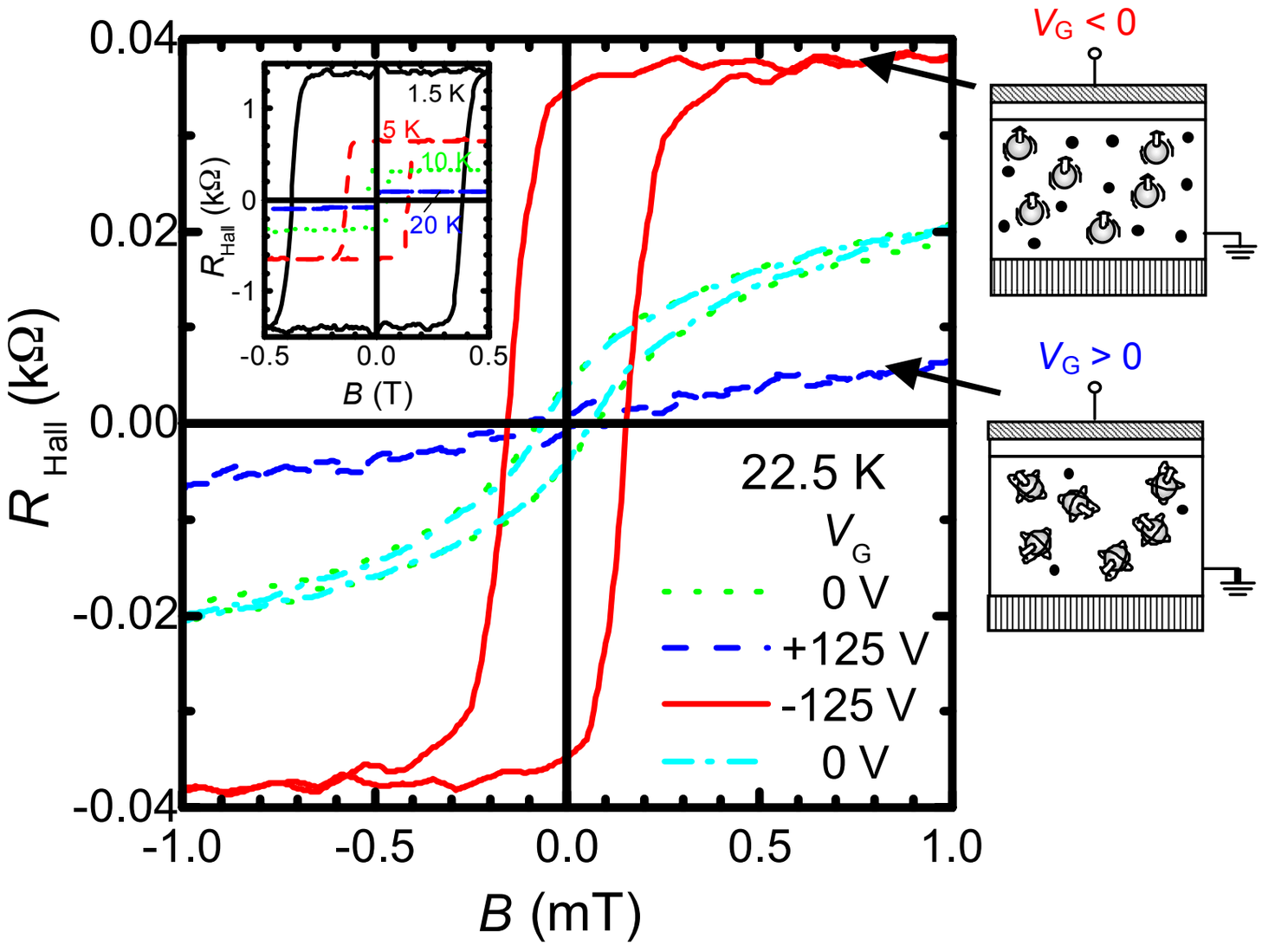
Curie Temperature



Curie 溫度與電洞密度1/3次方成正比。

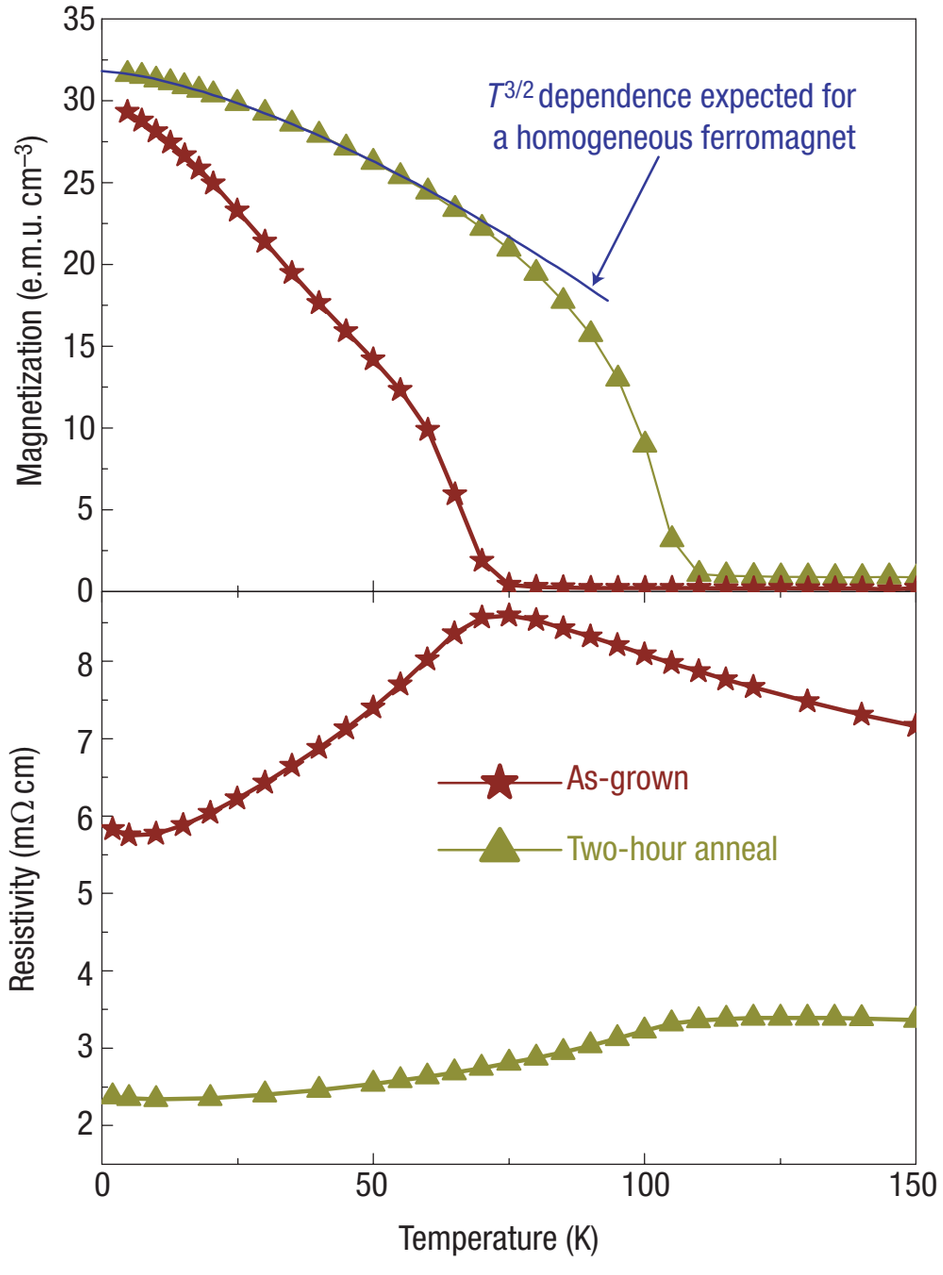
$$T_c \sim n_h^{1/3}$$

Field Effect



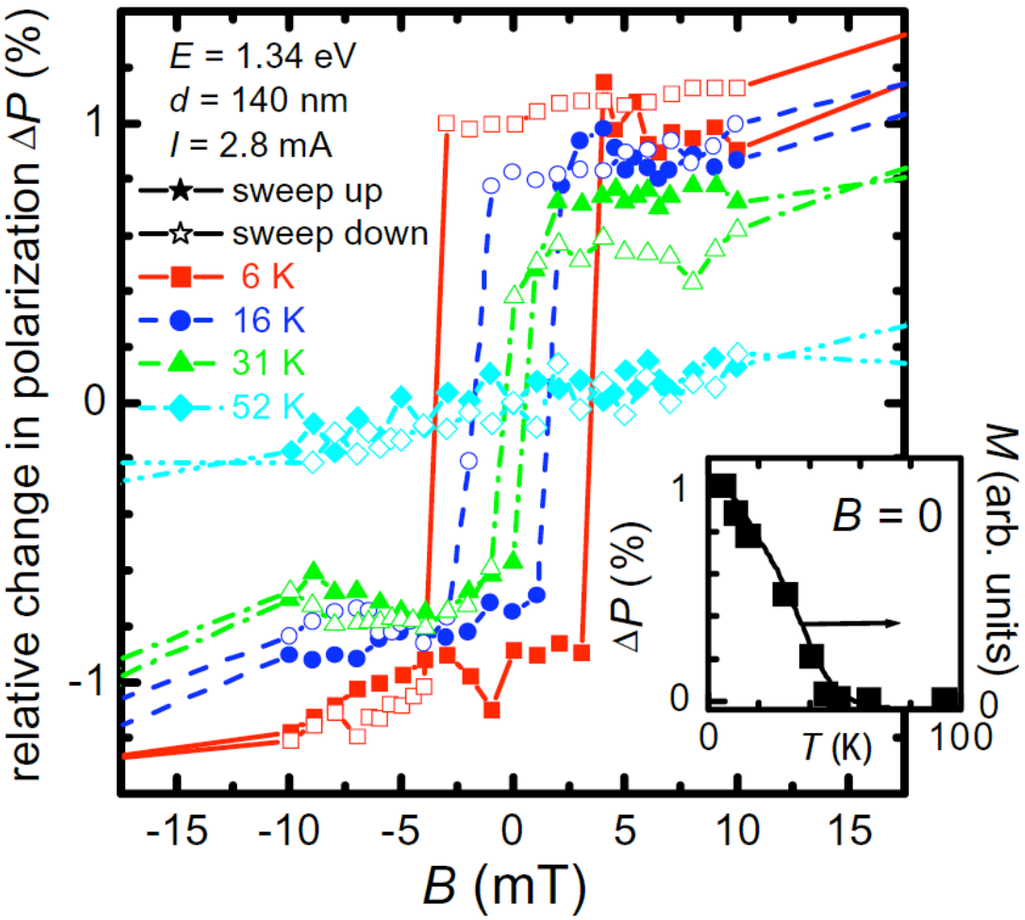
用電場可以讓磁性消失或存在

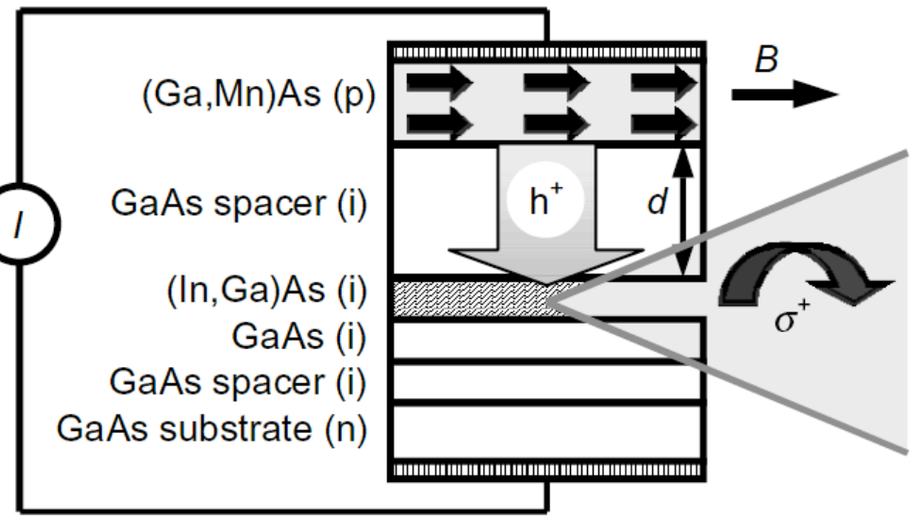
Transport and Magnetism



磁性與電阻有很強的關連性，為什麼？

Magnetism vs Optics

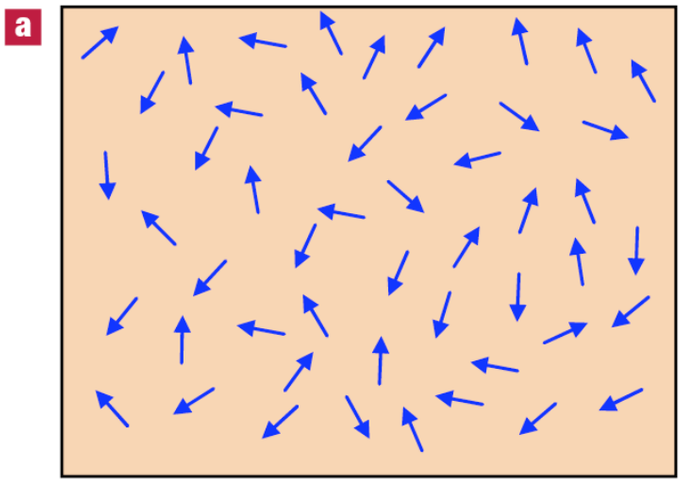


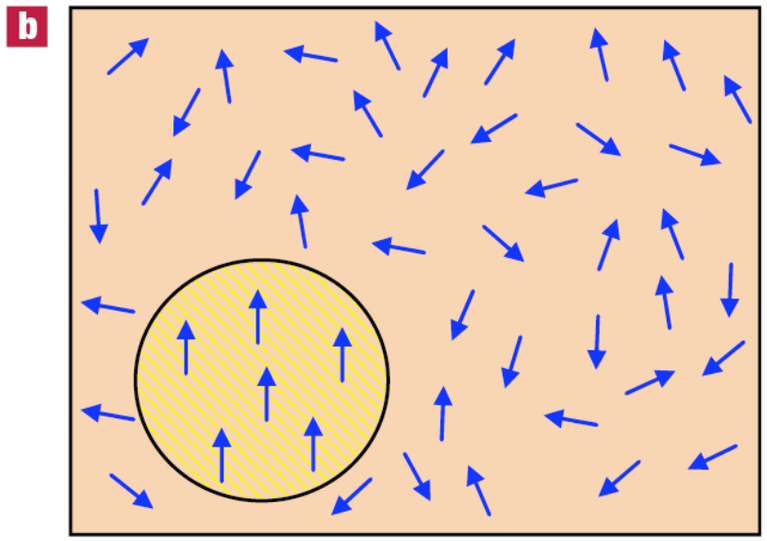


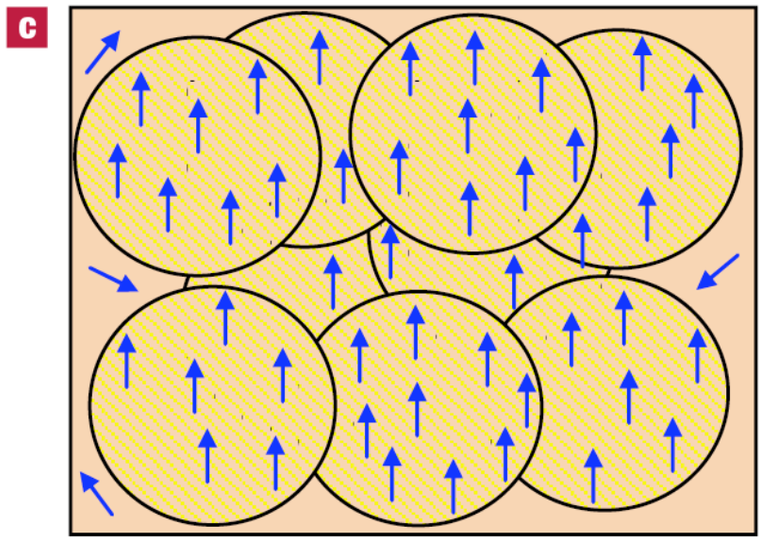
這下子，磁性和光學性質也扯在一起了

Carrier-Mediated Ferromagnetism

老師不在，
亂亂亂...

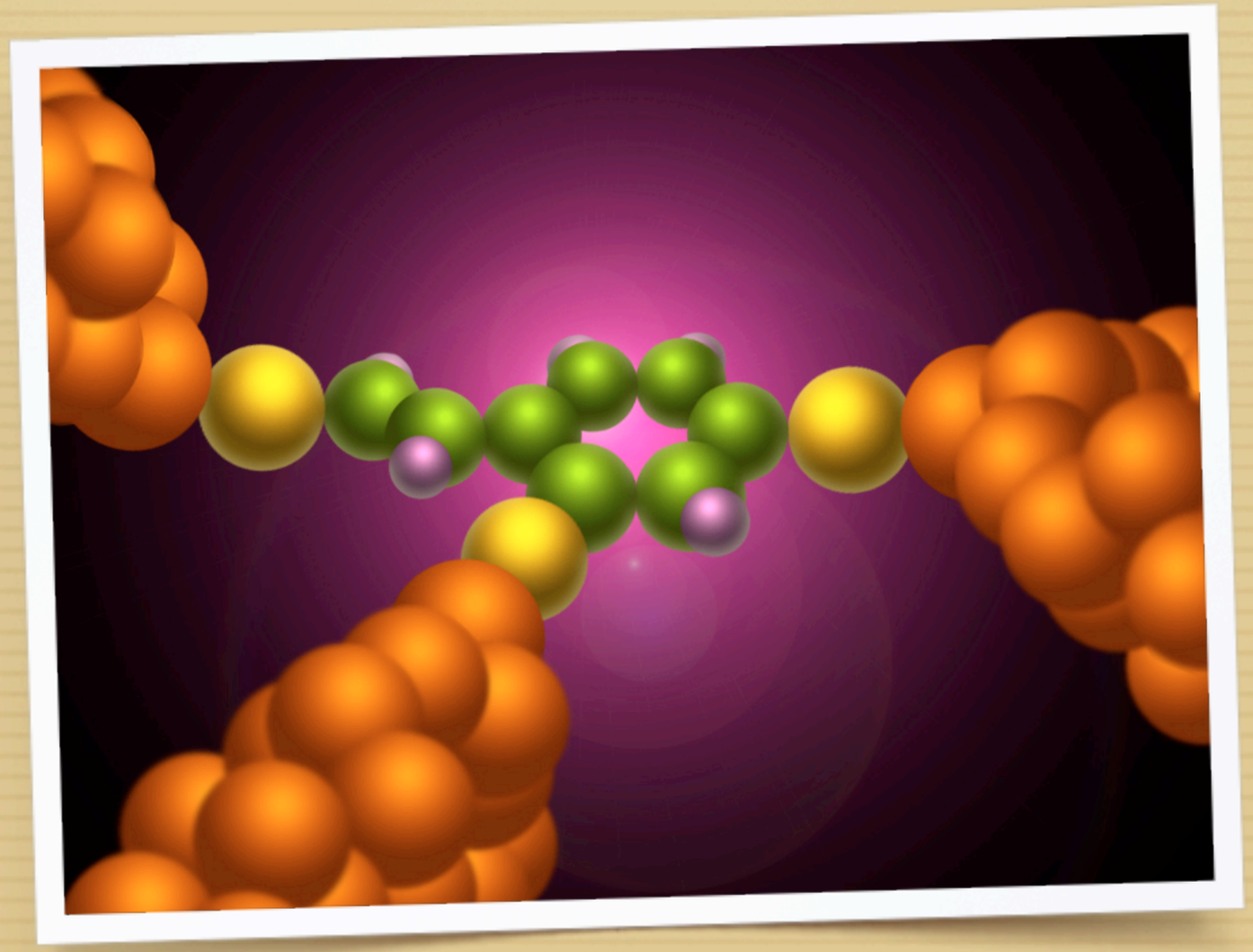






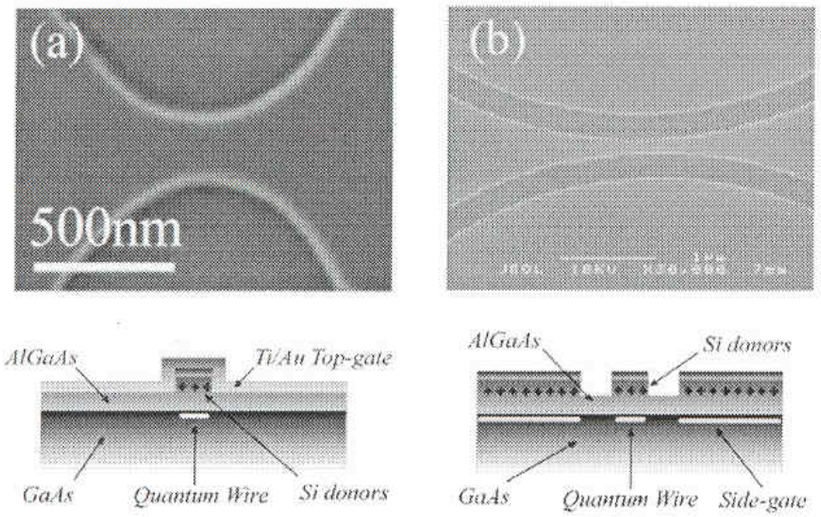
一位好老師，
幾個好學生。

一群好老師，
春風化雨。



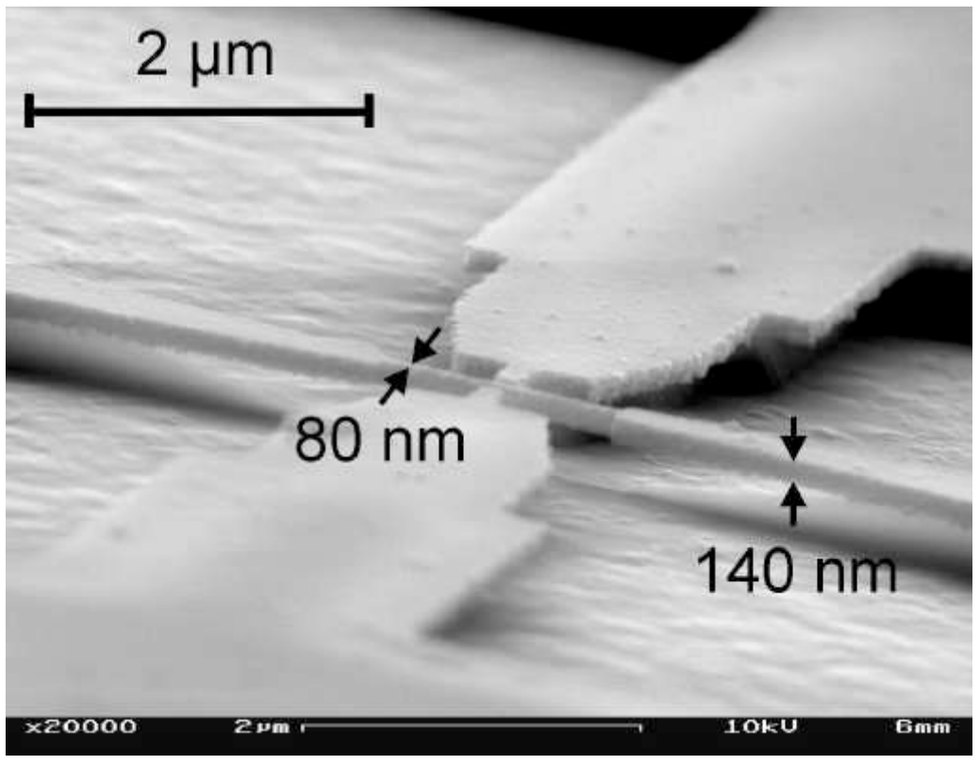
你了解 奈米傳輸嗎？

Quantum Wire



水管流量和截面積成正比，那量子線呢?

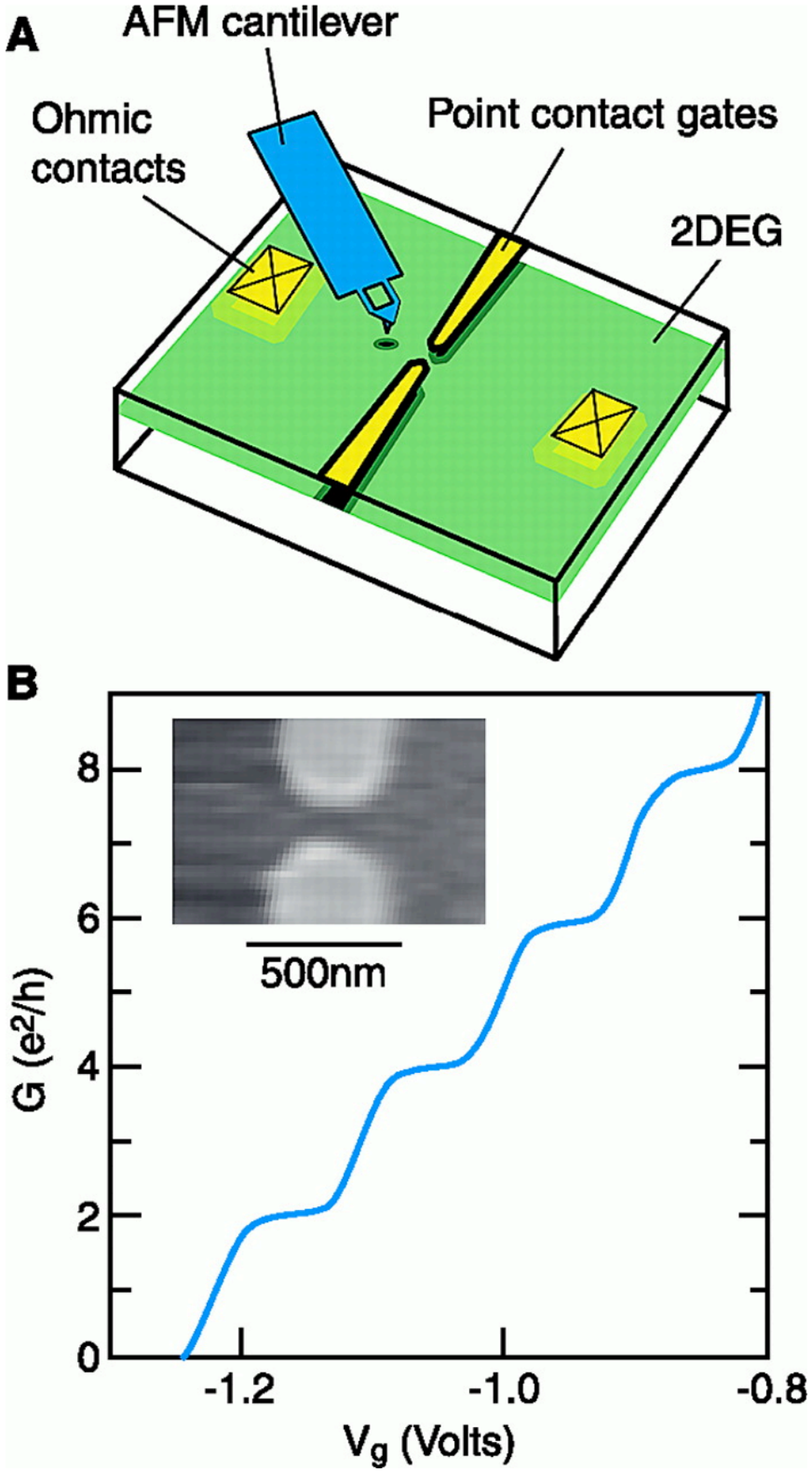
需要量子線來連接奈米元件



Nano MRT I

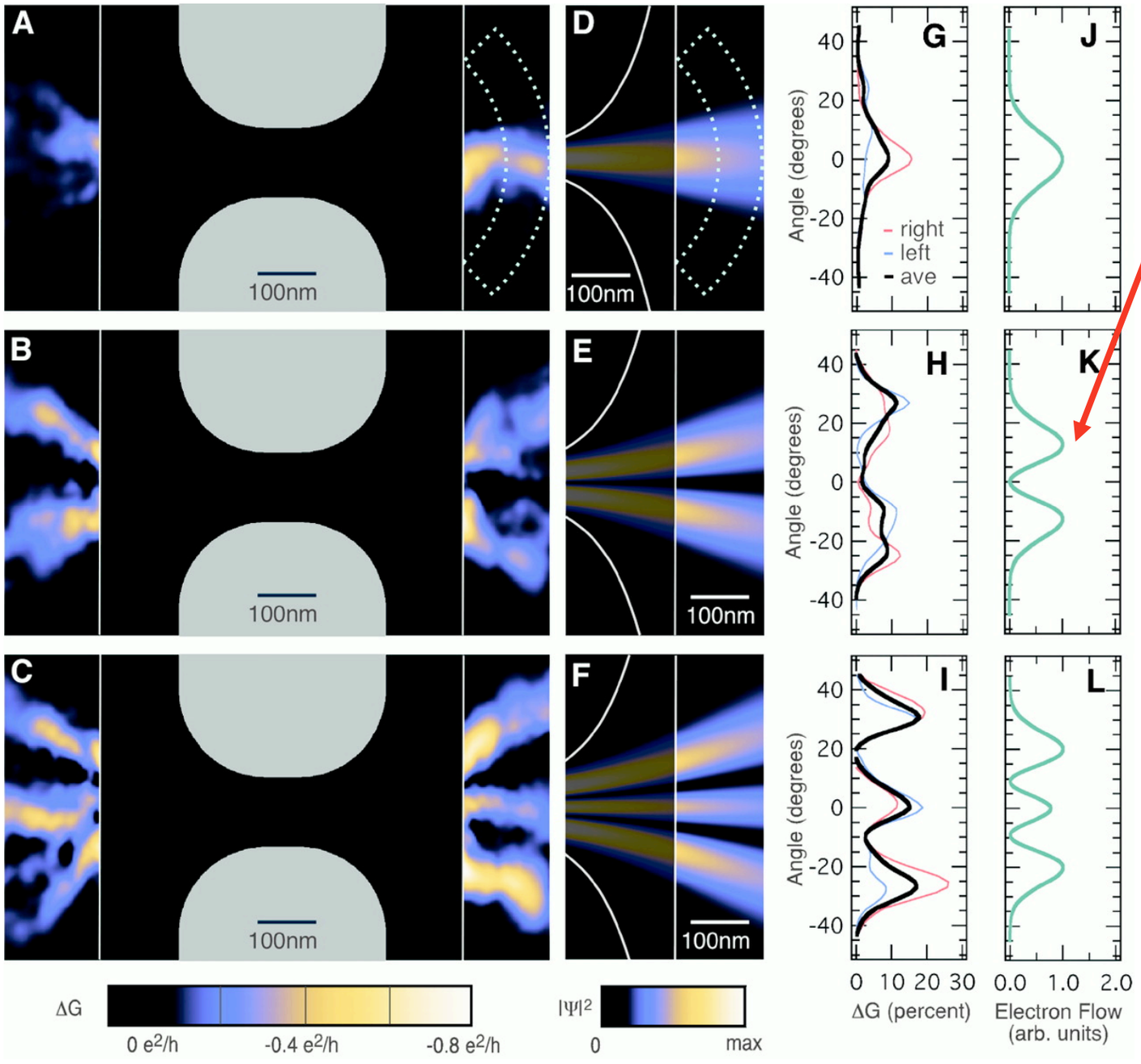
量子線的傳導與截面積並不成正比，而有量子化現象。

量子線的傳導像捷運系統一般，分成淡水線、板南線、木柵線等等。



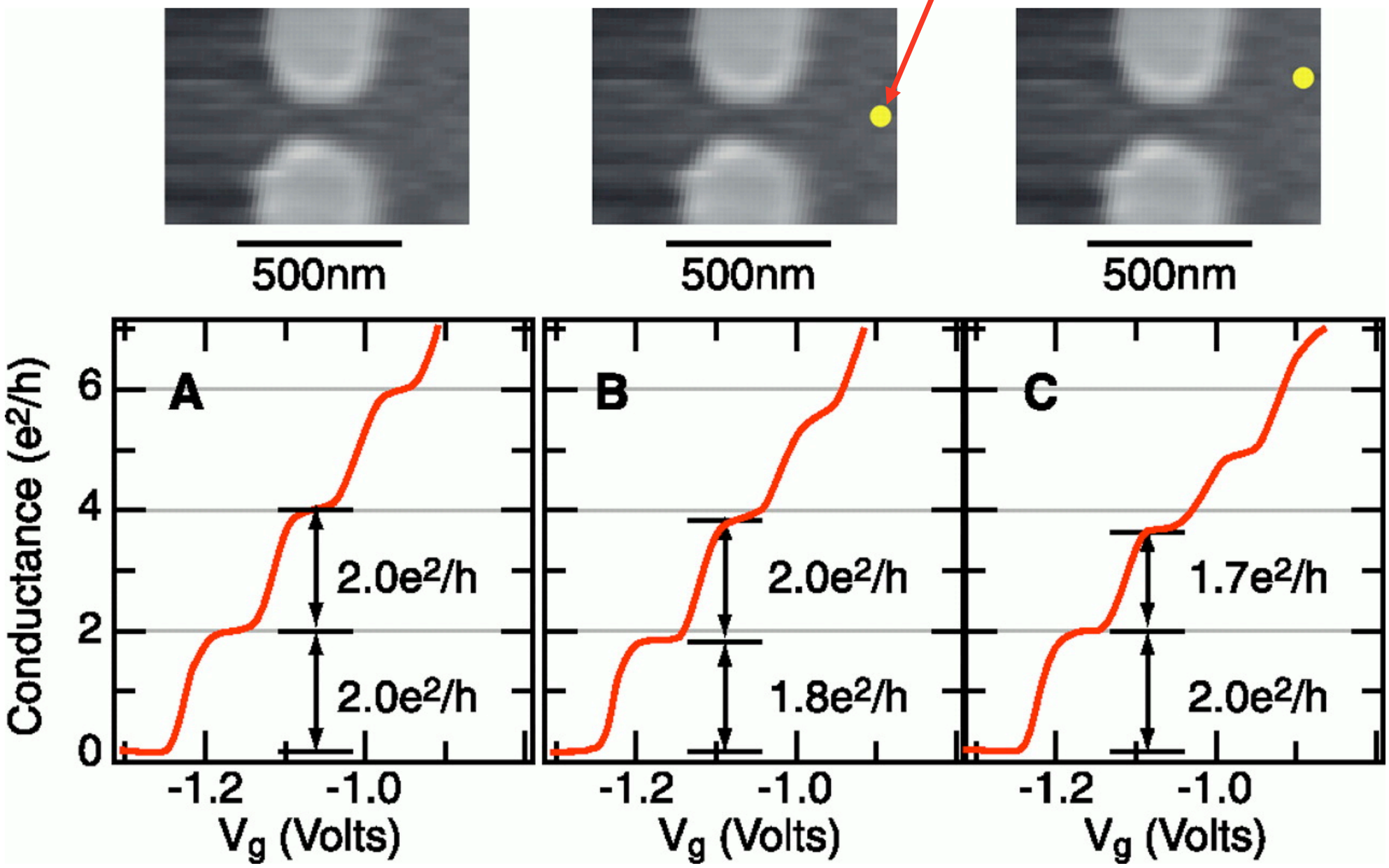
Nano MRT II

每一條捷運線標誌不同

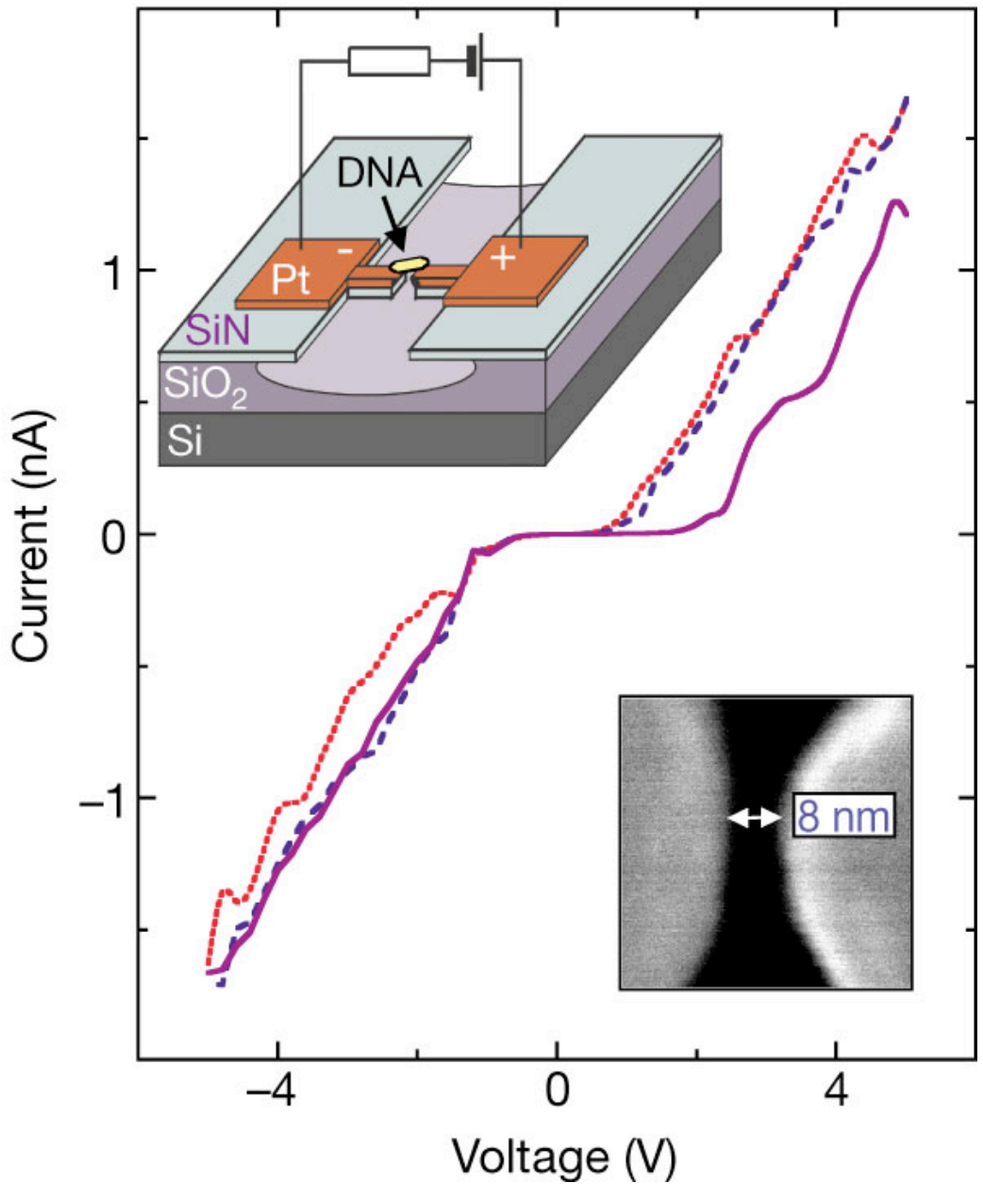


Nano MRT III

破壞一下，哪條捷運線斷掉了?



DNA Nanowire?



連 DNA 都可以拿來當電線

- 導體？
- 絕緣體？
- 半導體？
- 超導體？

Solve the Problem

Find the Solution

Thank You!!