看圖片說奈米

-量子物理與 奈米的憧憬

清華大學物理系 牟中瑜

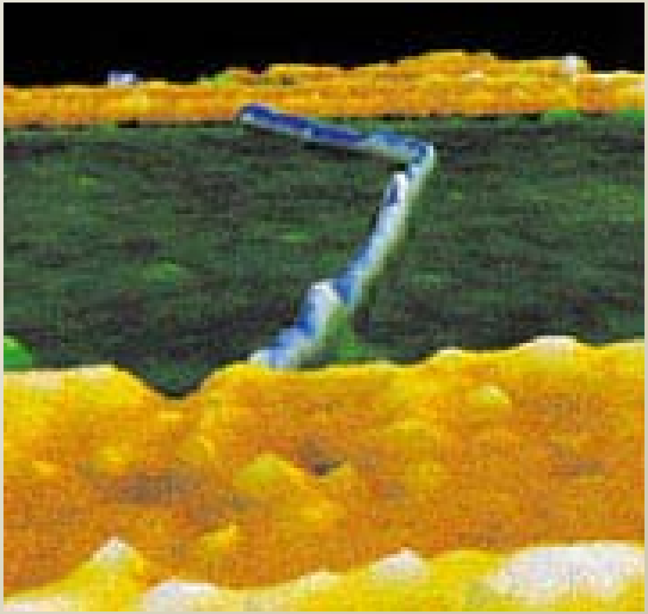
http://www.phys.nthu.edu.tw/~mou

何謂奈米?

奈米(nm)就是 1/1000000000 (10^{-9})公尺

精密外科手術：1/10000 公尺＝0.1 公釐

假想你變成與台灣島(~100公里~100000公尺)一般巨大，來為正常人動精密外科手術。



物理學家很早就注意到奈米…

•4th Century, Roman glassmaker: the color of glasses can be changed by mixing in metal particles
•1883, Films containing silver halides for photography were invented by George Eastman, founder of Kodak
•1908, Gustay Mie first provided the explanation of the size dependence of color
•Vision from Feynman in 1959: "There is plenty room at the bottom", and also recognized there are plenty of nature-given nanostructures in biological systems
•1950-1960, small metal particles were investigated by physicists
•1957, Ralph Landauer realized the importance of quantum mechanics plays in devices with small scales
•Before 1997 => **mesoscopic** (or low dimensional) physics: quantum dots, wells, wires…are known already

here's Plenty of Room at the Bottom

n Invitation to Enter a New Field of Physics

by Richard P. Feynman

This transcript of the classic talk that Richard Feynman gave on December 29th 1959 at the annual meeting of the American Physical Society the California Institute of Technology (Caltech) was first published in the February 1960 issue of Caltech's *Engineering and Science*, which owns the copyright. It has been made available on the web at http://www.zyvex.com/nanotech/feynman.html with their kind permission.

Information on the Feynman Prizes

Links to pages on Feynman

For an account of the talk and how people reacted to it, see chapter 4 of *Nano!* by Ed Regis, Little/Brown 1995. An excellent technical introduction to nanotechnology is *Nanosystems: molecular machinery, manufacturing, and computation* by K. Eric Drexler, Wiley 1992.

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magine experimental physicists must often look with envy at men like Kamerlingh Onnes, who discovered a field like low temperature, which see ttomless and in which one can go down and down. Such a man is then a leader and has some temporary monopoly in a scientific adventure. Perc idgman, in designing a way to obtain higher pressures, opened up another new field and was able to move into it and to lead us all along. The velopment of ever higher vacuum was a continuing development of the same kind.

would like to describe a field, in which little has been done, but in which an enormous amount can be done in principle. This field is not quite the e others in that it will not tell us much of fundamental physics (in the sense of, ``What are the strange particles?'') but it is more like solid-state phy

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hat I want to talk about is the problem of manipulating and controlling things on a small scale.

s soon as I mention this, people tell me about miniaturization, and how far it has progressed today. They tell me about electric motors that are the e nail on your small finger. And there is a device on the market, they tell me, by which you can write the Lord's Prayer on the head of a pin. But t othing; that's the most primitive, halting step in the direction I intend to discuss. It is a staggeringly small world that is below. In the year 2000, wh ok back at this age, they will wonder why it was not until the year 1960 that anybody began seriously to move in this direction.

hy cannot we write the entire 24 volumes of the Encyclopedia Brittanica on the head of a pin?

t's see what would be involved. The head of a pin is a sixteenth of an inch across. If you magnify it by 25,000 diameters, the area of the head of en equal to the area of all the pages of the Encyclopaedia Brittanica. Therefore, all it is necessary to do is to reduce in size all the writing in the cyclopaedia by 25,000 times. Is that possible? The resolving power of the eye is about 1/120 of an inch---that is roughly the diameter of one of t ts on the fine half-tone reproductions in the Encyclopaedia. This, when you demagnify it by 25,000 times, is still 80 angstroms in diameter---32 a ross, in an ordinary metal. In other words, one of those dots still would contain in its area 1,000 atoms. So, each dot can easily be adjusted in size quired by the photoengraving, and there is no question that there is enough room on the head of a pin to put all of the Encyclopaedia Brittanica.

rthermore, it can be read if it is so written. Let's imagine that it is written in raised letters of metal; that is, where the black is in the Encyclopedia, sed letters of metal that are actually 1/25,000 of their ordinary size. How would we read it?

we had something written in such a way, we could read it using techniques in common use today. (They will undoubtedly find a better way when

nformation on a small scale

ppose that, instead of trying to reproduce the pictures and all the information directly in its present form, we write only the information content in dots and dashes, or something like that, to represent the various letters. Each letter represents six or seven ``bits'' of information; that is, you need out six or seven dots or dashes for each letter. Now, instead of writing everything, as I did before, on the *surface* of the head of a pin, I am going e interior of the material as well.

t us represent a dot by a small spot of one metal, the next dash, by an adjacent spot of another metal, and so on. Suppose, to be conservative, that formation is going to require a little cube of atoms 5 times 5 times 5---that is 125 atoms. Perhaps we need a hundred and some odd atoms to make e information is not lost through diffusion, or through some other process.

ave estimated how many letters there are in the Encyclopaedia, and I have assumed that each of my 24 million books is as big as an Encyclopaed lume, and have calculated, then, how many bits of information there are (10^15). For each bit I allow 100 atoms. And it turns out that all of the formation that man has carefully accumulated in all the books in the world can be written in this form in a cube of material one two-hundredth of de--- which is the barest piece of dust that can be made out by the human eye. So there is *plenty* of room at the bottom! Don't tell me about micro

is fact---that enormous amounts of information can be carried in an exceedingly small space---is, of course, well known to the biologists, and res ystery which existed before we understood all this clearly, of how it could be that, in the tiniest cell, all of the information for the organization of a mplex creature such as ourselves can be stored. All this information---whether we have brown eyes, or whether we think at all, or that in the embr wbone should first develop with a little hole in the side so that later a nerve can grow through it---all this information is contained in a very tiny fra e cell in the form of long-chain DNA molecules in which approximately 50 atoms are used for one bit of information about the cell.

etter electron microscopes

I have written in a code, with 5 times 5 times 5 atoms to a bit, the question is: How could I read it today? The electron microscope is not quite goo ough, with the greatest care and effort, it can only resolve about 10 angstroms. I would like to try and impress upon you while I am talking about ese things on a small scale, the importance of improving the electron microscope by a hundred times. It is not impossible; it is not against the laws ffraction of the electron. The wave length of the electron in such a microscope is only 1/20 of an angstrom. So it should be possible to see the indi oms. What good would it be to see individual atoms distinctly?

e have friends in other fields---in biology, for instance. We physicists often look at them and say, ``You know the reason you fellows are making mmetrical? I put this out as a challenge: Is there no way to make the electron microscope more powerful?

he marvelous biological system

e biological example of writing information on a small scale has inspired me to think of something that should be possible. Biology is not simply
formation; it is *doing something* about it. A biological system can be exceedingly small. Many of the cells are very tiny, but they are very active;
anufacture various substances; they walk around; they wiggle; and they do all kinds of marvelous things---all on a very small scale. Also, they sto
formation. Consider the possibility that we too can make a thing very small which does what we want---that we can manufacture an object that ma
that level!

ere may even be an economic point to this business of making things very small. Let me remind you of some of the problems of computing mac
mputers we have to store an enormous amount of information. The kind of writing that I was mentioning before, in which I had everything down
stribution of metal, is permanent. Much more interesting to a computer is a way of writing, erasing, and writing something else. (This is usually be
n't want to waste the material on which we have just written. Yet if we could write it in a very small space, it wouldn't make any difference; it cou
rown away after it was read. It doesn't cost very much for the material).

iniaturizing the computer

lon't know how to do this on a small scale in a practical way, but I do know that computing machines are very large; they fill rooms. Why can't w
em very small, make them of little wires, little elements---and by little, I mean *little*. For instance, the wires should be 10 or 100 atoms in diameter
cuits should be a few thousand angstroms across. Everybody who has analyzed the logical theory of computers has come to the conclusion that t
ssibilities of computers are very interesting---if they could be made to be more complicated by several orders of magnitude. If they had millions c
many elements, they could make judgments. They would have time to calculate what is the best way to make the calculation that they are about t
ey could select the method of analysis which, from their experience, is better than the one that we would give to them. And in many other ways,
ould have new qualitative features.

I look at your face I immediately recognize that I have seen it before. (Actually, my friends will say I have chosen an unfortunate example here fo
bject of this illustration. At least I recognize that it is a *man* and not an *apple*.) Yet there is no machine which, with that speed, can take a picture c
d say even that it is a man; and much less that it is the same man that you showed it before---unless it is exactly the same picture. If the face is cha
m closer to the face; if I am further from the face; if the light changes---I recognize it anyway. Now, this little computer I carry in my head is easil

ıt there is plenty of room to make them smaller. There is nothing that I can see in the physical laws that says the computer elements cannot be ma
ormously smaller than they are now. In fact, there may be certain advantages.

Iiniaturization by evaporation Chemical Vapor Deposition and Molecular Beam Epitaxial Growt

ow can we make such a device? What kind of manufacturing processes would we use? One possibility we might consider, since we have talked a
iting by putting atoms down in a certain arrangement, would be to evaporate the material, then evaporate the insulator next to it. Then, for the ne
aporate another position of a wire, another insulator, and so on. So, you simply evaporate until you have a block of stuff which has the elements-
d condensers, transistors and so on---of exceedingly fine dimensions.

ıt I would like to discuss, just for amusement, that there are other possibilities. Why can't we manufacture these small computers somewhat like w
anufacture the big ones? Why can't we drill holes, cut things, solder things, stamp things out, mold different shapes all at an infinitesimal level? W
e limitations as to how small a thing has to be before you can no longer mold it? How many times when you are working on something frustratin
e your wife's wrist watch, have you said to yourself, ``If I could only train an ant to do this!'' What I would like to suggest is the possibility of tra
t to train a mite to do this. What are the possibilities of small but movable machines? They may or may not be useful, but they surely would be fu
ake.

onsider any machine---for example, an automobile---and ask about the problems of making an infinitesimal machine like it. Suppose, in the partic
sign of the automobile, we need a certain precision of the parts; we need an accuracy, let's suppose, of 4/10,000 of an inch. If things are more ina
an that in the shape of the cylinder and so on, it isn't going to work very well. If I make the thing too small, I have to worry about the size of the a
n't make a circle of ``balls'' so to speak, if the circle is too small. So, if I make the error, corresponding to 4/10,000 of an inch, correspond to an e
oms, it turns out that I can reduce the dimensions of an automobile 4,000 times, approximately---so that it is 1 mm. across. Obviously, if you rede
r so that it would work with a much larger tolerance, which is not at all impossible, then you could make a much smaller device.

is interesting to consider what the problems are in such small machines. Firstly, with parts stressed to the same degree, the forces go as the area yo
ducing, so that things like weight and inertia are of relatively no importance. The strength of material, in other words, is very much greater in prop
e stresses and expansion of the flywheel from centrifugal force, for example, would be the same proportion only if the rotational speed is increas
me proportion as we decrease the size. On the other hand, the metals that we use have a grain structure, and this would be very annoying at small
cause the material is not homogeneous. Plastics and glass and things of this amorphous nature are very much more homogeneous, and so we wou
make our machines out of such materials.

ut it is interesting that it would be, in principle, possible (I think) for a physicist to synthesize any chemical substance that the chemist writes down e orders and the physicist synthesizes it. How? Put the atoms down where the chemist says, and so you make the substance. The problems of cher d biology can be greatly helped if our ability to see what we are doing, and to do things on an atomic level, is ultimately developed---a developm hich I think cannot be avoided.

ow, you might say, ``Who should do this and why should they do it?'' Well, I pointed out a few of the economic applications, but I know that the at you would do it might be just for fun. But have some fun! Let's have a competition between laboratories. Let one laboratory make a tiny motor nds to another lab which sends it back with a thing that fits inside the shaft of the first motor.

igh school competition

st for the fun of it, and in order to get kids interested in this field, I would propose that someone who has some contact with the high schools think aking some kind of high school competition. After all, we haven't even started in this field, and even the kids can write smaller than has ever been fore. They could have competition in high schools. The Los Angeles high school could send a pin to the Venice high school on which it says, ``H s?'' They get the pin back, and in the dot of the ``i'' it says, ``Not so hot.''

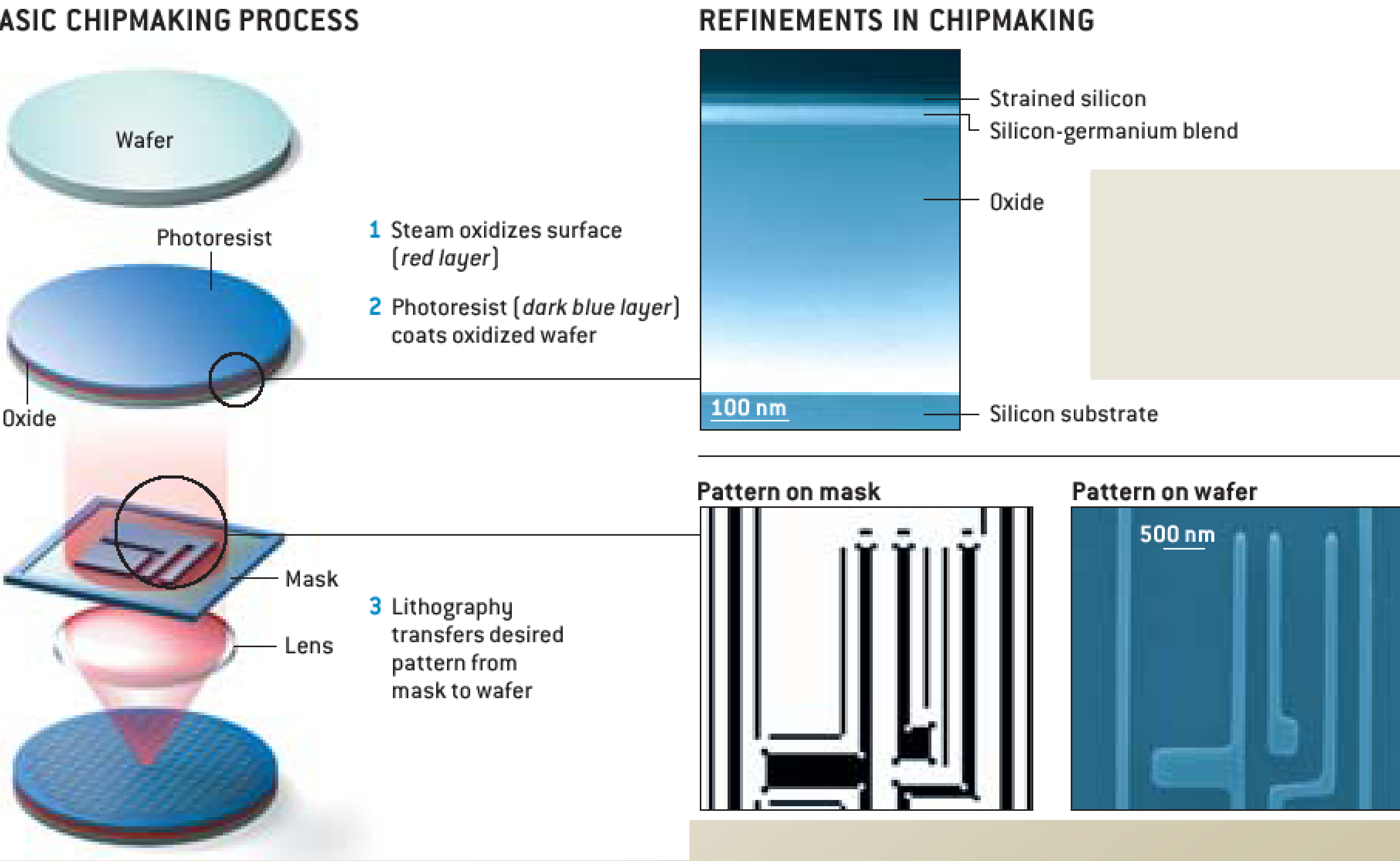
rhaps this doesn't excite you to do it, and only economics will do so. Then I want to do something; but I can't do it at the present moment, becaus ven't prepared the ground. It is my intention to offer a prize of $1,000 to the first guy who can take the information on the page of a book and pu ea 1/25,000 smaller in linear scale in such manner that it can be read by an electron microscope.

nd I want to offer another prize---if I can figure out how to phrase it so that I don't get into a mess of arguments about definitions---of another $1,(st guy who makes an operating electric motor---a rotating electric motor which can be controlled from the outside and, not counting the lead-in w ly 1/64 inch cube.

lo not expect that such prizes will have to wait very long for claimants.

This page is part of the nanotechnology web site.

Top-down approach dominates ….



近來大力推動奈米科技的背景

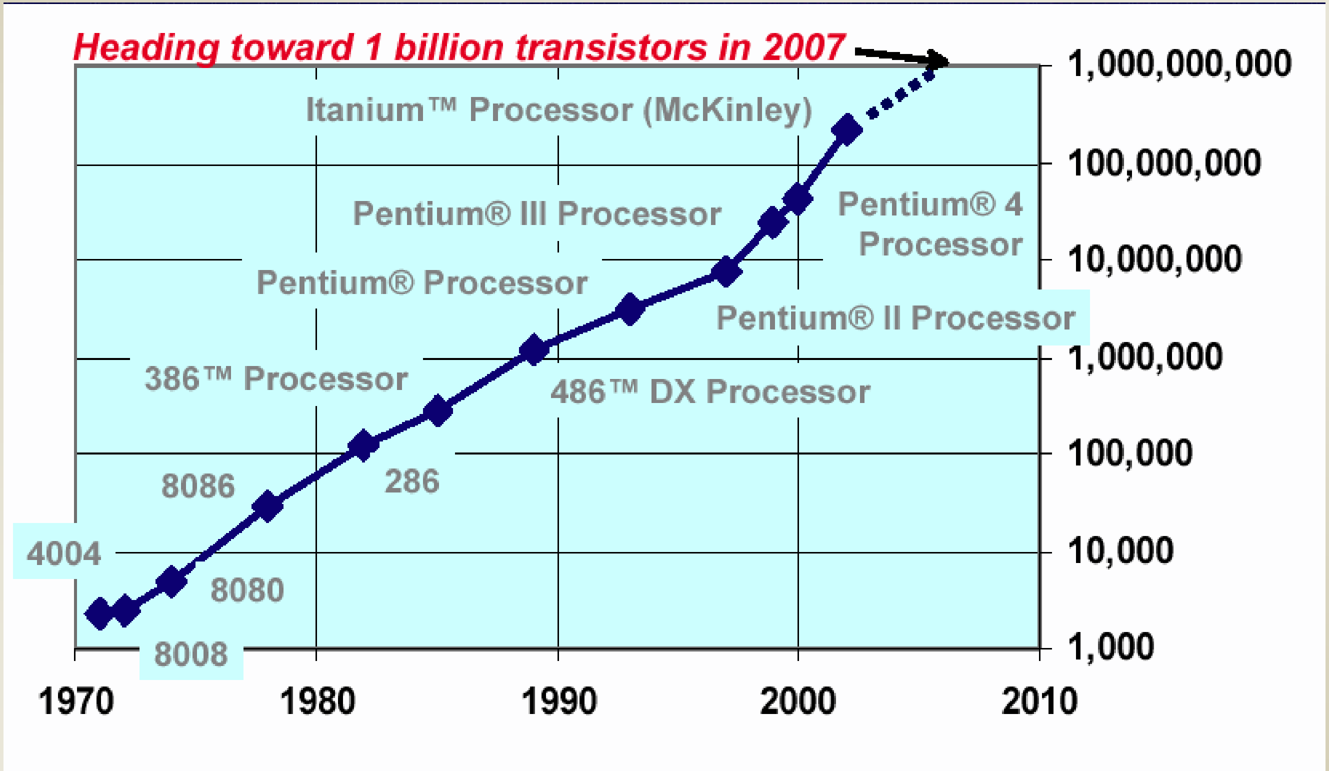
來自微電子學可能遭遇瓶頸的考慮

Moore's Law :

a 30% decrease in the size of printed dimensions every two years

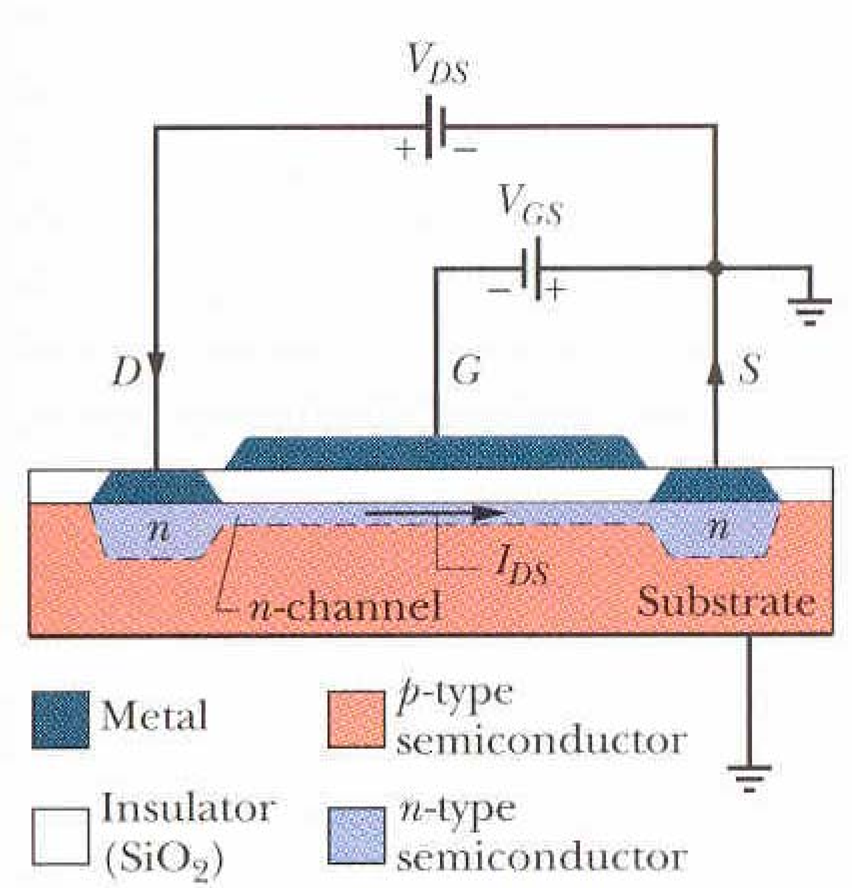
	Actual					Forecast		
1st Production	1993	1995	1997	1999	2001	2003	2005	2007
Generation	500	350	250	180	130	100	65	45nm
Gate Length	500	350	200	130	70	50	35	20nm

Peter Silverman, Intel, July, 2001



Y.Borodovsky, Intel, April, 2002 in PMJ 2002

到底會發生??事



預估以現行的半導體技術縮小的速度, 在**2015**左右, **device**大小達**50nm**以下.
電子的波動性不可再被忽略**…**

Refs.

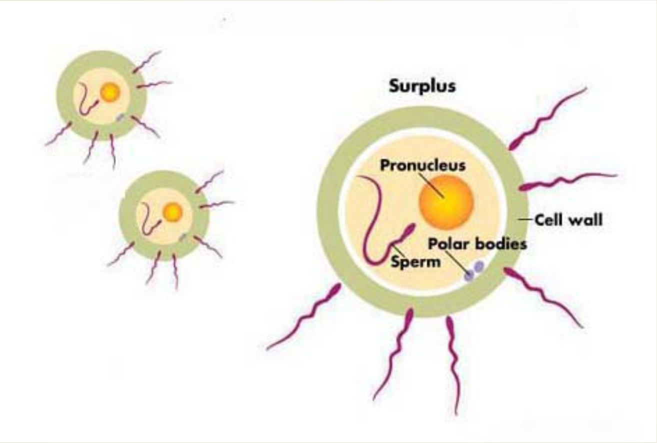
•Fowler, Physics Today Oct. 50-54(1997)

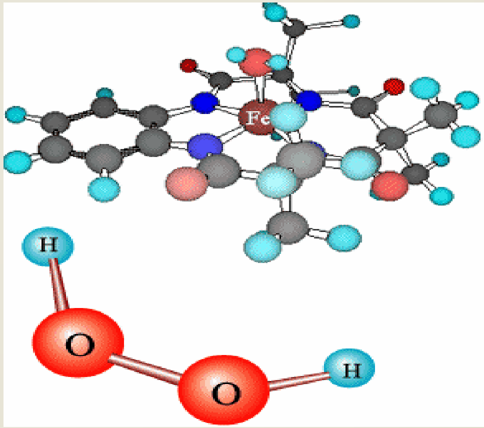
•Glattii, Nature 393, 516(1998

可能遭遇的問題

- 需要製造更小的pattern 的技術 (advanced lithographic techniques, 如 e-beam, x-ray, ..)
- 電子量子特性的重要性??
- 記憶元件運作原理的不適用
- ..etc.

跨領域最小單位逐漸重疊



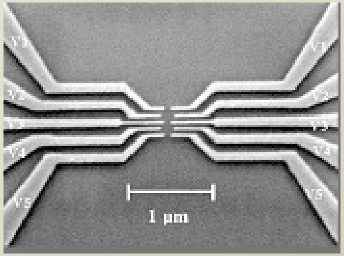


電機工程

生物

材料

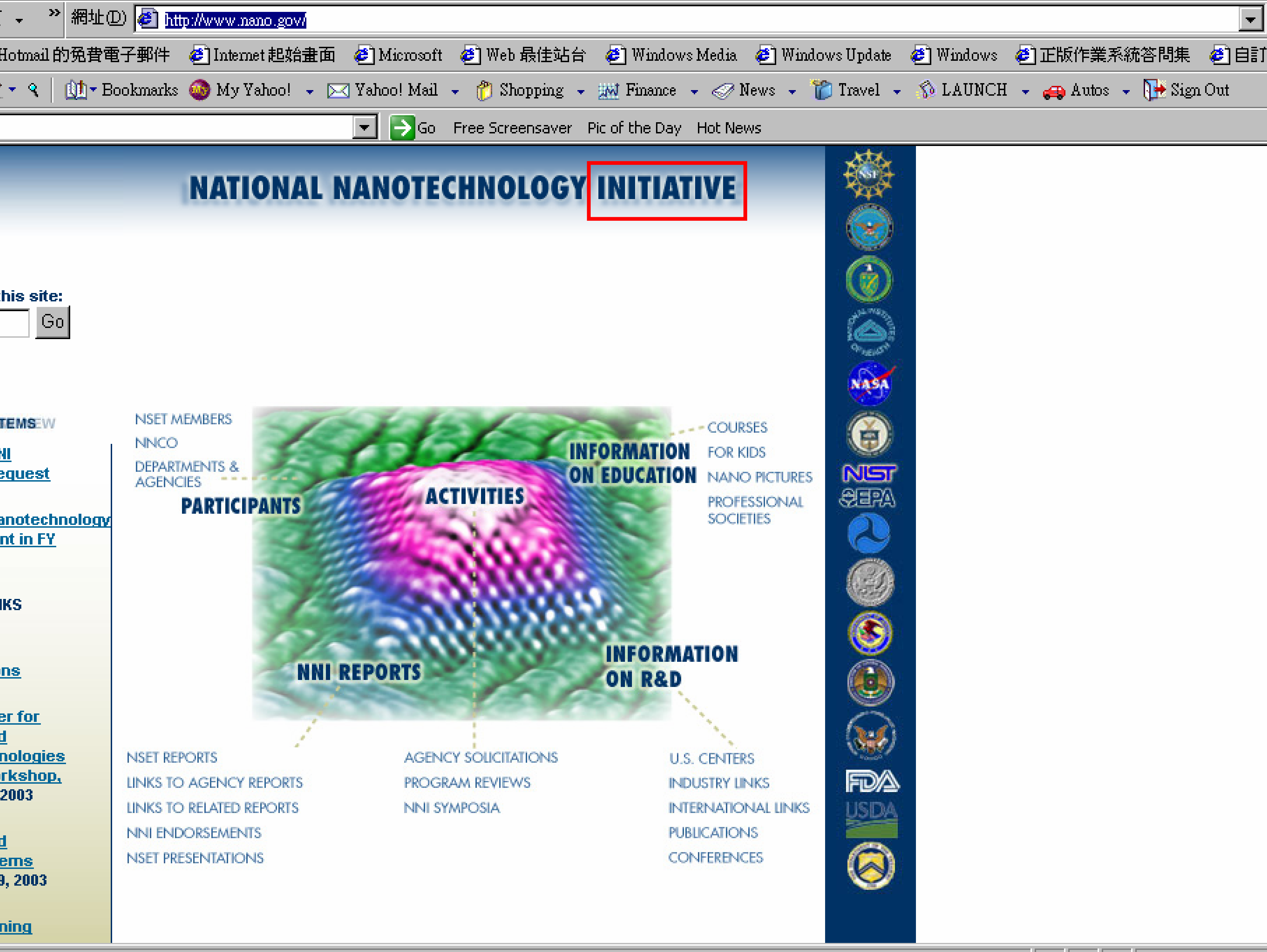
奈米



奈米科技的起源

1996-1998年間, 以美國NSF為主要贊助者, 由World Technology Evaluation Center (WTEC)出面組織的委員對奈米尺度下之可能的科技作了仔細的評估

結論是奈米科技極具潛力, 發展它有可能有重要且影響廣泛的技術突破..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http://www.nano.gov/
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FOR KIDS
NANO PICTURES
PROFESSIONAL SOCIETIES
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NSET REPORTS
LINKS TO AGENCY REPORTS
LINKS TO RELATED REPORTS
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U.S. CENTERS
INDUSTRY LINKS
INTERNATIONAL LINKS
PUBLICATIONS
CONFERENCES
NSF
NASA
NIST
EPA
FDA
USDA

	2003	2004	Difference from 2003 to 2004	Percent Difference fro[m] 2003 to 2004
ational Science Foundation	221	247	26	11.8%
efense	243	222	-20	-8.3%
nergy	133	197	64	48.1%
ational Institutes of Health	65	70	5	7.7%
ommerce	69	62	-7	-10.1%
ASA	33	31	-2	-6.1%
griculture	1	10	9	900.0%
PA	6	5	-1	-16.7%
omeland Security	2	2	0	0.0%
ustice	1	1	0	0.0%
OTAL	**774**	**847**	**74**	**9.5%**

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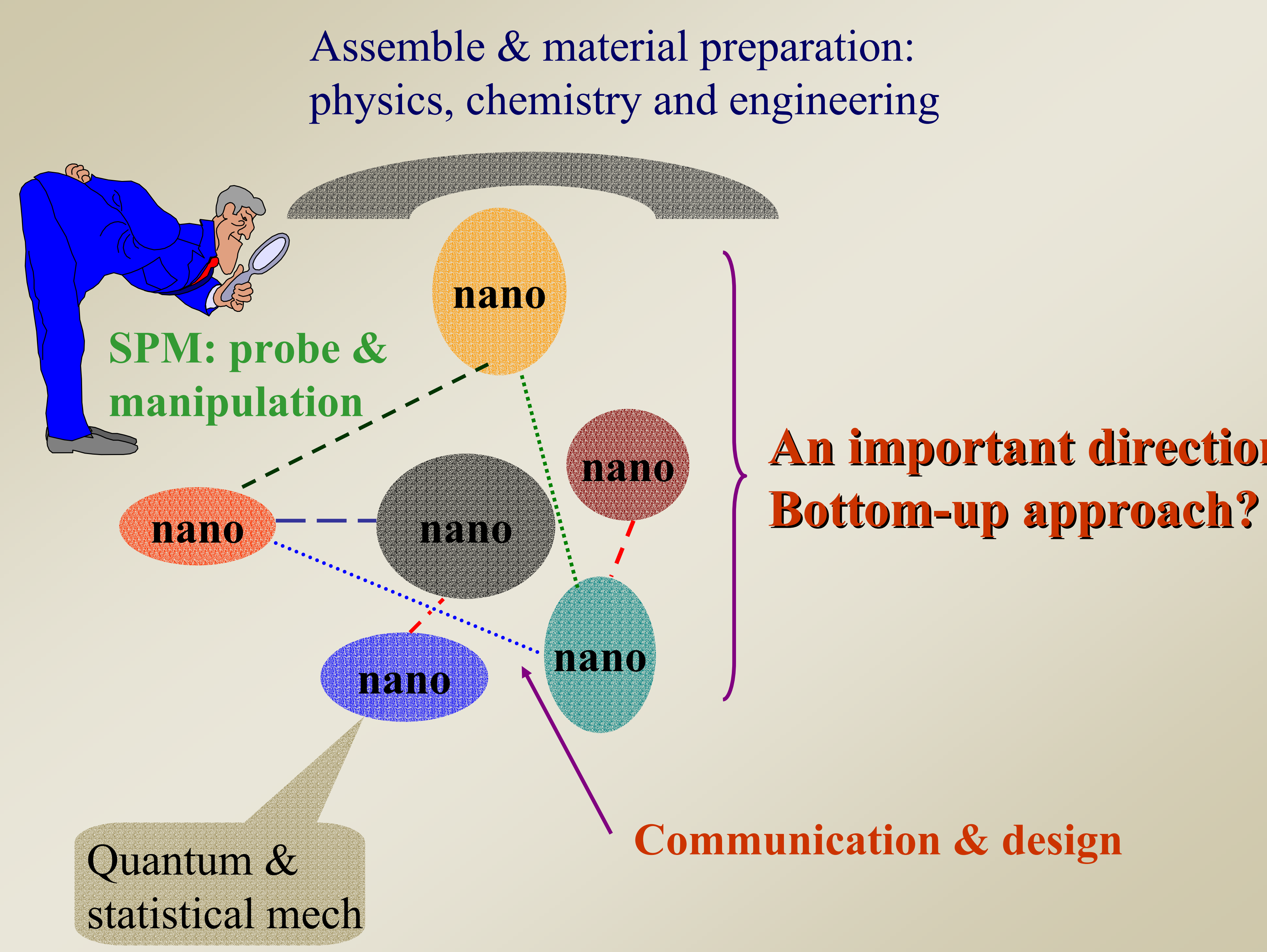
Assemble & material preparation:
physics, chemistry and engineering
SPM: probe &
manipulation
nano
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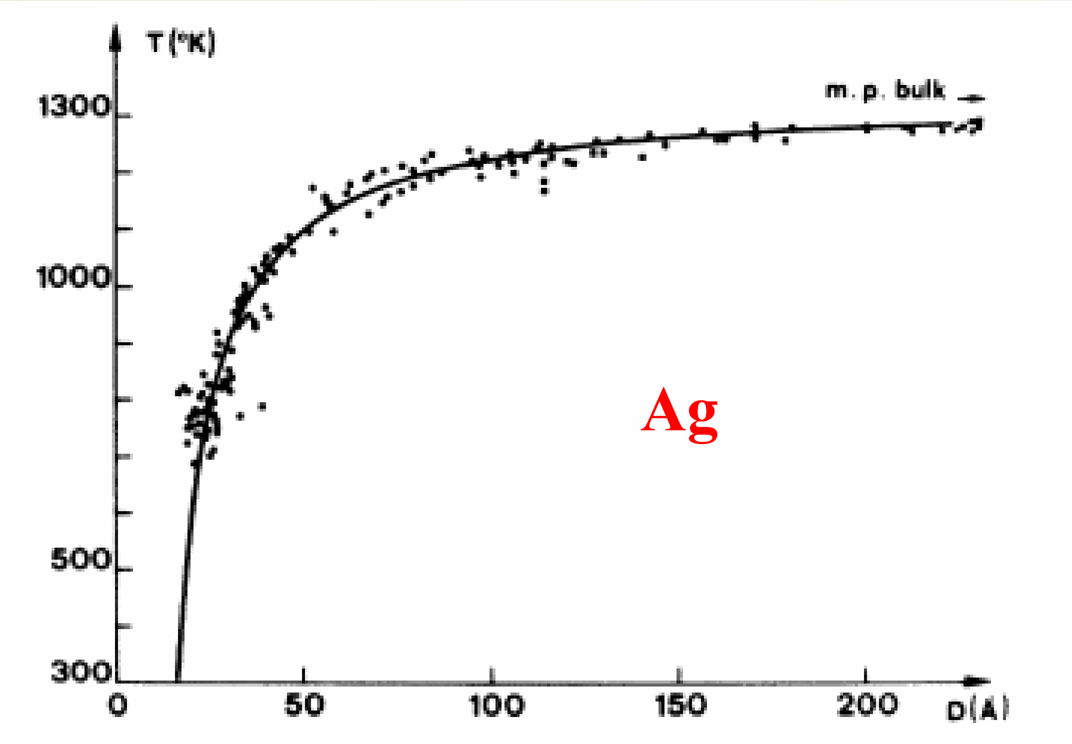
nano
An important directio
Bottom-up approach?
Communication & design
Quantum &
statistical mech

First Lesson

塊材到奈米的轉變

(bulk-to-nano transition)

例： size-dependence of melting temperature



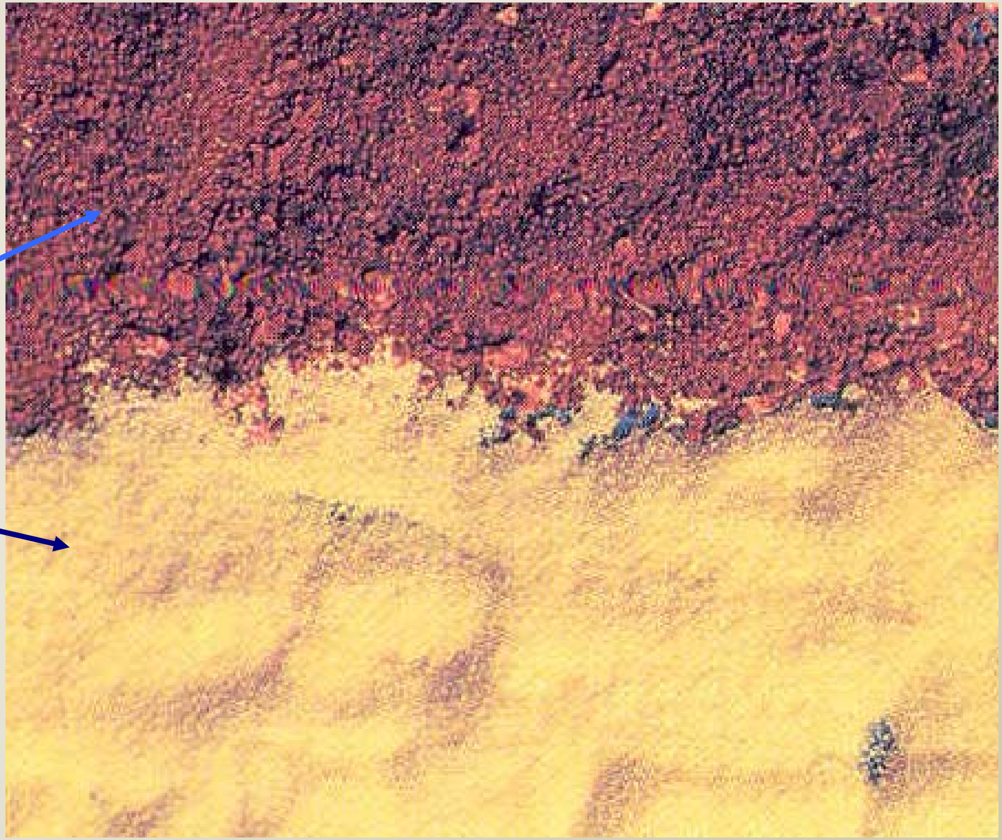
Ph. Buffat and J-P. Borel, Phys. Rev. A13, 2287 (1976)

例: size-dependence of color

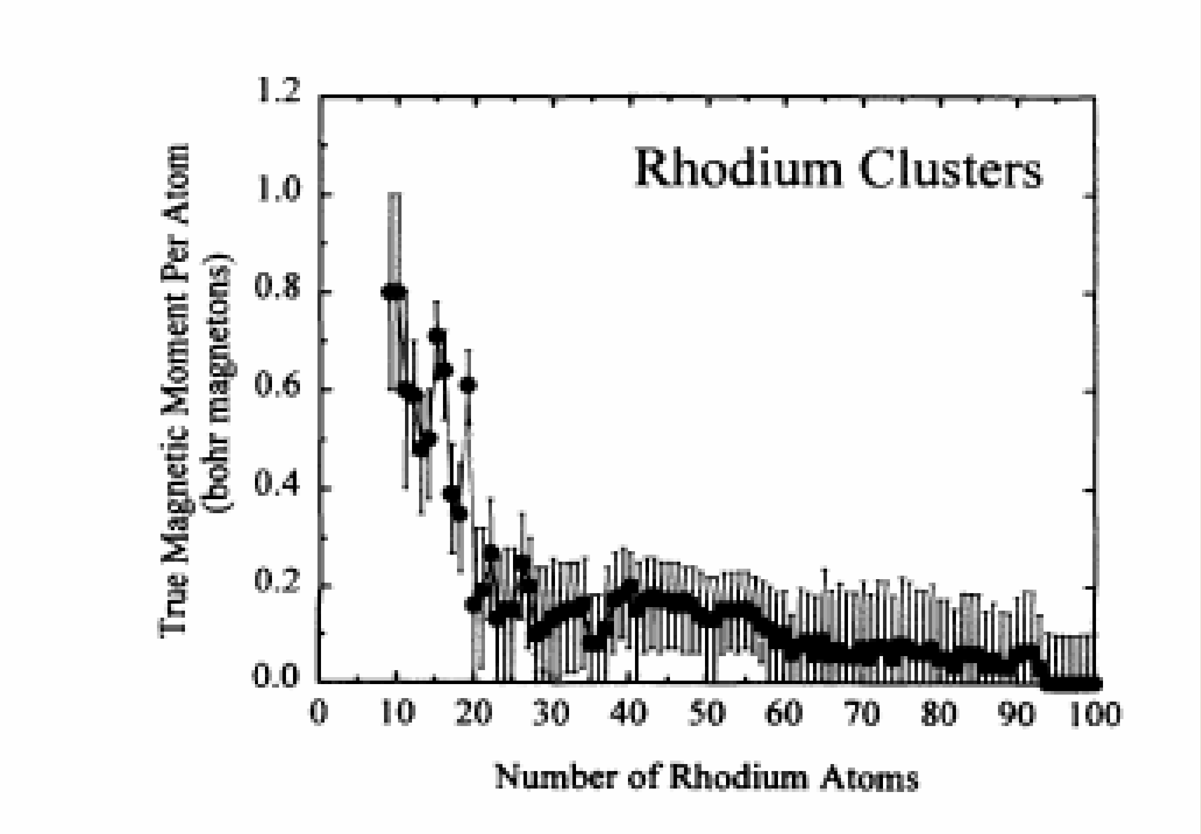
powered cadmium selenide

larger

smaller

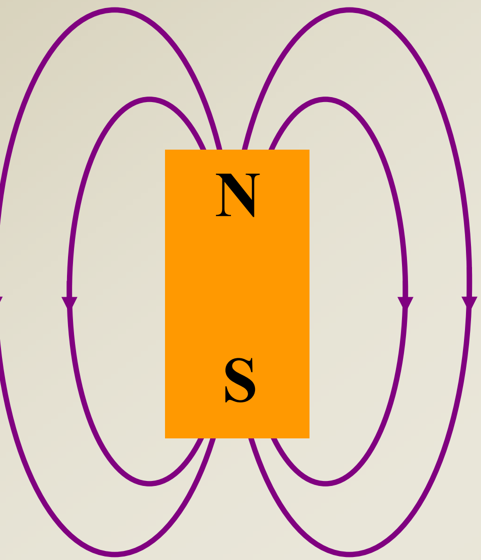


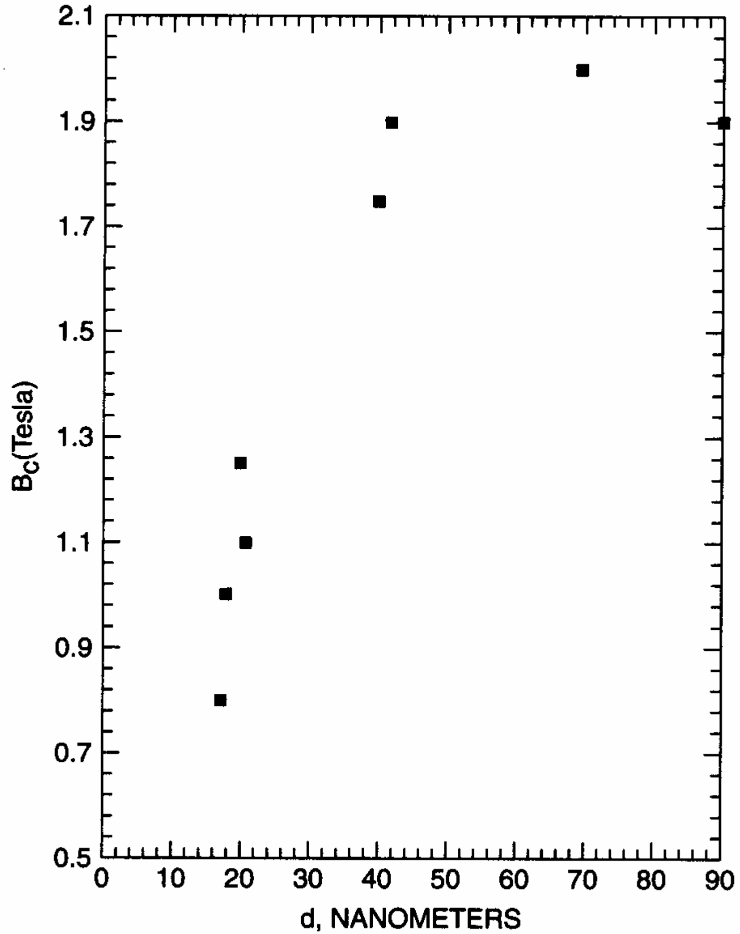
例：size-dependence of magnetism



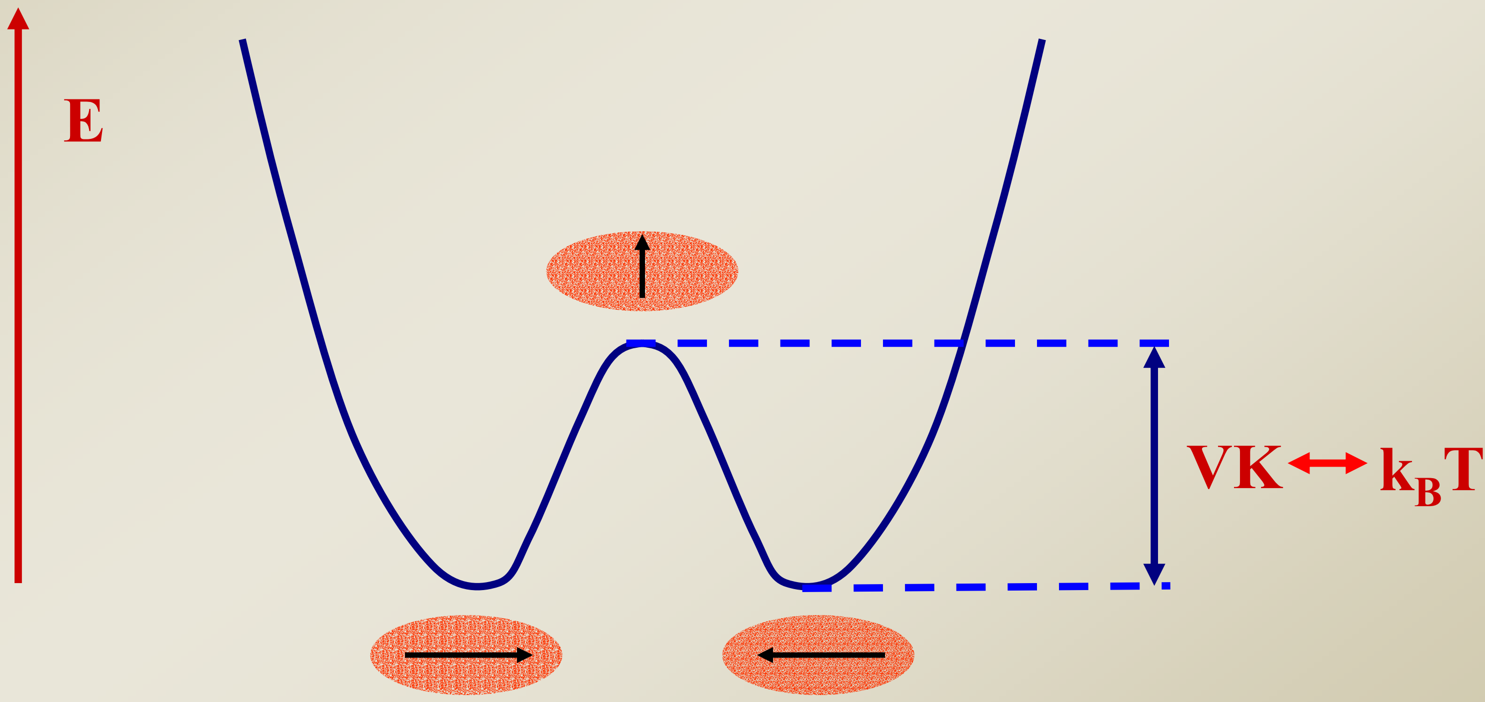
A. J. Cox et al. Phys. Rev. B49, 12295 (1994)

超順磁現象(superparamagnetism)



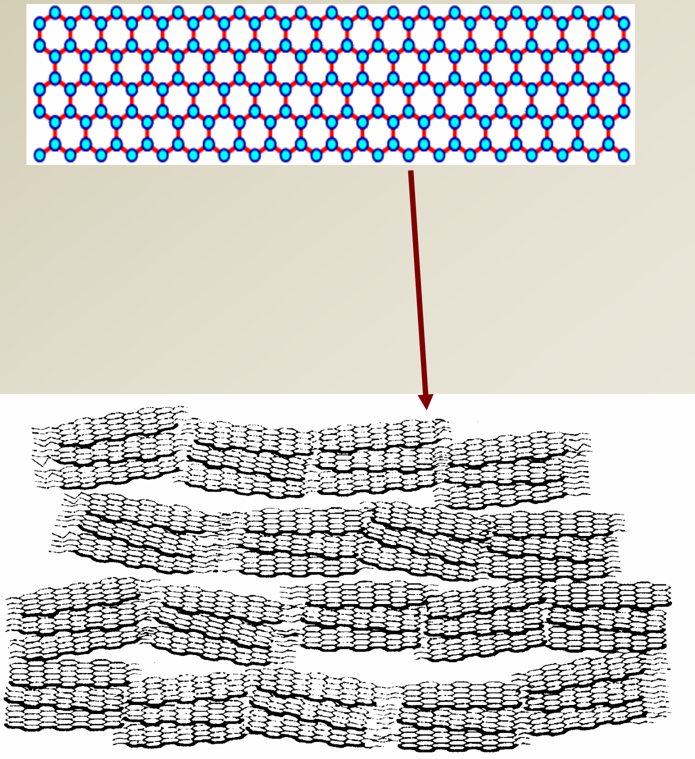


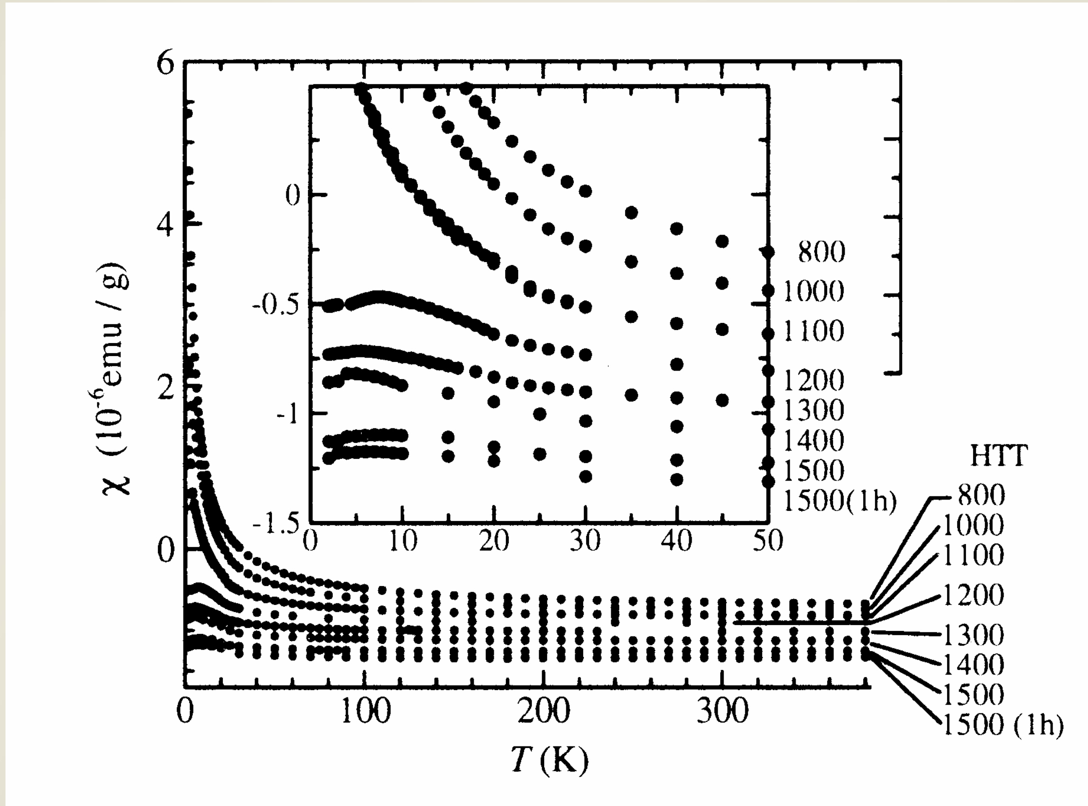
Dependence of the coercive field B_c (i.e., H_c) on the granular particle size *d* of Nd–B–Fe permanent magnet. [Adapted from A. Manaf et al., *J. Magn. Magn. Mater.* **10** 360 (1991).]



∴ Conventional magnetic recording is limited by the superparamagnetic limit.

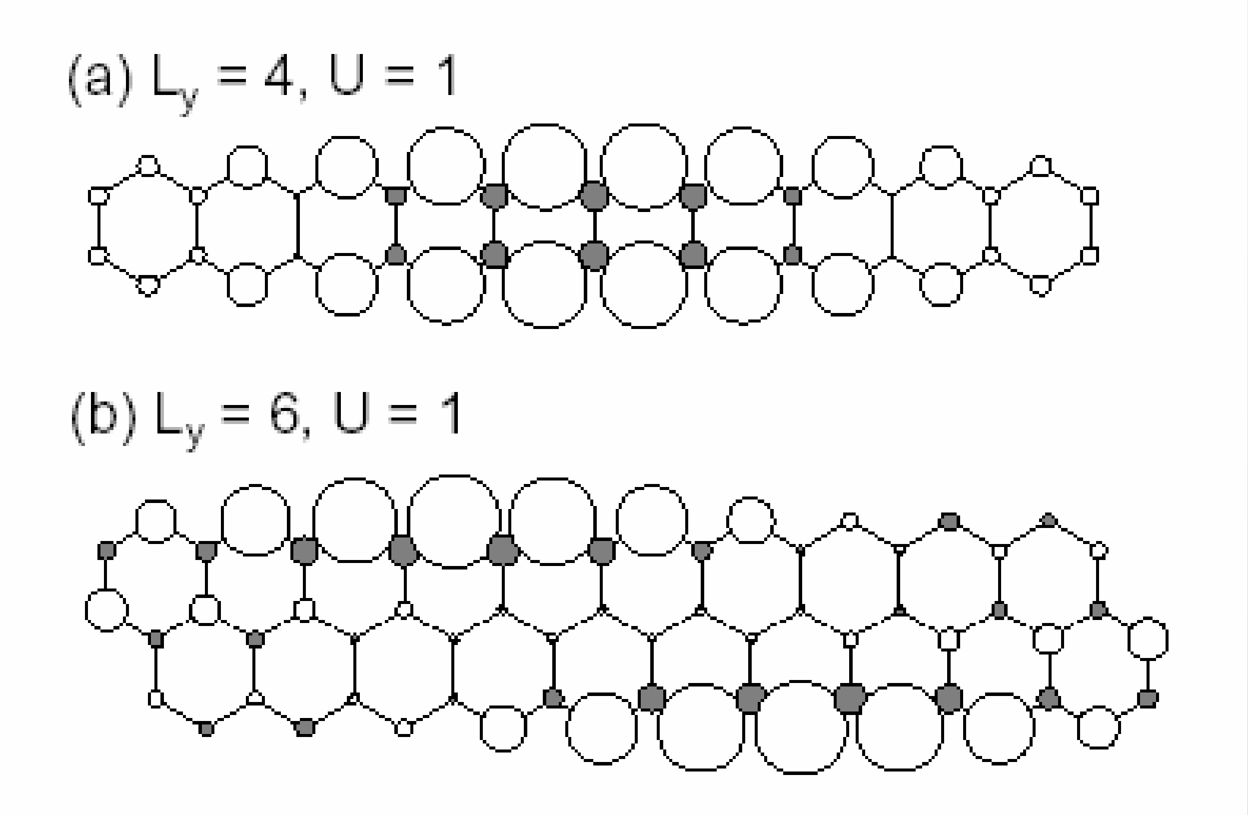
例: 邊界態(edge mode)的重要性增加





Phys. Rev. Lett. 87, 1744(2000)

M=1



Hikihara, Hu, Lin, and Mou, Phys. Rev. B 68, 035432(2003)

量子物理的重要

尺度變化的起源

- **邊界的影響**
  - 邊界佔有比例的增加
  - 邊界態(**surface/edge modes**)的存在
  - 幾何結構的重整
- **粒子數的減少(束縛減弱,擾動增加,連續性的不適用..)**
- **不同物理量有不同的尺度變化**
- **量子效應 => 最有可能產生新的突破**
- **..**
- **..**

奈米尺寸的物性/應用

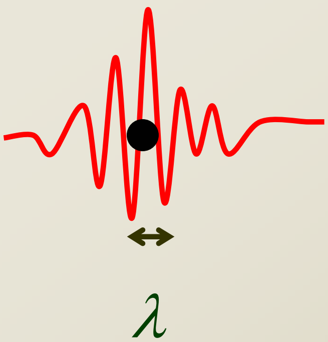
以電子為基礎
(如 奈米電子學)

以原子/離子
為基礎

物質波與力學性質的聯繫

h = Planck constant
(6.626×10^{-34} joule-sec)

DeBroglie:
λ =h/p



Einstein:
E=hν=p^2/2m

自由電子: $\lambda_{th}(300K) = 6.2nm$

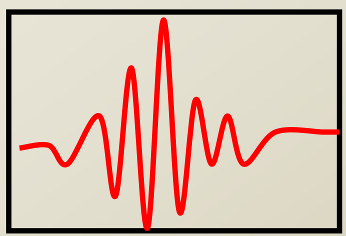
(半導體中$10nm \le \lambda \le 100nm$)

原子: $\lambda_{th}(300K) \le 0.2nm$

塊材極限 ↔ 奈米極限

$$L \gg \lambda$$

$$L \approx \lambda$$

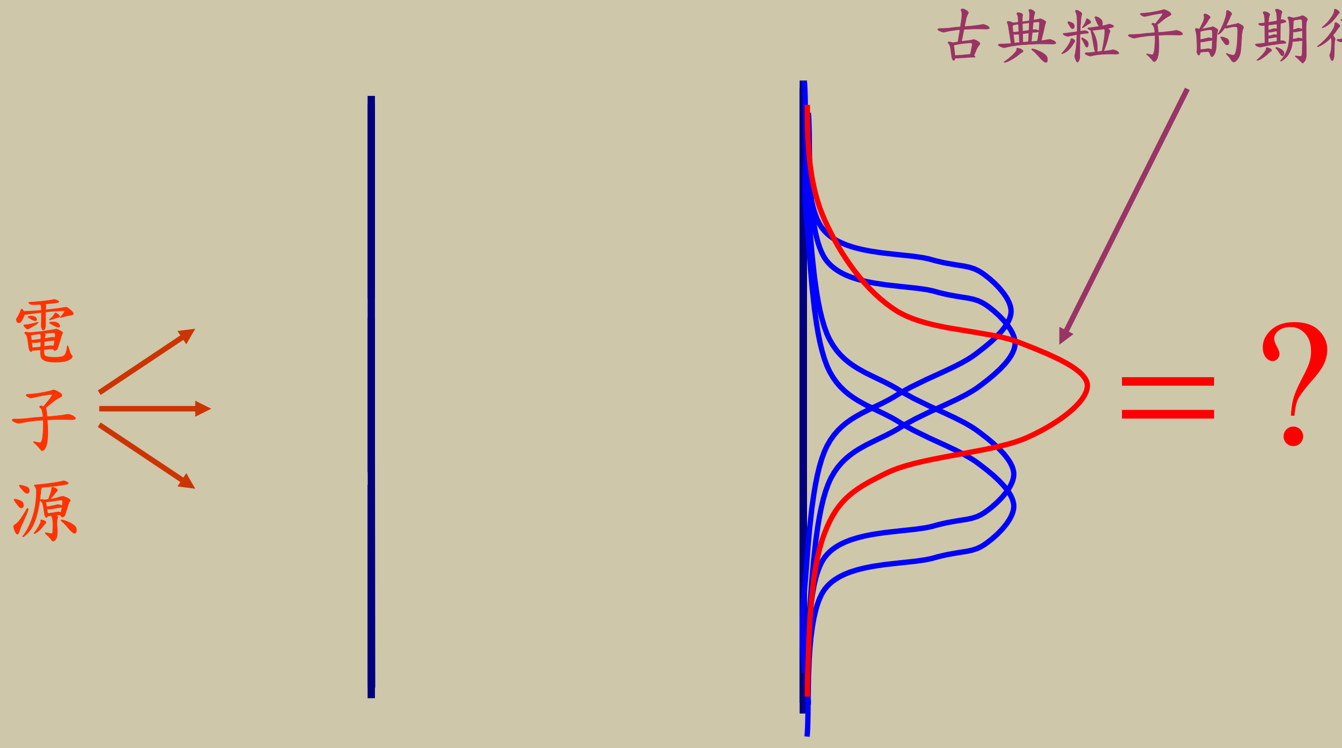


奈米尺度
的
五大量子效應

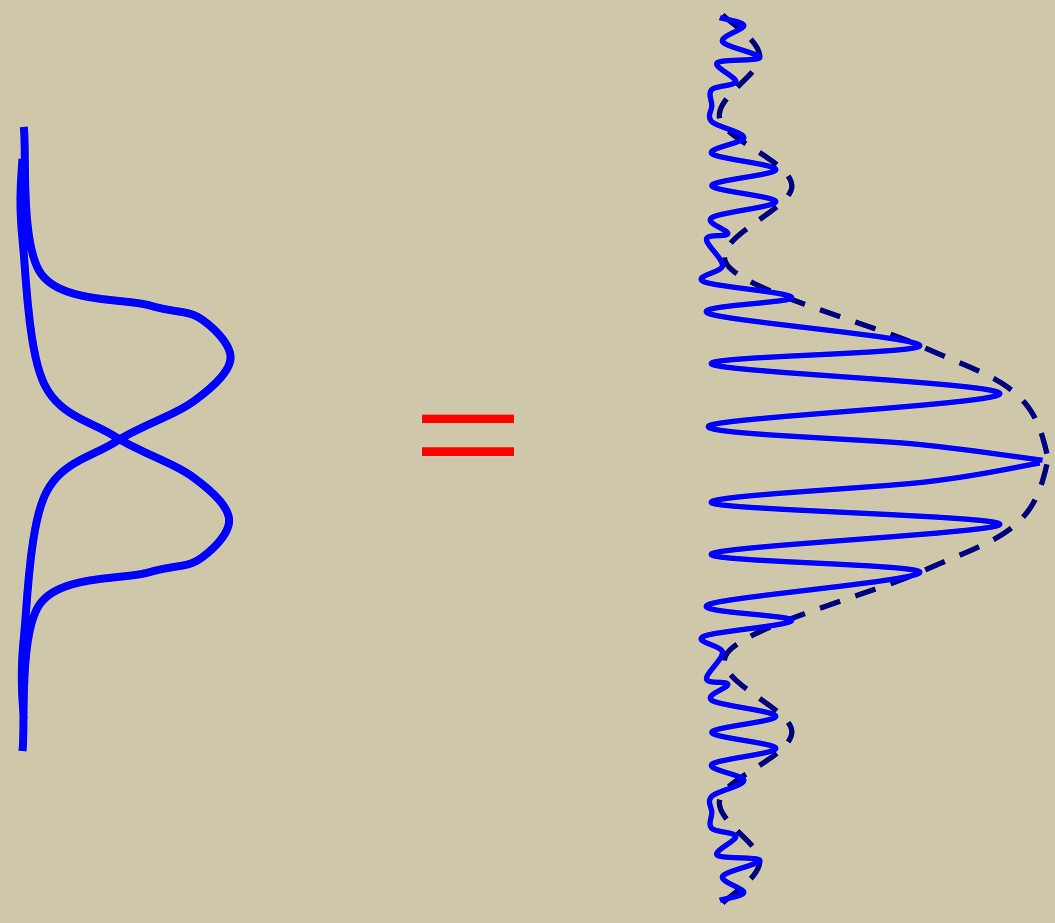
(I) 干涉

(Interference)

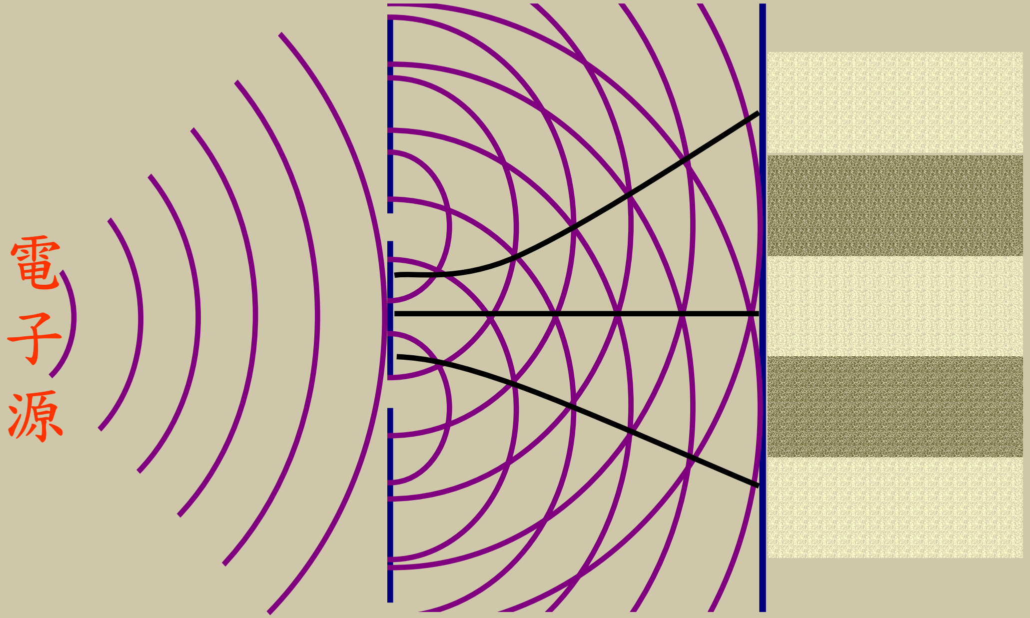
神奇的電子波動性

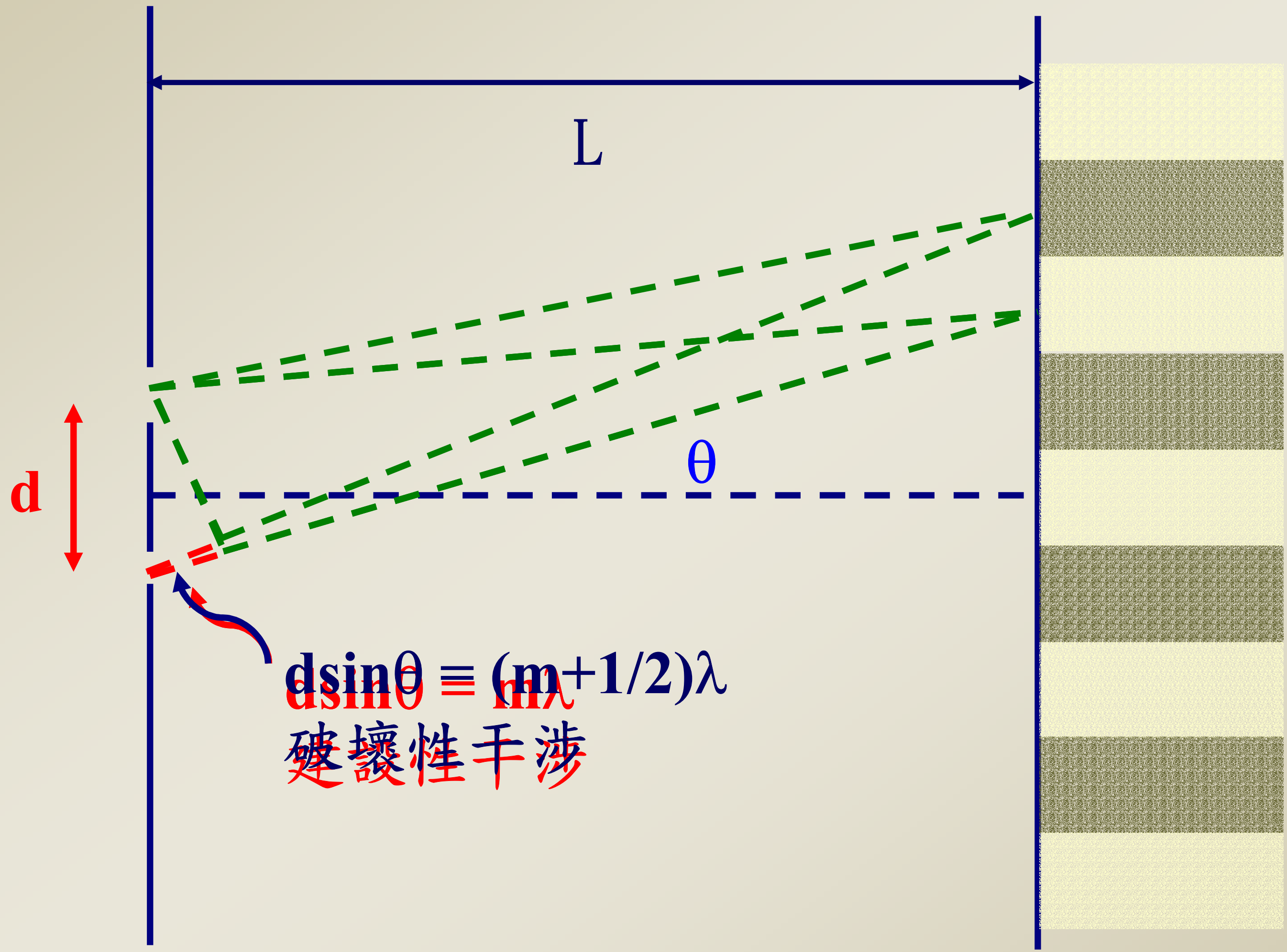


電子波動性



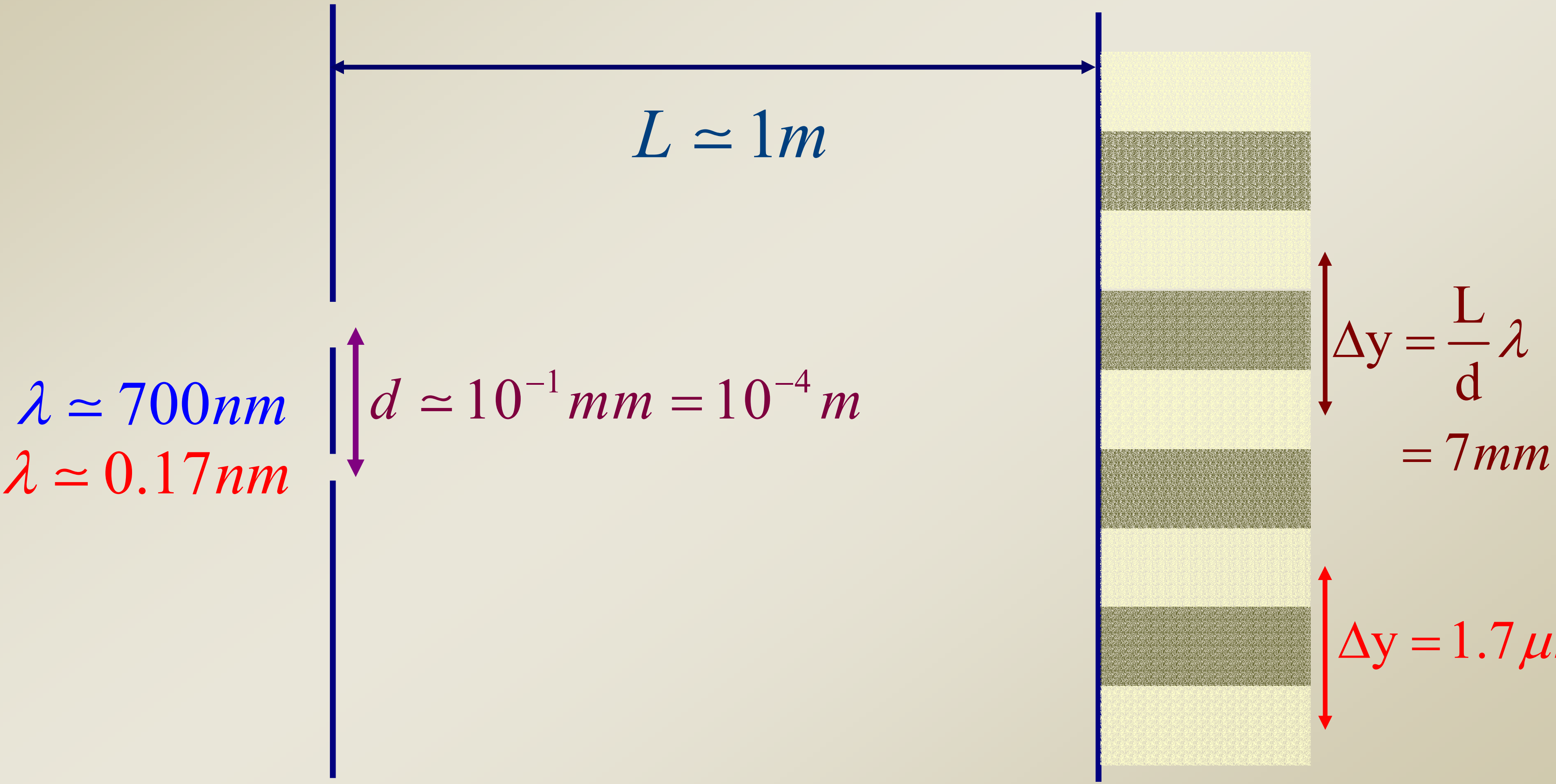
電子的雙狹縫干涉





$$\Delta y = \frac{L}{d}\lambda$$

$$d\frac{\Delta y}{L} = \lambda$$


$L \simeq 1m$
$\lambda \simeq 700nm$
$\lambda \simeq 0.17nm$
$d \simeq 10^{-1}mm = 10^{-4}m$
$\Delta y = \frac{L}{d}\lambda$
$= 7mm$
$\Delta y = 1.7\mu$

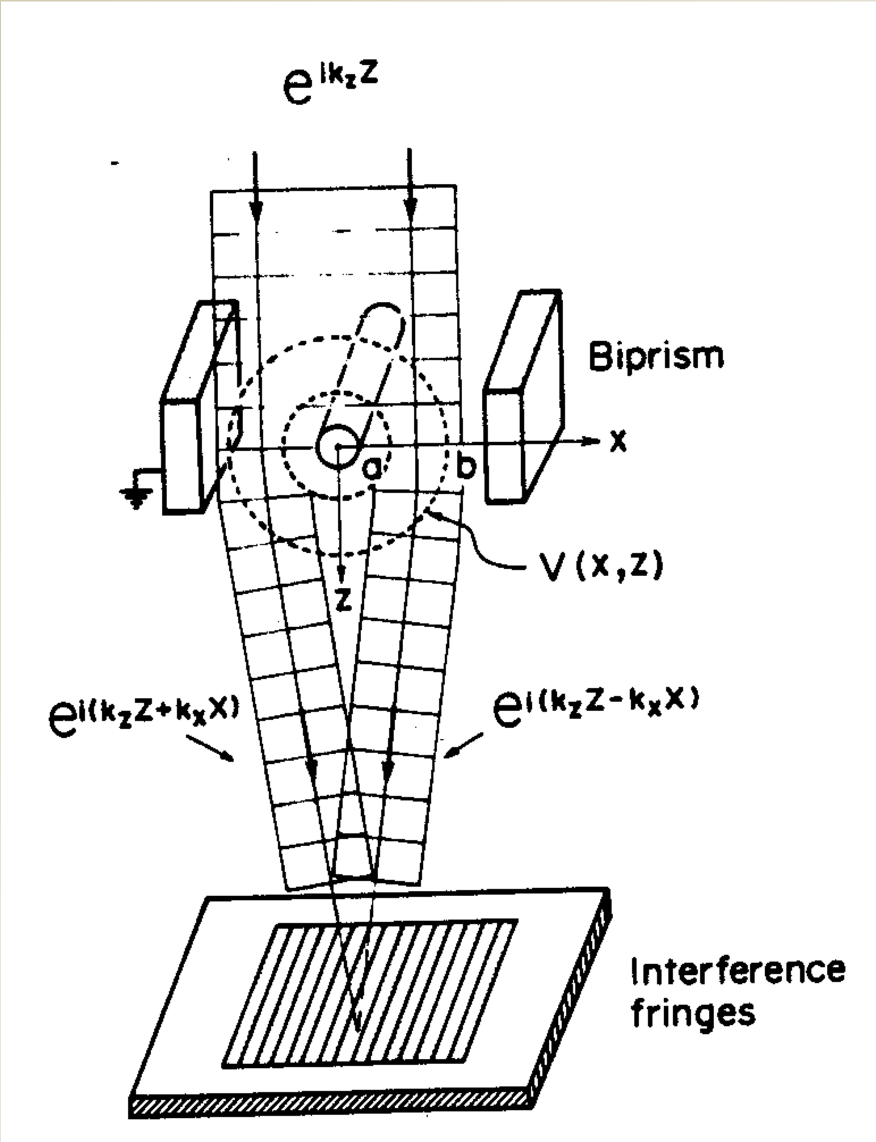
The Feynman Lectures on Physics (III) p. 1-4~1-5

…This experiment has never been done in just this way. The trouble is that the apparatus would have to be made on an impossible small scale … We are doing a "thought experiment"…

參考值:

Davisson and **Germer** 之電子繞射實驗

電子波長為**0.165nm(1.65 Å, 50eV)**



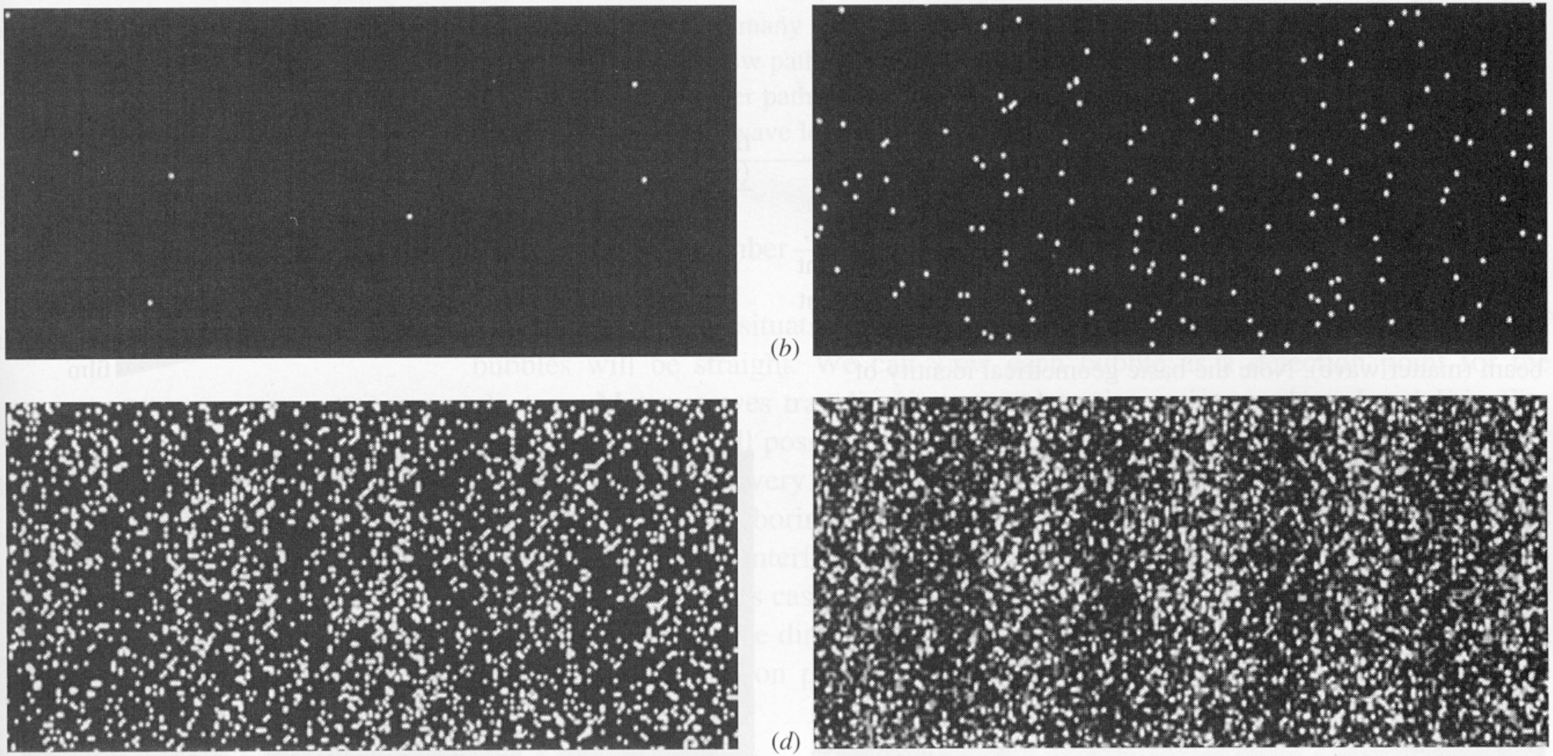
Tonomura et al.

American Journal of Physics 57, 117(1989)

$\lambda = 0.054$ Å (50kV), $V_a = 10$V

$a = 0.5\mu$m, $b = 5$mm

spacing = 700nm



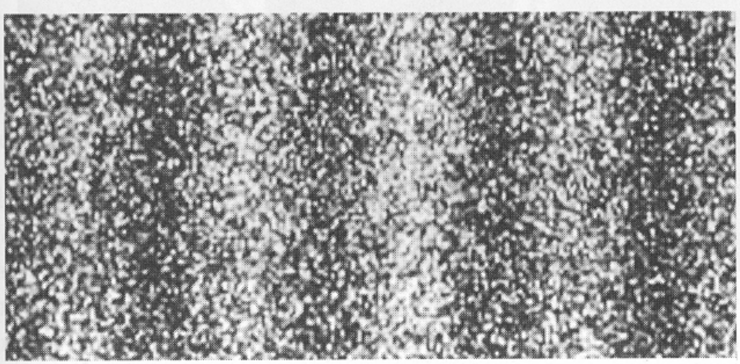


Fig. 39-8 Photographs showing the buildup of an interference pattern by a beam of electrons in a two-slit interference experiment like that of Fig. 39-6. Matter waves, like light waves, are *probability waves*. From top to bottom the approximate numbers of electrons involved are 7, 100, 3000, 20 000, and 70 000.

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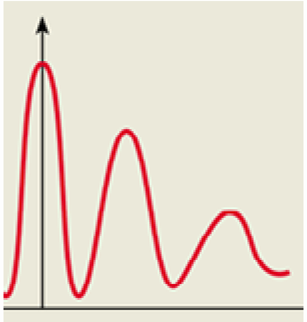
The double-slit experiment

Editorial: September 2002

Who performed the most beautiful experiment in physics?



What is the most beautiful experiment in physics? This is the question that Robert Crease asked *Physics World* readers in May - and more than 200 replied with suggestions as diverse as Schrödinger's cat and the Trinity nuclear test in 1945. The top five included classic experiments by Galileo, Millikan, Newton and Thomas Young. But uniquely among the top 10, the most beautiful experiment in physics - Young's double-slit experiment applied to the interference of single electrons - does not have a name associated with it.

Most discussions of double-slit experiments with particles refer to Feynman's quote in his lectures: "We choose to examine a

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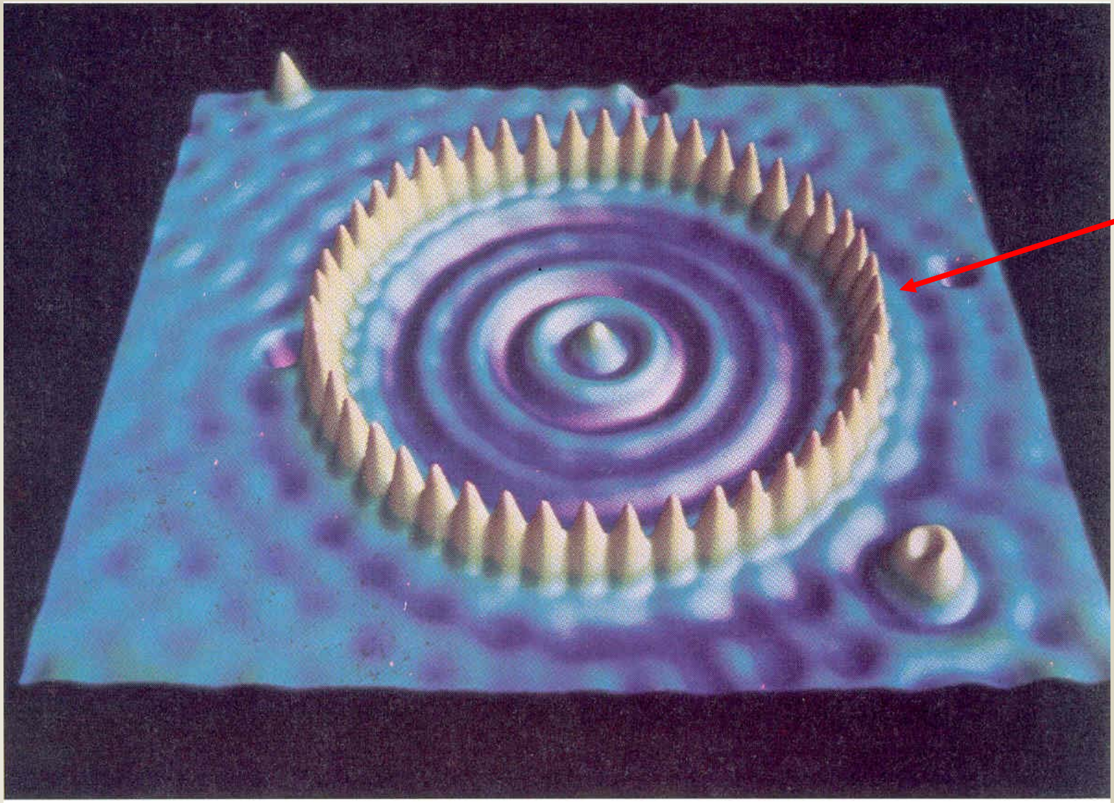
From the *New York Times*: Science's 10 most beautiful experiments

Author
Peter Rodgers

量子柵欄 (Quantum Corral)

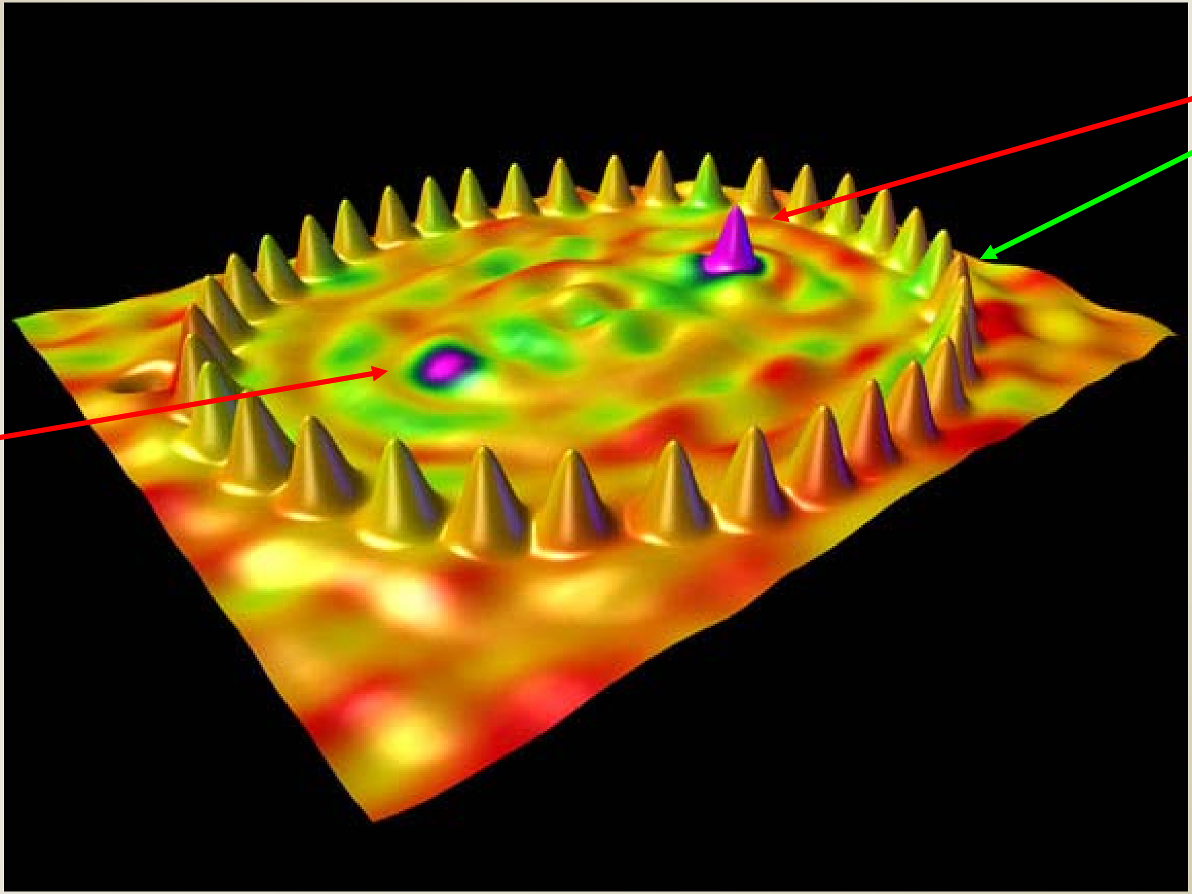


Fe

Crommue, Luts, and Eigler, Science 262, 218-220, 1993

Quantum Mirage

Co

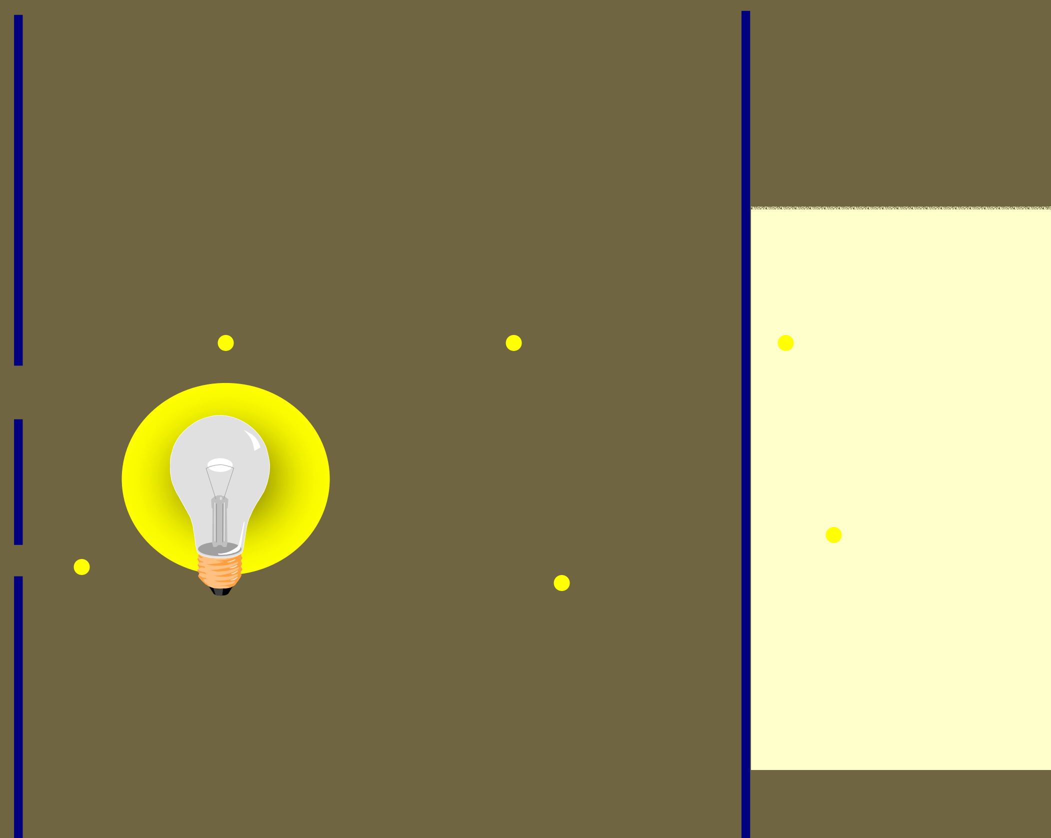


"mirage"

IBM Almaden Research Center, 2000

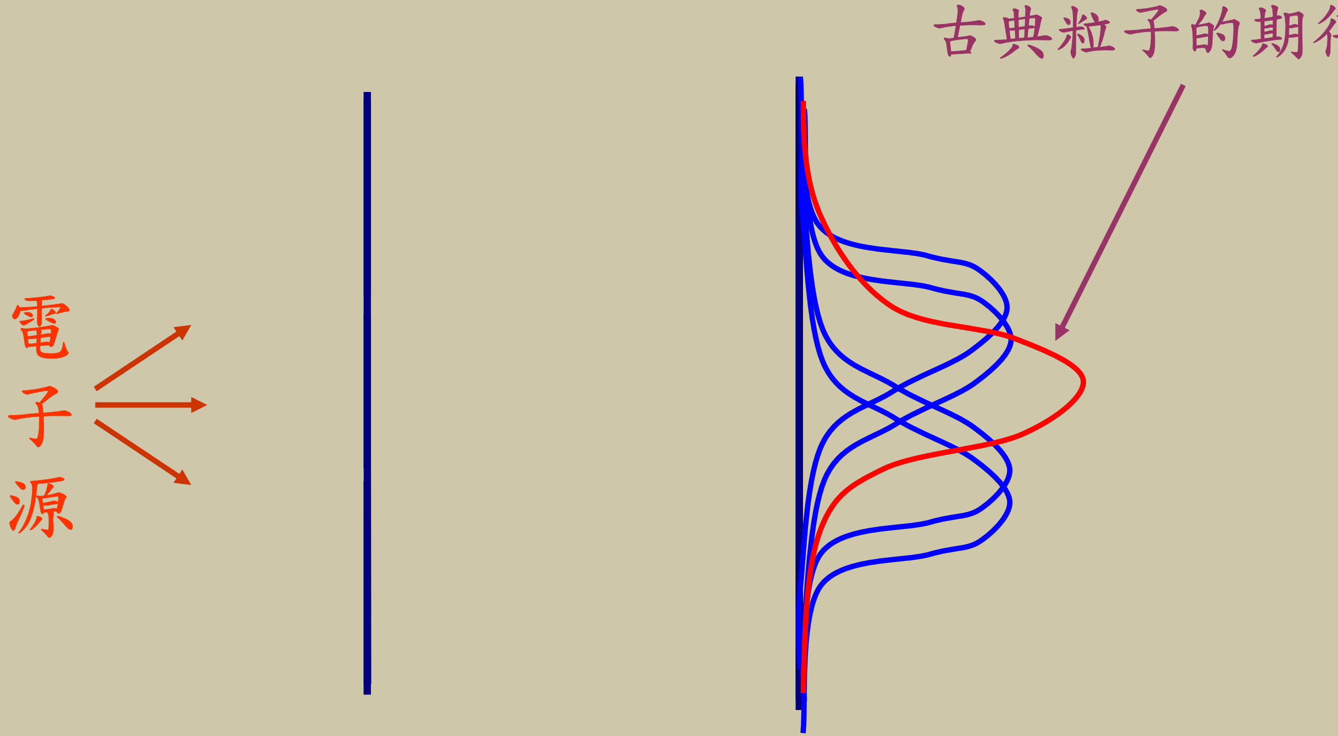
害羞的電子與 which-way experiment

電子源

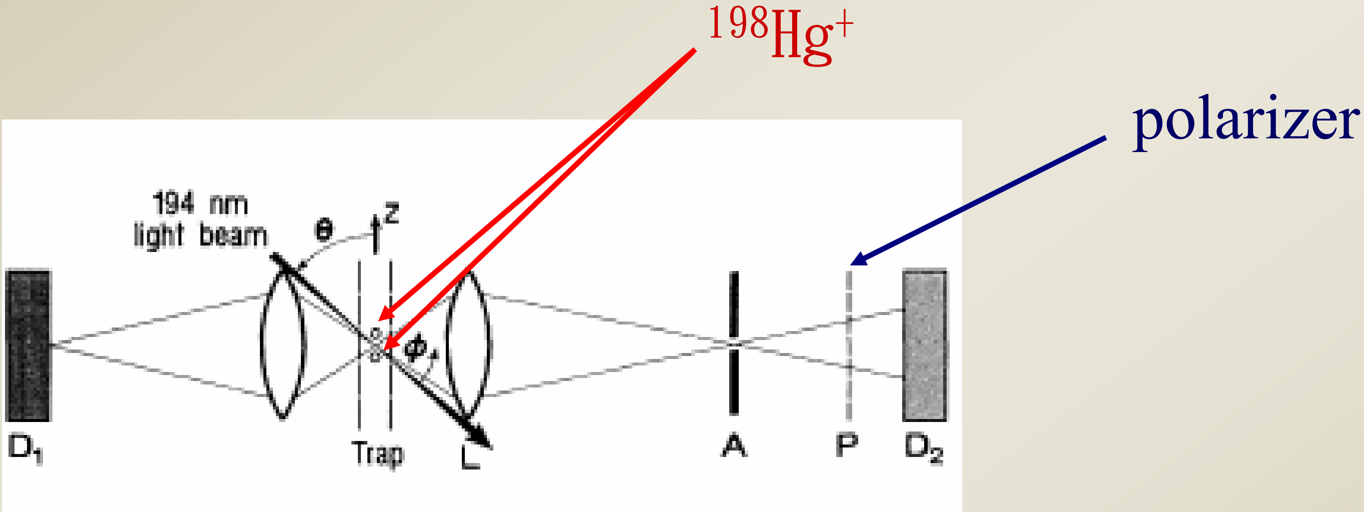


Nature 395, 33(1998)
PRL70,2359(1993)

一旦知道 which-way. . .
=>粒子性(complimentary)

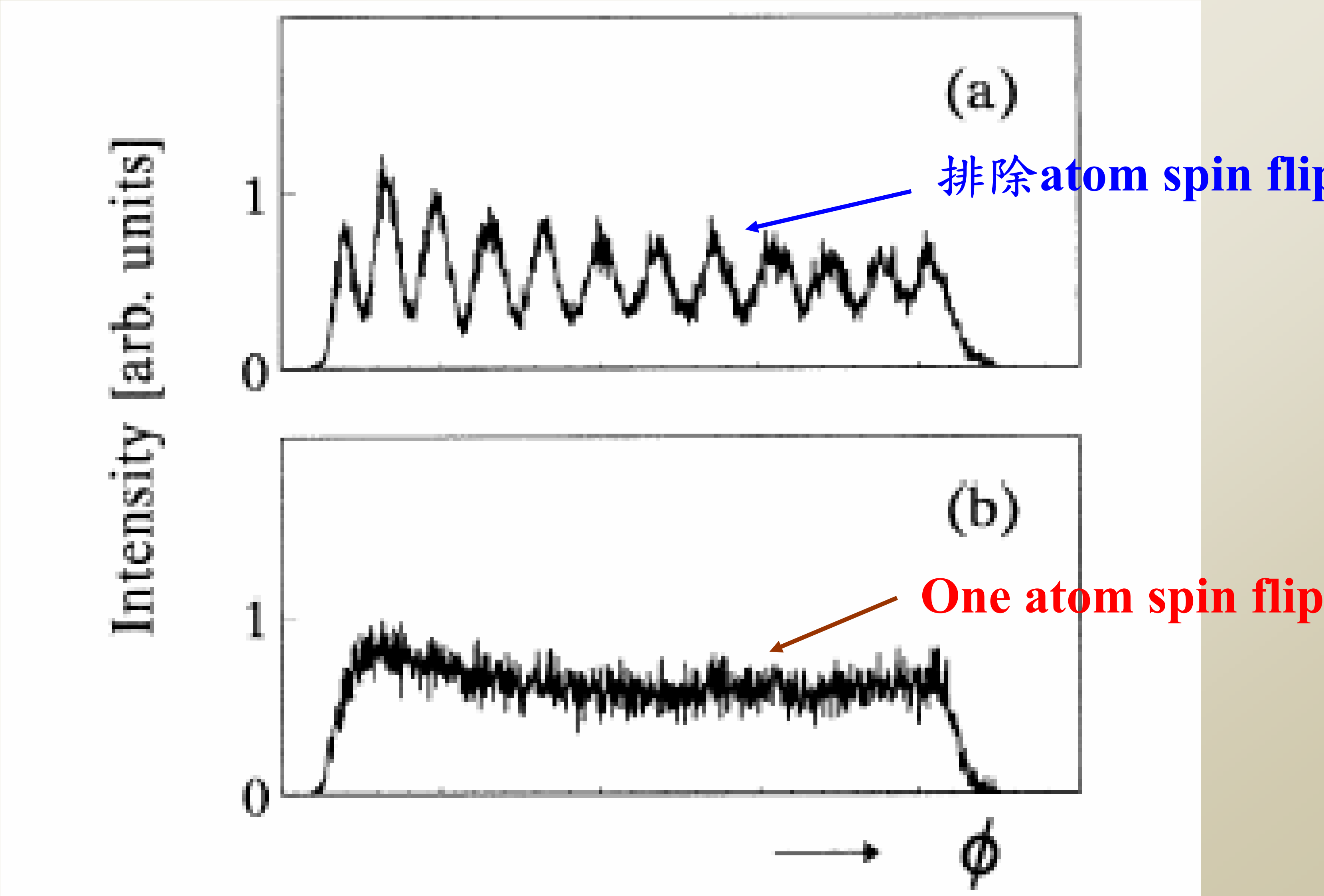


Which-way(welcher Weg) experiment



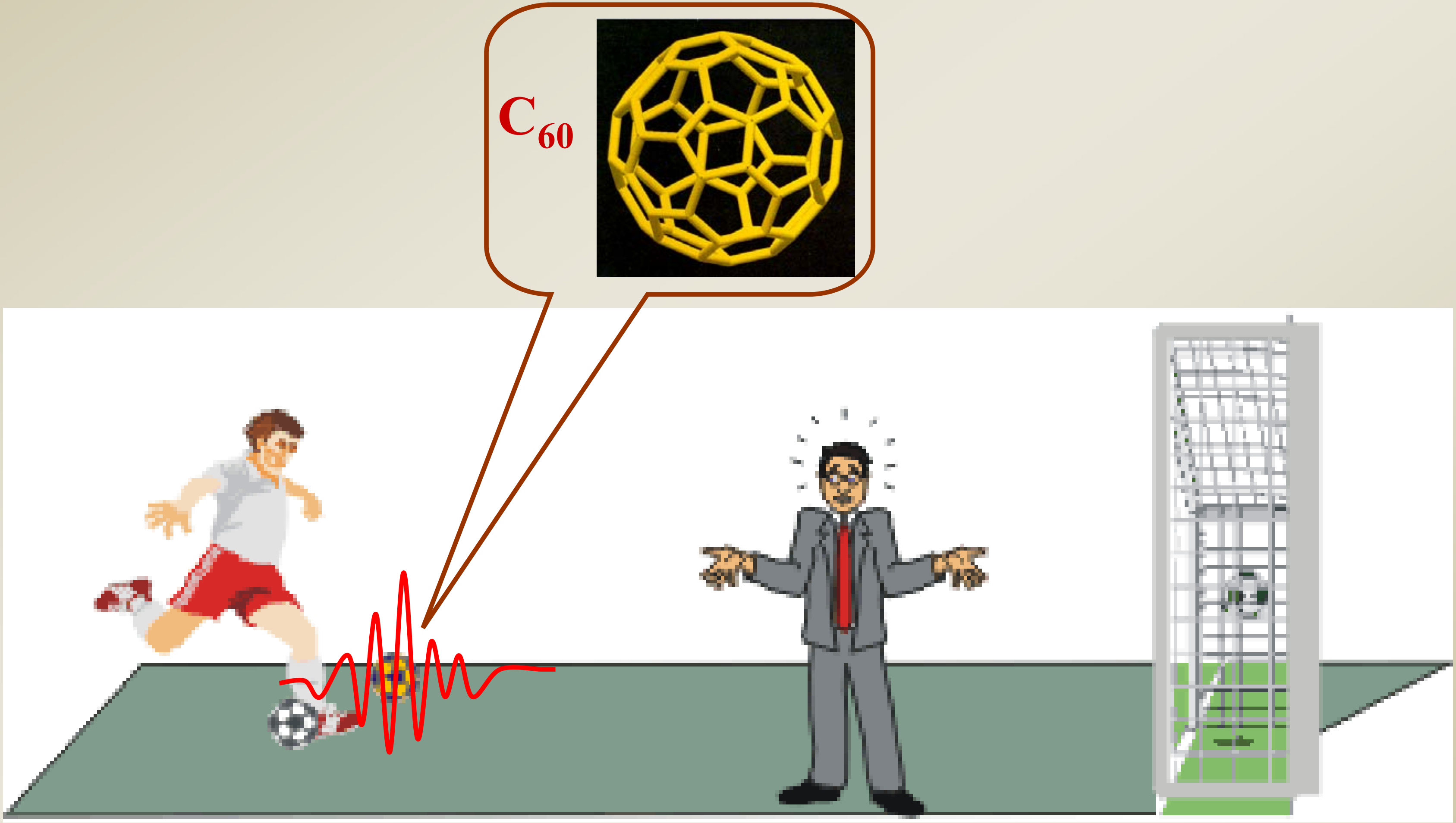
Phys. Rev. Lett. 70, 2359(1993)

利用**polarizer**選擇所要觀察光子的**polarization**

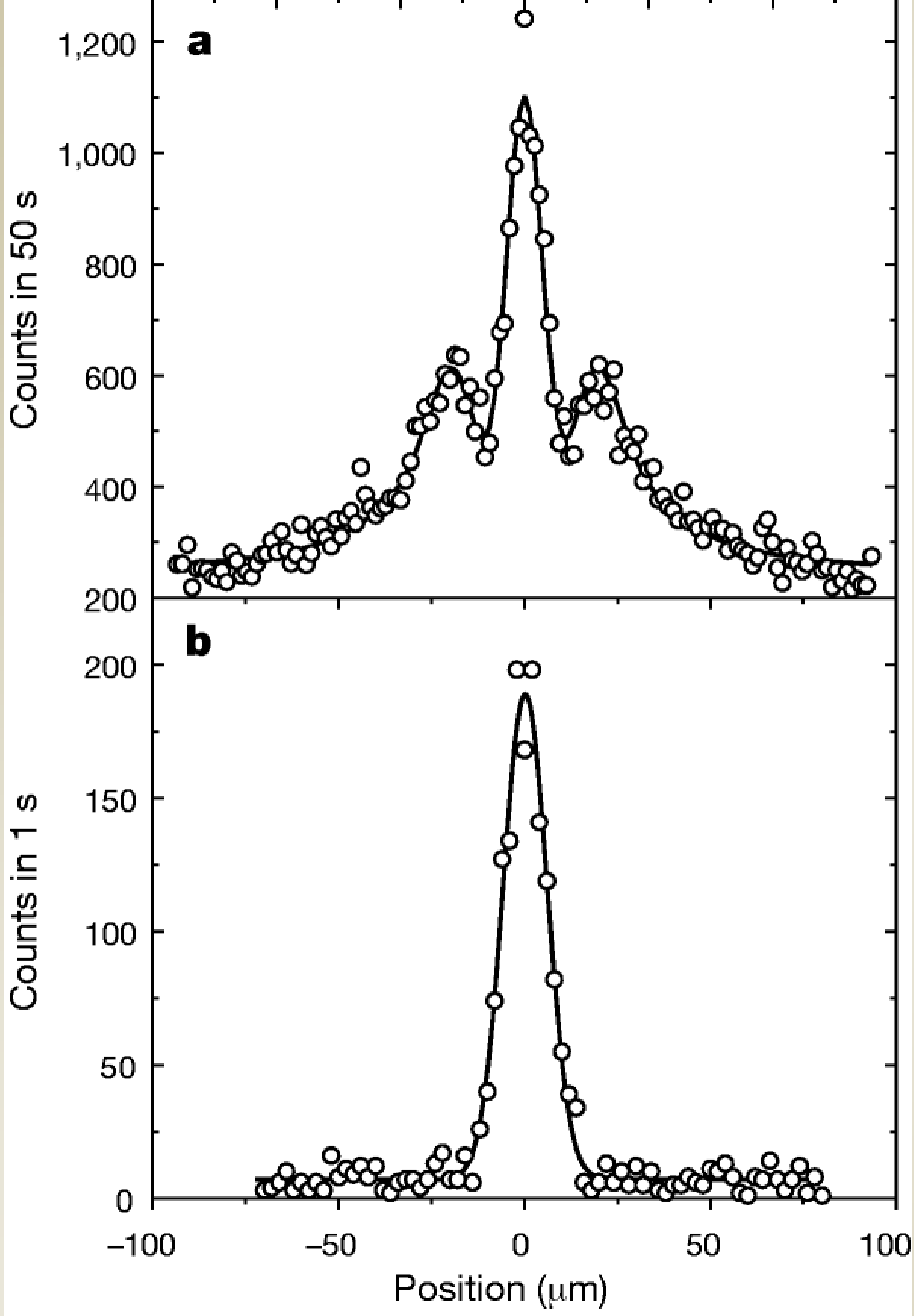


(a)
排除atom spin flip
(b)
One atom spin flip
Intensity [arb. units]
1
0
1
0
ϕ

Matter Wave of Large Molecules

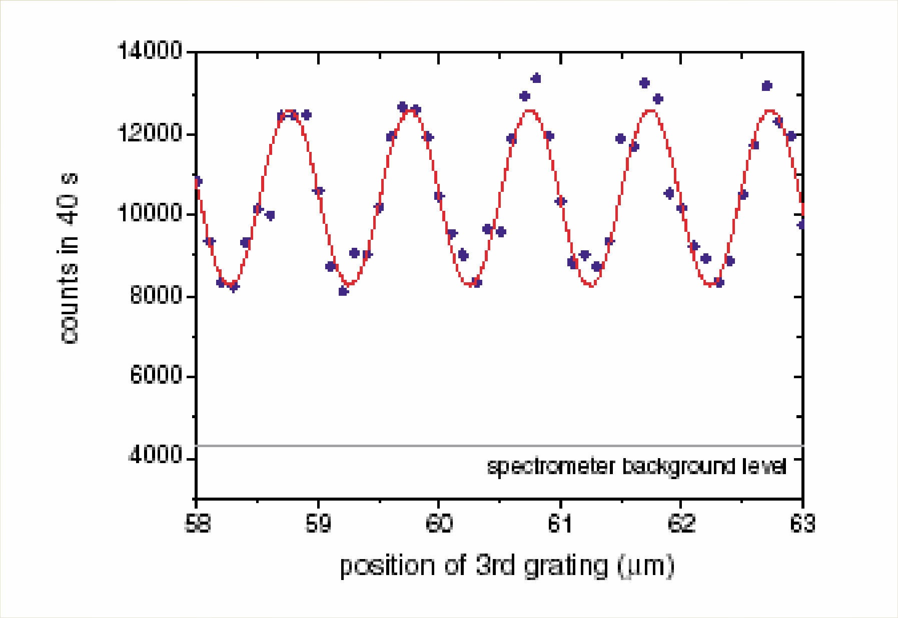


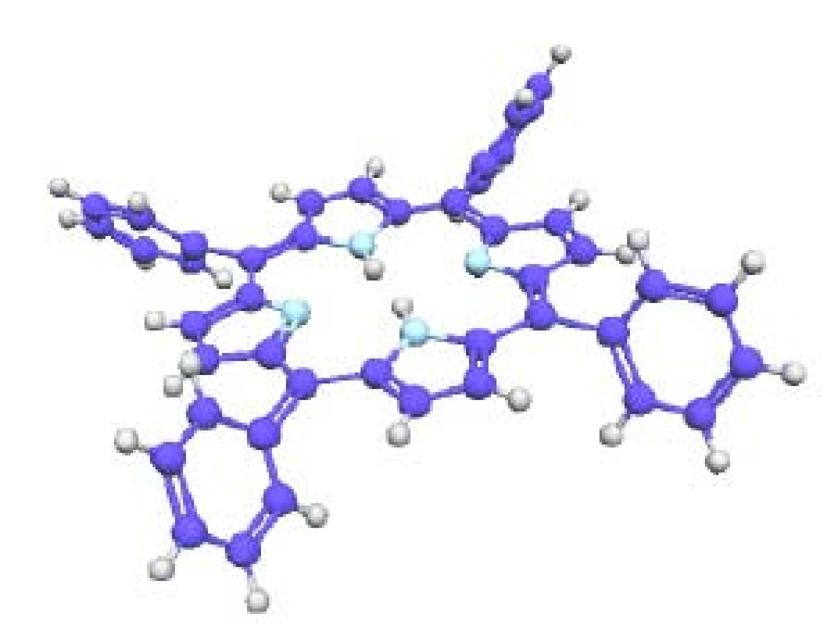
http://www.quantum.univie.ac.at/research/c60/index.html



Other atoms:
Na, Phys. Rev. 66, 2693 (1991

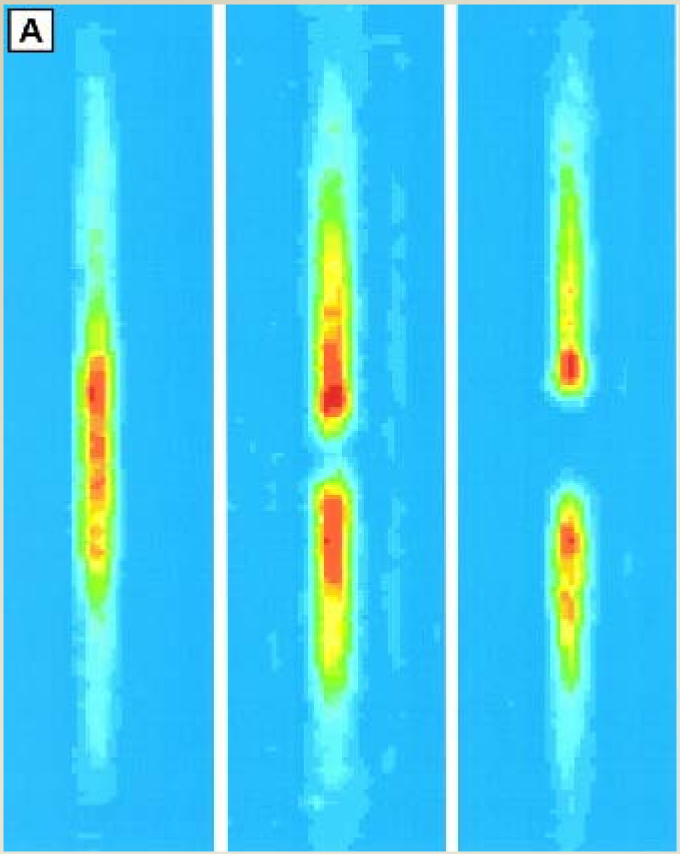
Biomolecules

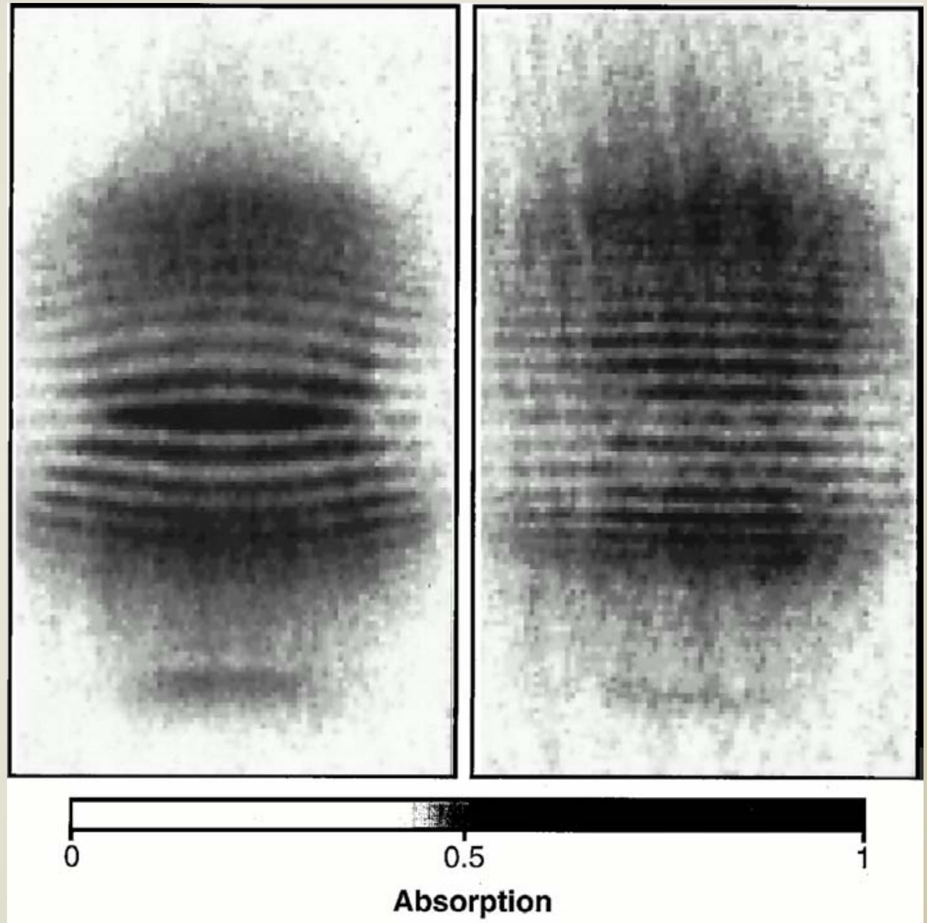




3D structure of tetraphenylporphyrin $C_{44}H_{30}N_4$(TPP)

Interference between condensates





Science 275, 637 (1997): ~10^6 Sodium atoms

(II) 量子化 (Quantization)

物質波的束縛

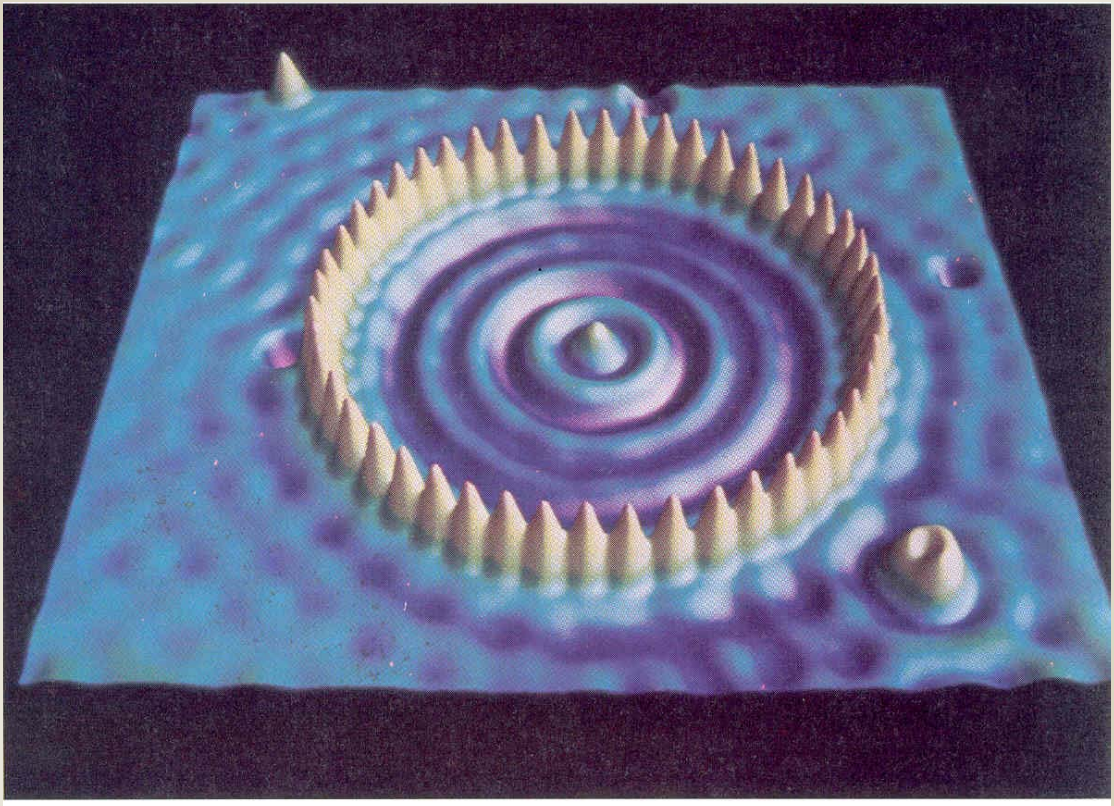
↓

駐波

↓

量子化

量子柵欄 (Quantum Corral)



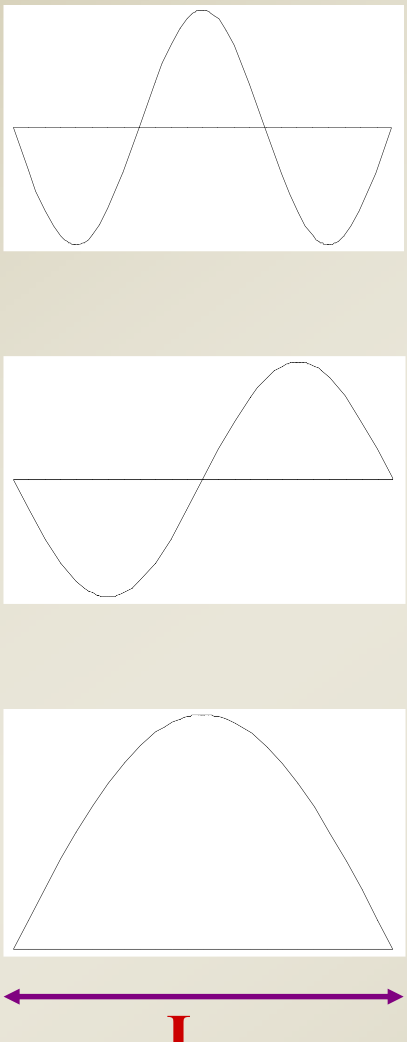
Crommue, Luts, and Eigler, Science 262, 218-220, 1993

能量的量子化

n = 3

n = 2

n = 1



$$\delta E \propto 1/L^2$$

$$L = \frac{n}{2}\lambda$$

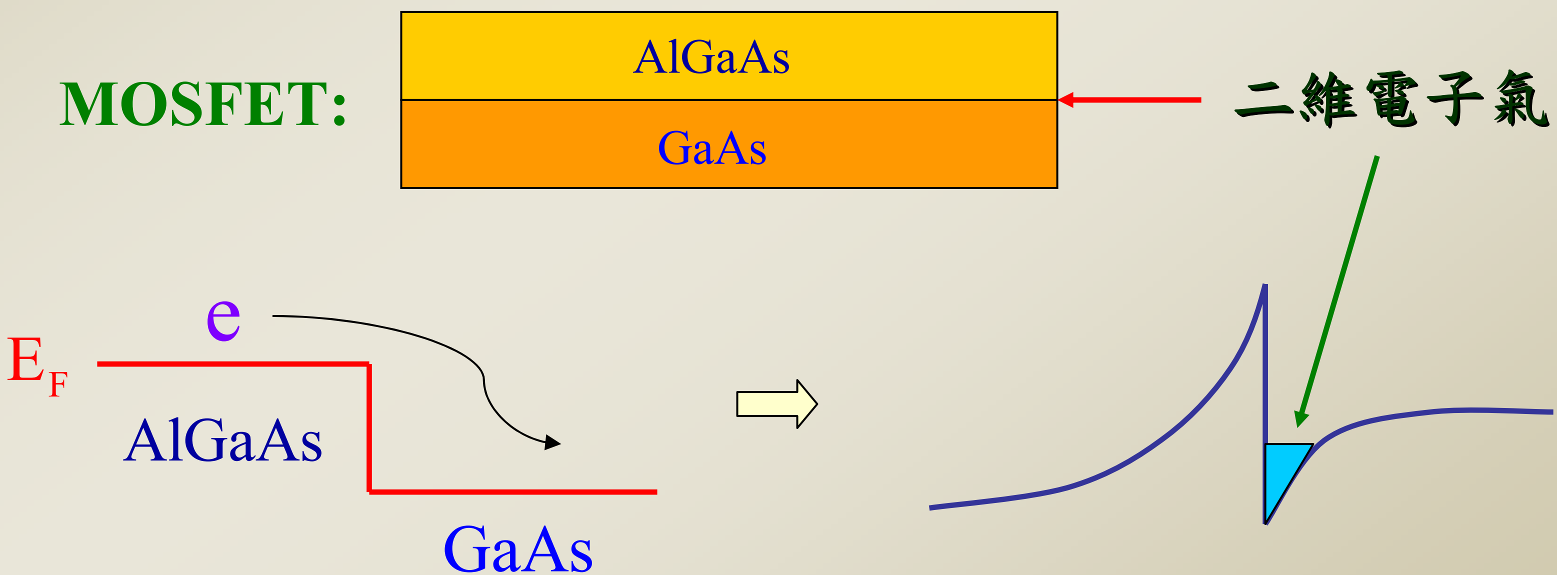
$$p = \frac{h}{\lambda} = \frac{nh}{2L}$$

$$E_n = \frac{p^2}{2m} = \frac{n^2h^2}{8mL^2}$$

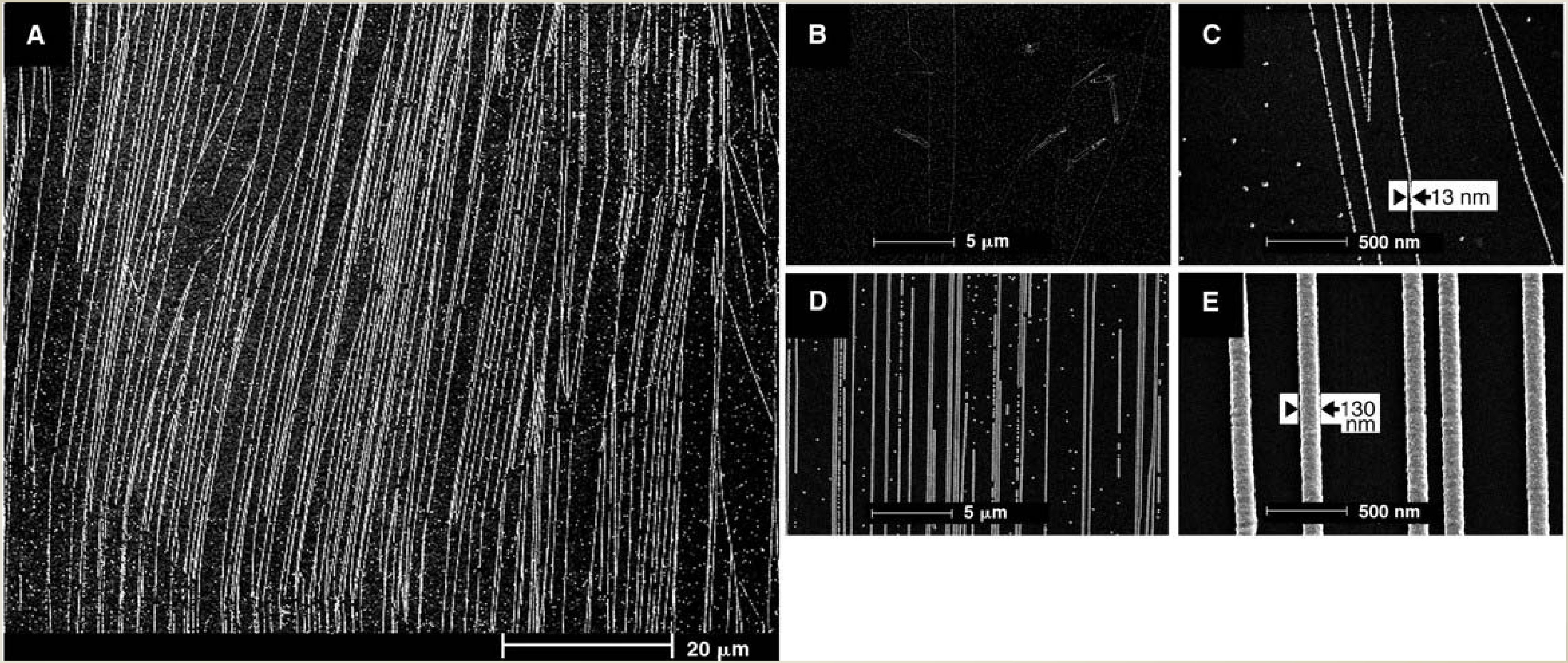
束縛結構的分類

依被束縛方向的數目分類:

量子井(quantum well): 1個束縛方向

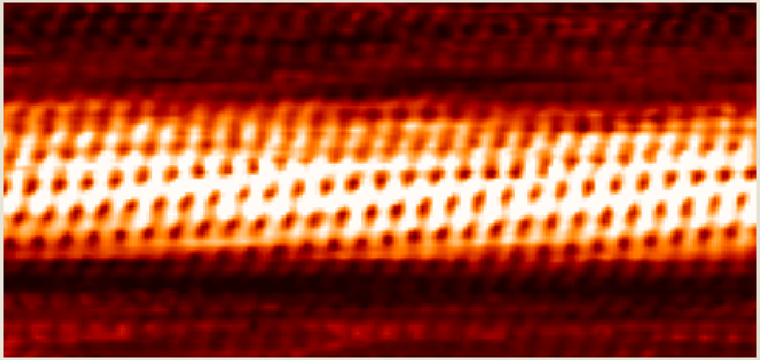


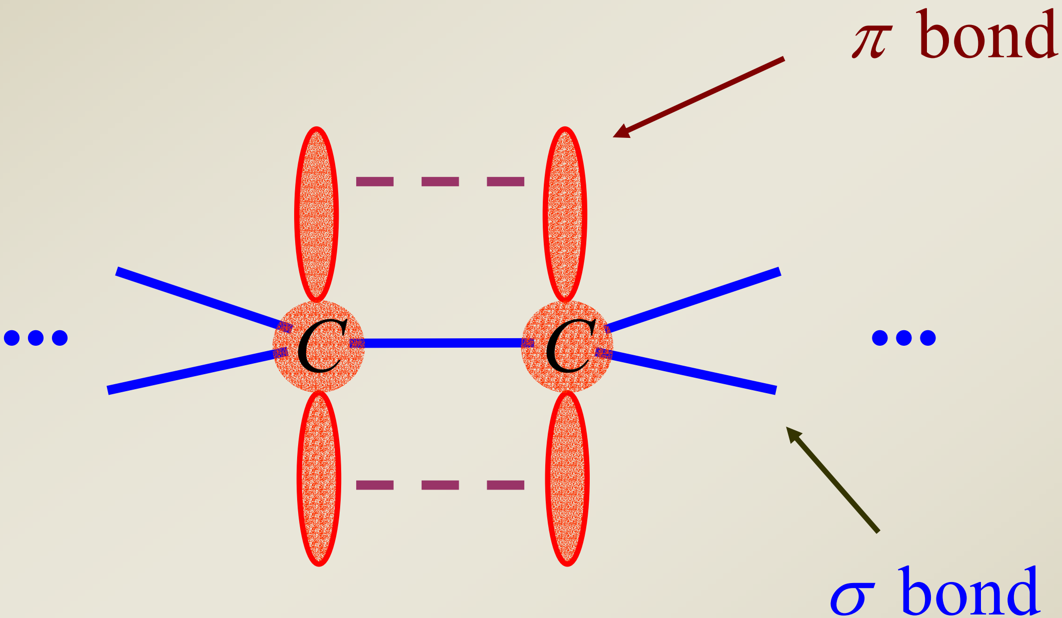
量子線(quantum wire): 2個束縛方向

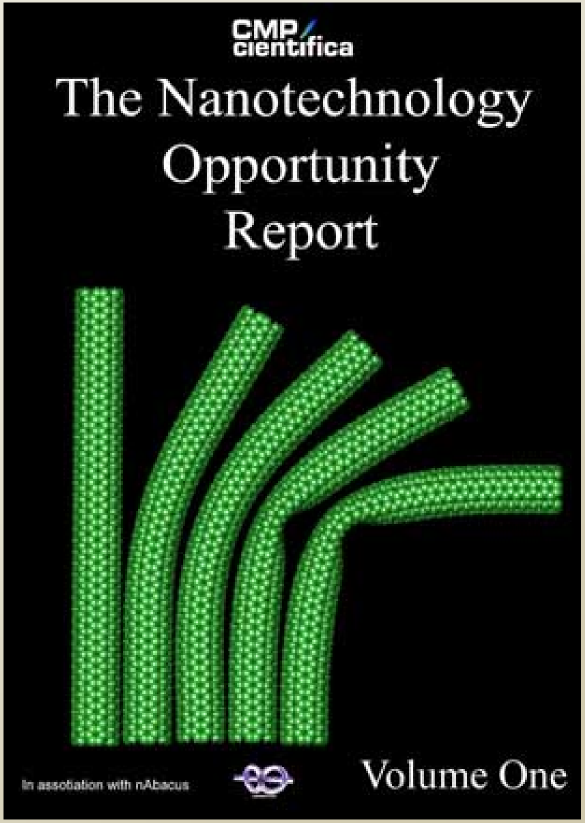


SEM images of MoOx nanowires on graphite surfaces
Science 290, 2120-2123, (2000)

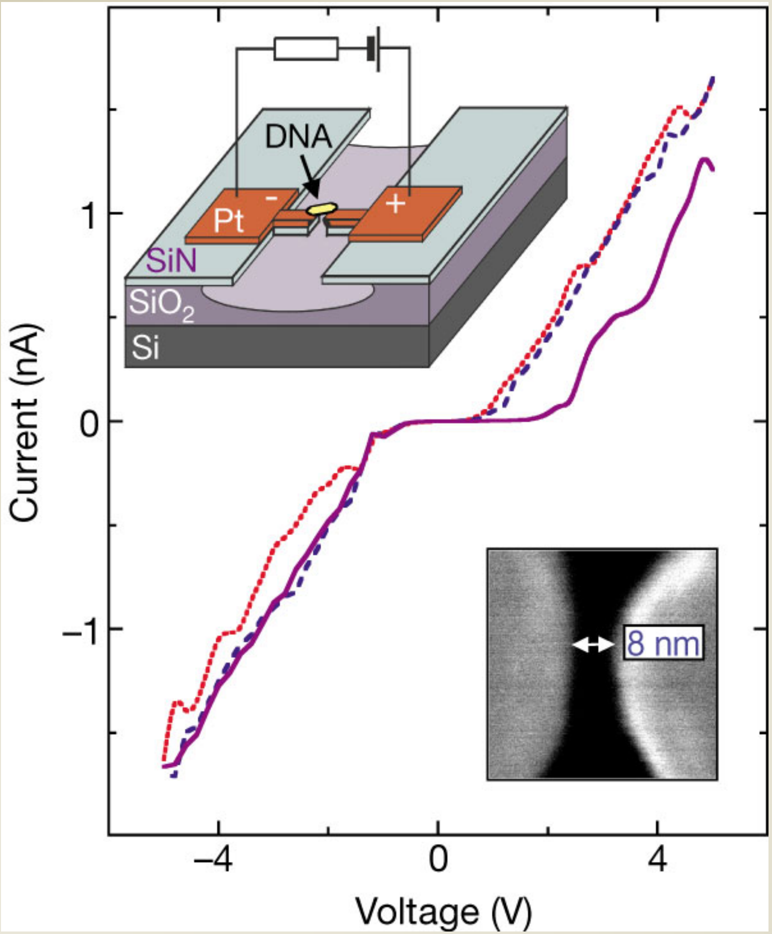
奈米碳管




π bond
C
C
σ bond

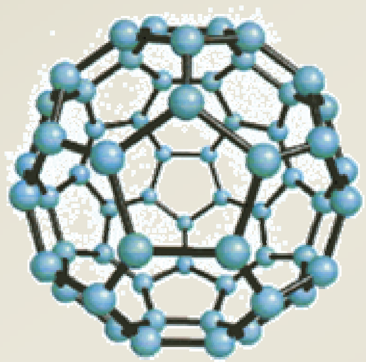

CMP científica
The Nanotechnology Opportunity Report
Volume One
In association with nAbacus

DNA線

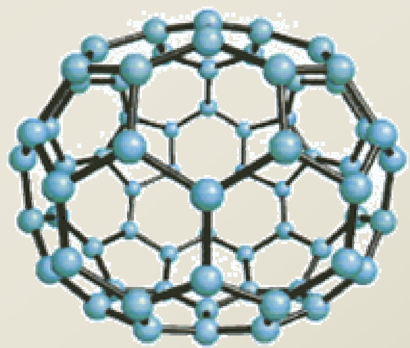


DNA 可以拿來當電線嗎

量子點(quantum dot): 3個束縛方向

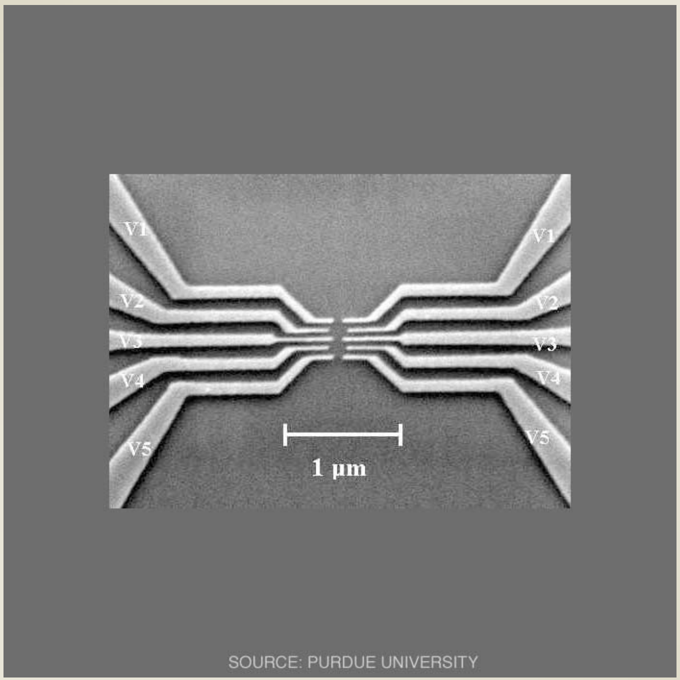


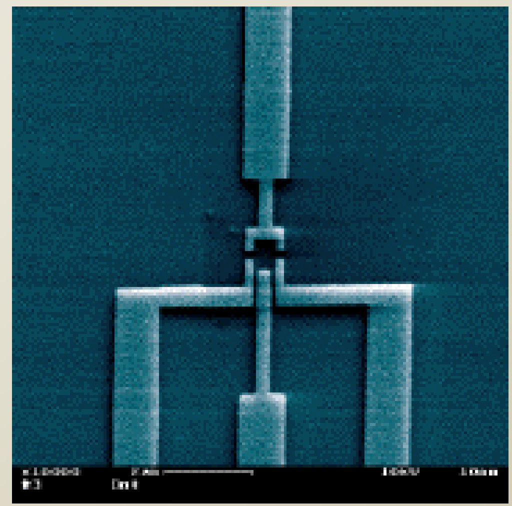
C_{60}



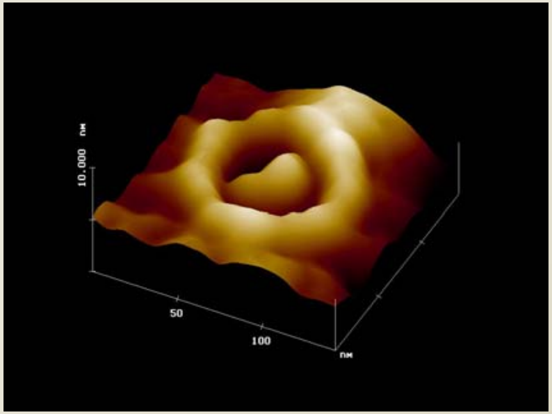
C_{70}

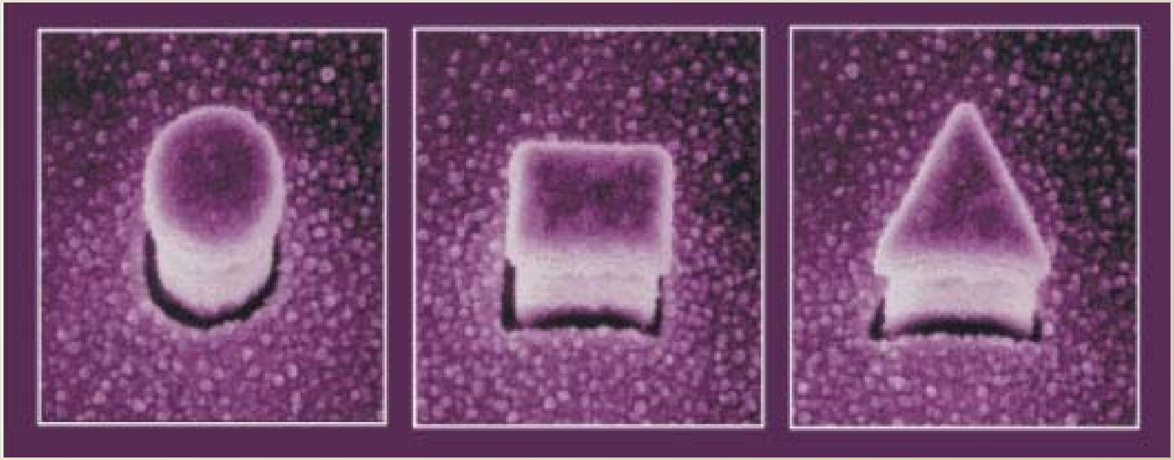
用電壓把電子關起來 -- 量子點

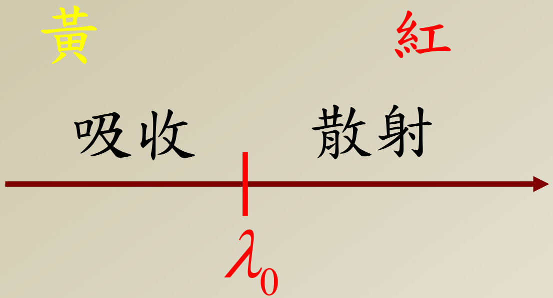


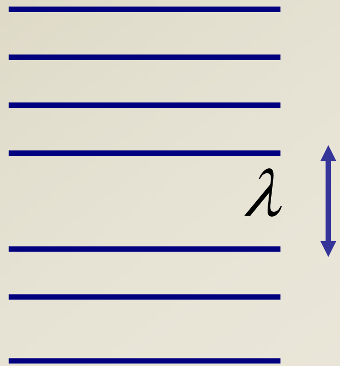


不同形狀的量子點



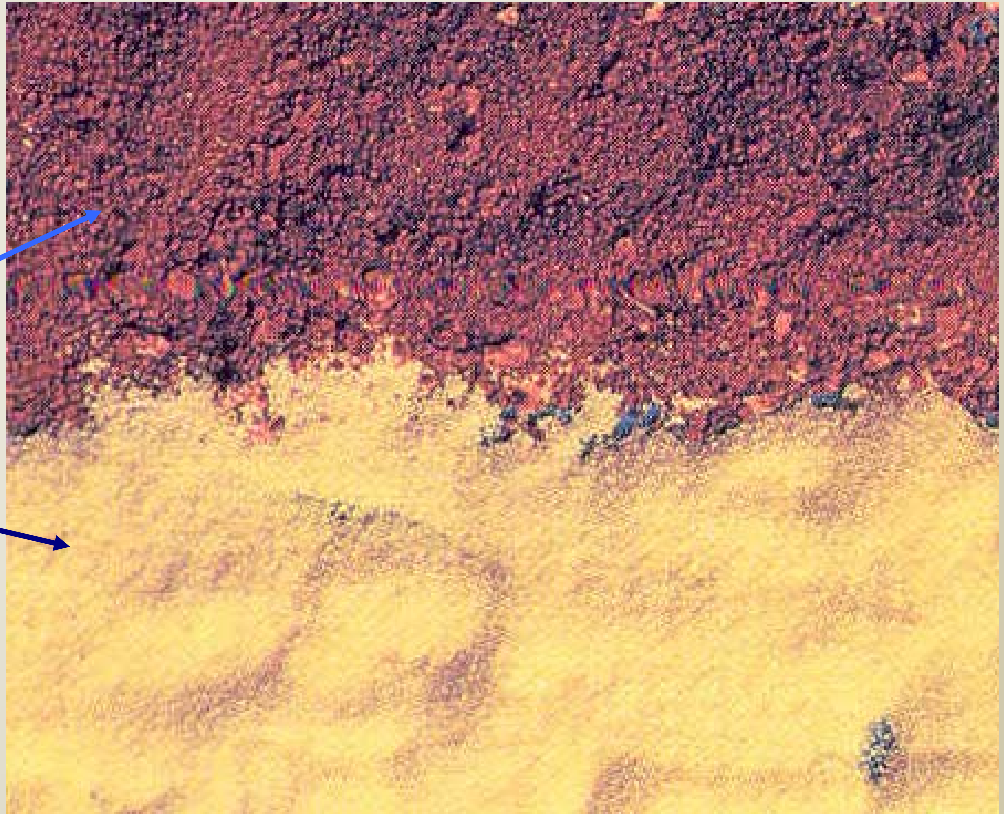




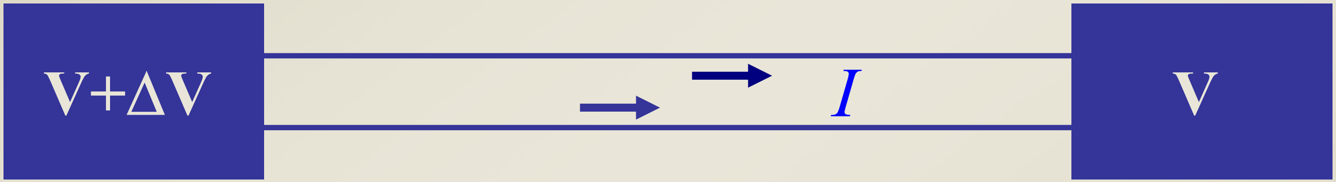


$$E = hc/\lambda \propto 1/L^2$$

powered cadmium selenide



部分束縛(partial confinement)與"奈米捷運線"

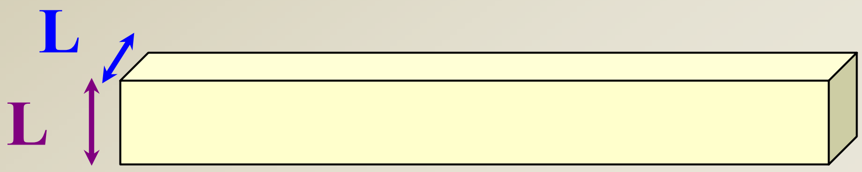


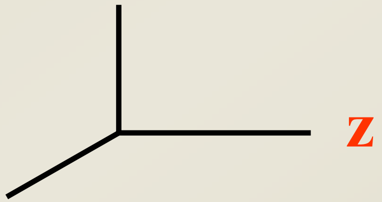
量子線

$$G = \frac{I}{\Delta V}$$

流量和截面積成正比嗎？

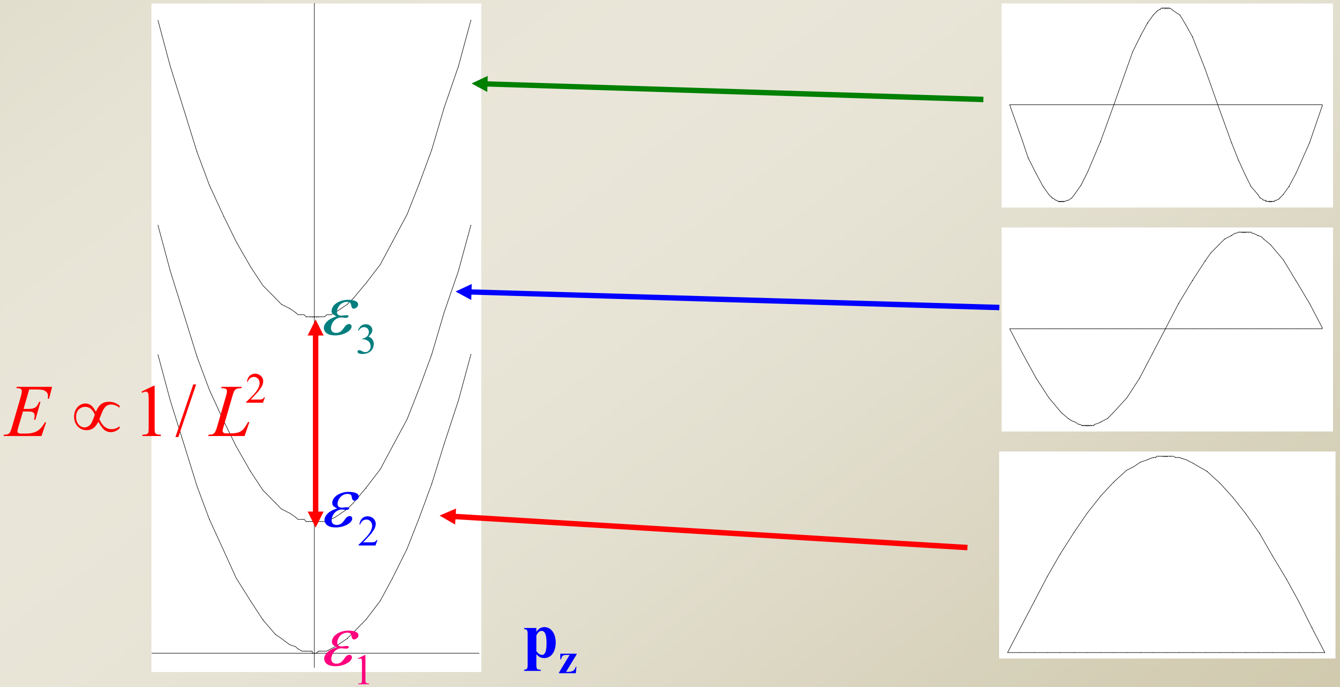
Partial confinement



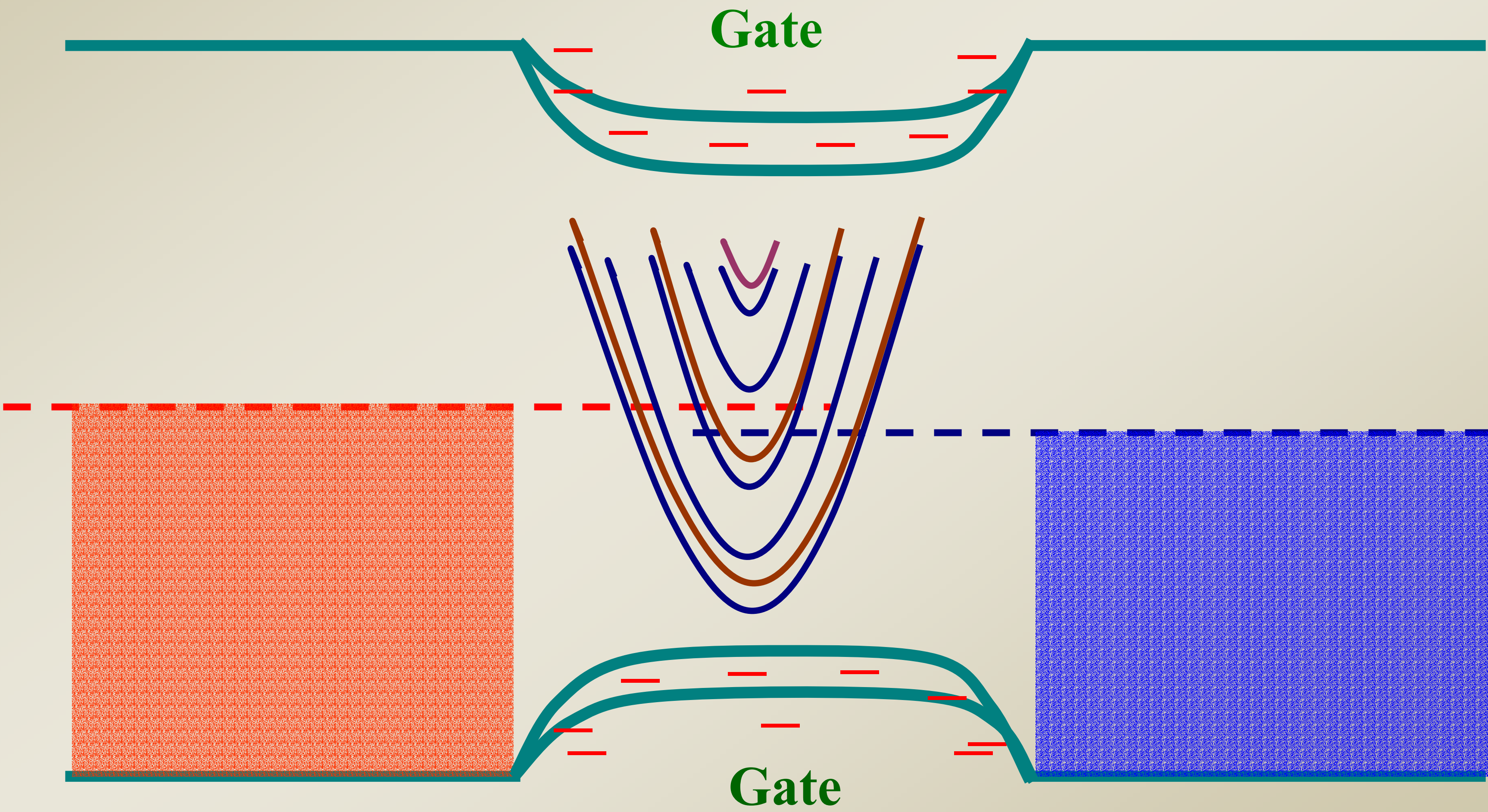


$$E = \frac{p_z^2}{2m} + \varepsilon_n$$

不同橫向的駐波為不同的頻道

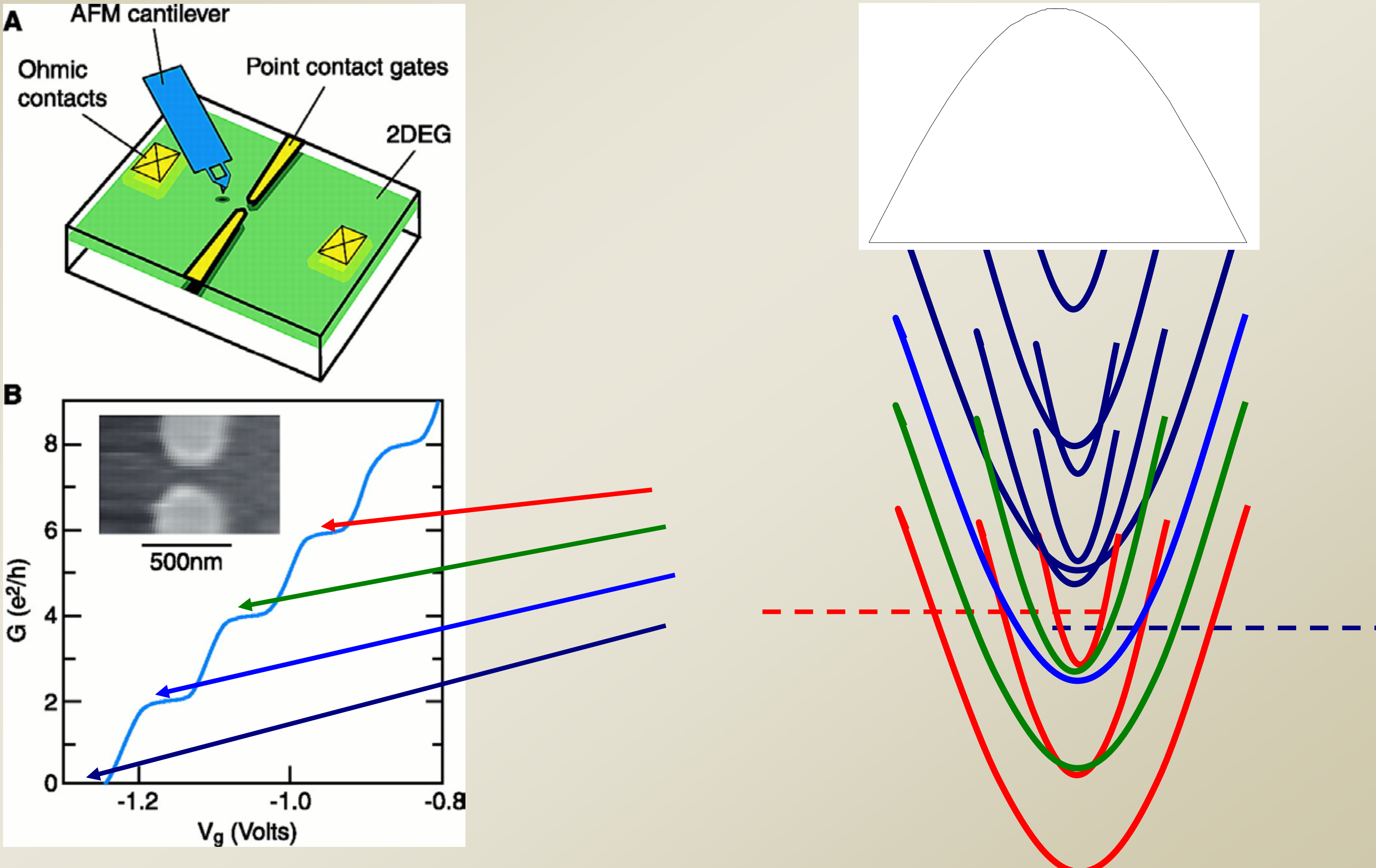


以電壓控制參與電導之頻道數

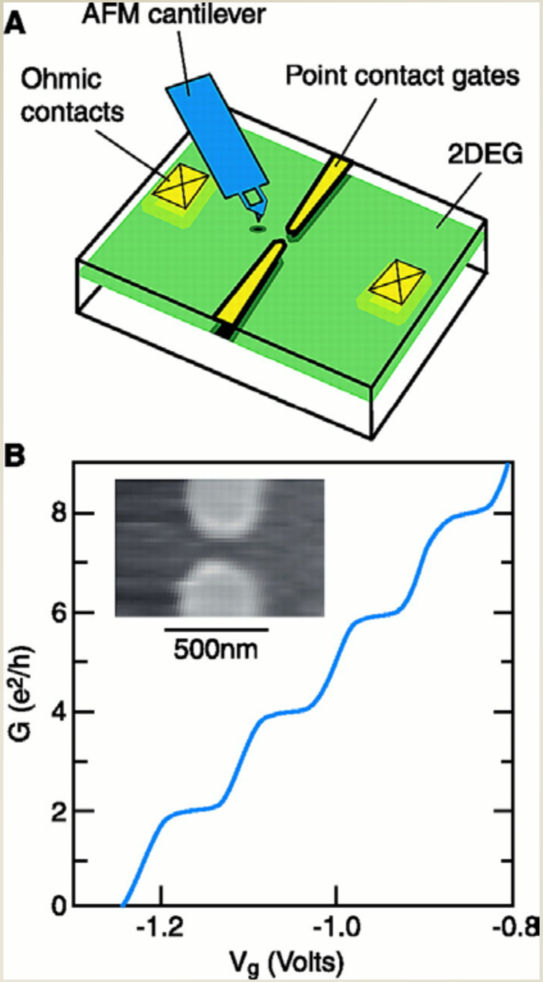


傳導係數量子化

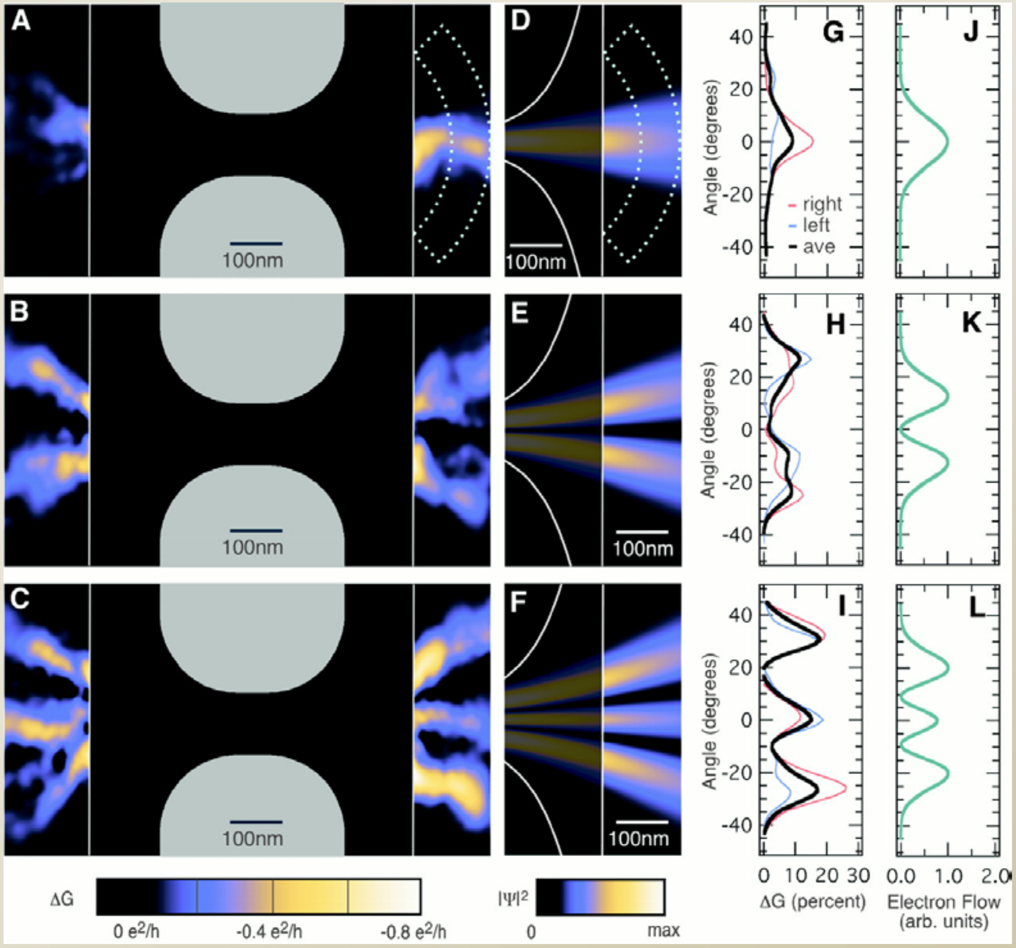
Science **289**, 2323 (2000)

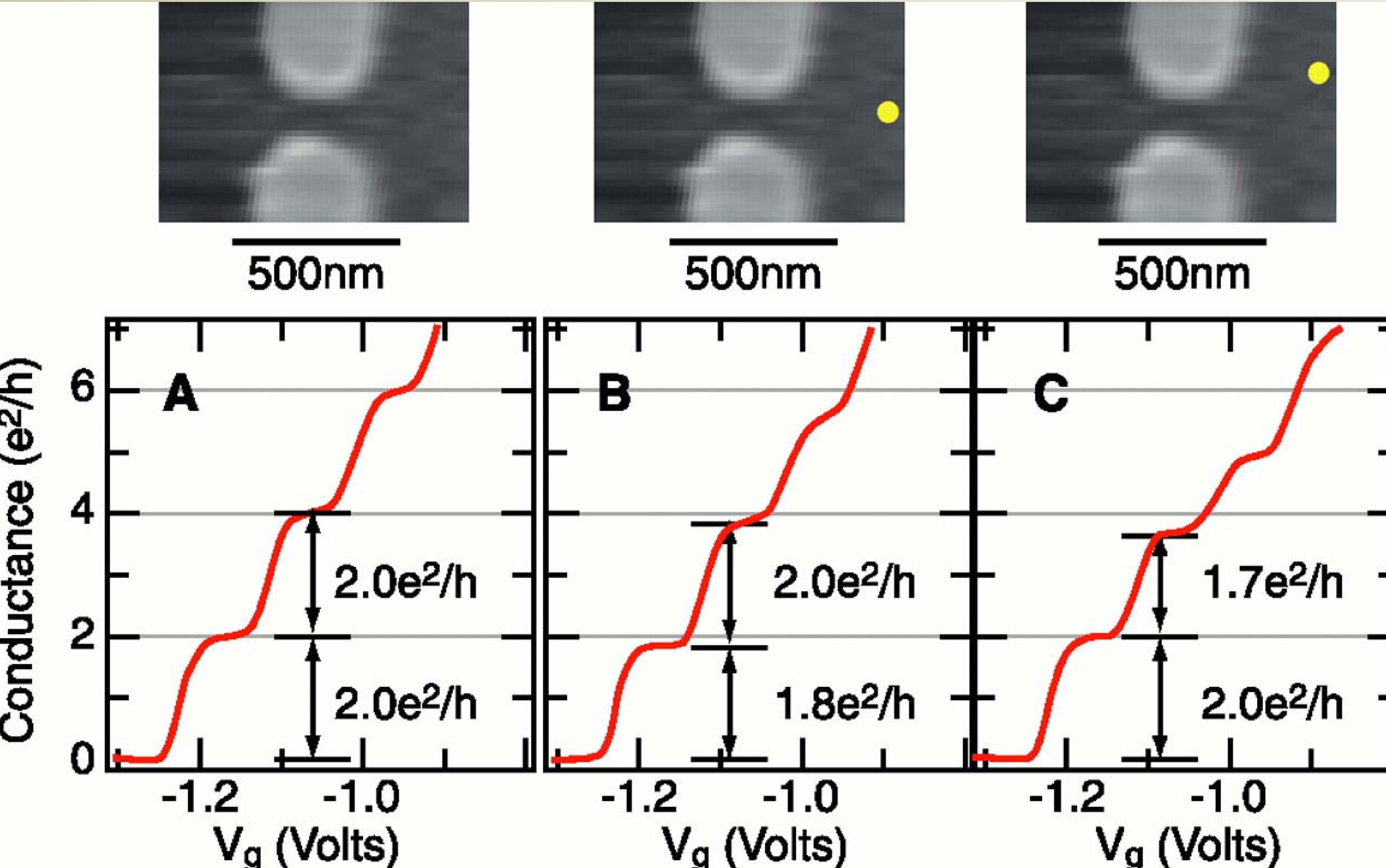


直接觀察頻道

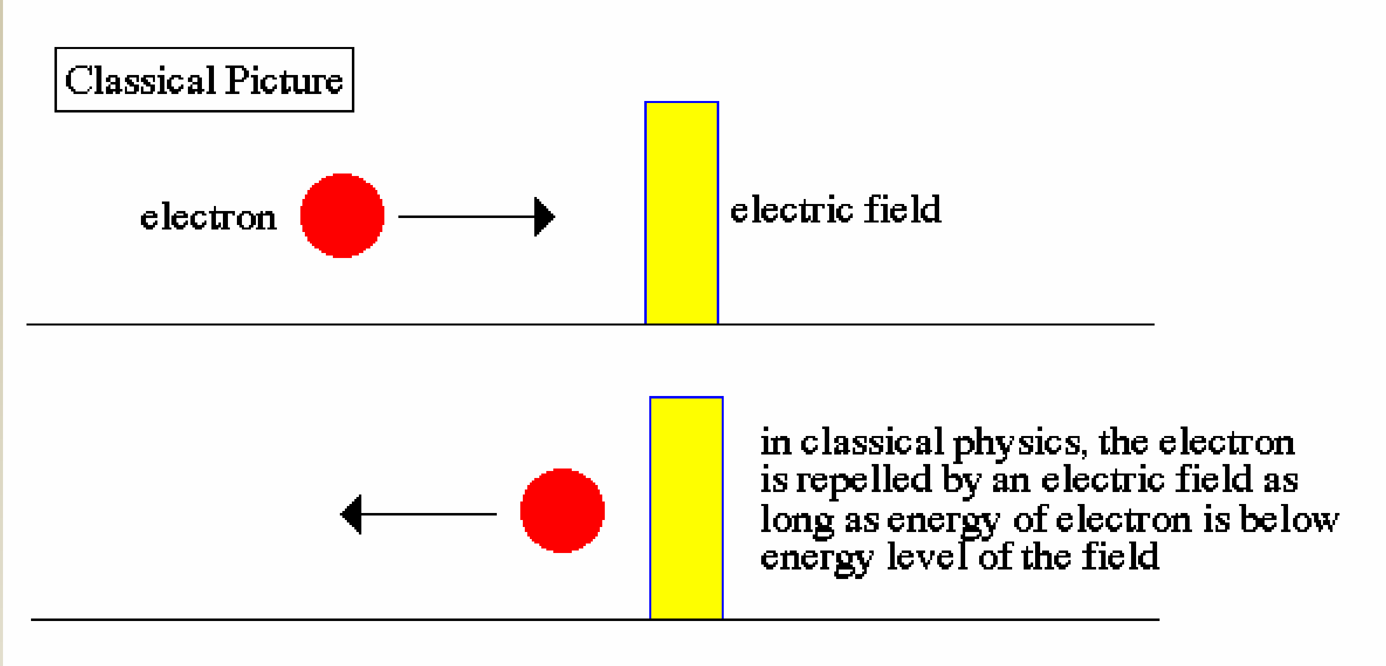


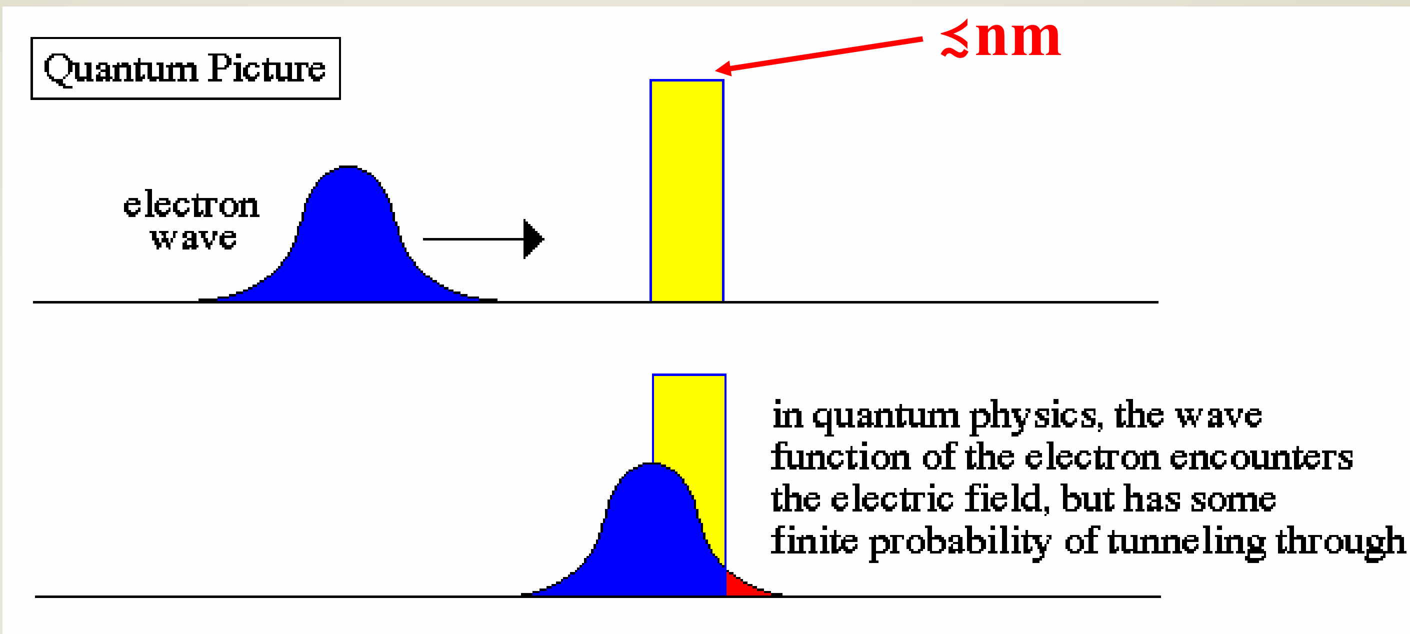
Science **289**, 2323 (2000)



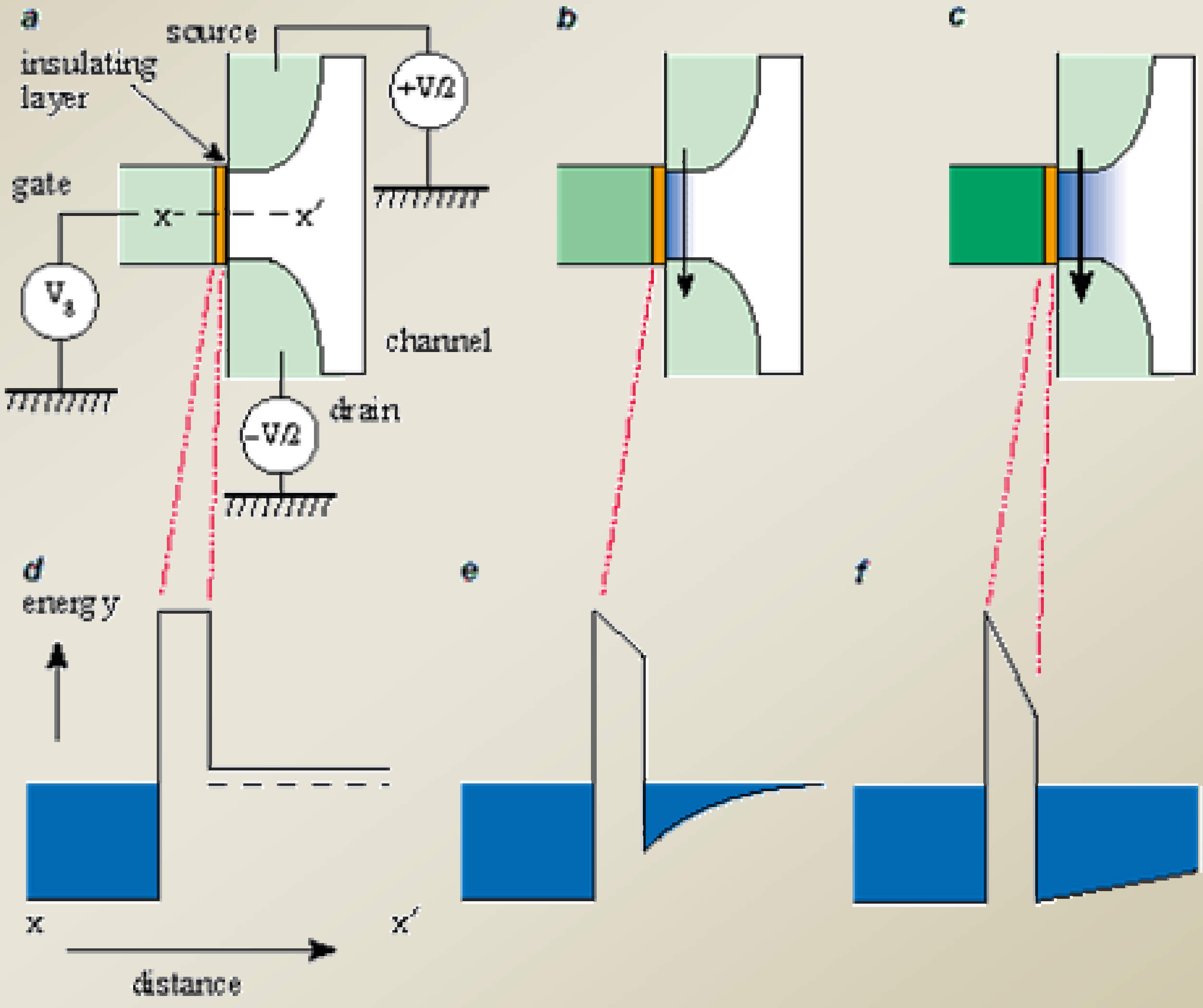

500nm
500nm
500nm
A
B
C
Conductance (e2/h)
0
2
4
6
2.0e2/h
2.0e2/h
2.0e2/h
1.8e2/h
1.7e2/h
2.0e2/h
-1.2
-1.0
Vg (Volts)
Vg (Volts)
Vg (Volts)

(III) 穿隧效應 (Tunneling)

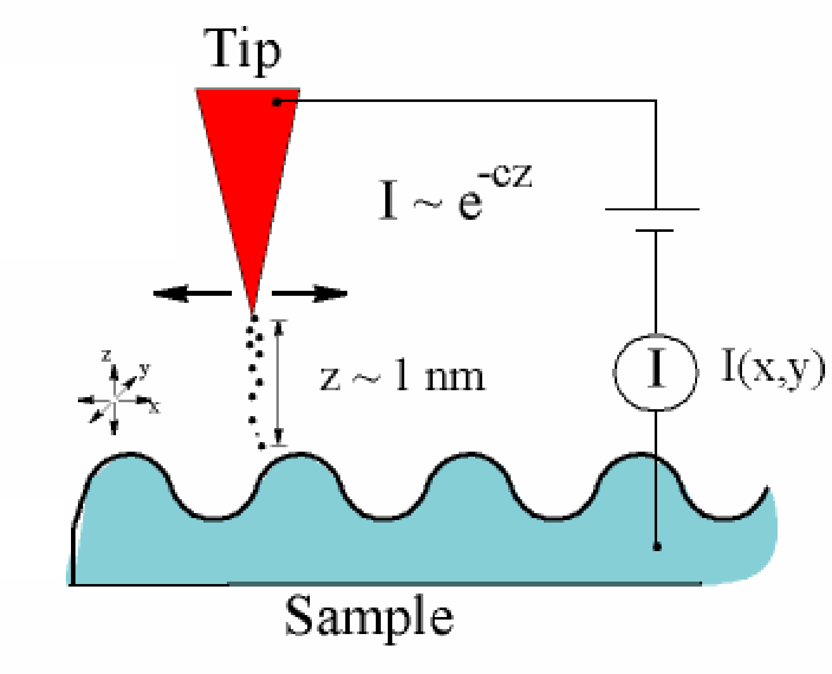

Classical Picture
electron
electric field
in classical physics, the electron
is repelled by an electric field as
long as energy of electron is below
energy level of the field

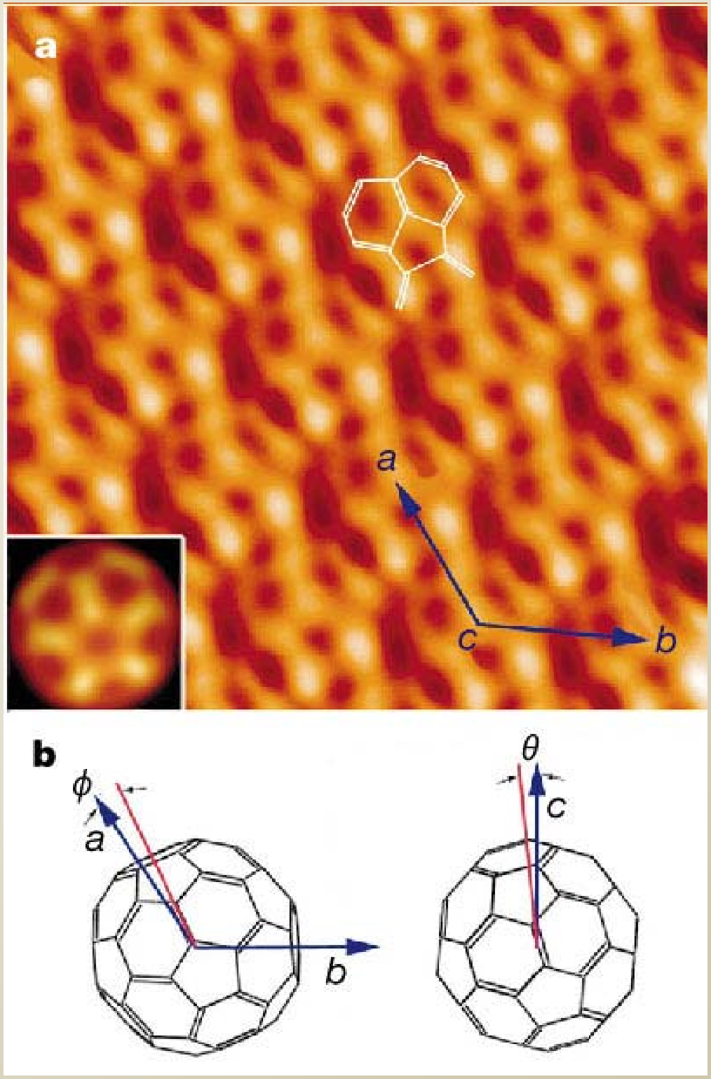

Quantum Picture
≲nm
electron
wave
in quantum physics, the wave
function of the electron encounters
the electric field, but has some
finite probability of tunneling through

穿隧效應是電晶體尺寸變小時可能失敗的主因



但穿隧效應卻被物理學家用以觀看奈米結構

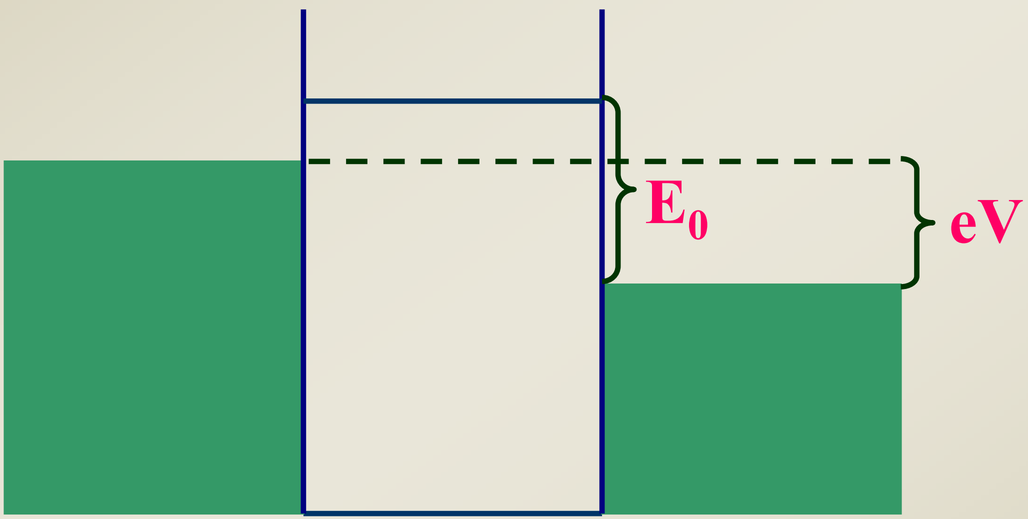


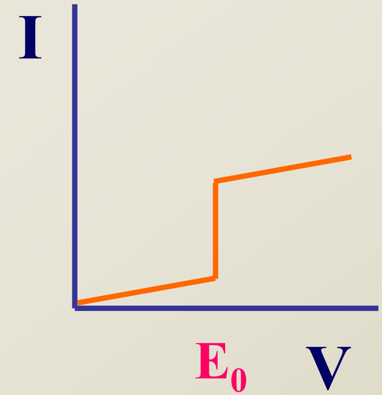


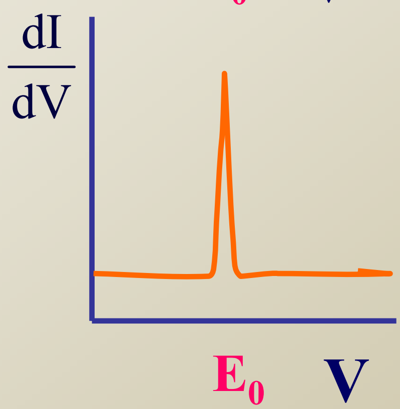
Nature 409, 304(2001)

STM中的共振式穿隧效應

T=0



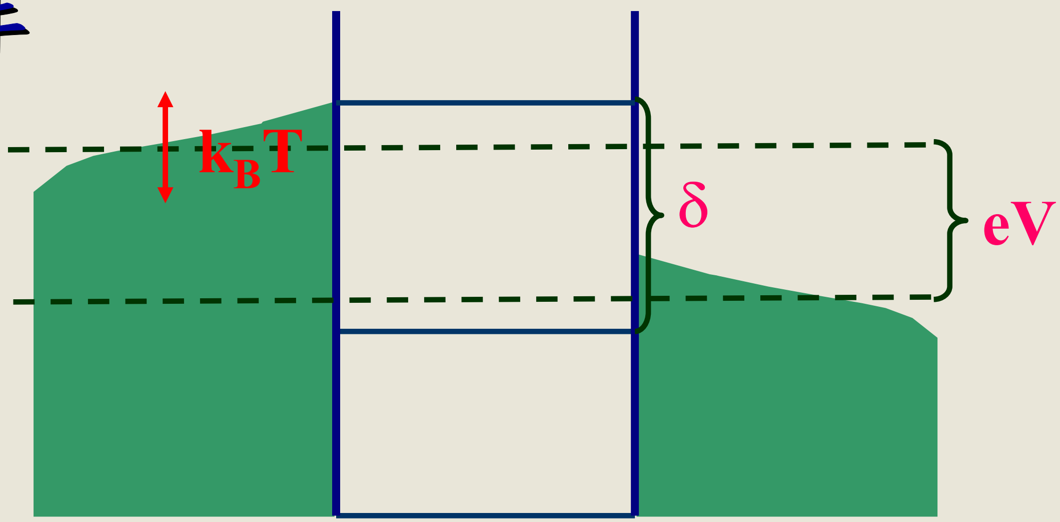


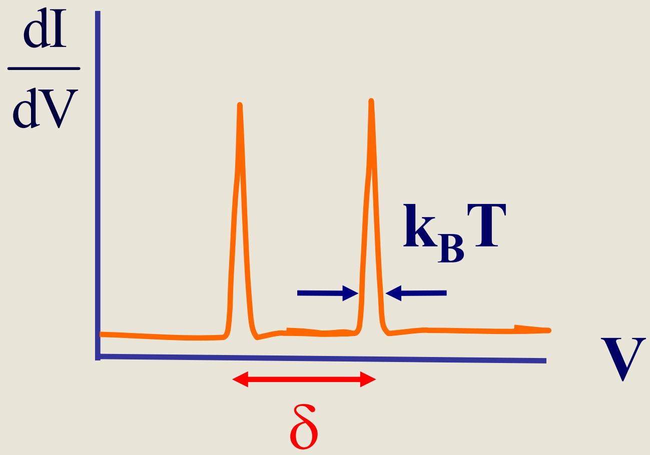


用途:可以用來察看奈米結構的能譜

觀測條件

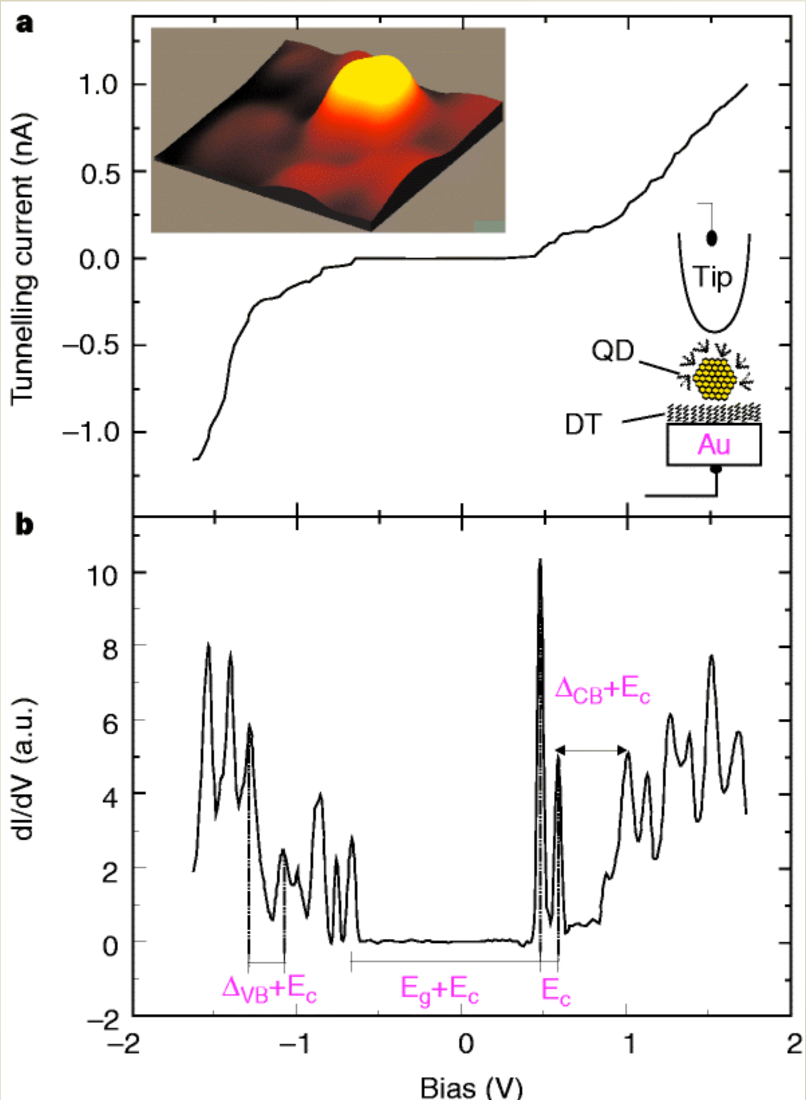
T > 0





維持peak的條件: $\delta \ll k_BT$

例一: 3.2nm InAs 奈米晶體的能譜

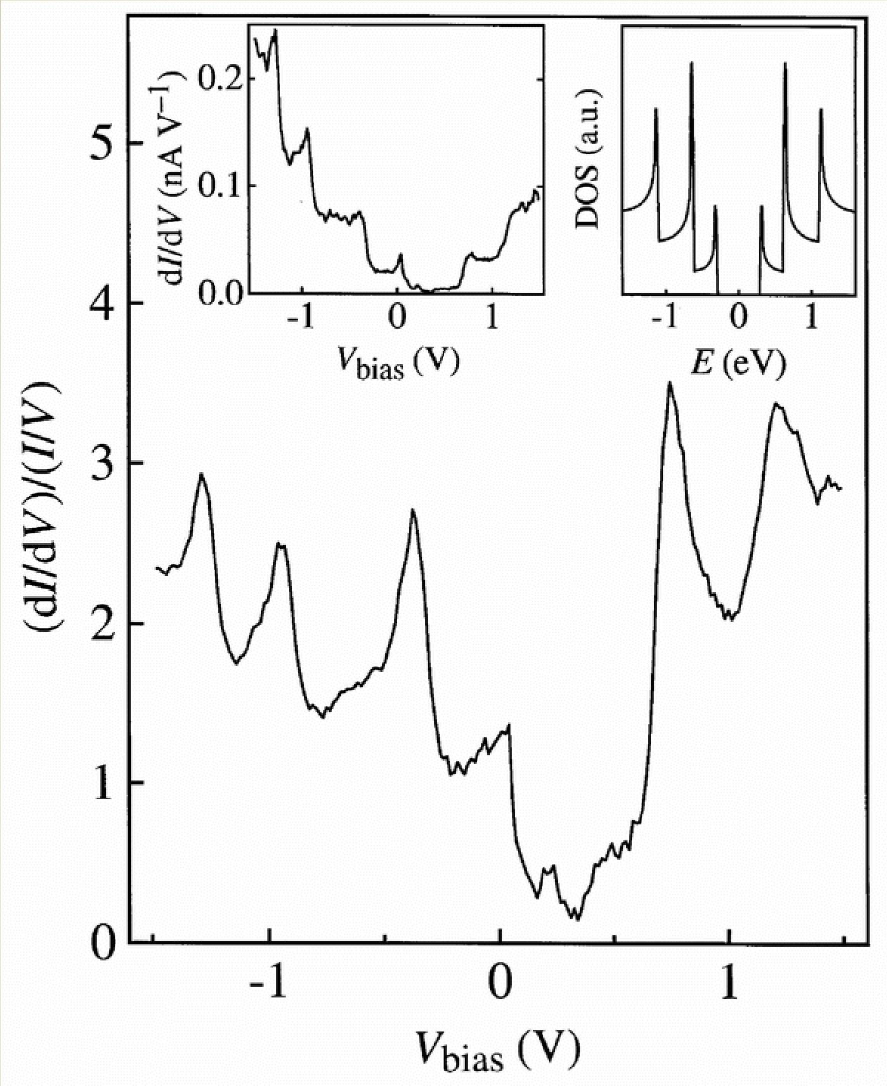


T=4.2K

DT= hexane dithiol molecules

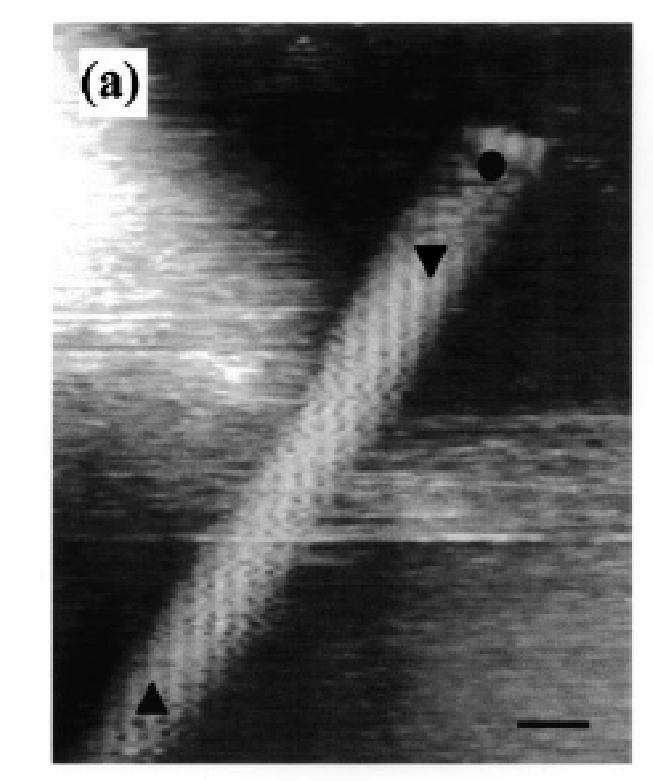
Nature 400, 542(1999)

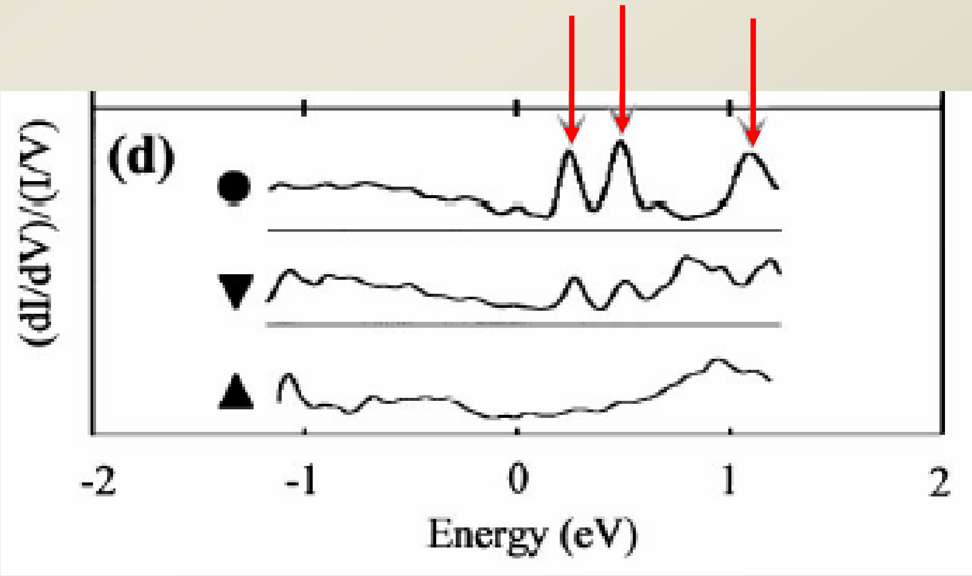
例二: 奈米碳管中的頻道



Nature 391,49(1998)
zig-zag (16,0) tube

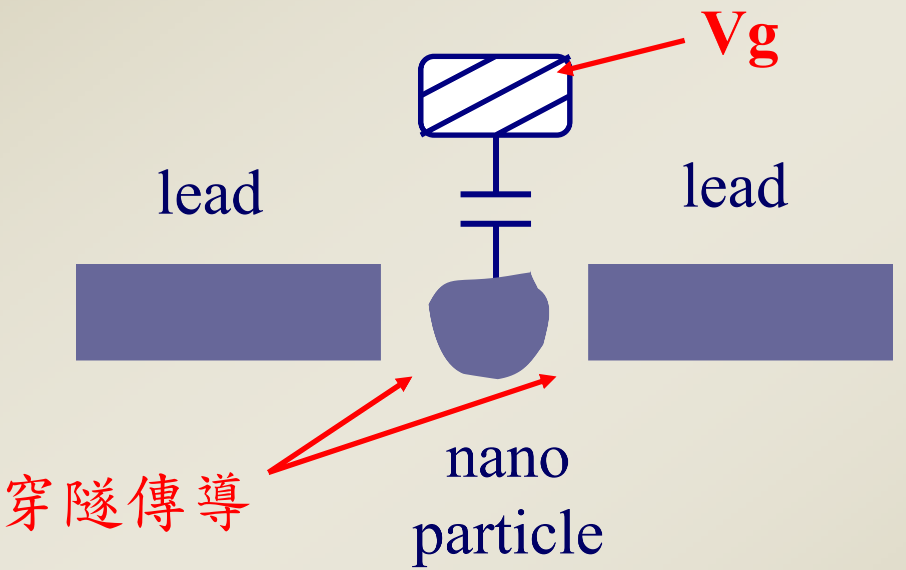
例三: 奈米碳管端點的電子能態

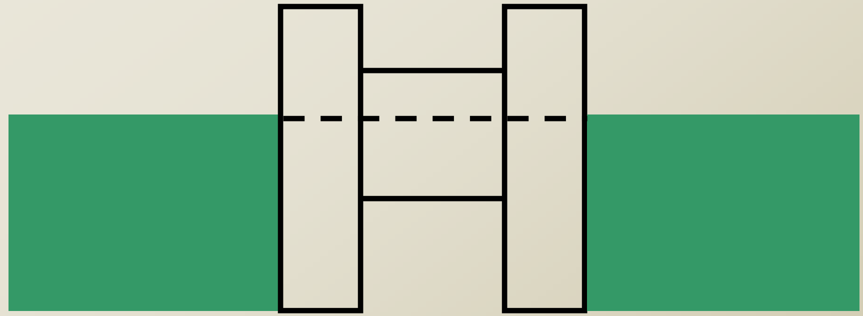




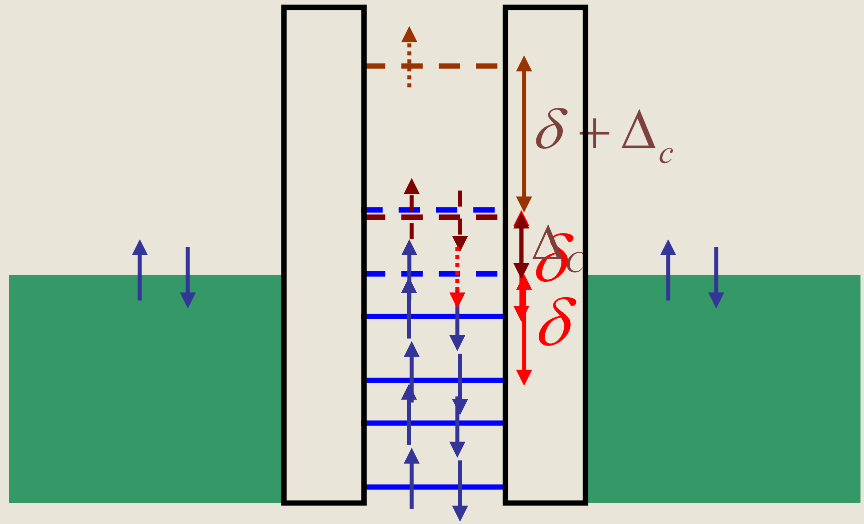
Phys. Rev. Lett. 82, 1225 (1998)
(13,-2) tube

單電子電晶體 (SET)組態

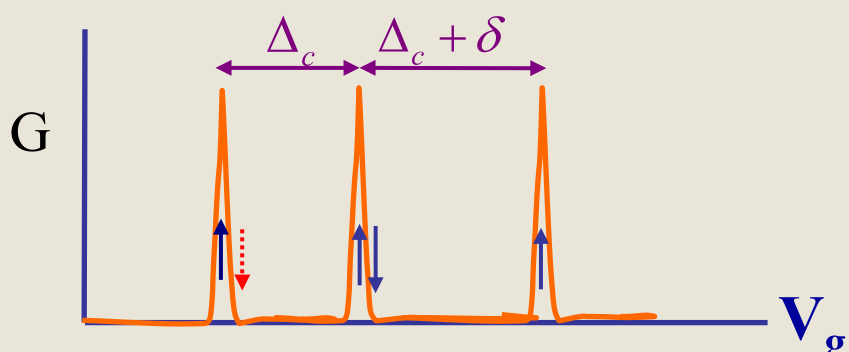




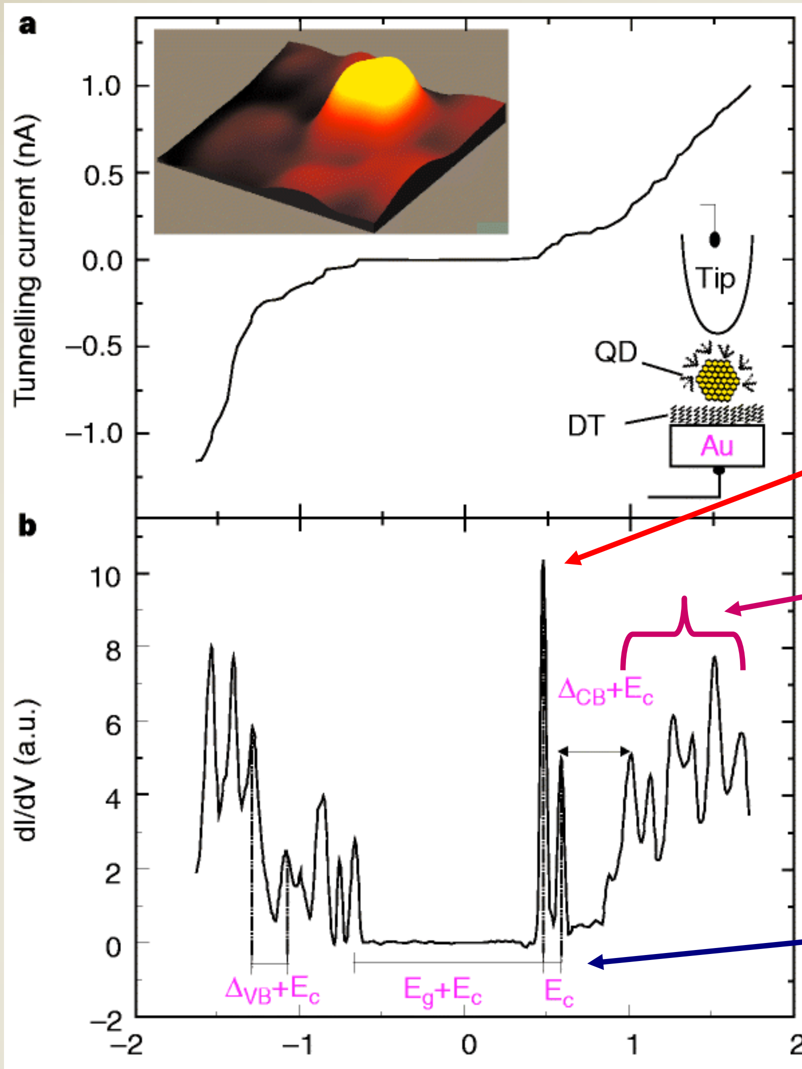
Couloumb Blockade現象
-- 單電子傳導的基礎



even-odd effect



回顧 InAs 奈米晶體的能譜

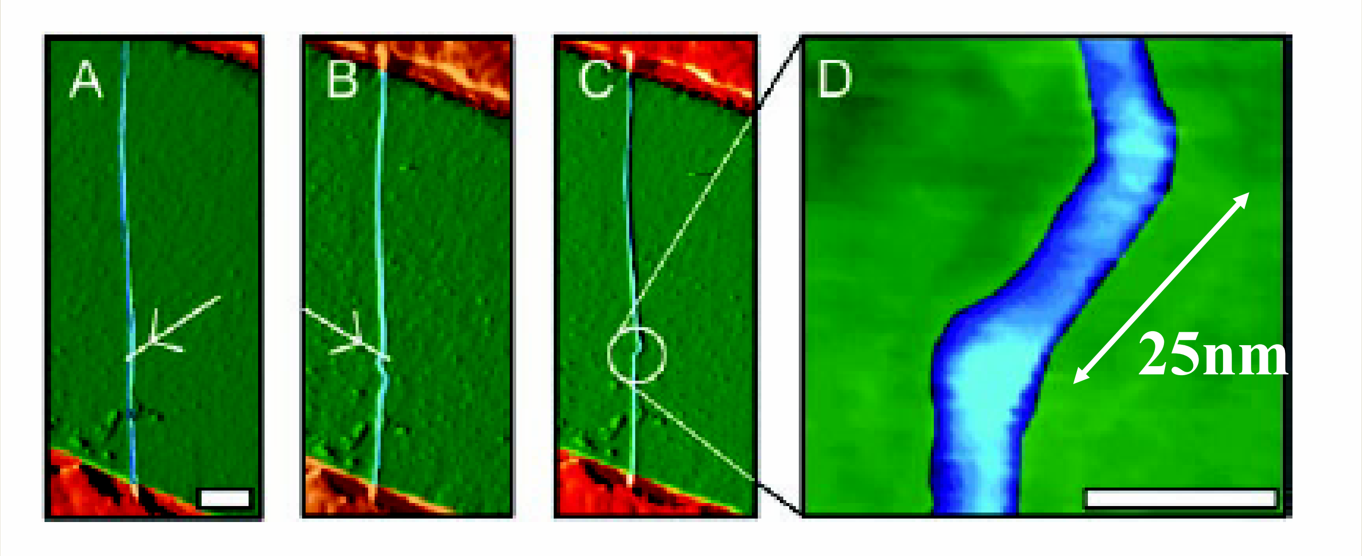


1S

1P

$$E_c = \Delta_c$$

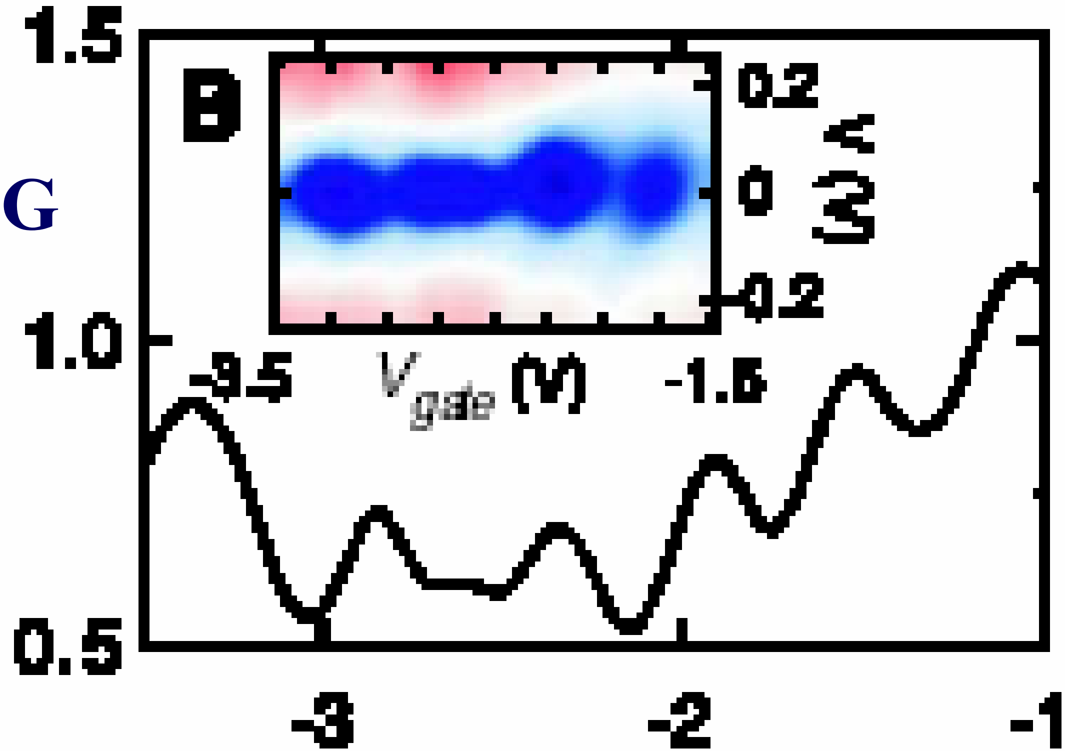
以奈米碳管為基礎的室溫SET



利用AFM製造兩個彎曲(buckle)點

Henk et al. Science 293, 76 (2001)

G



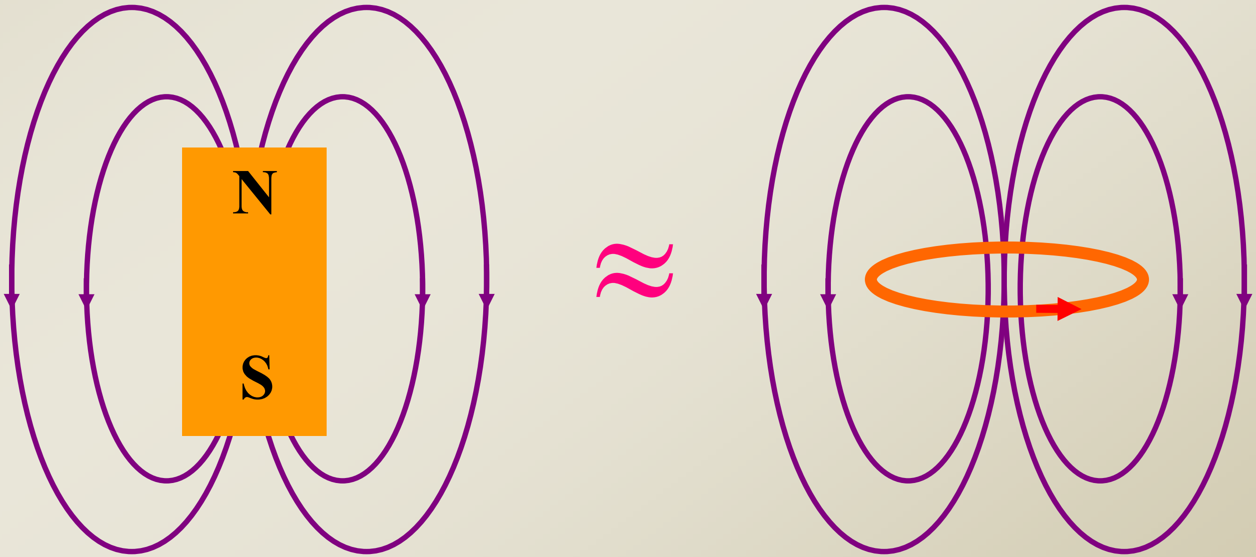
Gate Voltage

(IV) 自旋

(Quantum Spin)

自旋(spin)與科技的關係

自旋為磁性的最小單位,
源自於量子力學



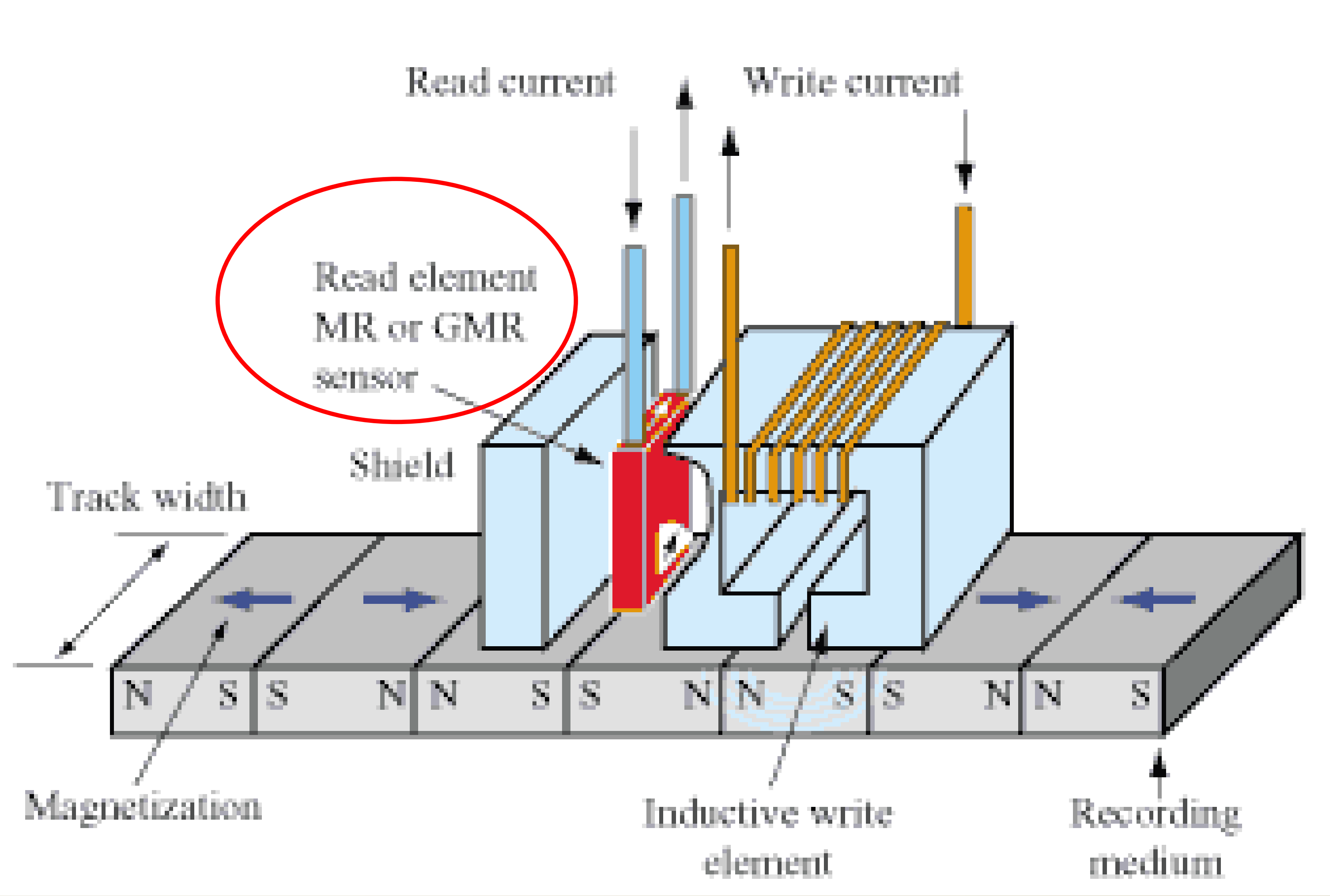
以往主要被用來作記憶使用如:硬碟..(magnetic recording)有300億市場

Well read: spintronics has dramatically increased data storage densities in hard drives.

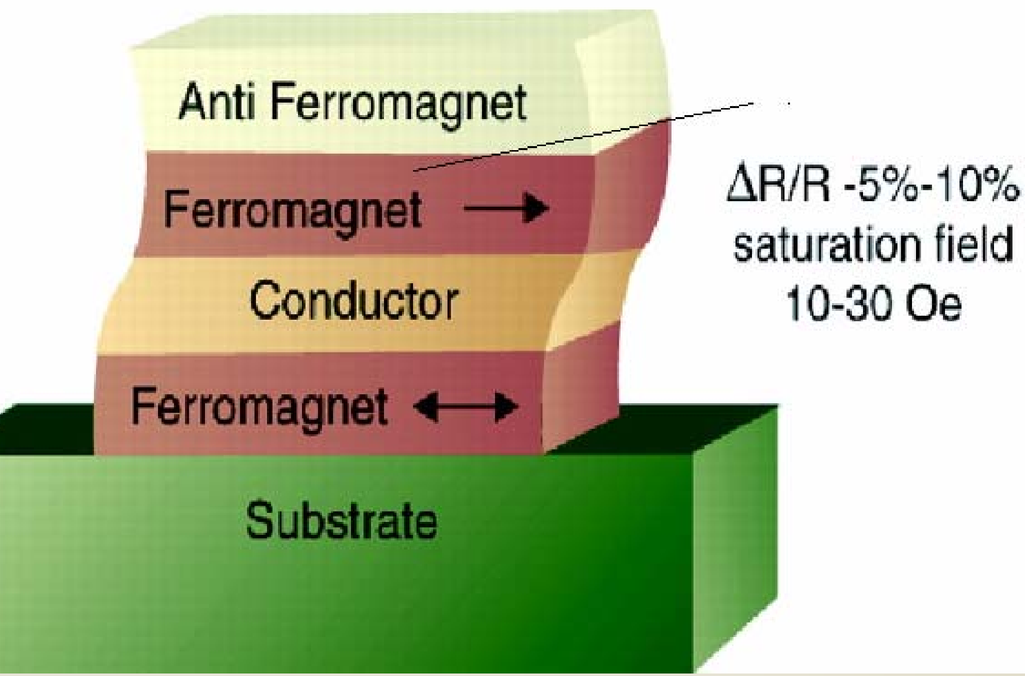
現在的努力重點是希望能以自旋的組態作控制:

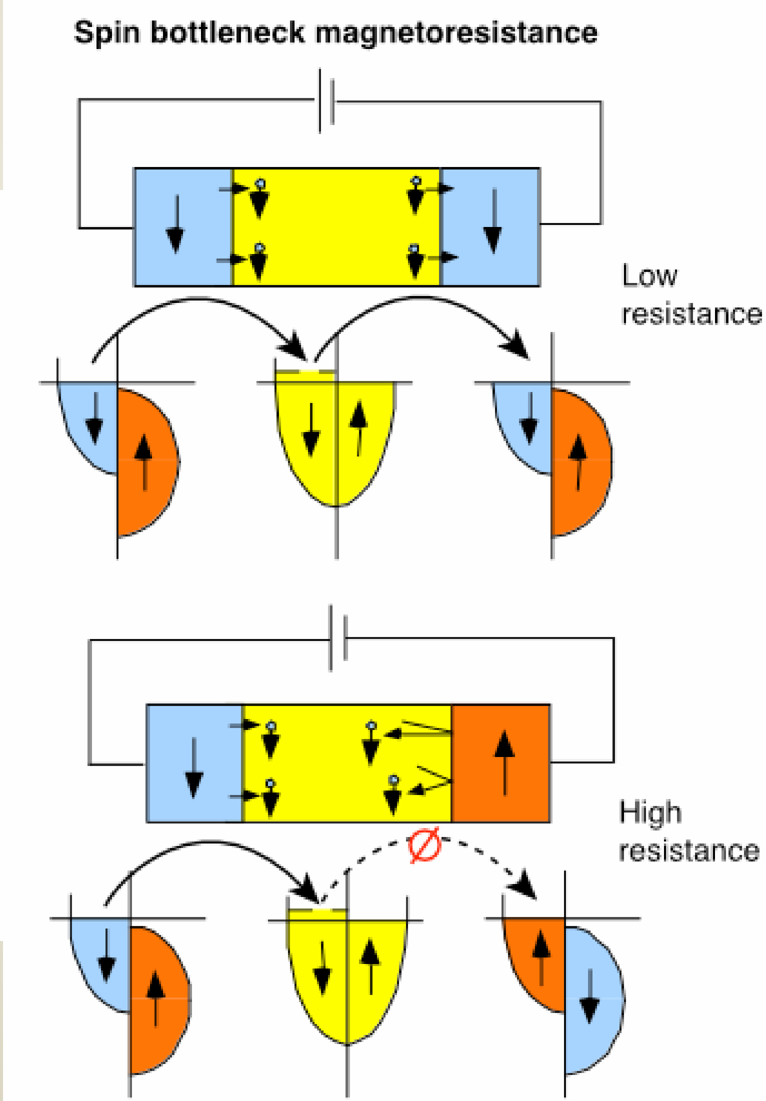
spintronics ⇔ electronics

自旋電子學!


Read current
Write current
Read element
MR or GMR
sensor
Shield
Track width
N S S N N S S N N S S N N S
Magnetization
Inductive write
element
Recording
medium

基本的GRM結構


Anti Ferromagnet
Ferromagnet
Conductor
Ferromagnet
Substrate
ΔR/R -5%-10%
saturation field
10-30 Oe


Spin bottleneck magnetoresistance
Low
resistance
High
resistance

新一代電腦

運算儲存一次完成

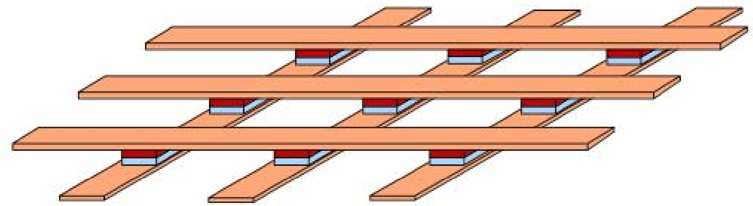
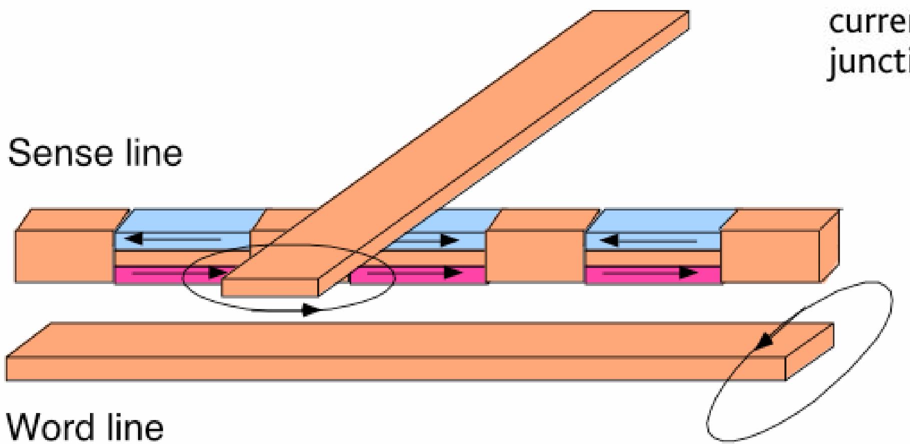


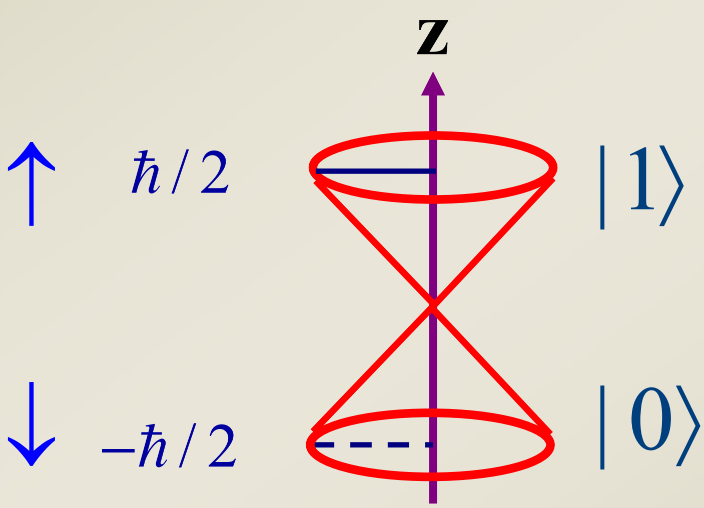
Fig. 7. A schematic representation of RAM that is constructed of magnetic tunnel junctions connected together in a point contact array. The conducting wires provide current to the junctions and permit voltage measurements to be made. They also enable the manipulation of the magnetization of the elements by carrying currents both above and below the magnetic junctions to create magnetic fields.



電源一開電腦就

磁鐵的量子行為

-以自旋為量子位元(qubit)

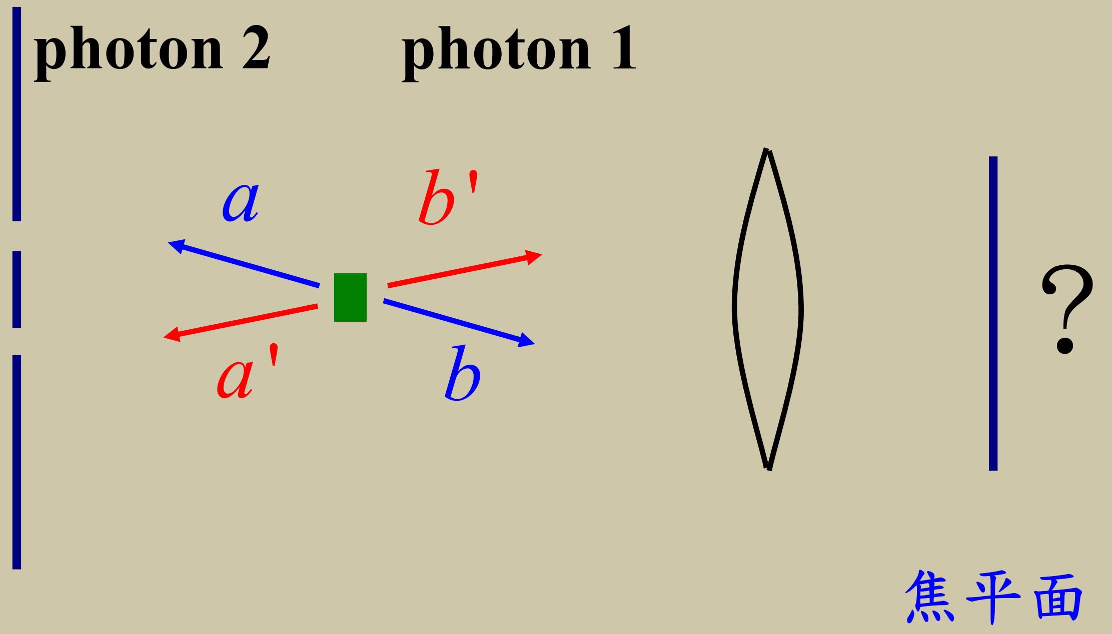


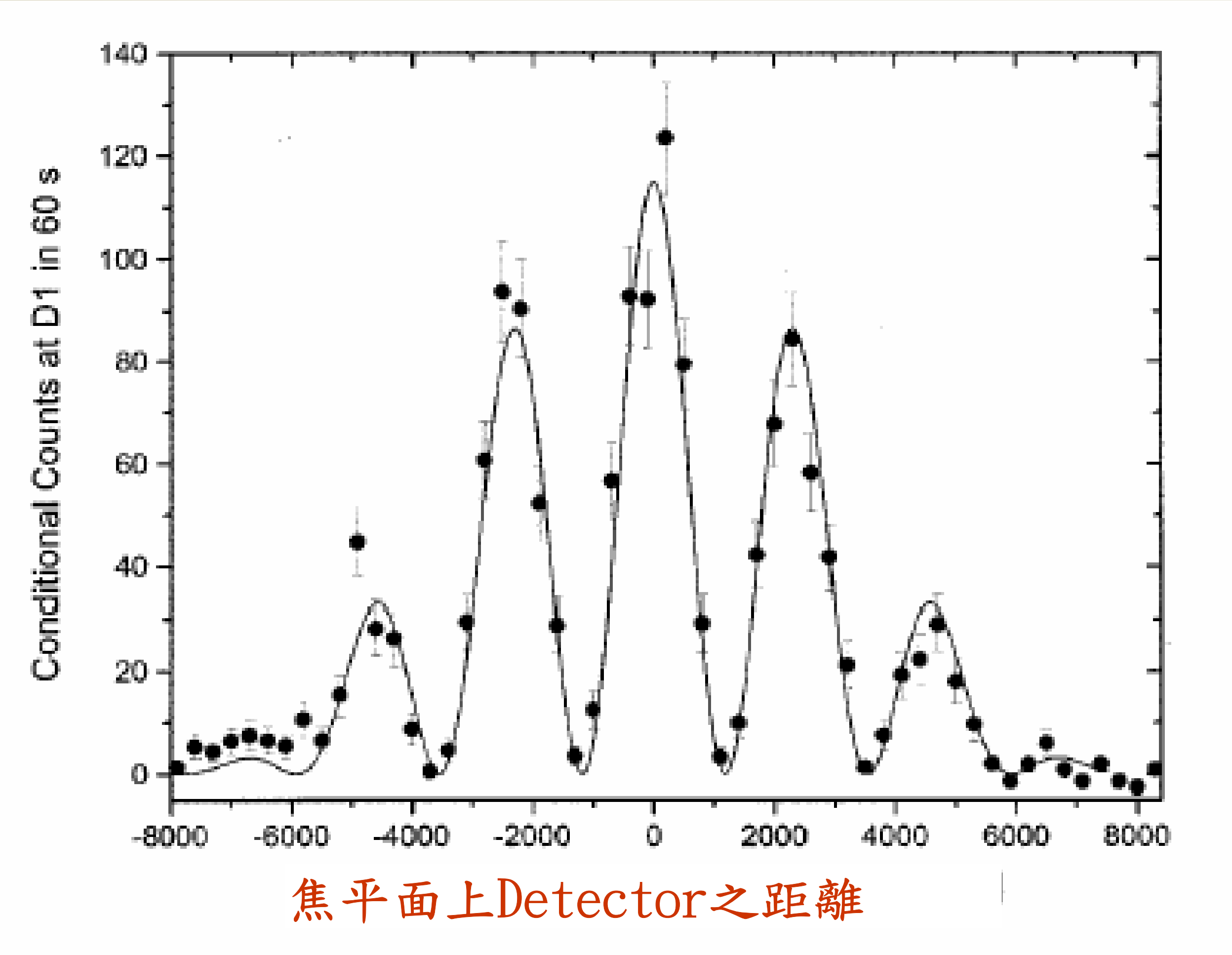
$$qubit = \alpha\,|0\rangle + \beta\,|1\rangle$$

Due to superposition
More information!

(V) 量子心電感應 (Entanglement/糾纏)

Interference with Entangled photons





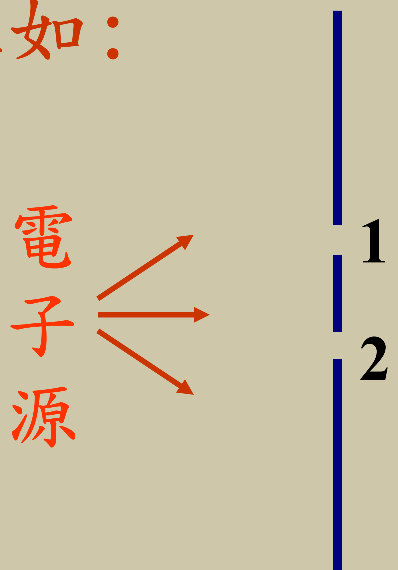
Dopfer, B., 1998

Zeilinger, Rev. Mod. Phys. S288, (1999)

$$|\psi\rangle = \frac{1}{\sqrt{2}}(|ab\rangle + |a'b'\rangle) \neq$$ 1000個光子對中

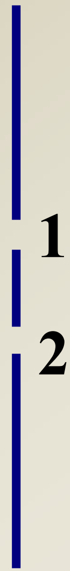
有500對在 $|ab\rangle$ 而另500對在 $|a'b'\rangle$

正如：



電子不是通過1或通過2,
而是“同時通過1與2”

bit versus qubit



電子通過1=>|0>
通過2=>|1>
} **bit**

$$qubit = \alpha\,|0\rangle + \beta\,|1\rangle$$

≈ 同時通過1與2

Due to superposition, get more information!

⇨ **Quantum Information Science**

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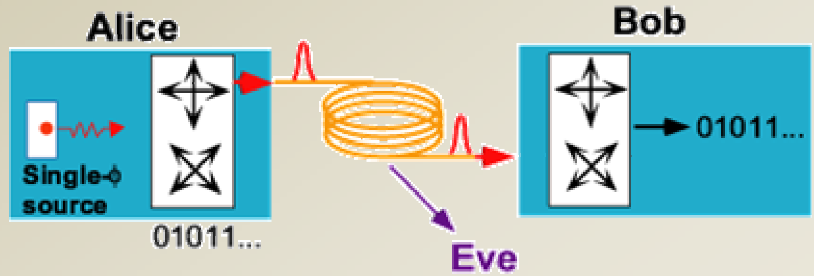
h Physics 219: John Preskill and Alexei Kitaev's Quantum Information course; ...
research.ibm.com/quantuminfo/ - 5k - 頁庫存檔 - 類似網頁

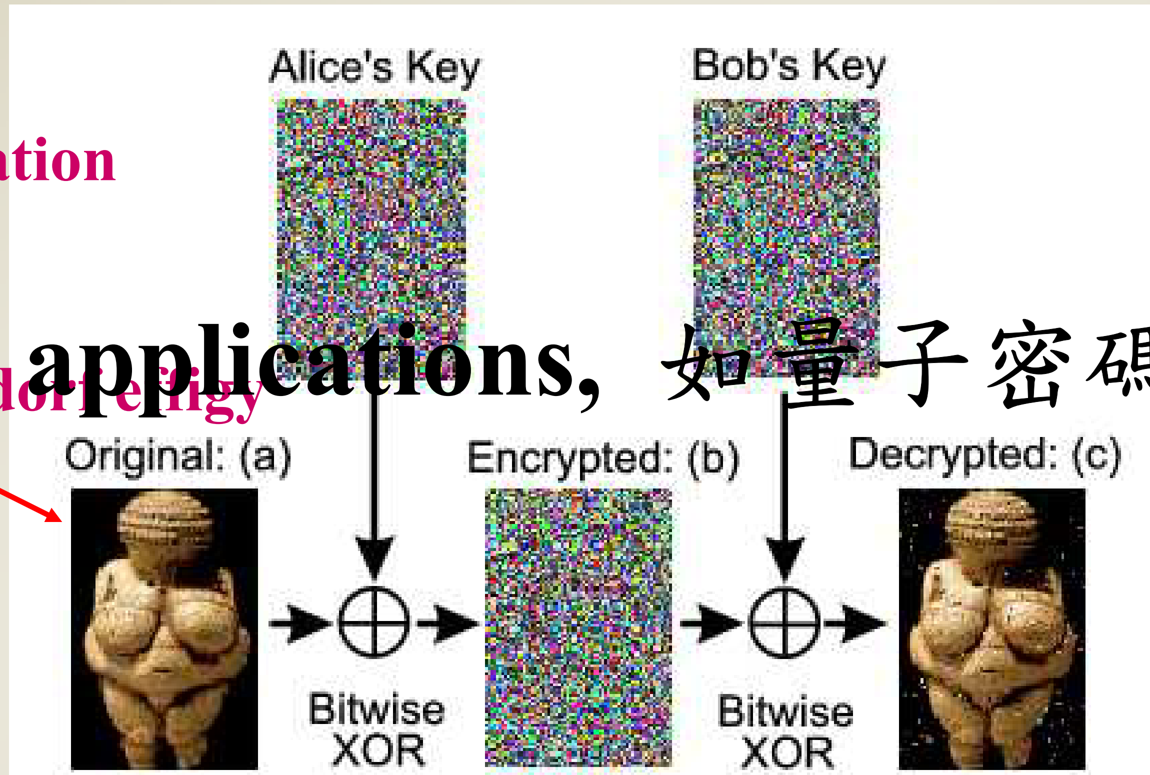
cs 219 Course Information

e theory of quantum information and quantum computation. Overview of classical information theory.

Many applications, 如量子密碼...



0x90 pixels
bit color information
er pixel + header
49984bits
'enus von Willendorf effigy



Phys. Rev. Lett. 84, 4729-4732 (2000)

(Ekert scheme, using entangled photons)

Summary

奈米尺度的五大量子效應

- Interference
- Quantization
- Tunneling
- Quantum Spin
- Entanglement

這些效應對人類生活的衝擊正在發展進行中!