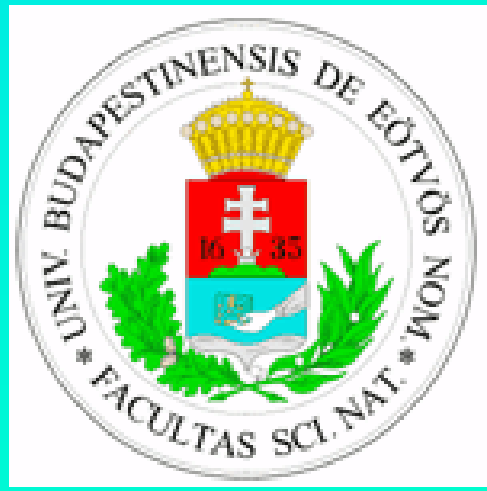
Cserti József

A nanofizika új eredményei

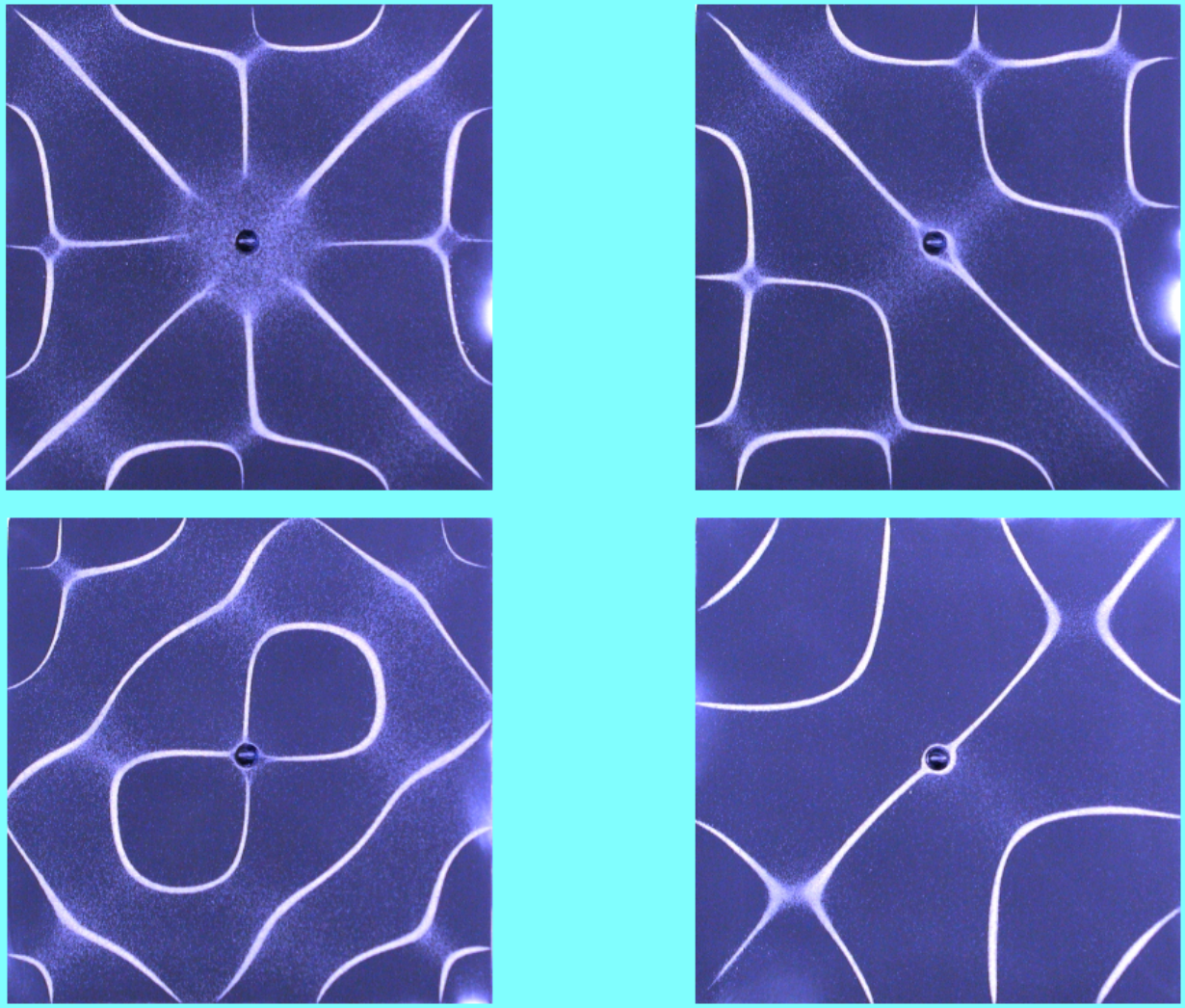
Eötvös Loránd Tudományegyetem
Komplex Rendszerek Fizikája Tanszék



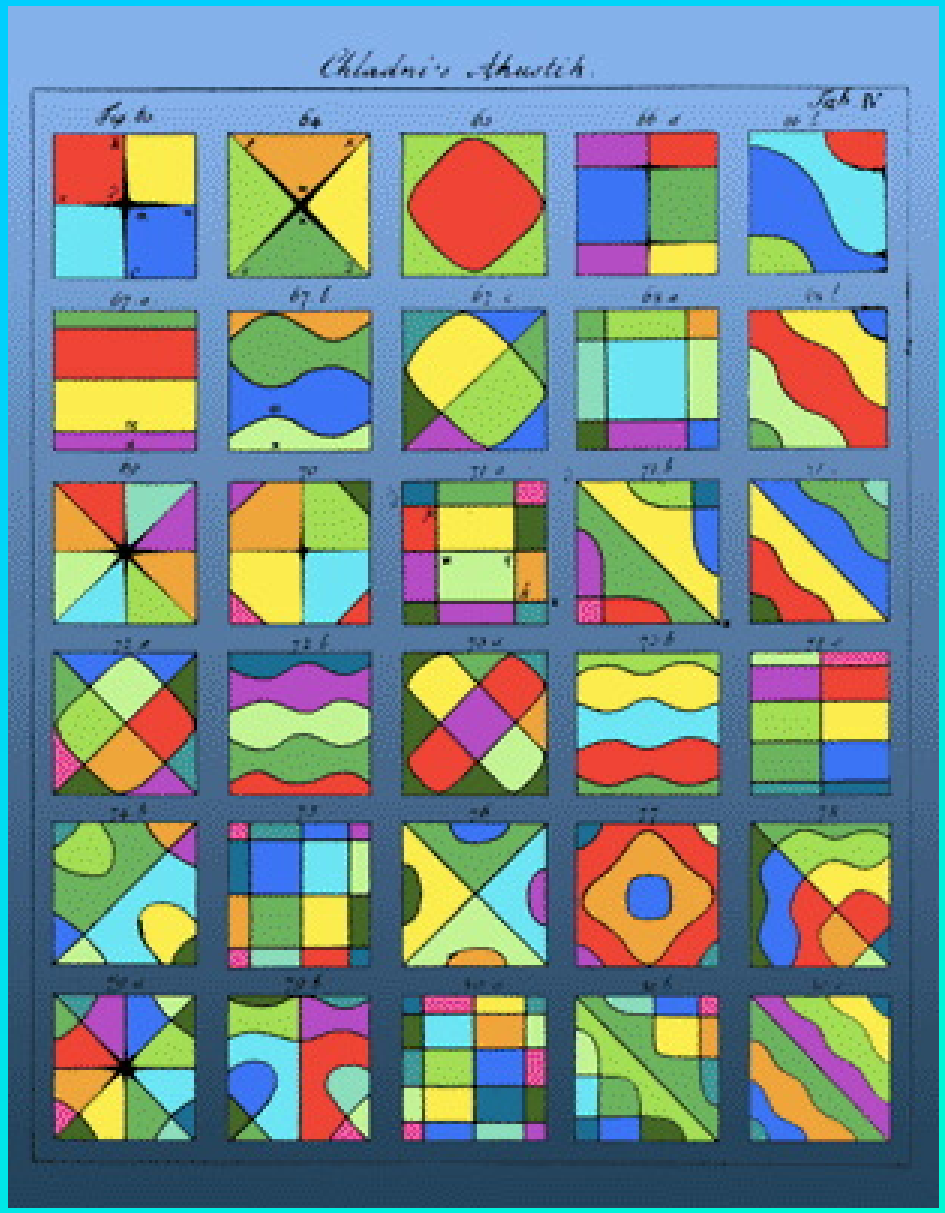
Az atomtól a csillagokig, 2006. április 27.

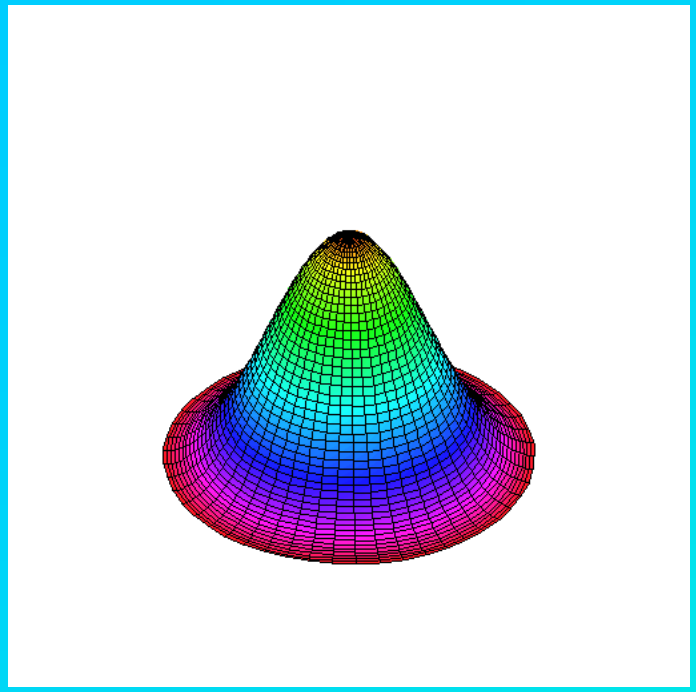
Chladni lemezek

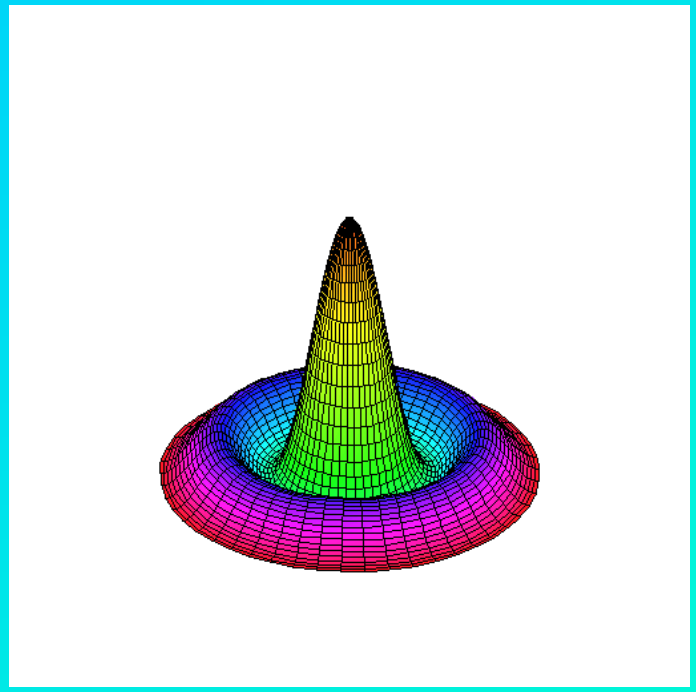
Bérces György
Eötvös Loránd Tudományegyetem
Anyagfizikai Tanszék

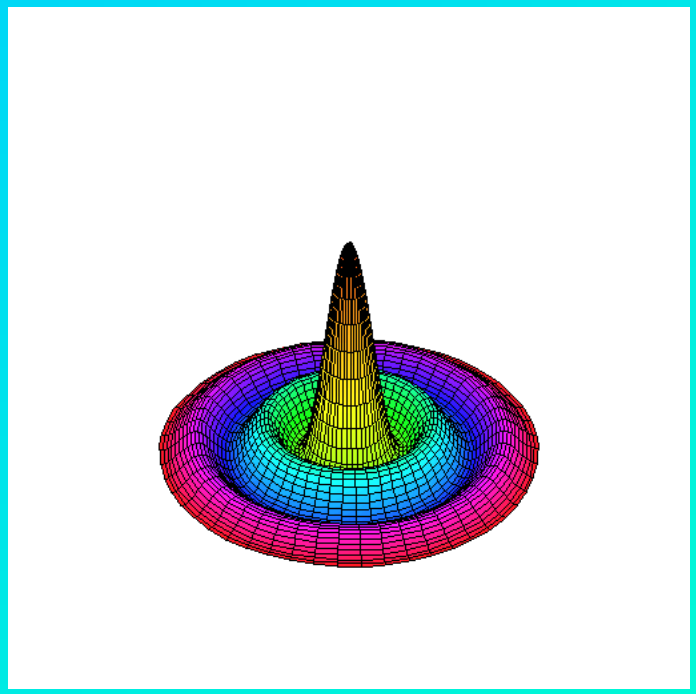


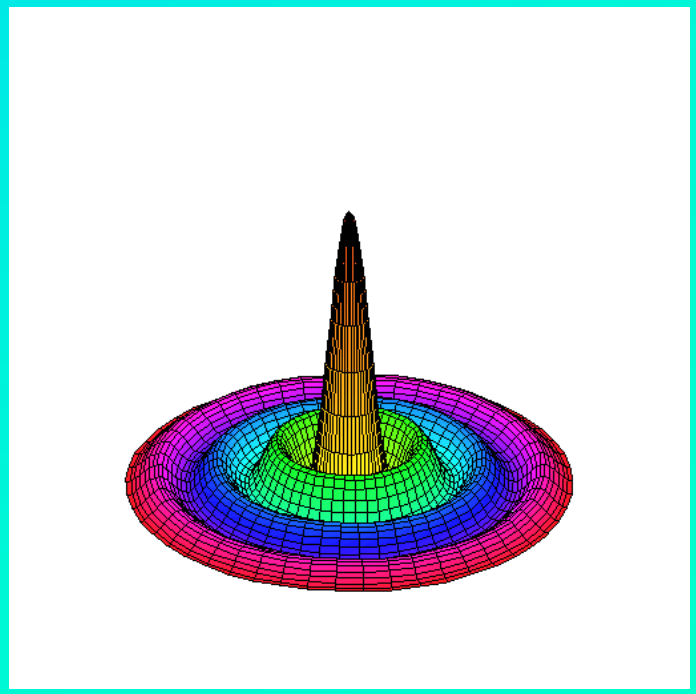
Ernest Florens Friedrich Chladni (1756 - 1827)

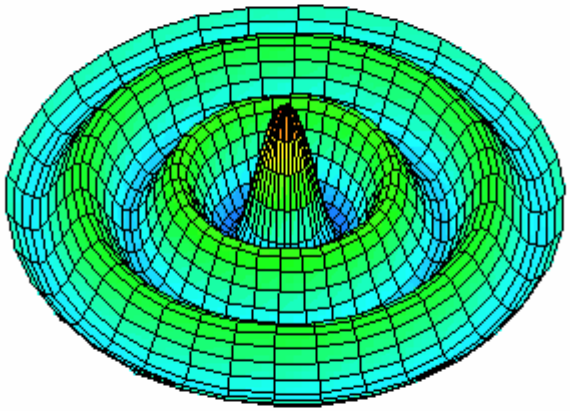


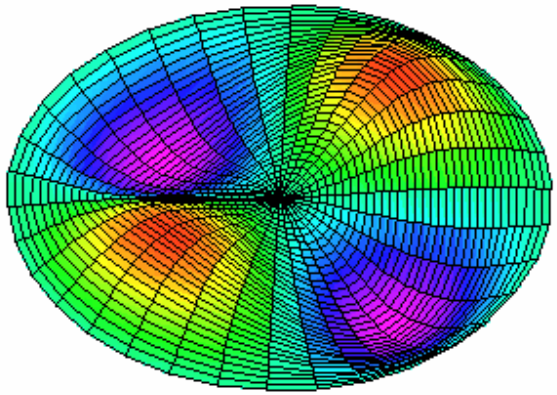


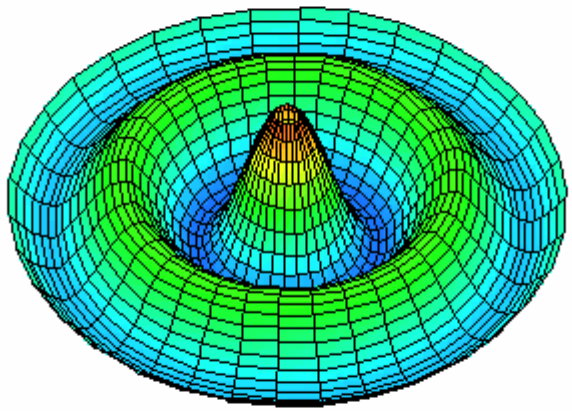


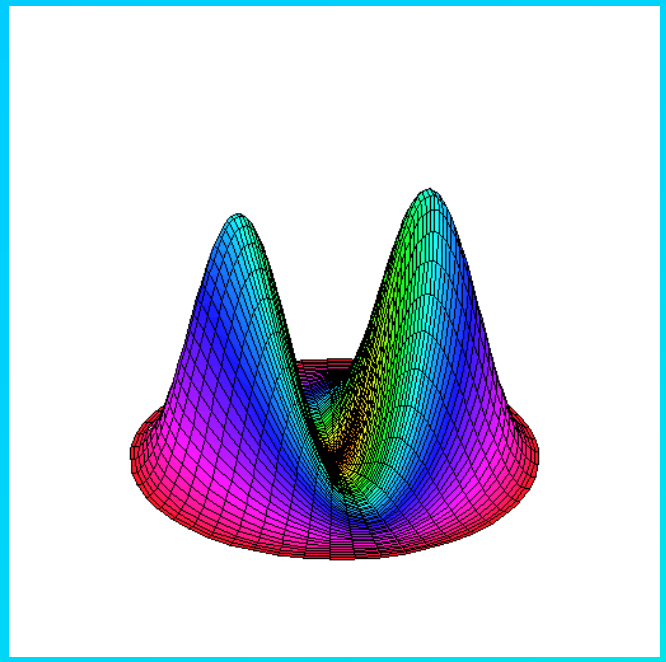


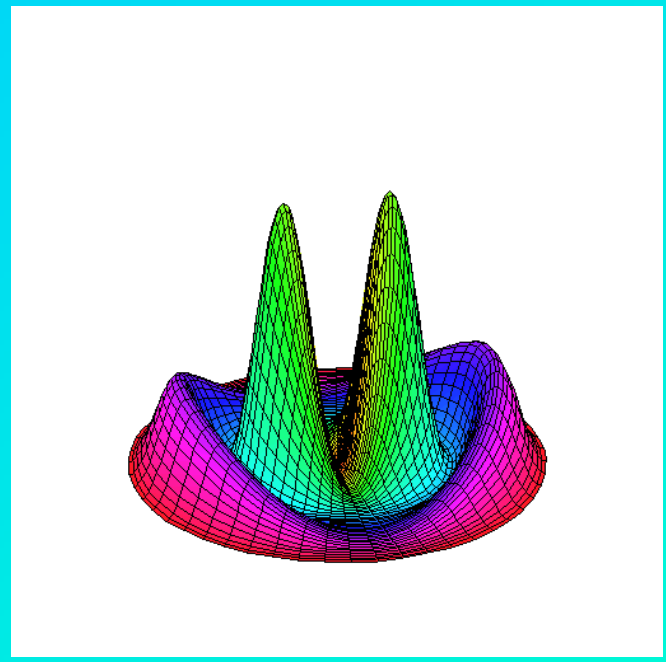


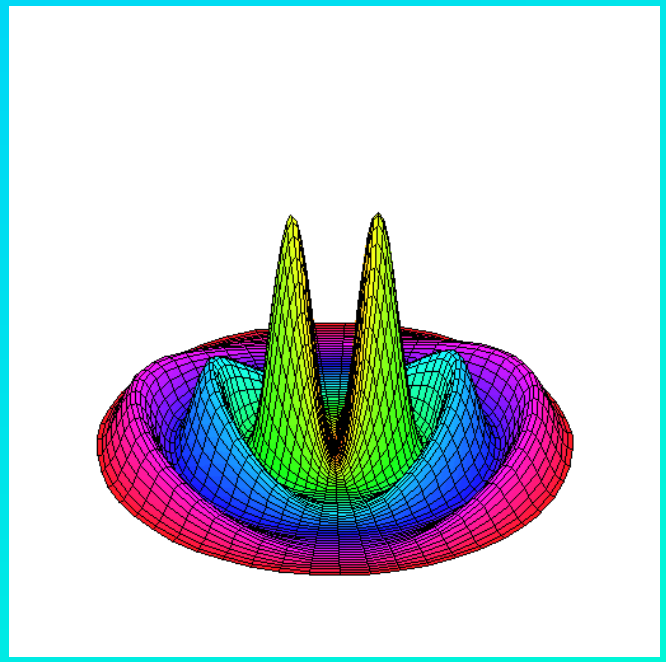


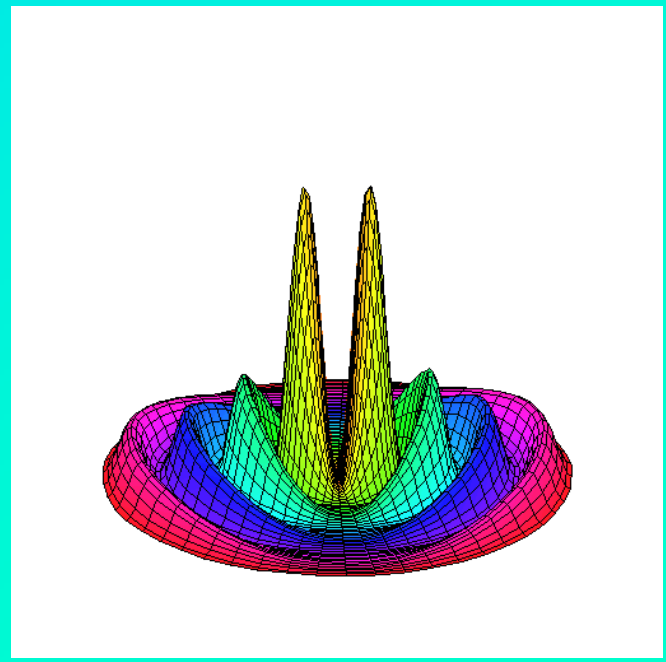


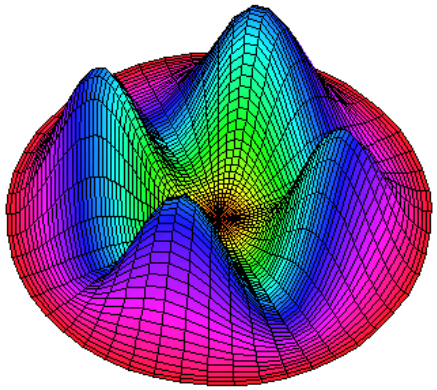


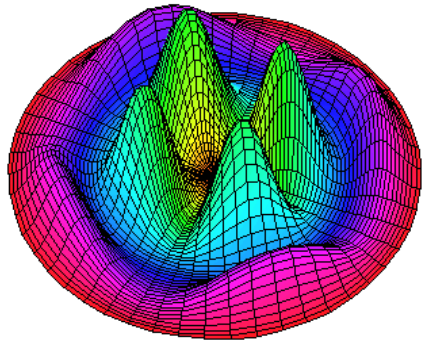


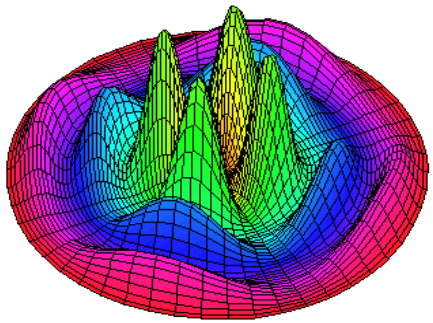


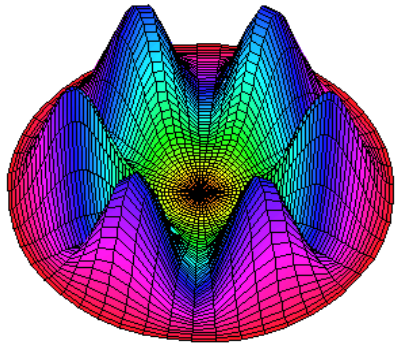




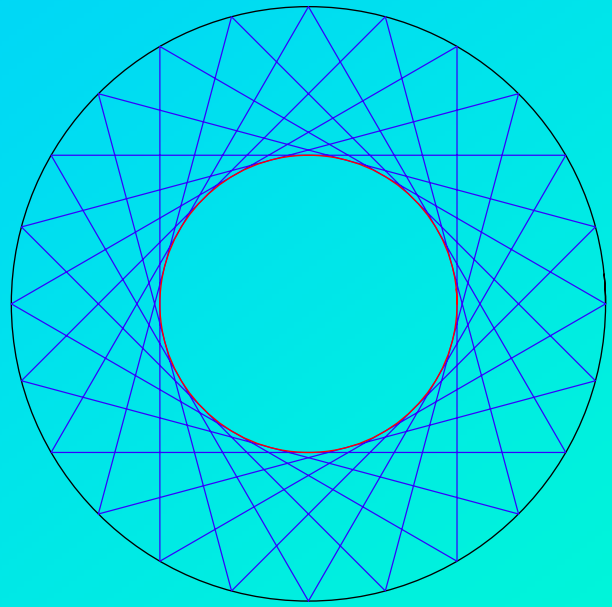






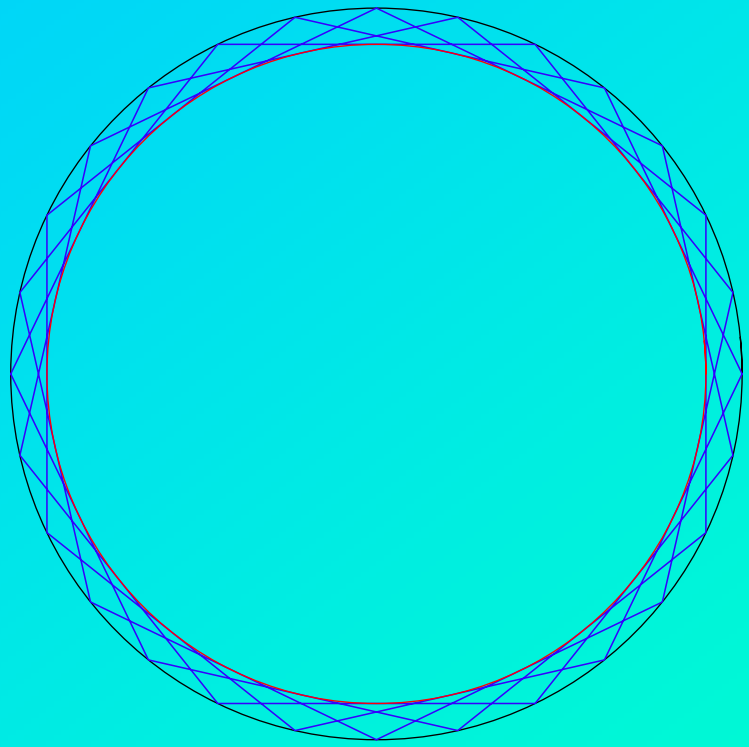


Klasszikus biliárdok

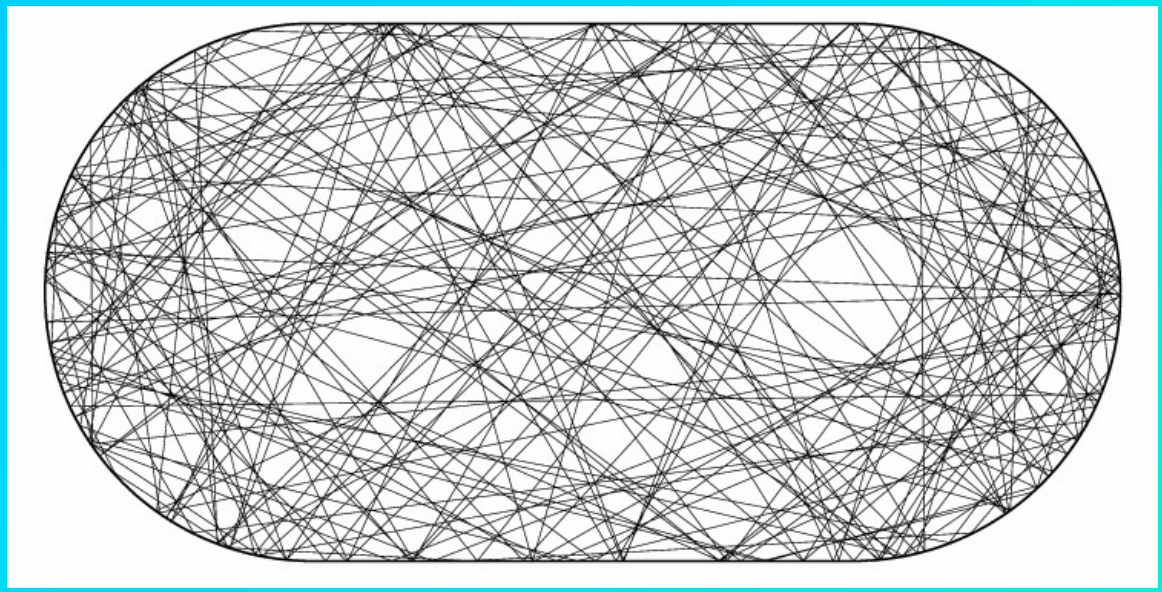


N = 3 pattogás a falon

N = 7 pattogás a falon



Stadion biliárd



Kaotikus biliárd

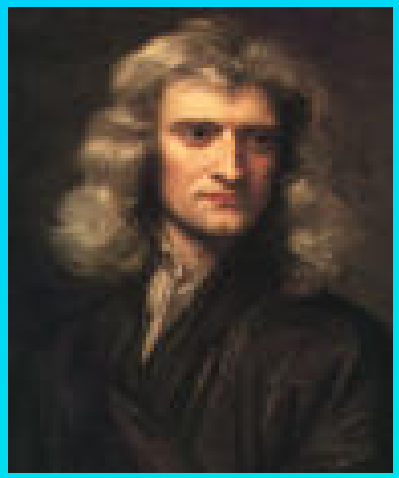
Hendrik Antoon **Lorentz**
(1853-1928)

Makroszkopikus világ

Klasszikus fizika

Mikroszkopikus világ
atomi méret

Kvantumfizika



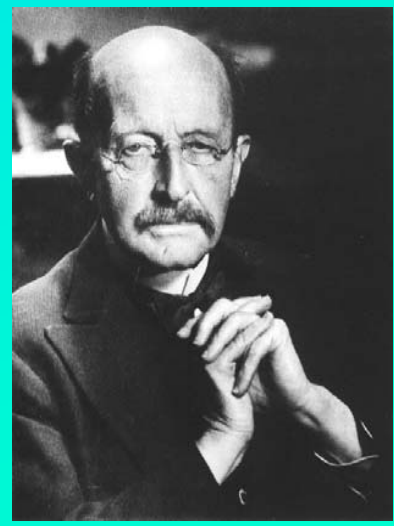
Sir Isaac **Newton**
(1643-1727)

Mezoszkopikus

Nanométeres méretek

Kvantumfizika

Nanofizika



Max **Planck**
(1858-1947)

Mekkora 1nm ?

1μm = 1mm /1000

1nm = 1μm /1000

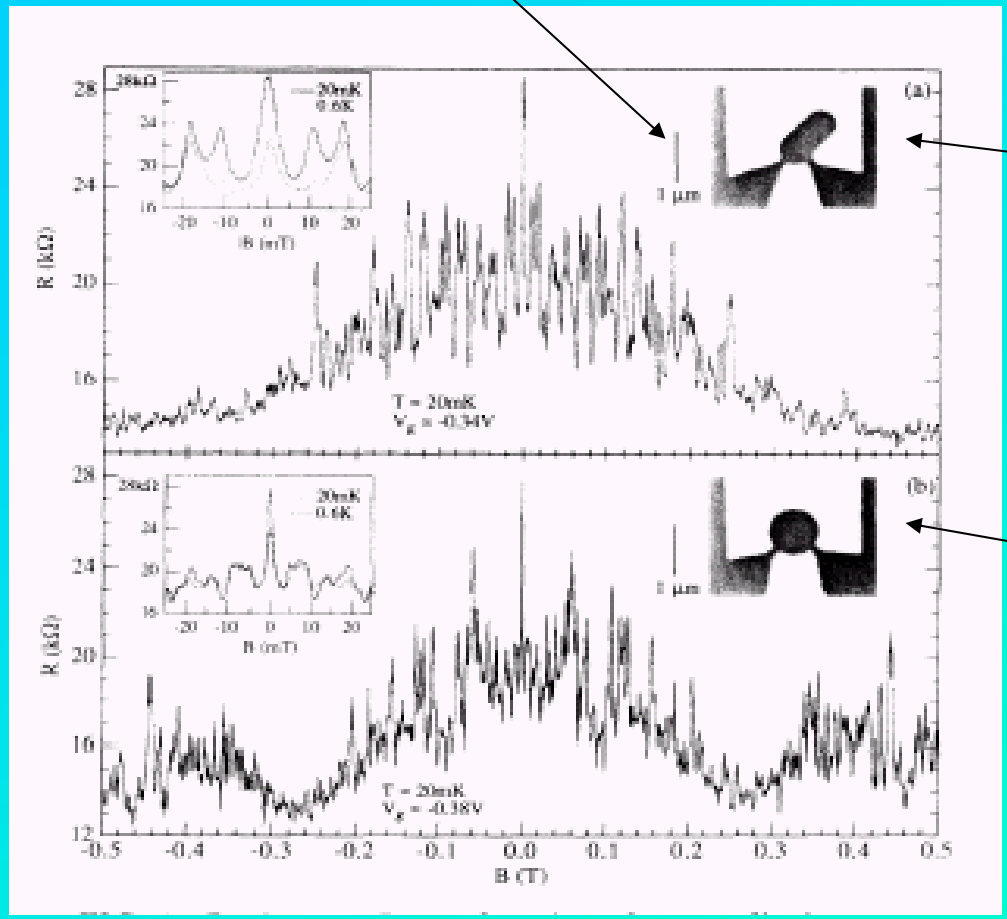
1nm = 1 mm 1 milliomod része

Ha a Nap – Föld = **1 m** → futballpálya = **1 nm**

Kvantumbiliárdok
Kísérleti megvalósítás

1992

1μm



Ellenállás

Stadion alakú

Kör alakú

A hőmérséklet mK alatt van

mágneses tér

Kvantumbiliárdok

A biliárd mérete: néhány száz nanométer

100 biliárd egy tű hegyén

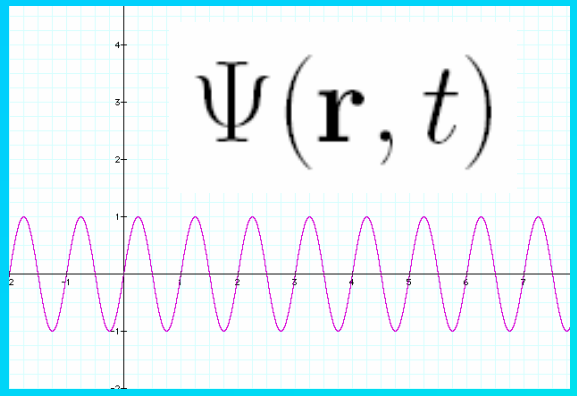
elektron sebessége kb. 2700 Km/sec

szabadúthossz < a biliárd méreténél

- nagy tisztaság
- alacsony hőmérséklet

Kvantumfizika

de Broglie-hullám:



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

Planck-állandó

elektron sebessége

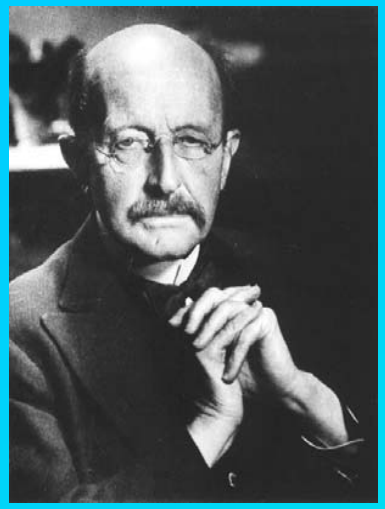
$|\Psi|^2$ Az elektron megtalálási valószínűsége

Schrödinger-egyenlet $\longleftrightarrow$ lemez mozgása

$\updownarrow$ $\updownarrow$

$\Psi(\mathbf{r},t)$ hullámfüggvény $\longleftrightarrow$ u($\mathbf{r}$,t) a lemez kitérése

Kvantumfizika

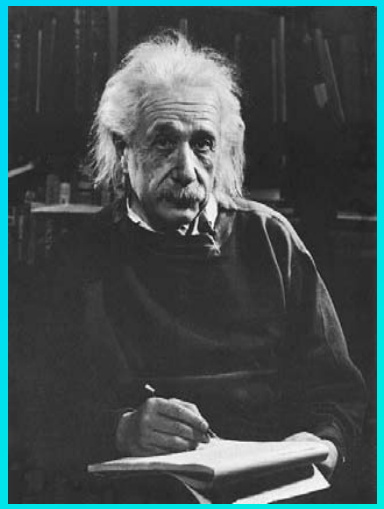


Max **Planck**
(1858-1947)

Niels **Bohr**
(1885-1962)

David **Hilbert**
(1862-1943)

Louis **de Broglie**
(1892-1981)



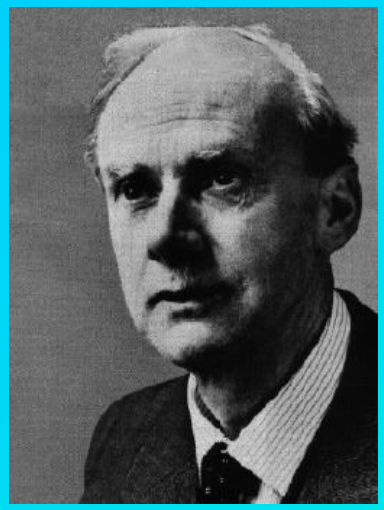
Albert **Einstein**
(1879-1955)

Erwin **Schrödinger**
(1887-1961)

Werner **Heisenberg**
(1901-1976)

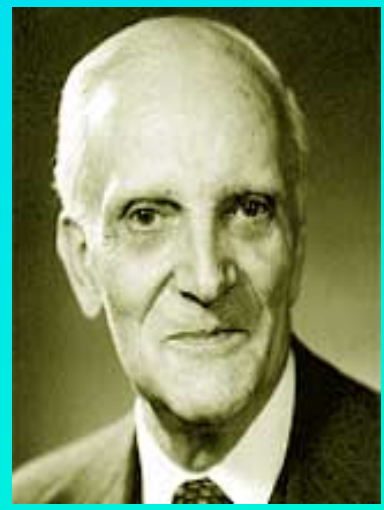
Wigner Jenő
(1902-1995)

Wolgang **Pauli**
(1900-1958)

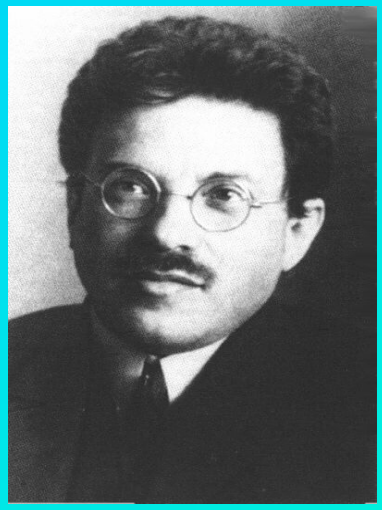


Paul **Dirac**
(1902-1984)

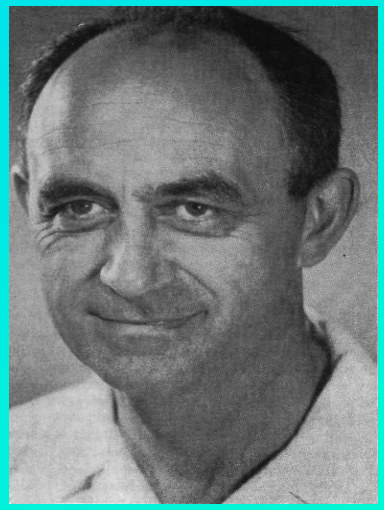
Neumann János
(1903-1957)



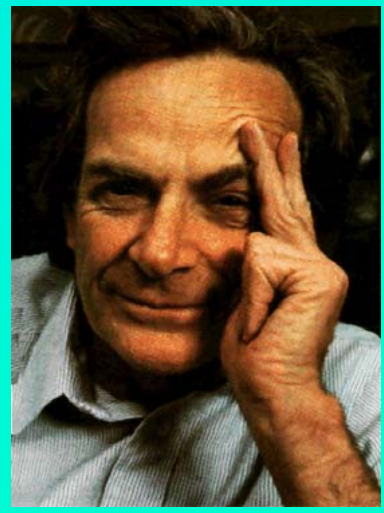
Leon **Brillouin**
(1889-1969)



Paul **Ehrenfest**
(1880-1933)

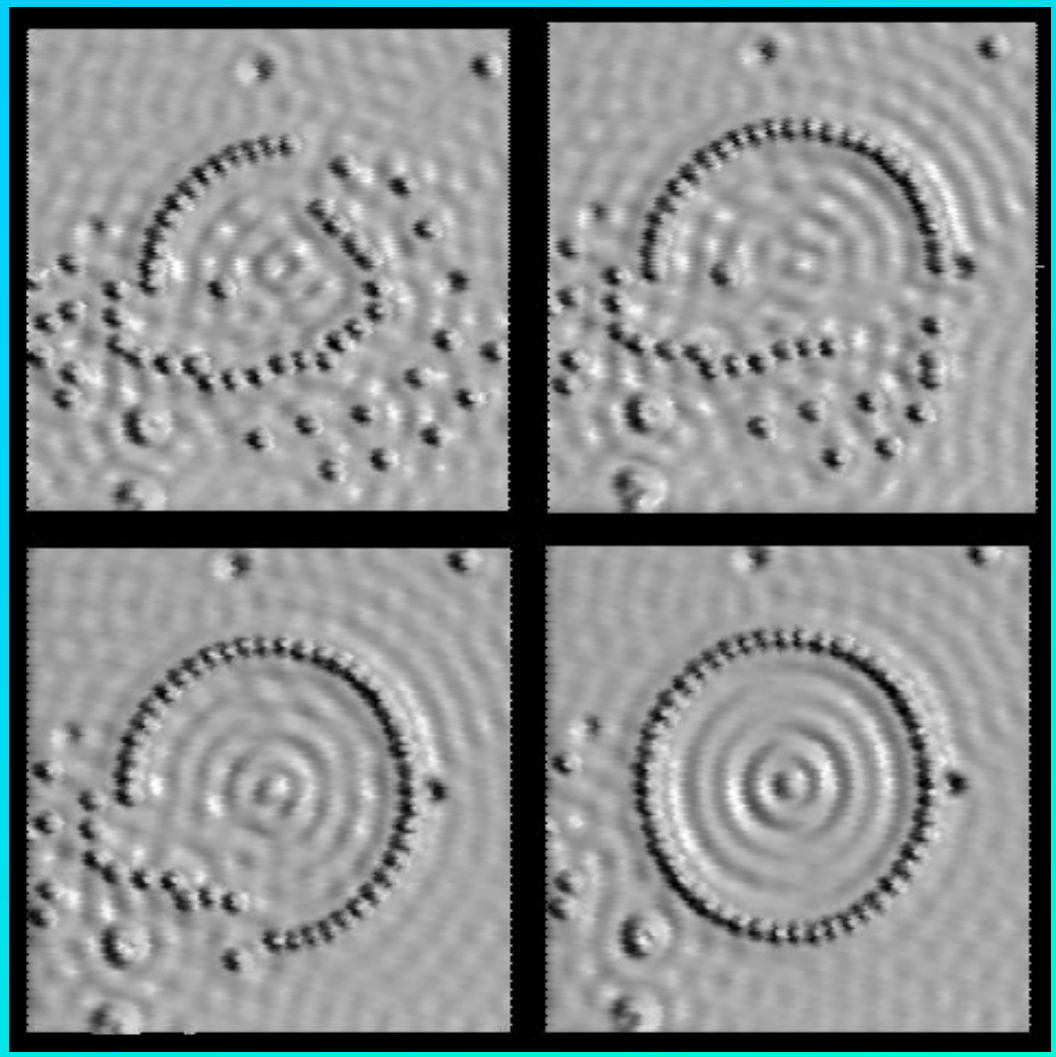


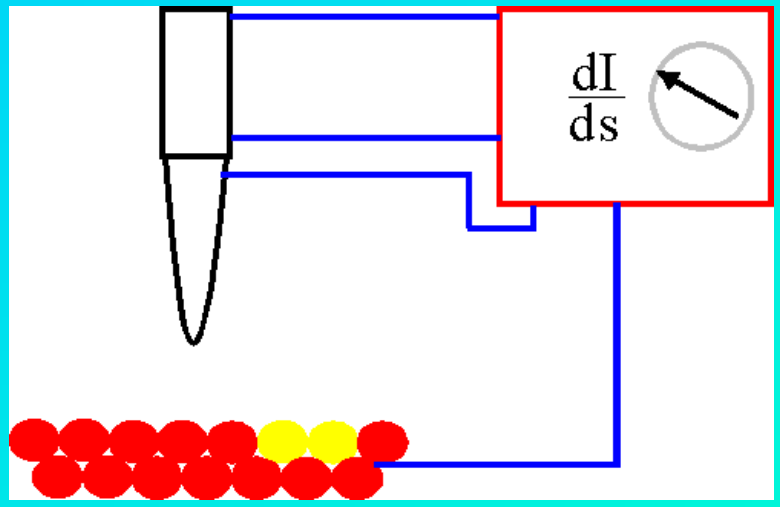
Enerico **Fermi**
(1901-1954)

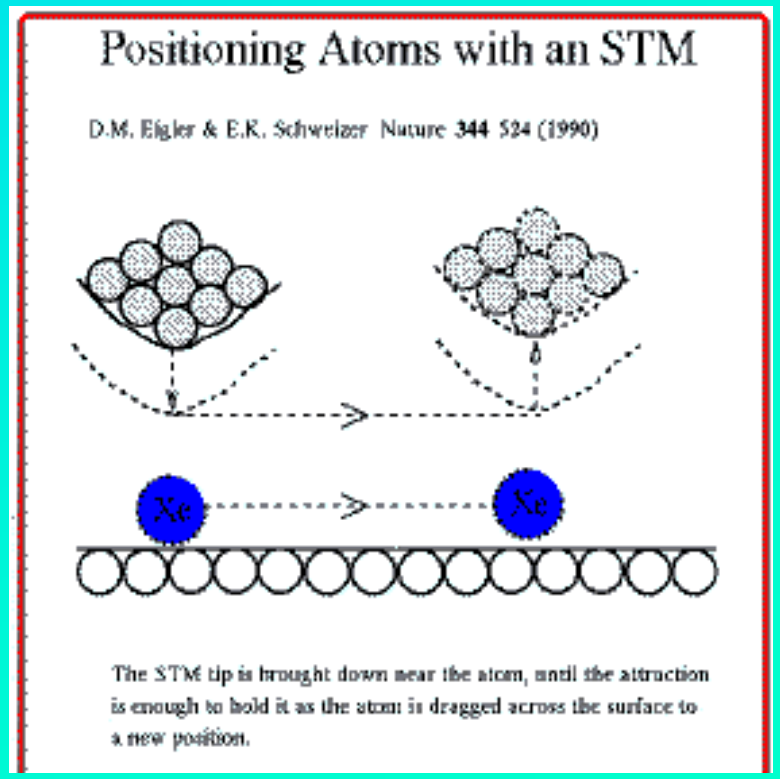


Richard Phillips **Feynman**
(1918-1988)

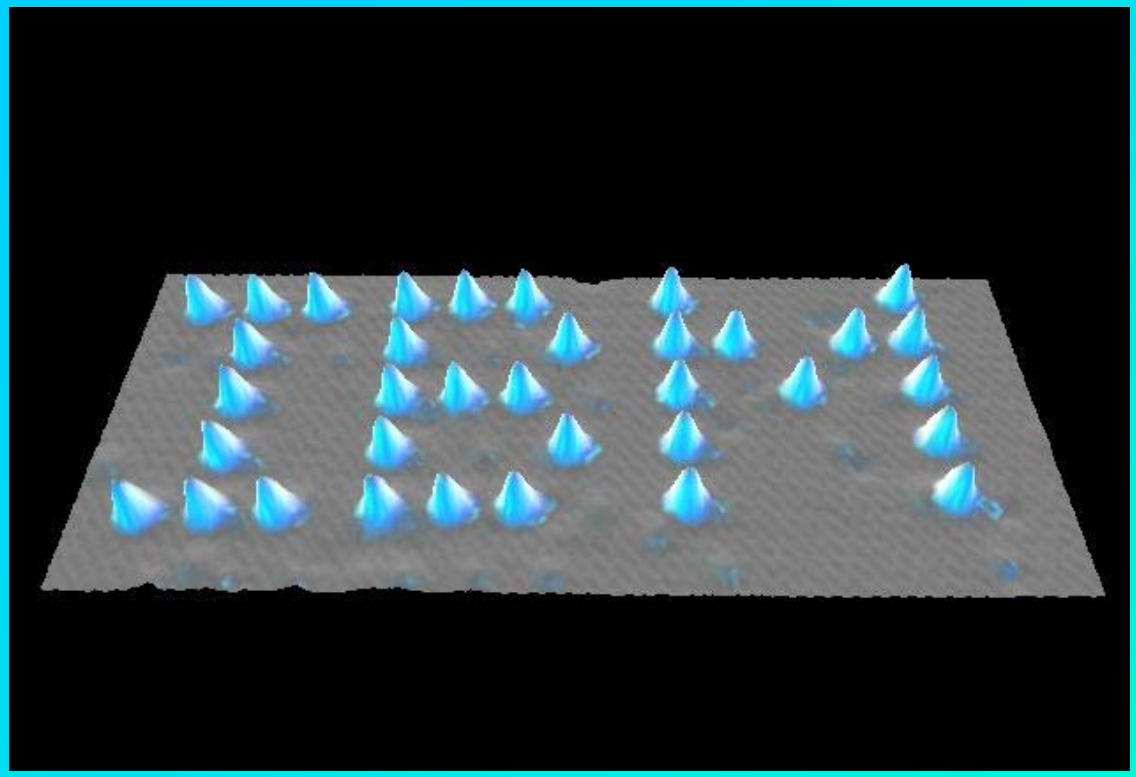
Pásztázó alagútmikroszkóp

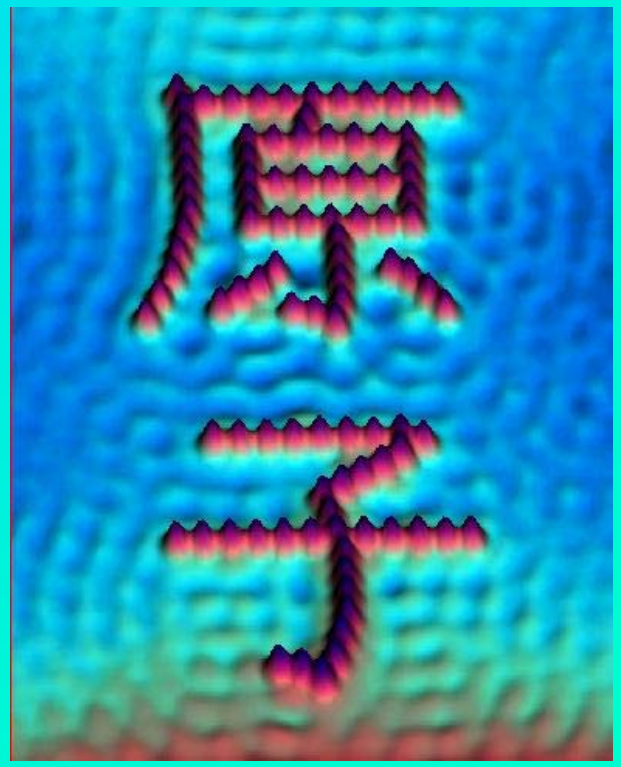






Atomok elhelyezése egy felületen



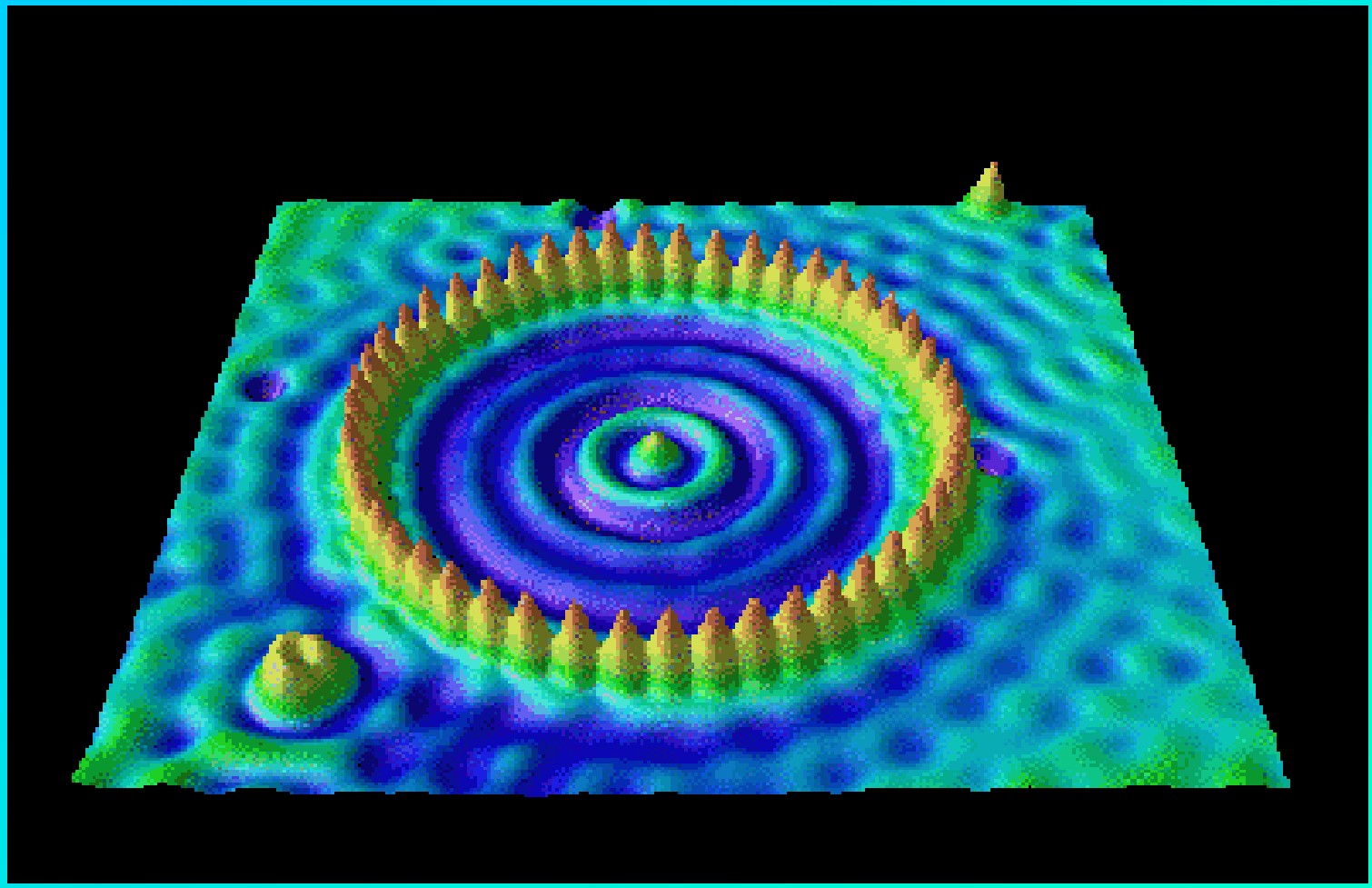


35 Xenon atom Nickel felületen,
He hőmérsékleten, IBM Zürich Research Laboratory 1990

Kvantum karám

Cu lapon elhelyezett 48 Fe atom egy R=71,8 A sugarú kör mentén

elektron-állóhullámok



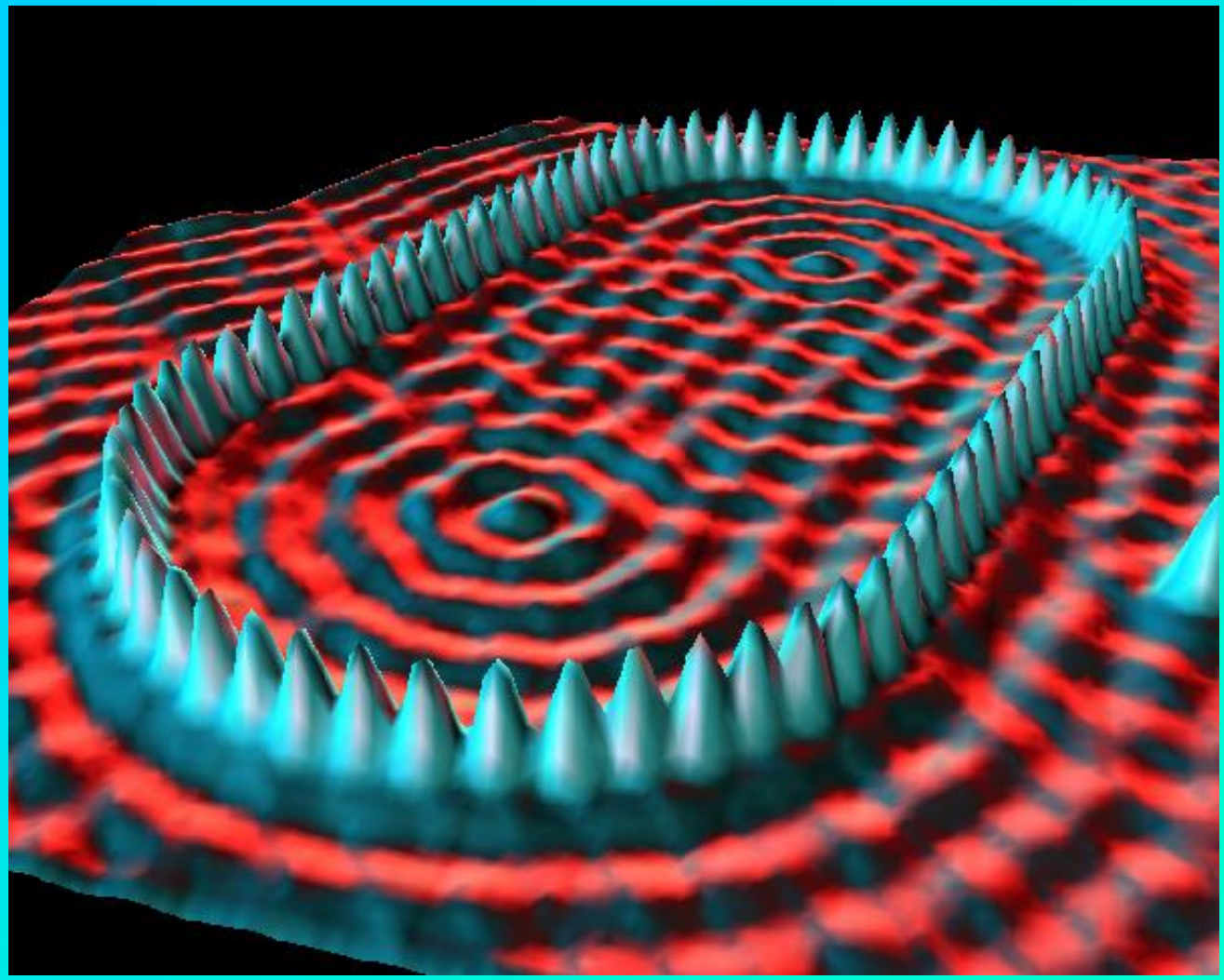
$|\Psi|^2$

mérése

M.F. Crommie, C.P. Lutz, D.M. Eigler. Confinement of electrons to quantum corrals on a metal surface. *Science 262, 218-220 (1993).*

Kvantum stadion

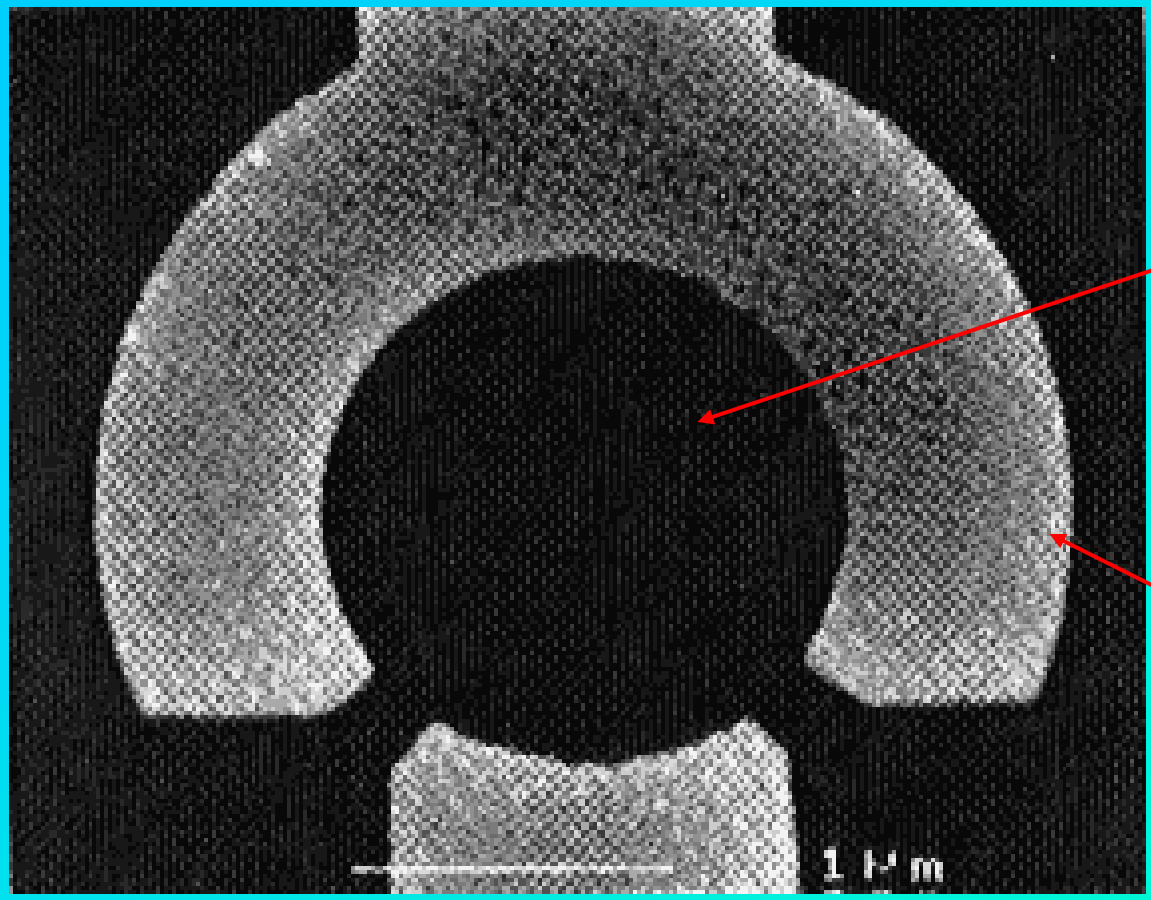
1995



M.F. Crommie, C.P. Lutz, D.M. Eigler, E.J. Heller. Waves on a metal surface and quantum corrals.
Surface Review and Letters 2 (1), 127-137 (1995).

Cs. J.: KÖMAL 2004. április szám

Mezoszkopikus biliárd



elektronok 2 dimenzióban

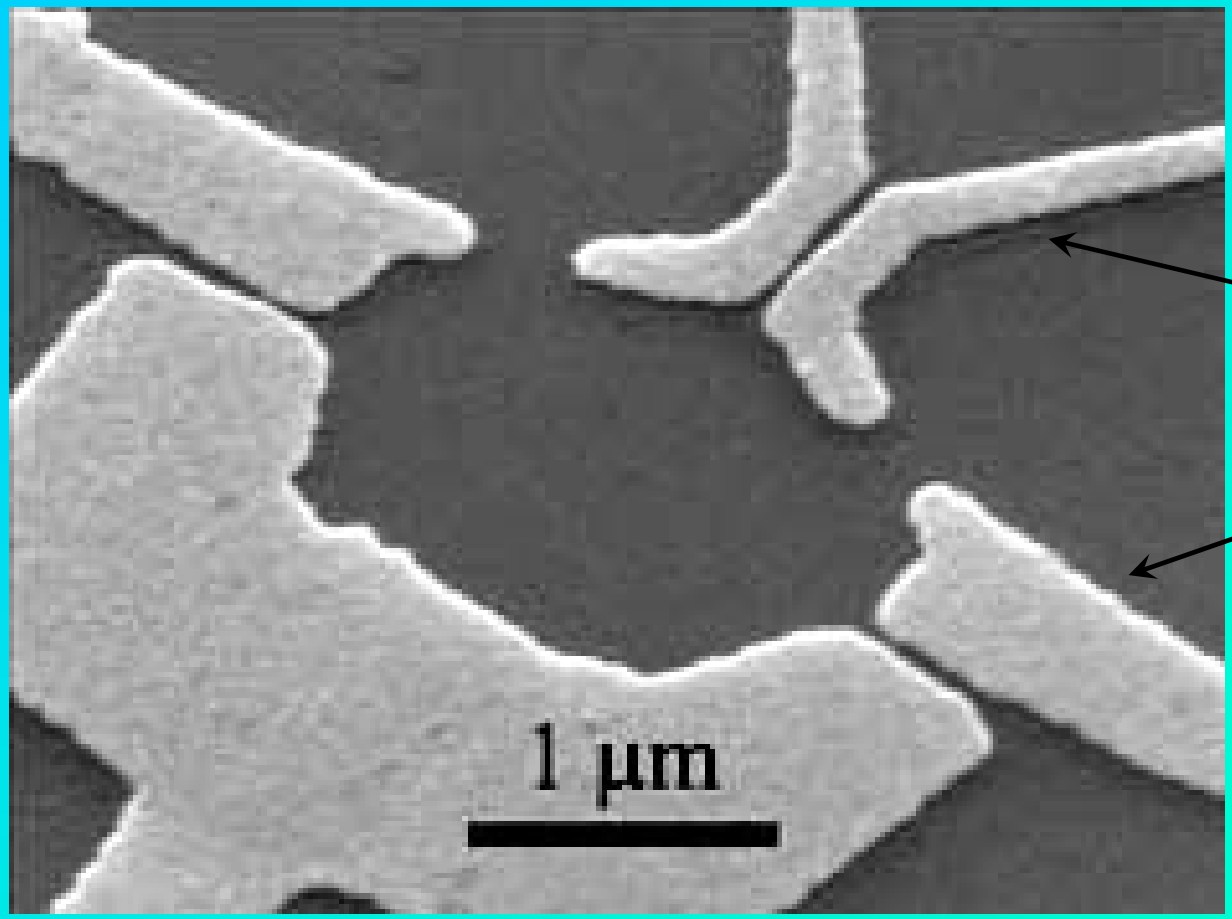
elektródák

Az elektron a fekete tartományban mozog,
elkerülve az elektródákat

1994

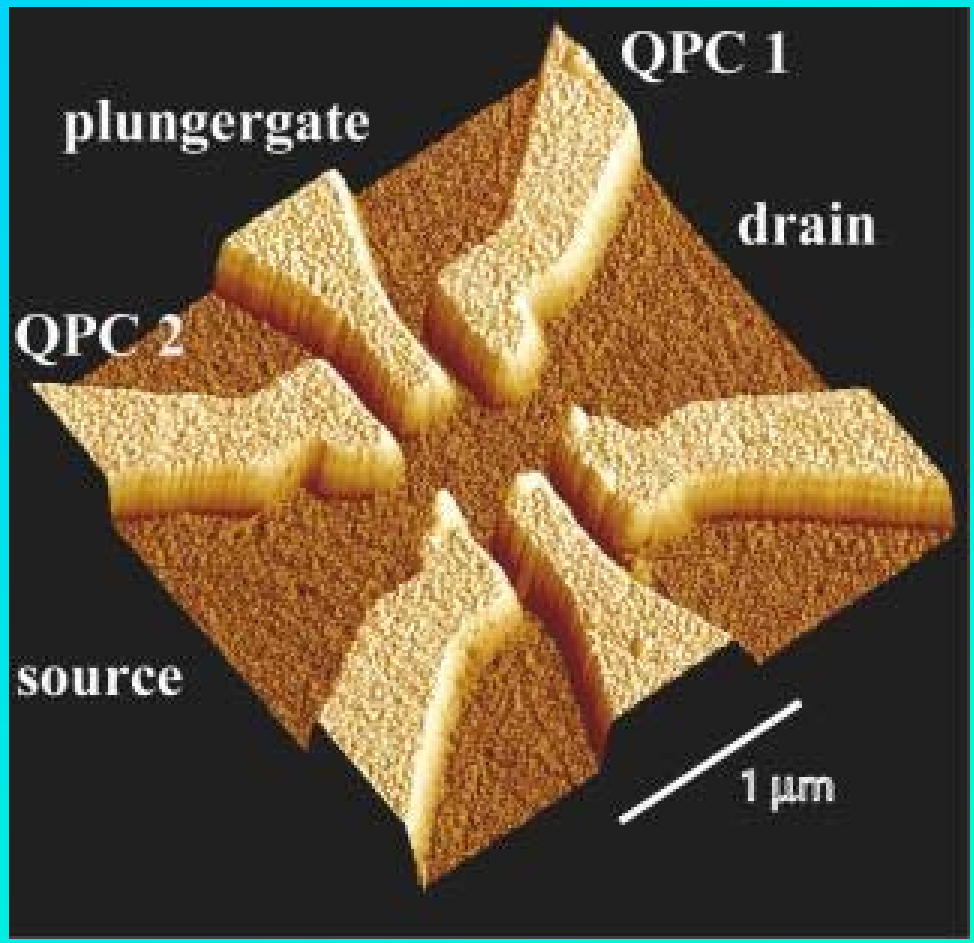
Kvantum pöttyök

Elektron mozgása kétdimenzióban
GaAs félvezető-rétegszerkezetben

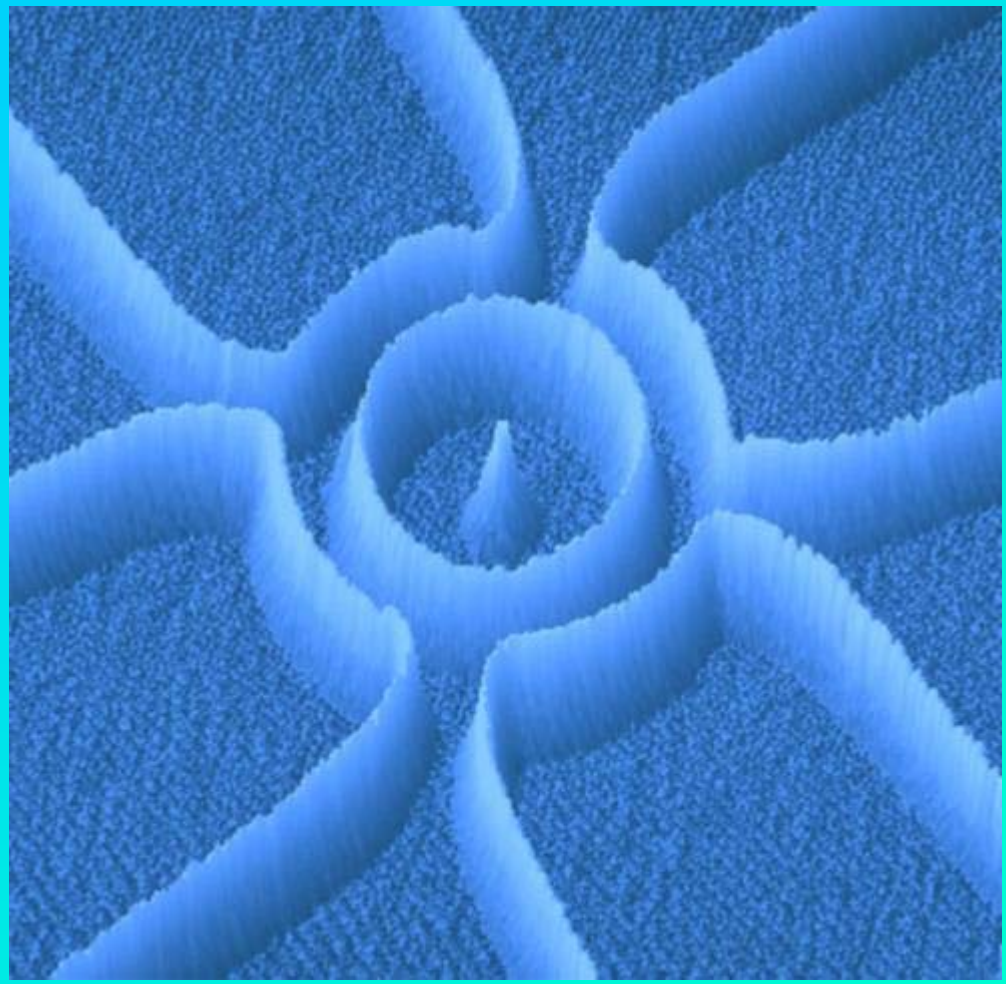


Negatívan
töltött elektrodák

Kvantum pöttyök

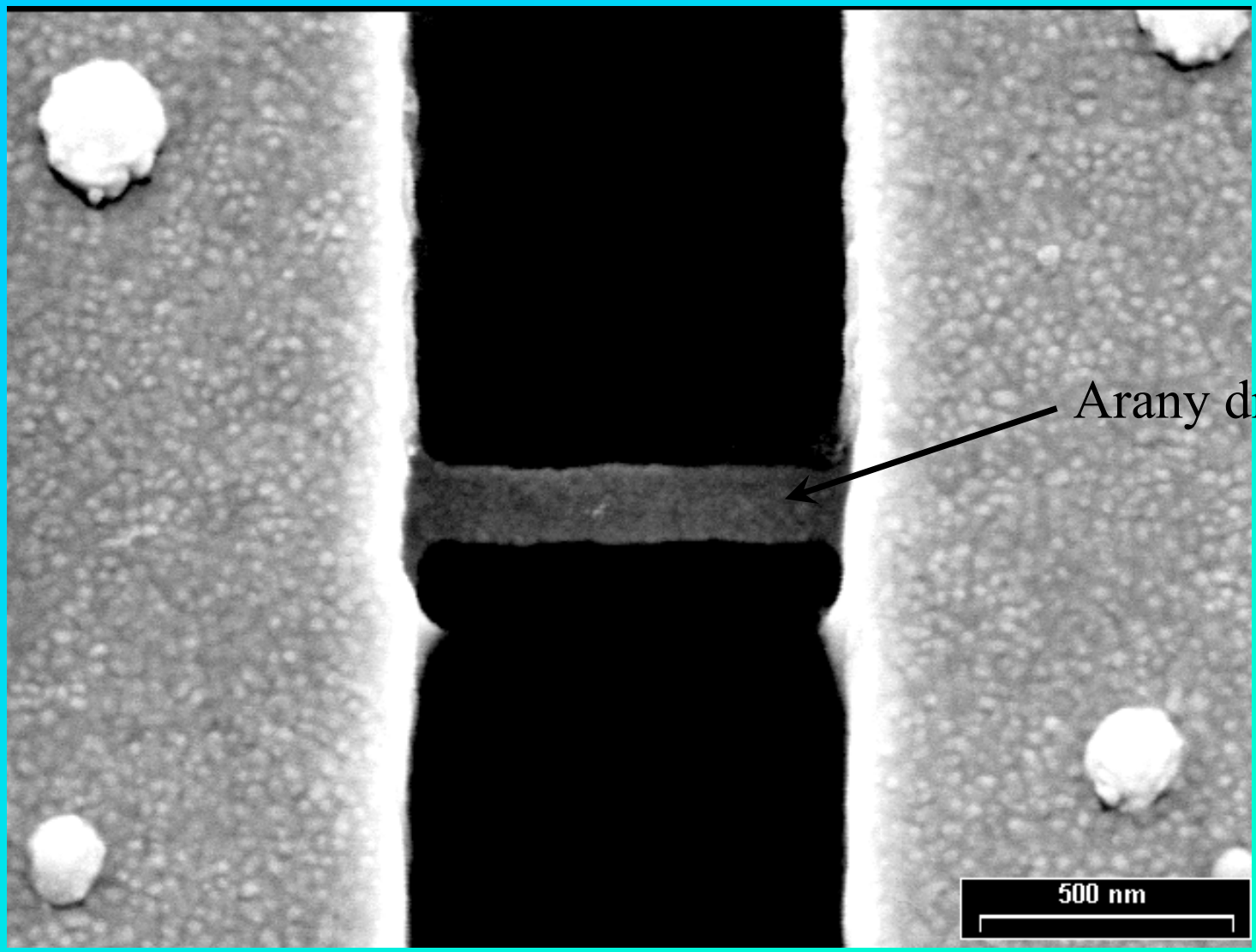


Kvantum gyűrűk

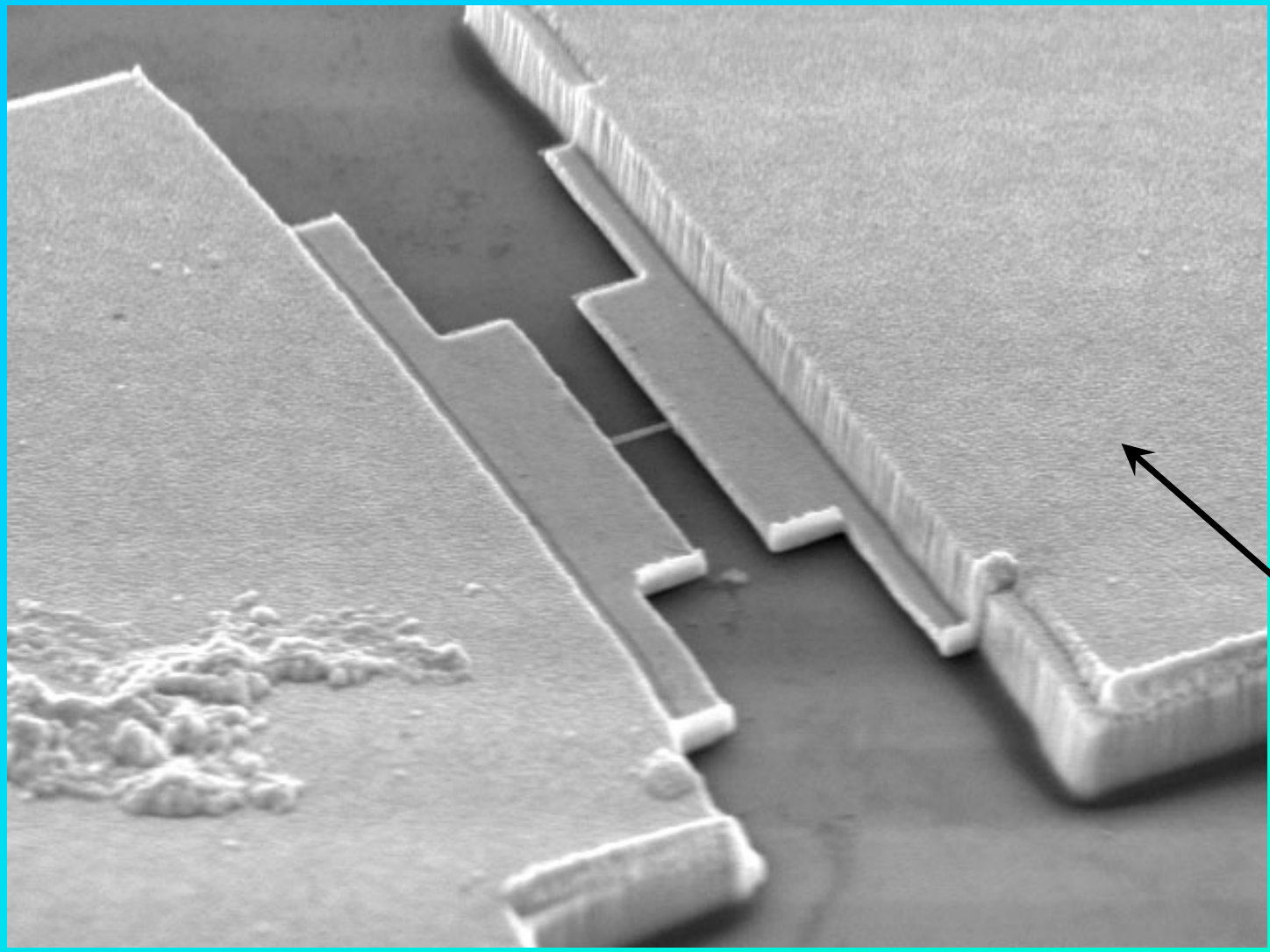


NCCR Nanoscale Science
Institute of Physics, University of Basel

Nanodrótok



áram kb. 0,1 mA

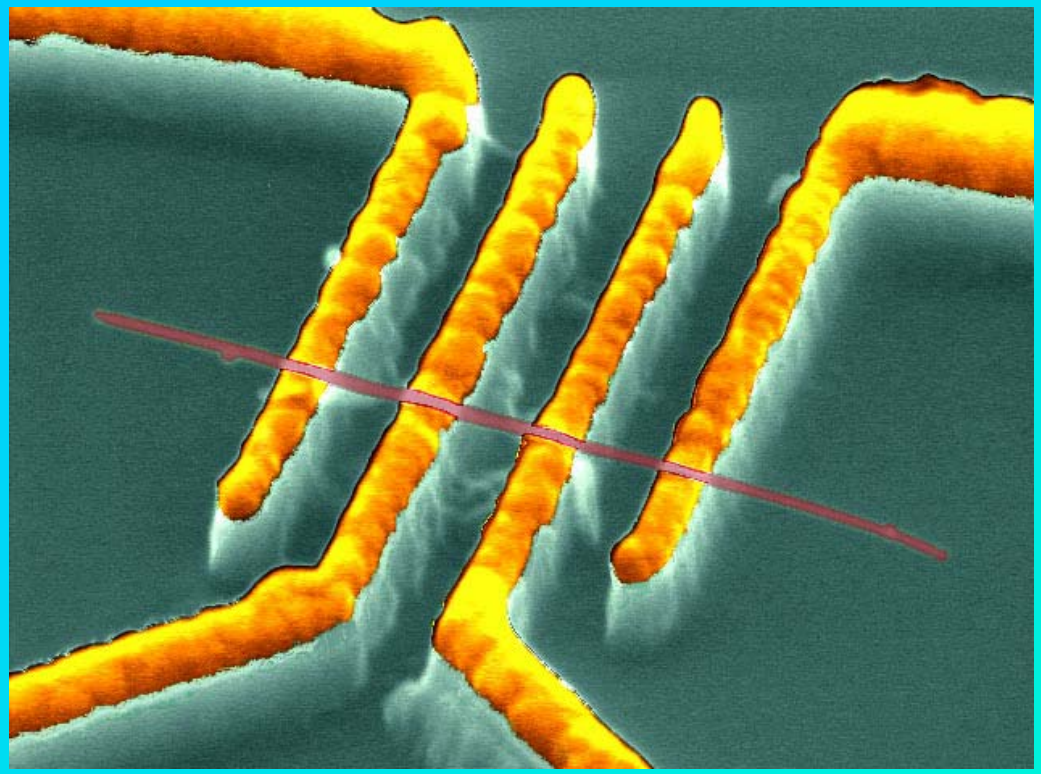


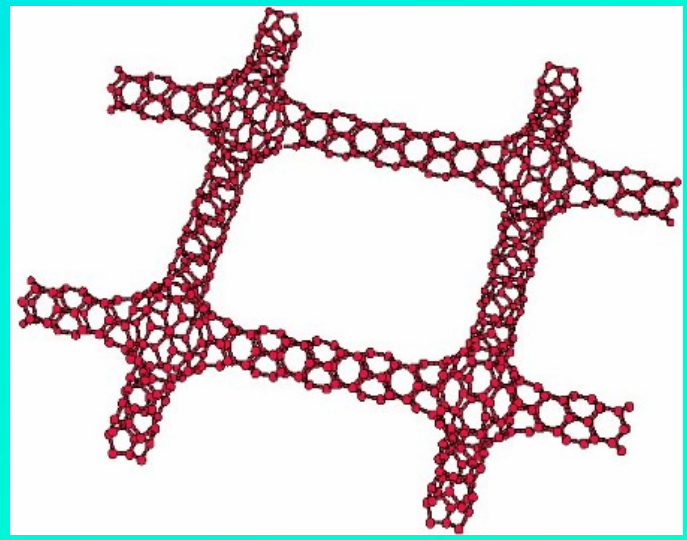
Hőmérséklet
270 mK

Cu tömb

100 nm széles, 1 mm hosszú Au drót

Szén nanocsövek

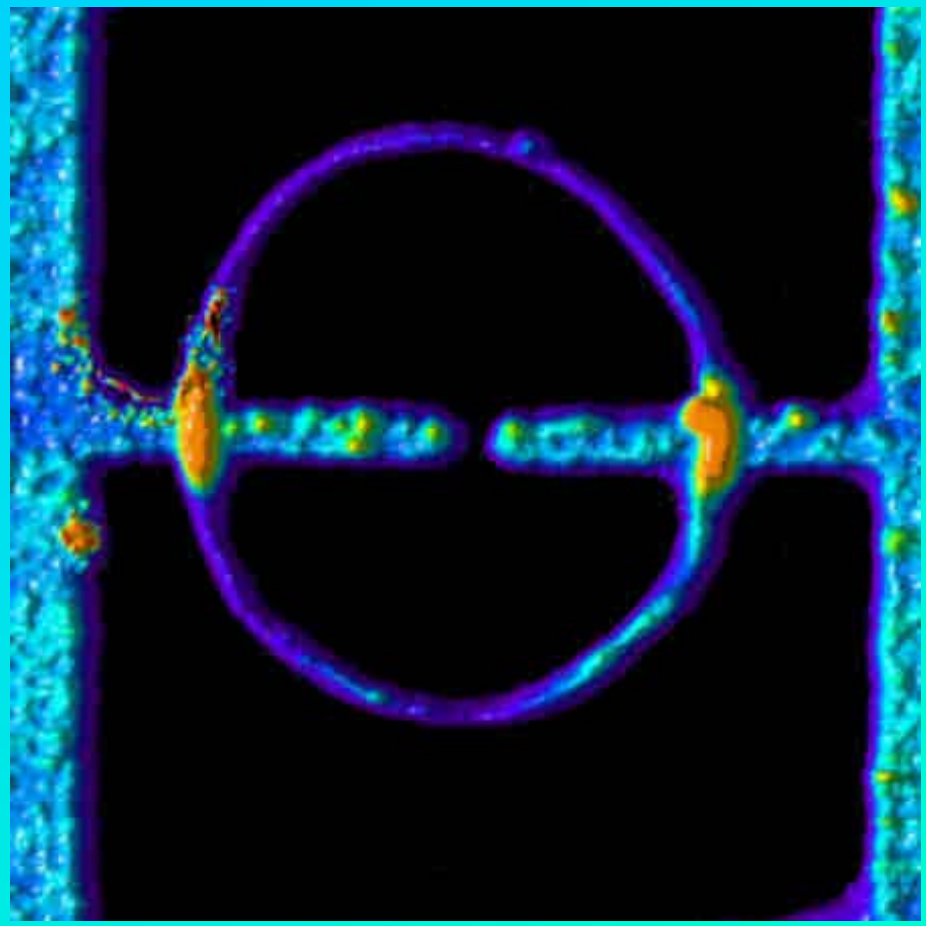




Kürti Jenő: Szén nanocsövek: mik azok és mire jók?
(Az atomoktól a csillagokig)

Szén nanocsőből készült karika

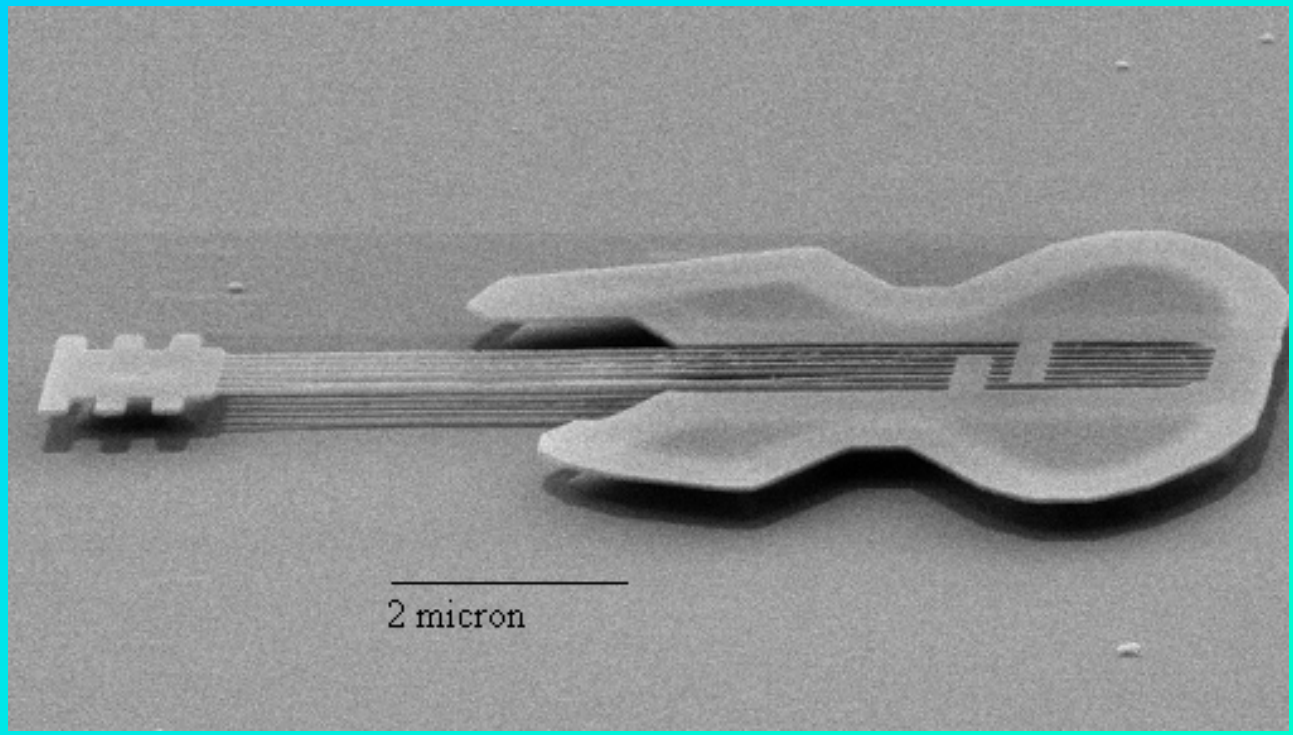
R = 700 nm



Electrical Transport in Rings of Single-Wall Nanotubes: One-Dimensional Localization"
Phys. Rev. Lett. 84 (19) 4441. 8 May 2000

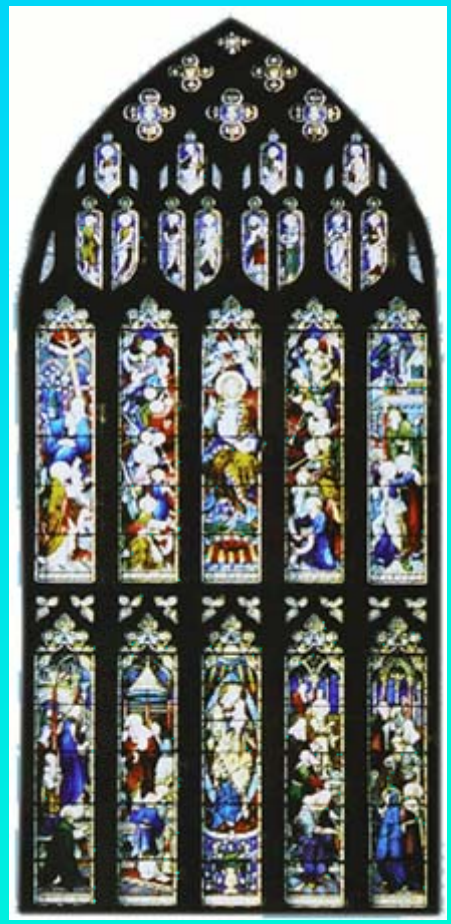
Nano gitár

A világ legkisebb gitárja, hossza 10 μm = 1/100 mm,
a hajszál vastagságának 20-ad része!



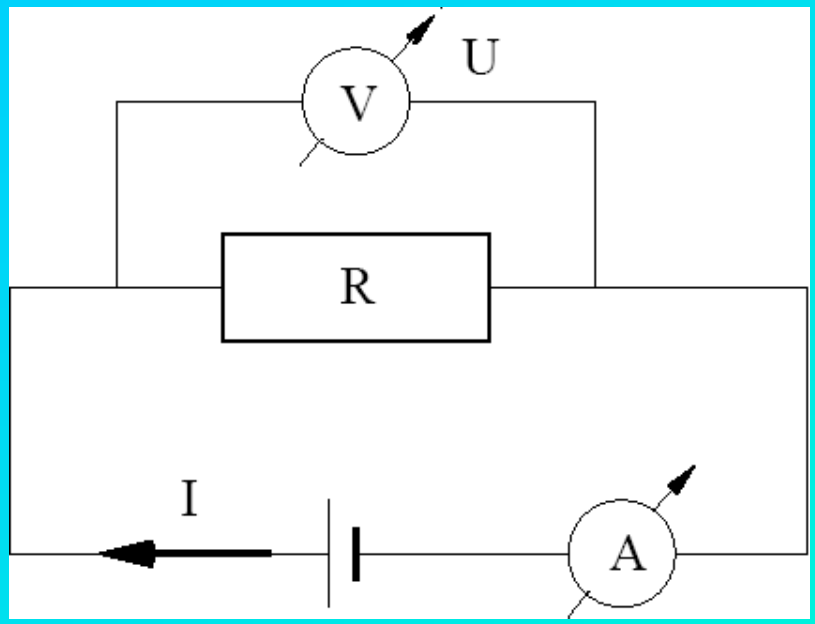
Templomok színes ablakai

Nanométer méretű fém szemcséket kevertek az üvegbe



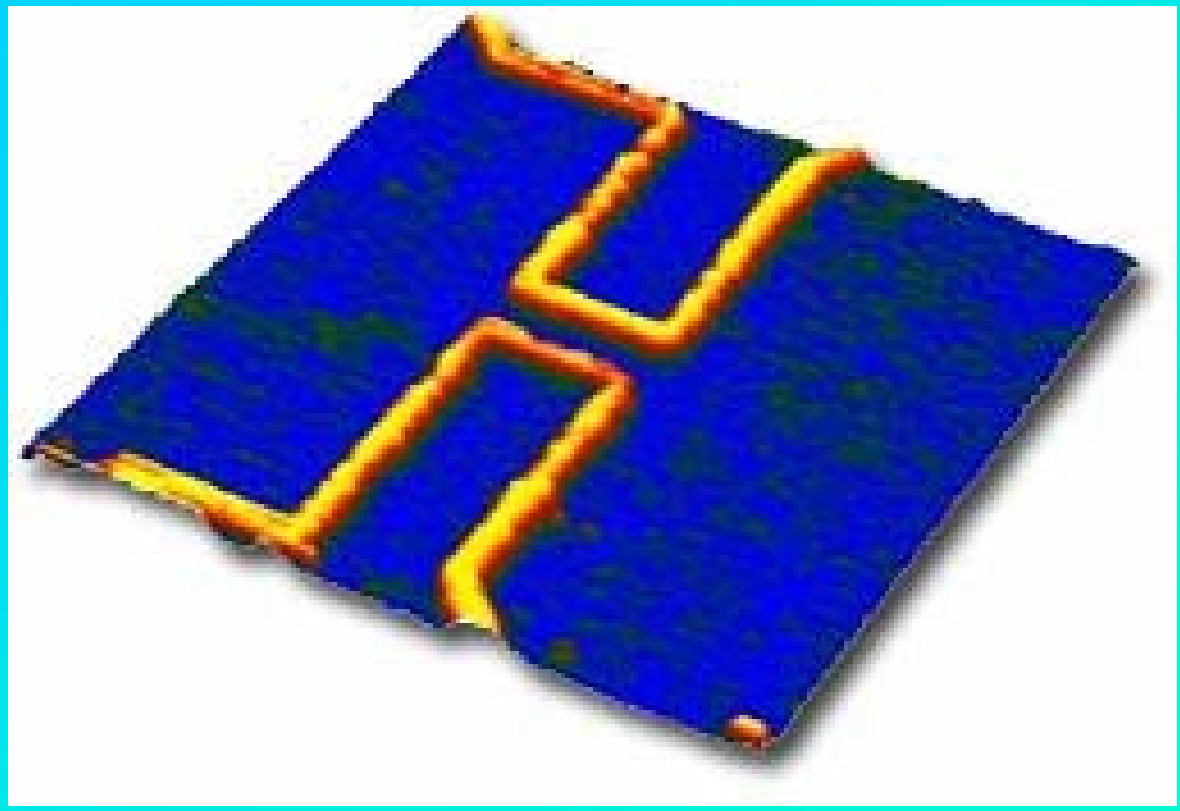
Már a 10. században alkalmazták

Ohm-törvénye
Az ellenállás



$$R = \frac{U}{I}$$

Nem igaz az Ohm-törvény a nanofizikában!



Ellenállás kvantum

$$R = \frac{1}{N}\frac{h}{2e^2}$$

Planck-állandó

Egész szám

Elektron töltése

$$\frac{h}{2e^2} = ?$$

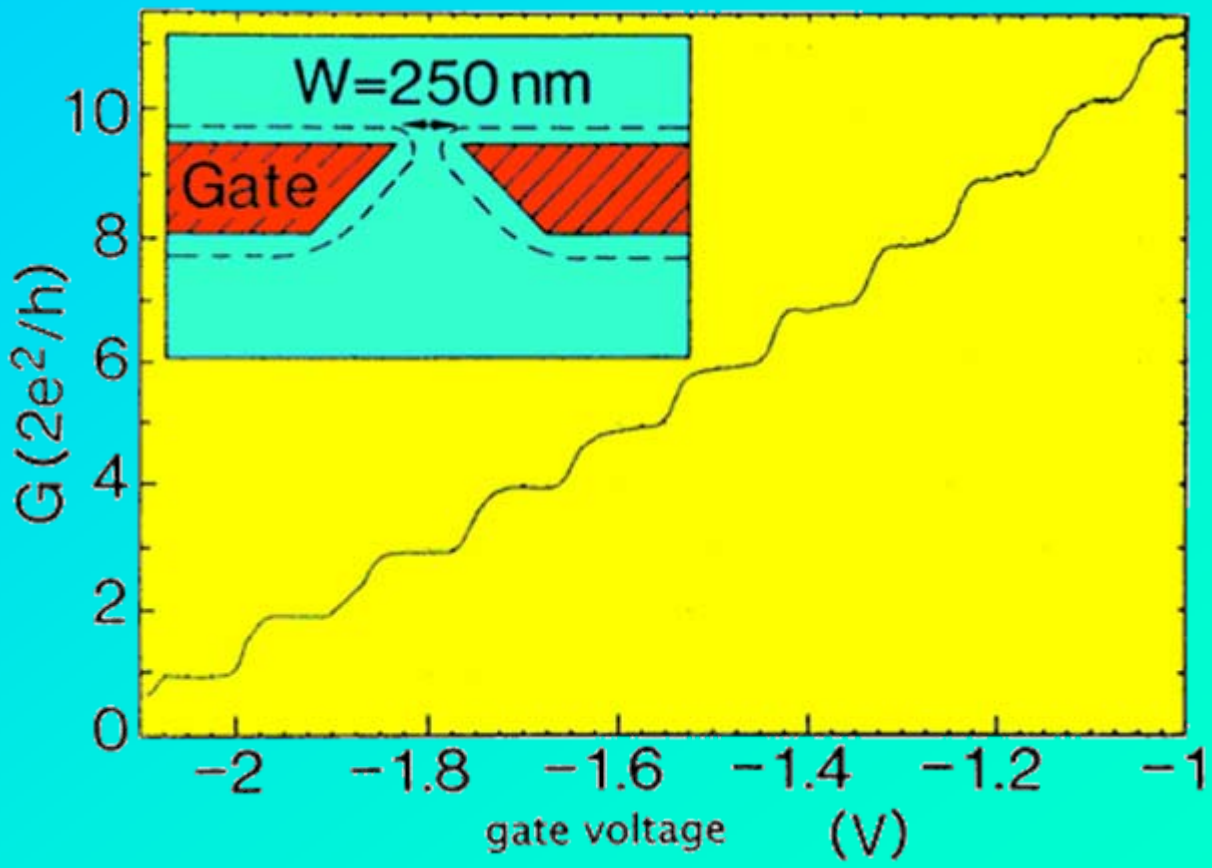
$$\frac{h}{2e^2} = 12906\,\Omega = 12{,}906\,k\Omega$$

Az első mérés

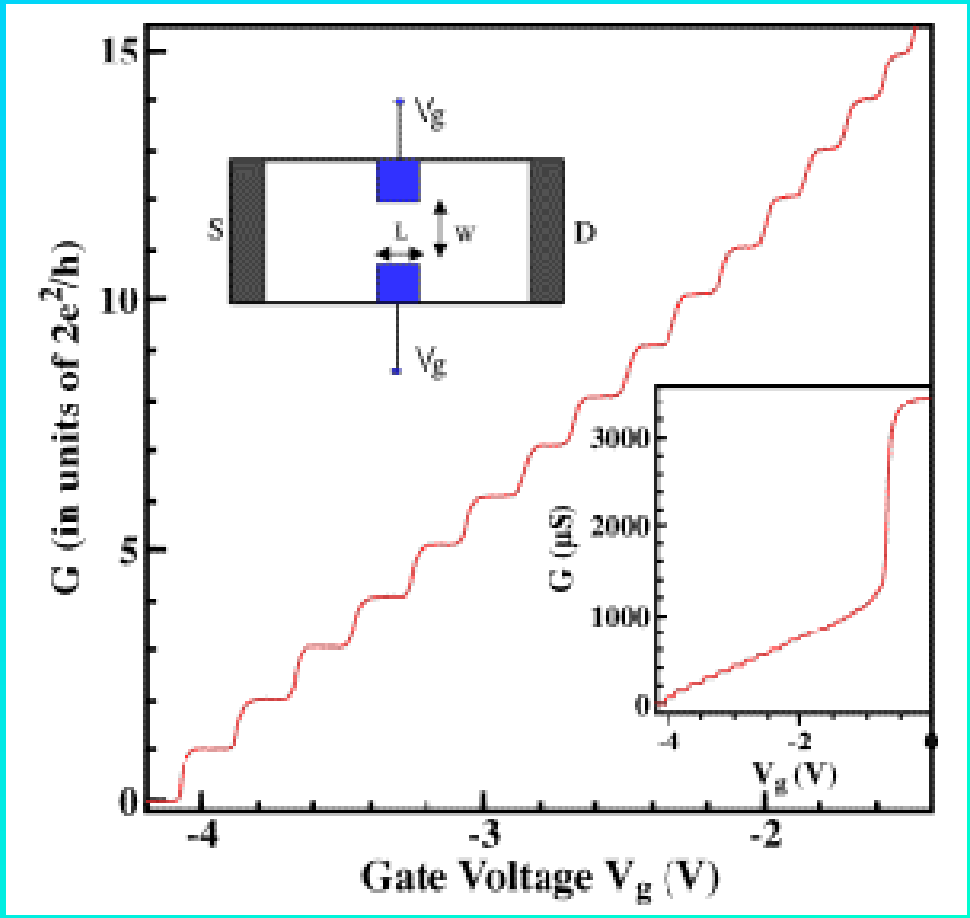
1988

Vezetőképesség,
az ellenállás reciproka

$$G = \frac{1}{R} = N\frac{2e^2}{h}$$



B. J. van Wees et al., *Phys. Rev. Lett.* **60,** 848 (1988)


15
10
5
0
-4
-3
-2
G (in units of 2e²/h)
Gate Voltage V_g (V)
V_g
S
L
W
D
V_g
3000
2000
1000
0
G (μS)
-4
-2
V_g (V)

Adattárolás

„There's Plenty of Room at the Bottom."

Richard Feynman, 1959

100 atom → 1 bit információ

0,1 mm élű kocka → Világ összes írott anyaga

KÁROLYHÁZY FRIGYES

IGAZ VARÁZSLAT

GONDOLAT ZSEBKÖNYVEK

„Napjainkban bontakozik ki a hatékony logikát és harmonikus szépségélményt kináló természettudományos világkép.”

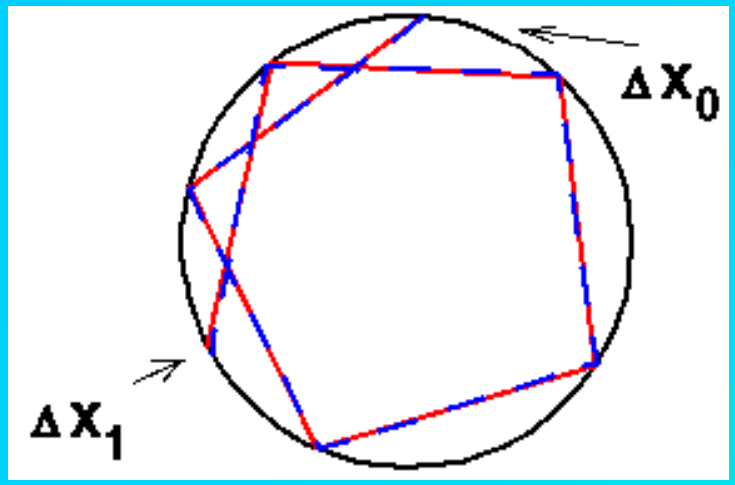
Marx György: Életrevaló atomok

„Hogy átsző mindent az Egész!
Egyik a másikba hat s tenyész!”

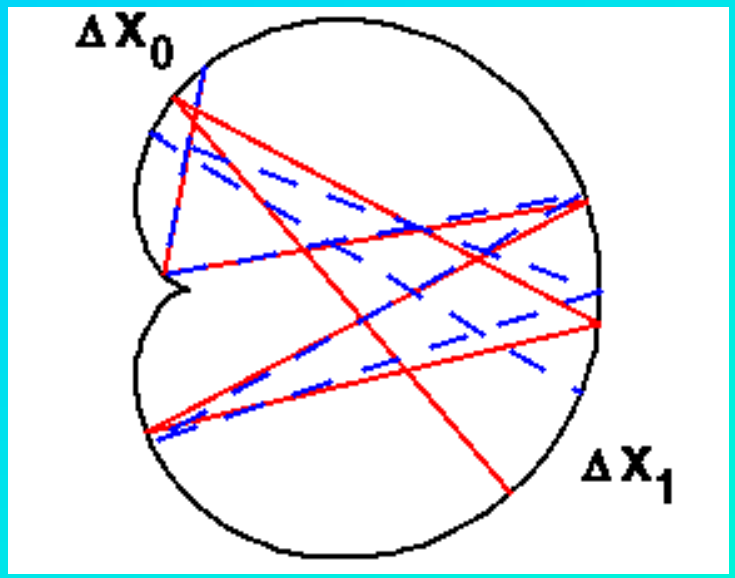
Goethe: Faust (Jékely Zoltán fordítása)

„A kvantummechanikáról szólni száz oldalon olyan feladat, mint egy induló vonat ablakából szerelmet vallani.”

Károlyházi Frigyes: Igaz varázslat

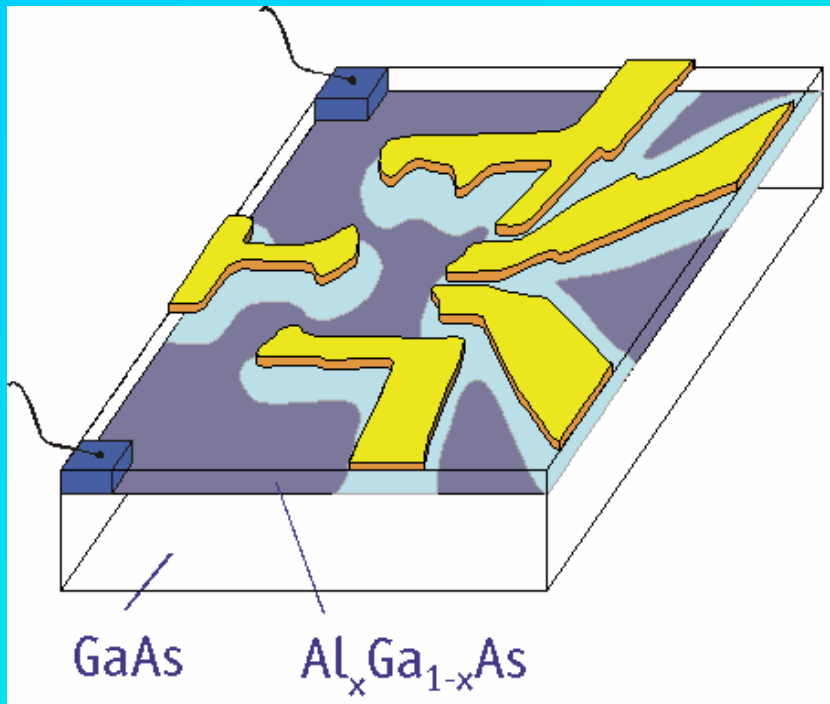


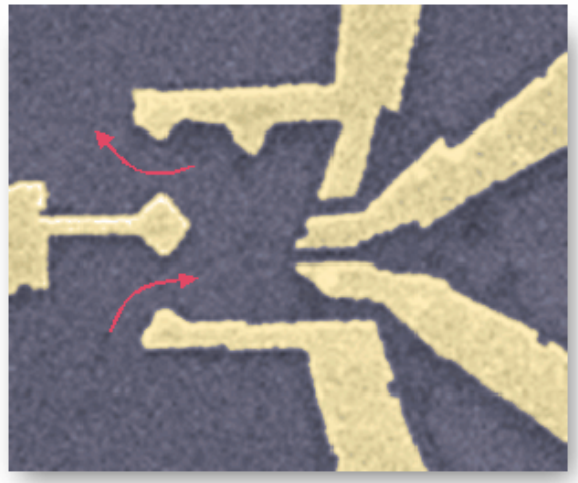
Nem érzékeny
a kezdőfeltételre



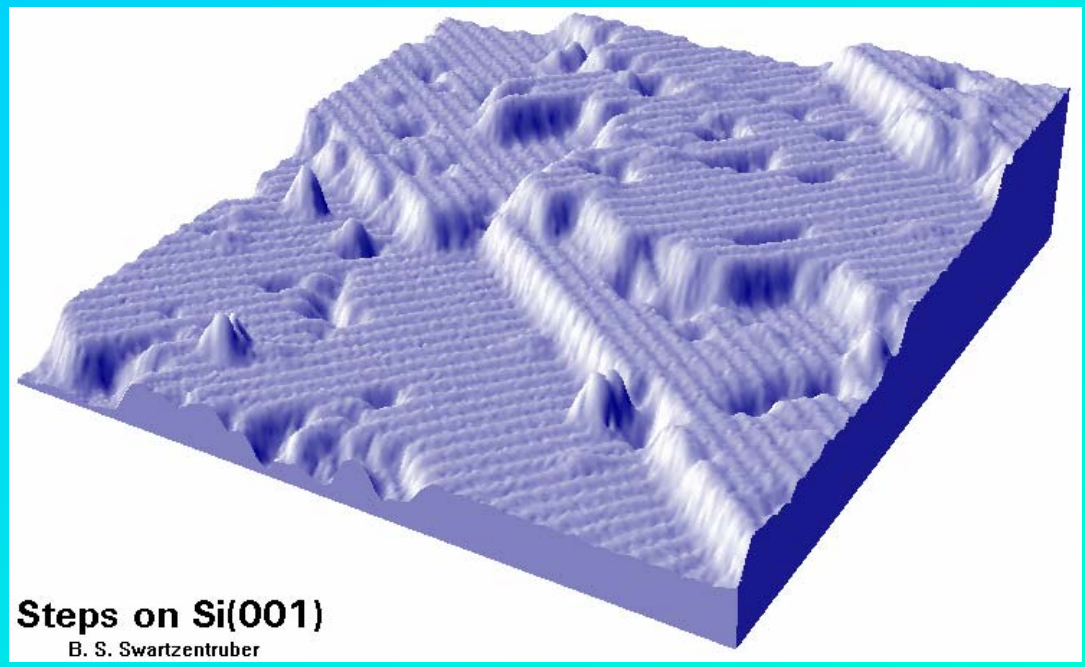
Érzékenység
a kezdőfeltételre

Kaotikus biliárd



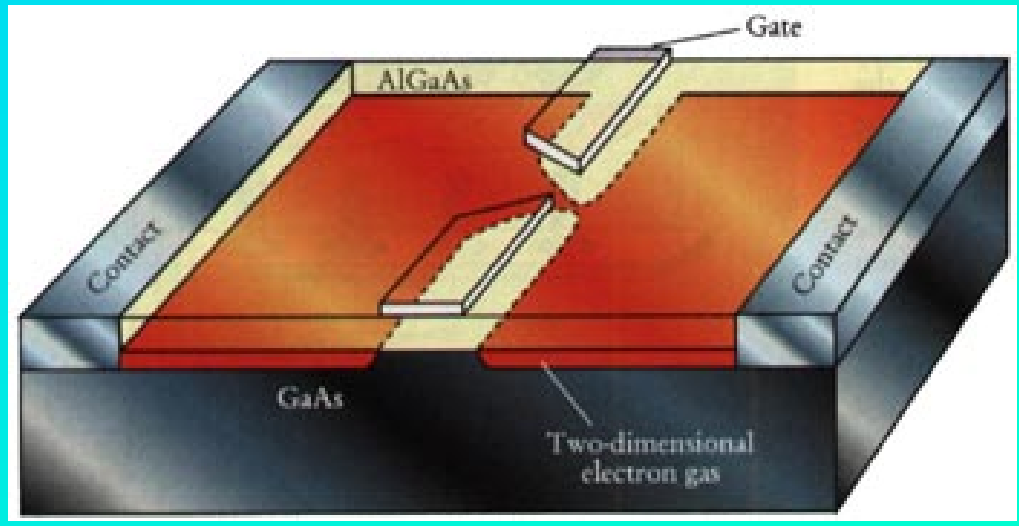


1μm

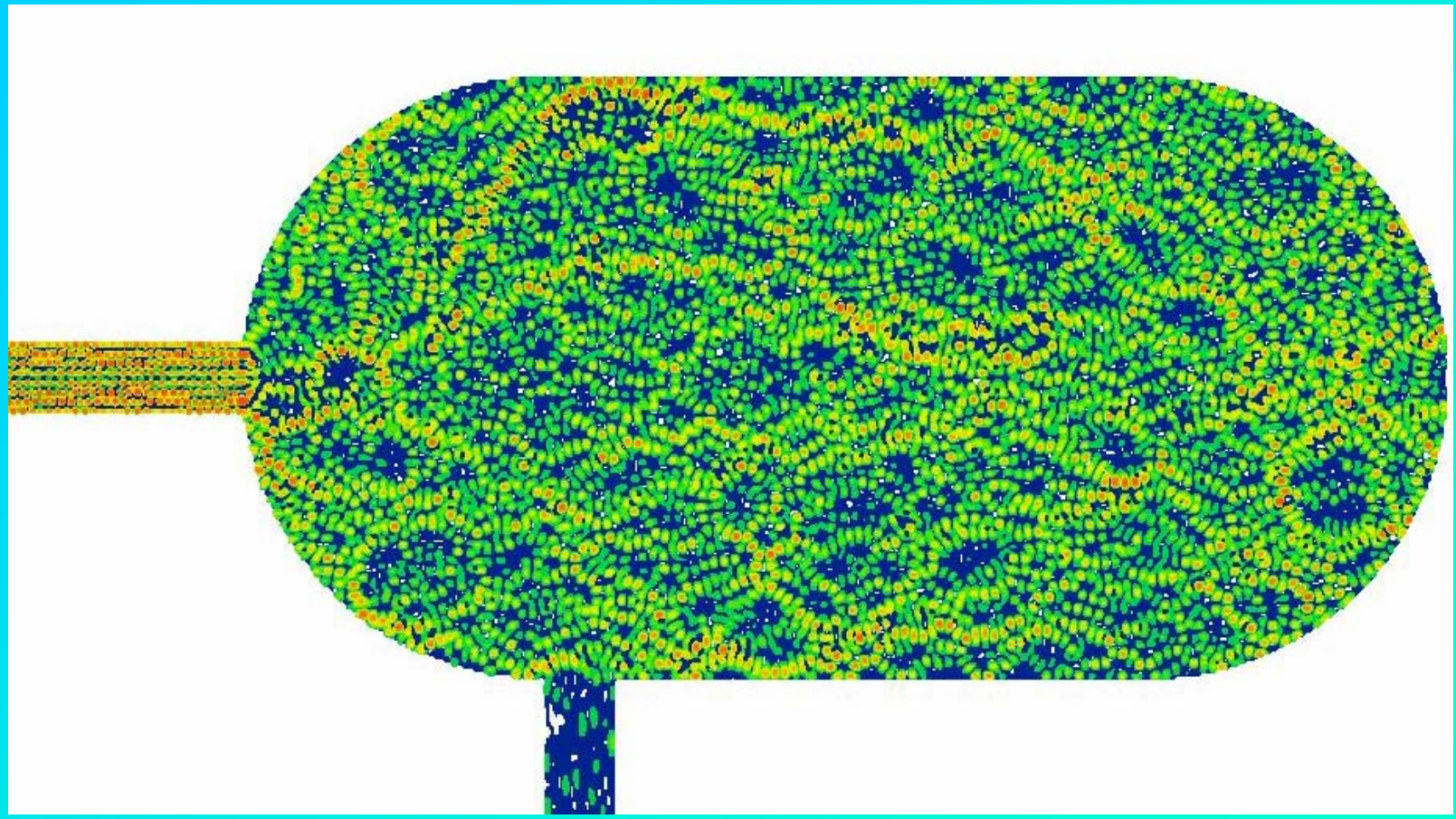


Steps on Si(001)

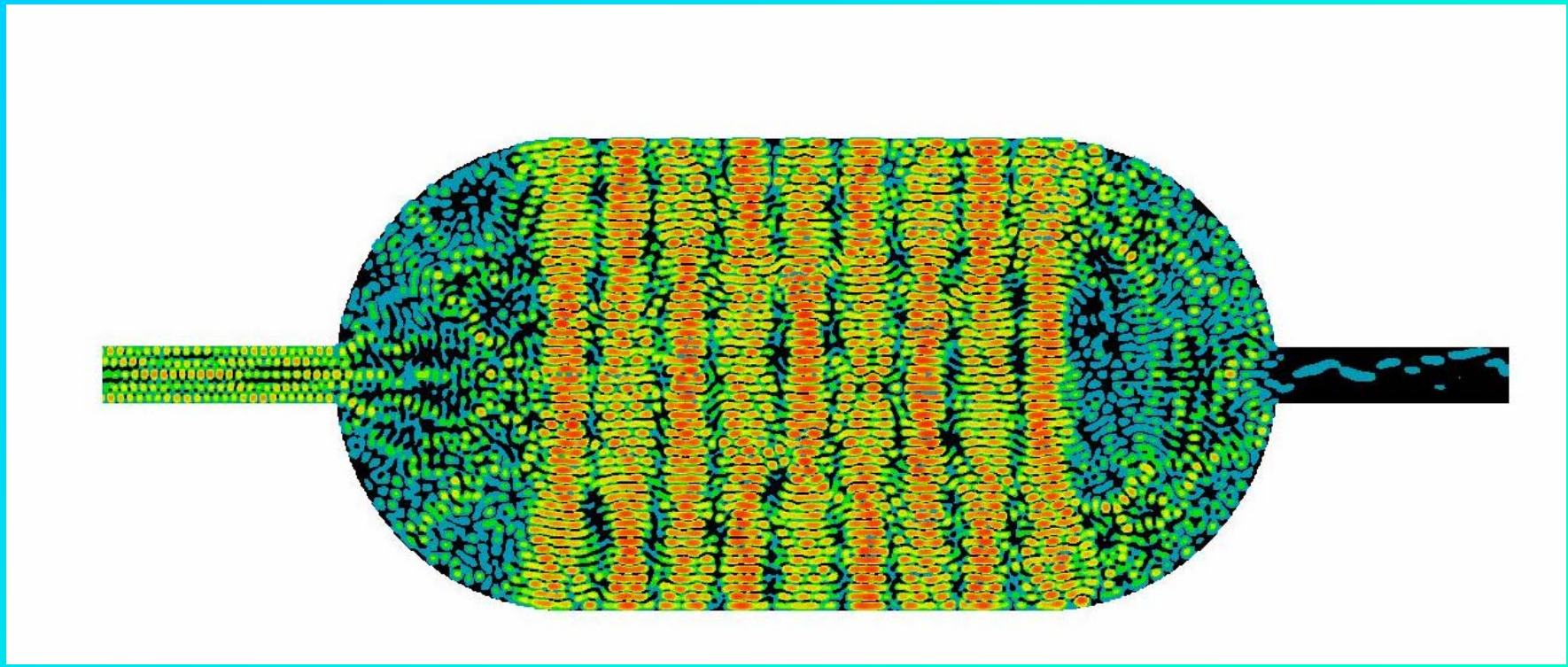
B. S. Swartzentruber


Gate
AlGaAs
Contact
Contact
GaAs
Two-dimensional
electron gas

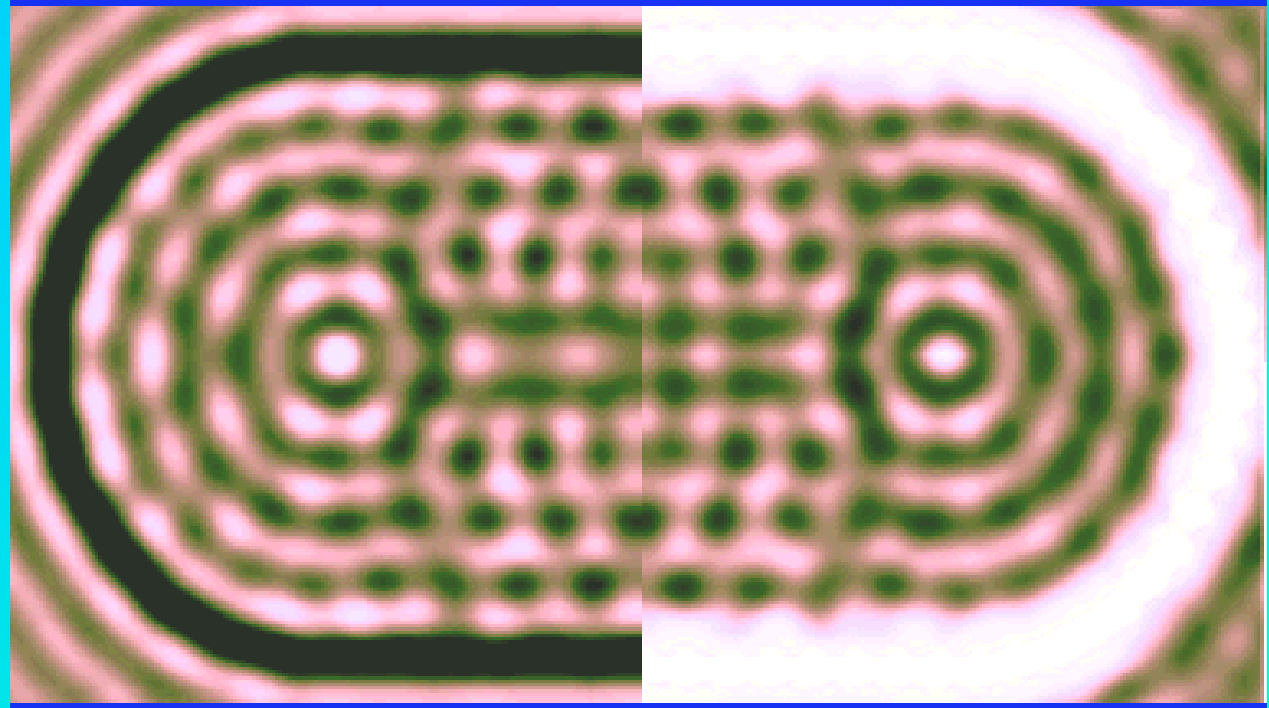
Hullámfüggvény stadionban



Pattogó módus



Theory Experiment



STM Image of 76 Atom Corral