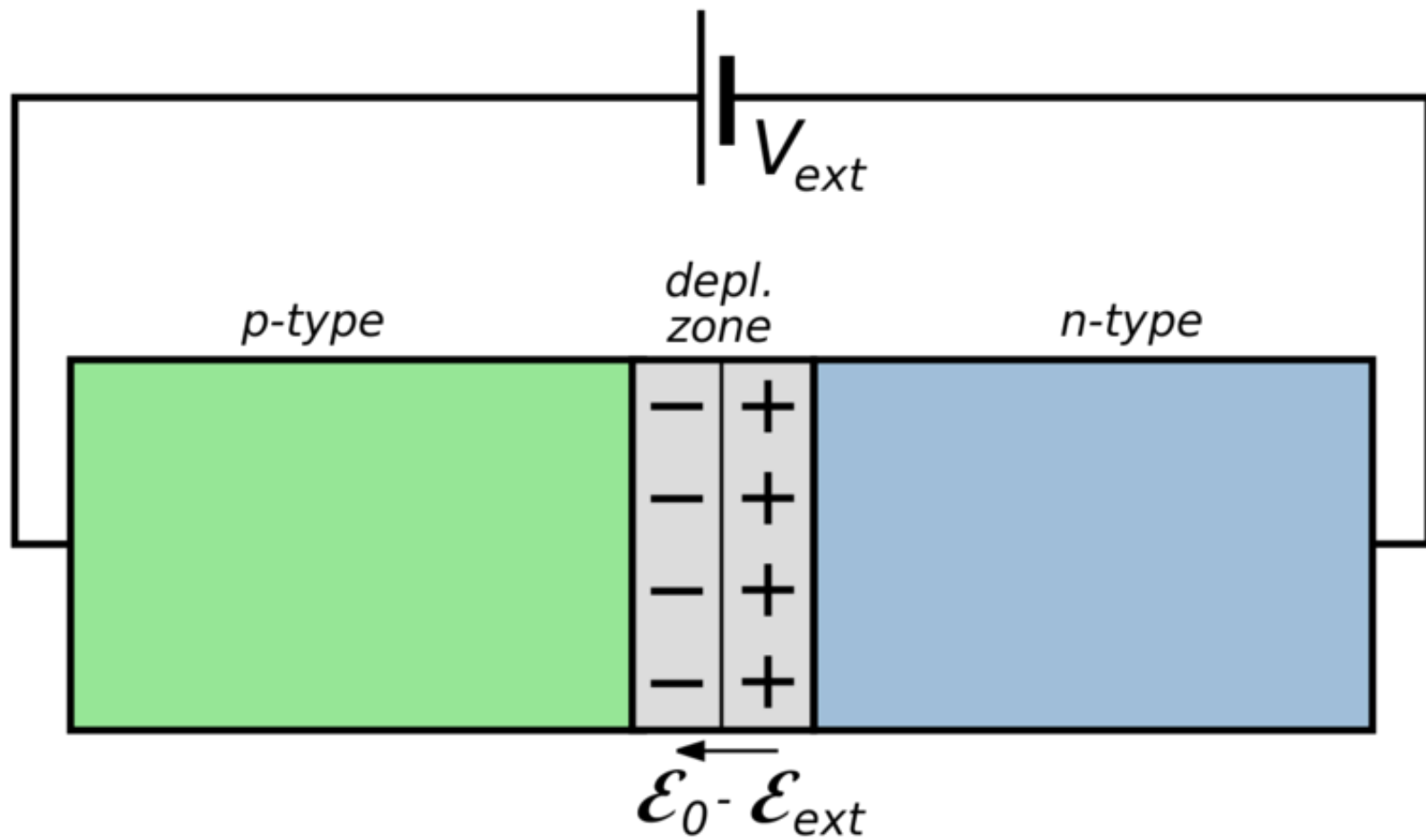


PN átmenet



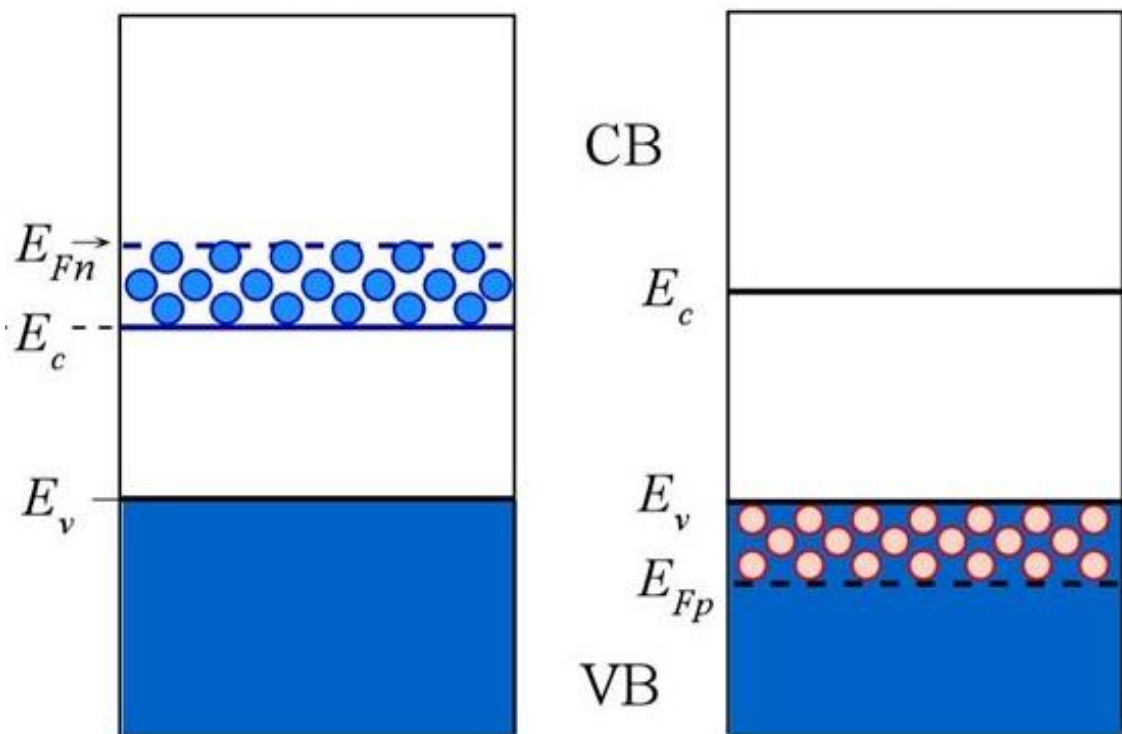
- Rekombináció
- Kiürítési réteg
- Beépített elektromos tér
- Külső elektromos tér

Esaki dióda

Degenerált félvezető

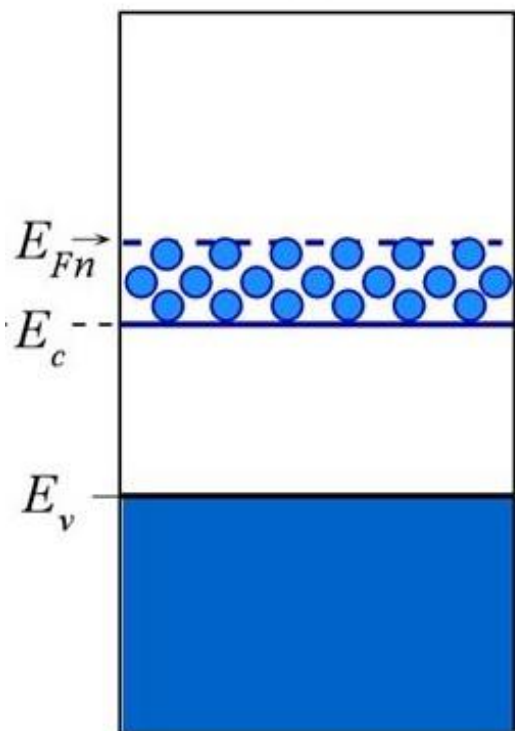
n-típusú

p-típusú

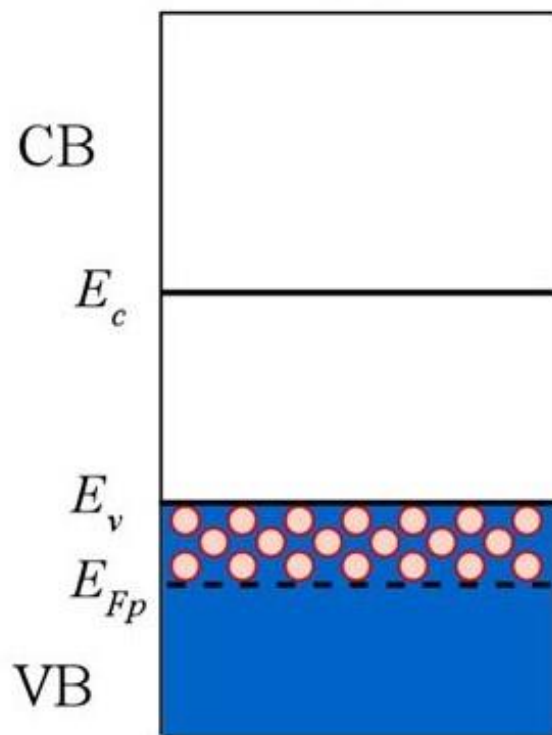


Degenerált félvezető

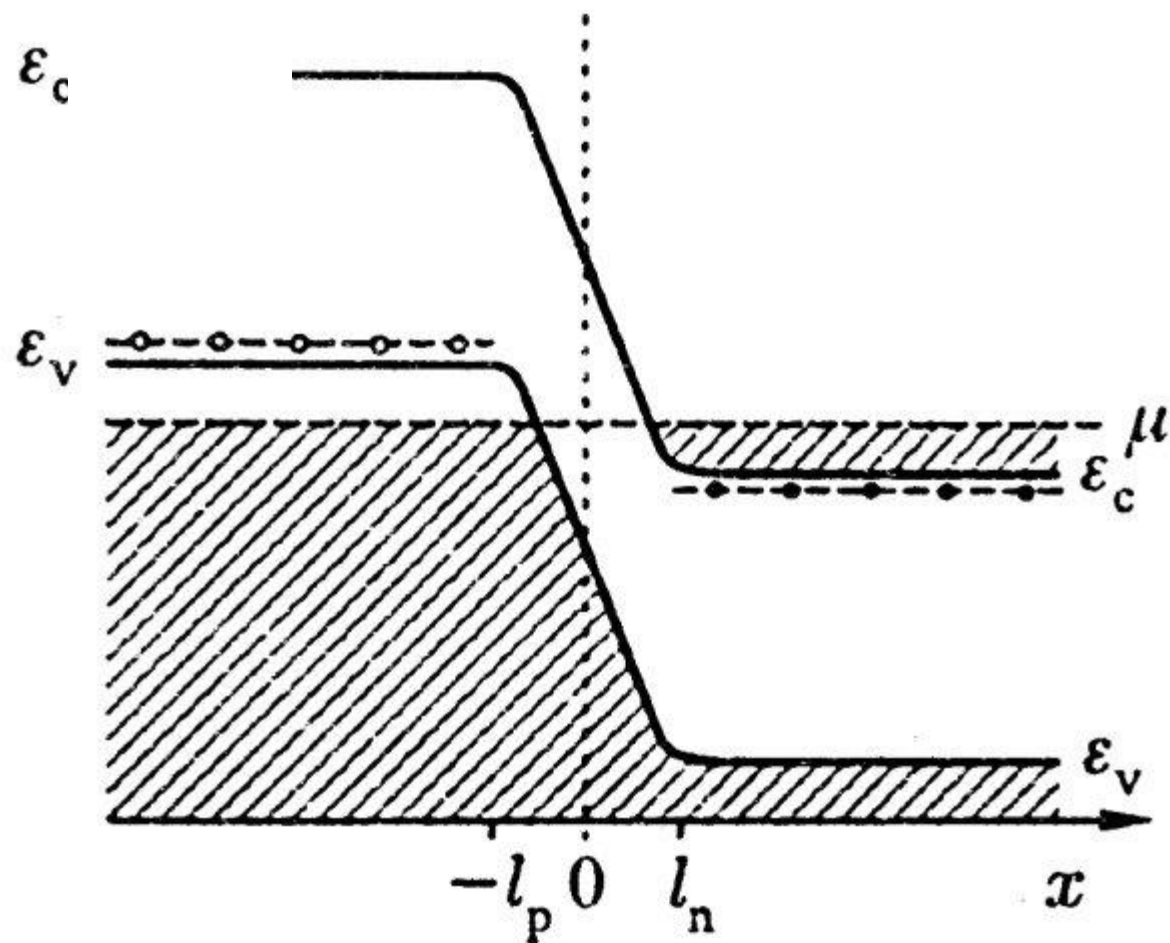
n-típusú



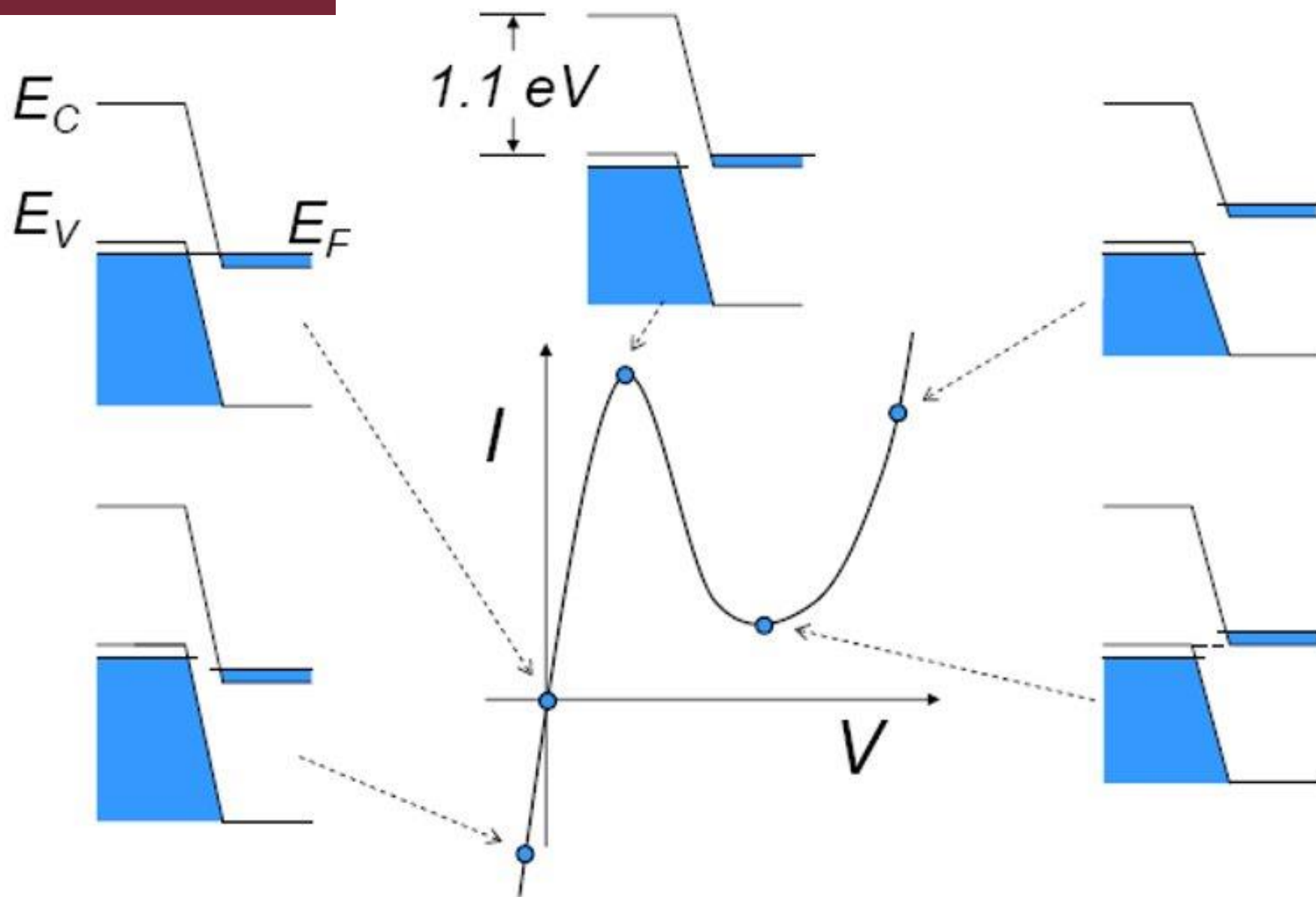
p-típusú



Sávszerkezet

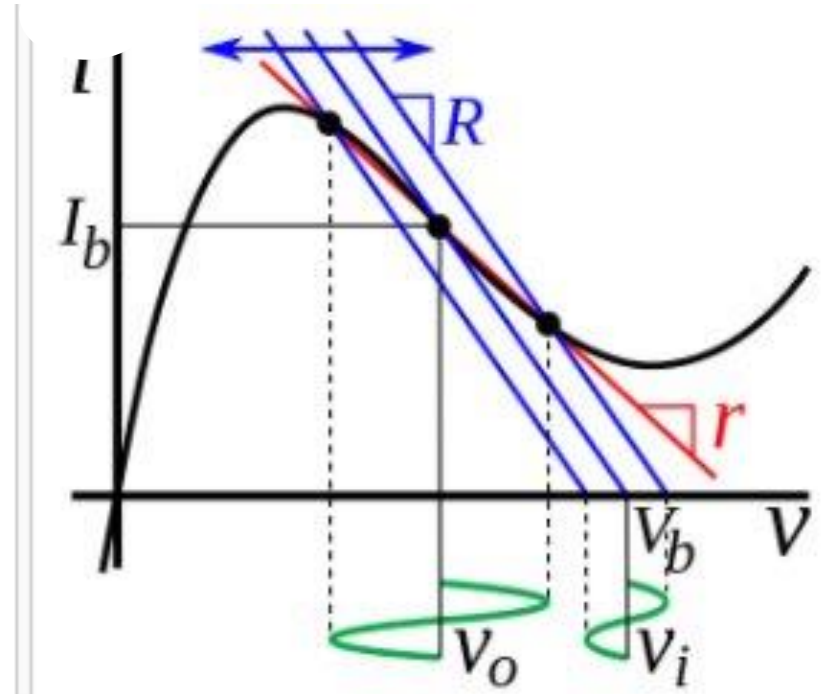
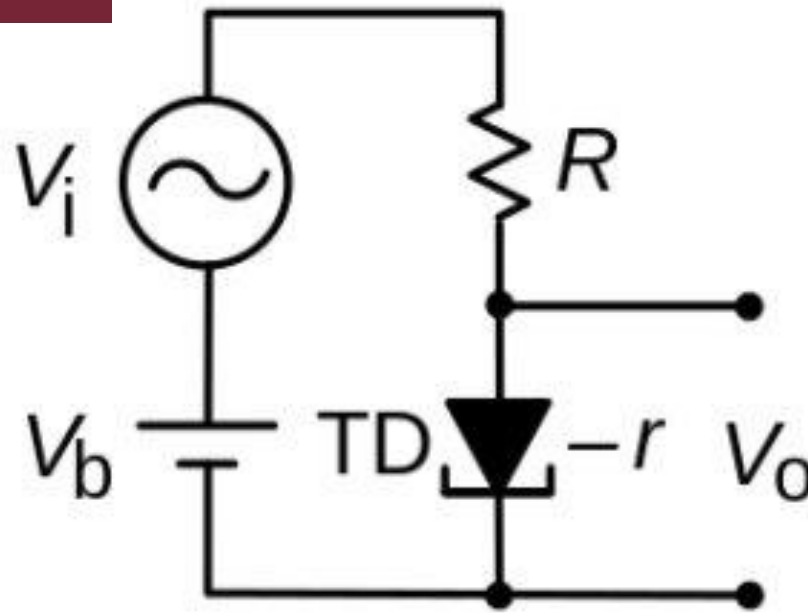


Esaki dióda



Esaki dióda

$$\Delta v / \Delta i = -r$$

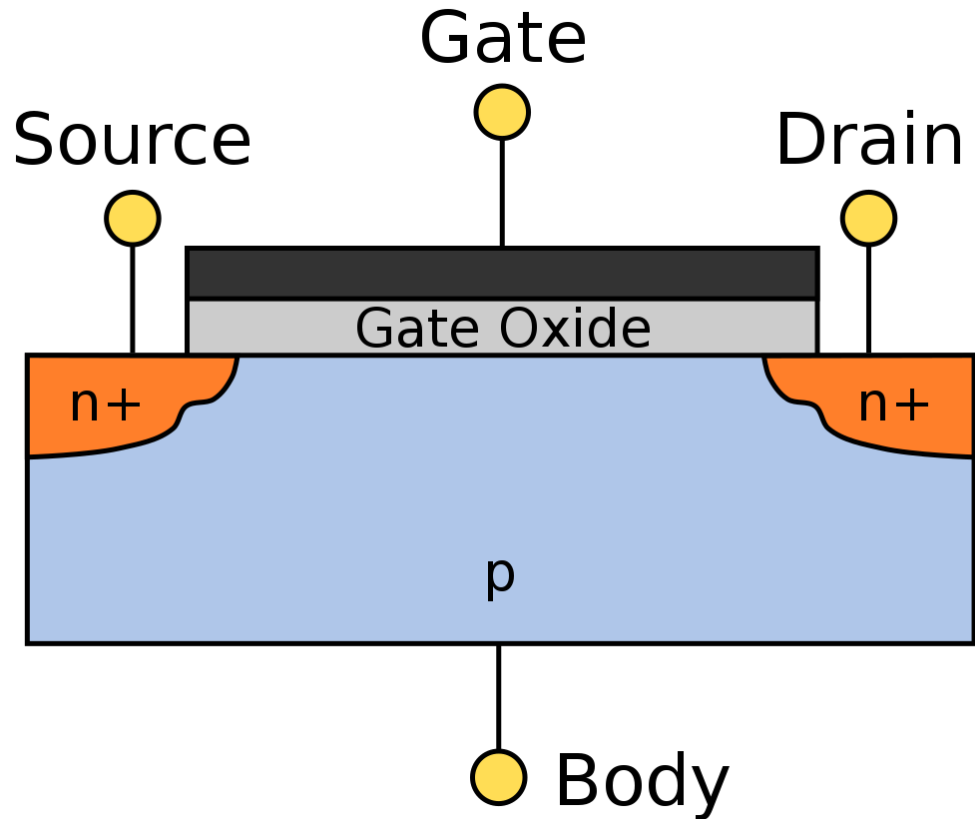


- Erősítő áramkör
- V_i AC jel, ezt erősítem
- V_b DC feszültség

$$v_o = \frac{-r}{R - r} v_i = \frac{r}{r - R} v_i$$

voltage gain $G_v = \frac{r}{r - R}$

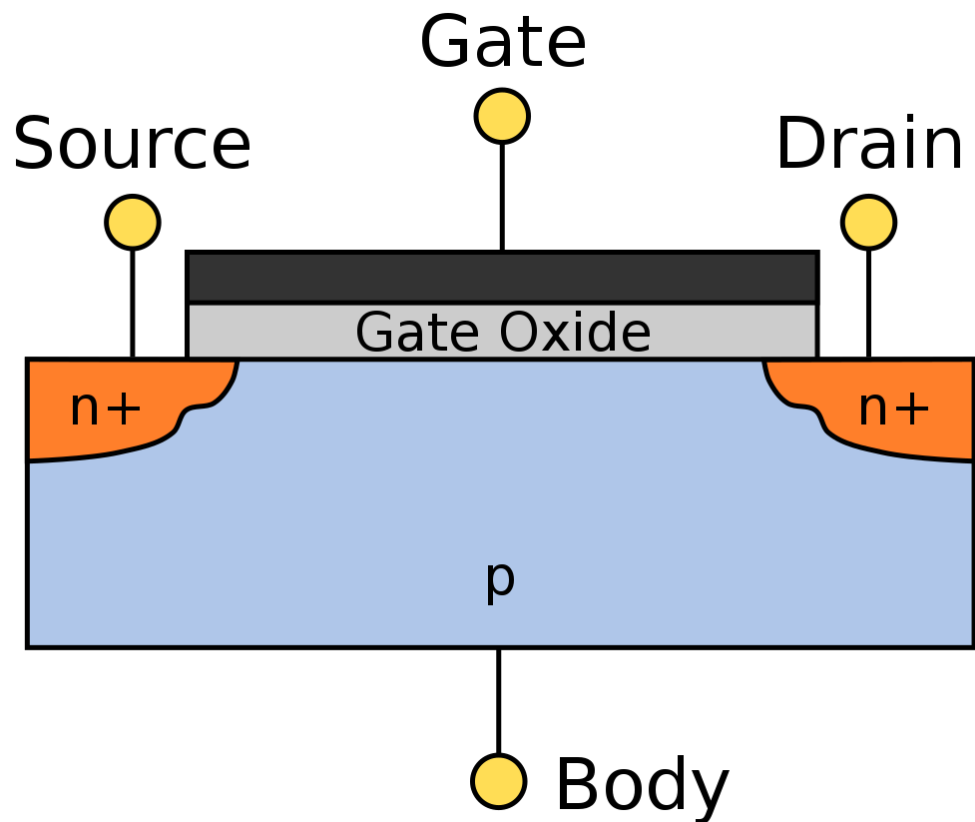
Tranzisztor (FET)



$V_{\text{kapu}} > 0$  áram folyik

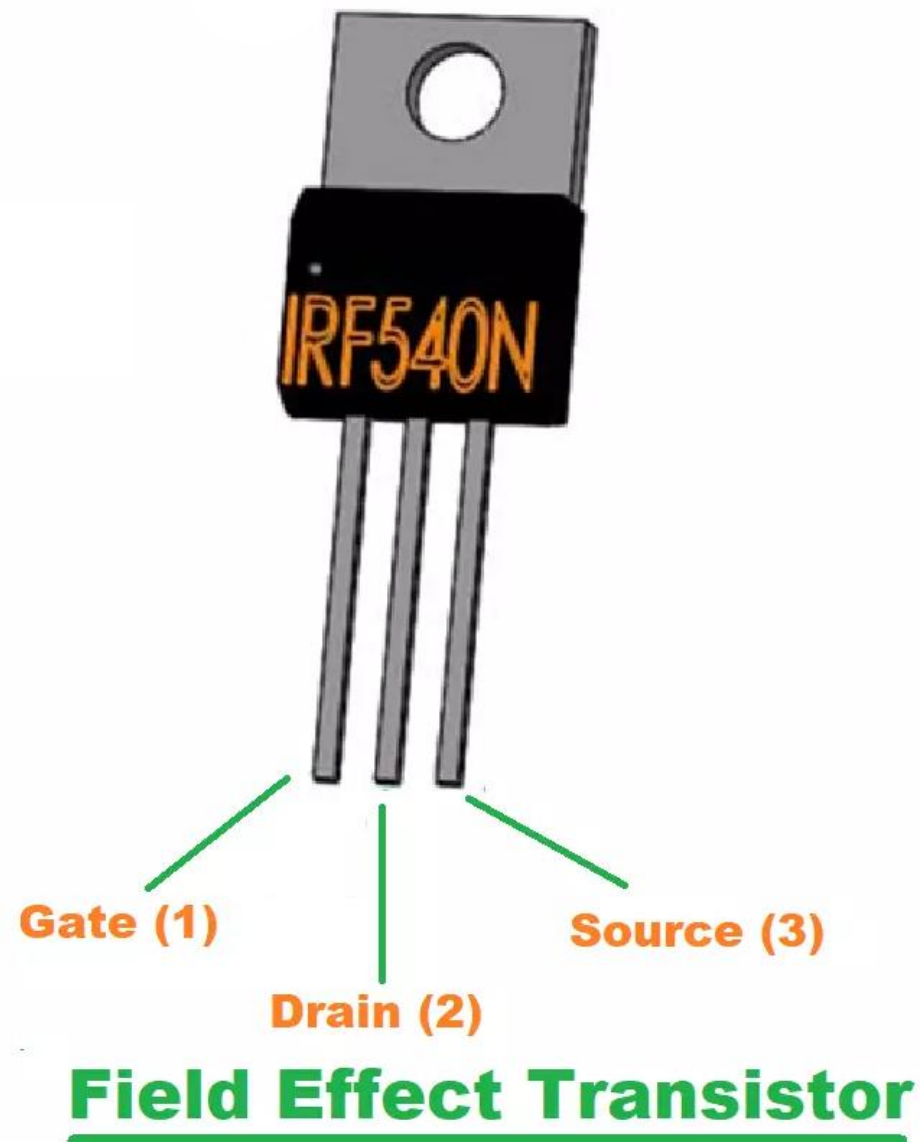
$V_{\text{kapu}} \leq 0$  nem folyik áram

Tranzisztor (FET)

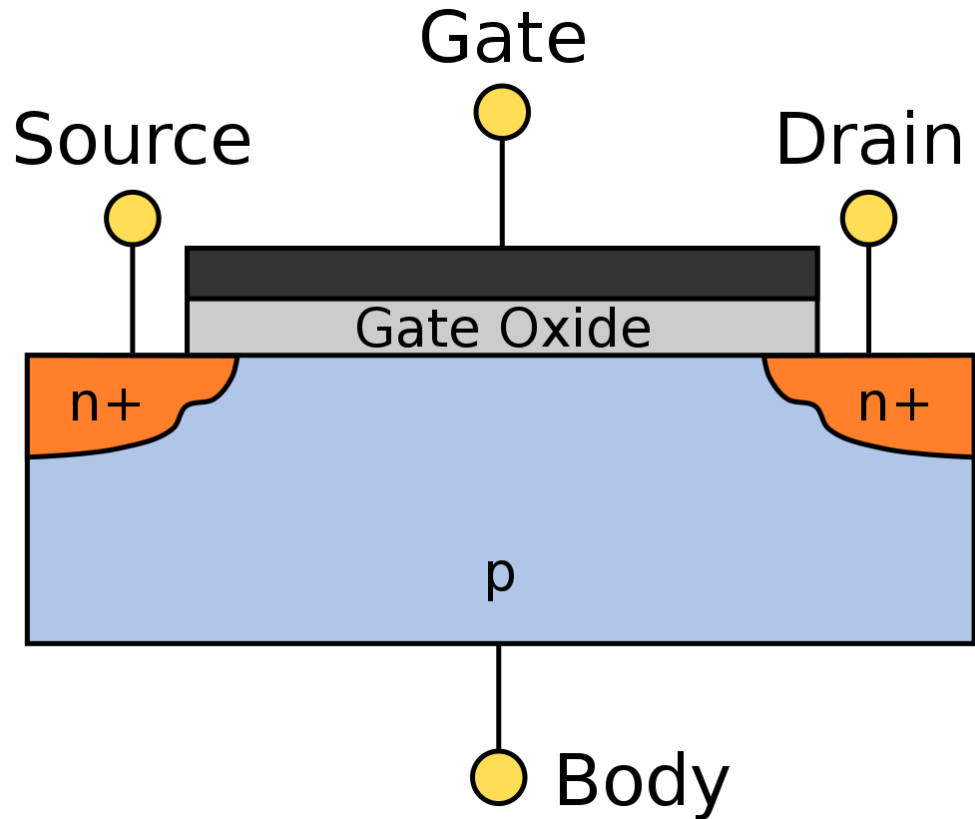


$V_{\text{kapu}} > 0$ → áram folyik

$V_{\text{kapu}} \leq 0$ → nem folyik áram

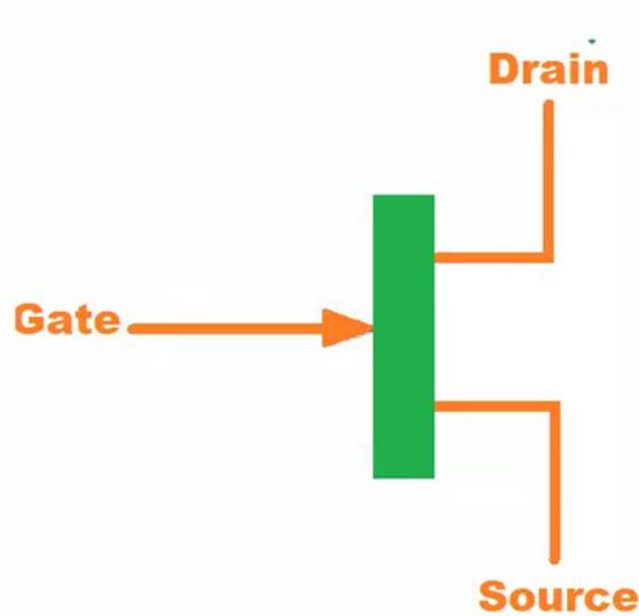


Tranzisztor (FET)

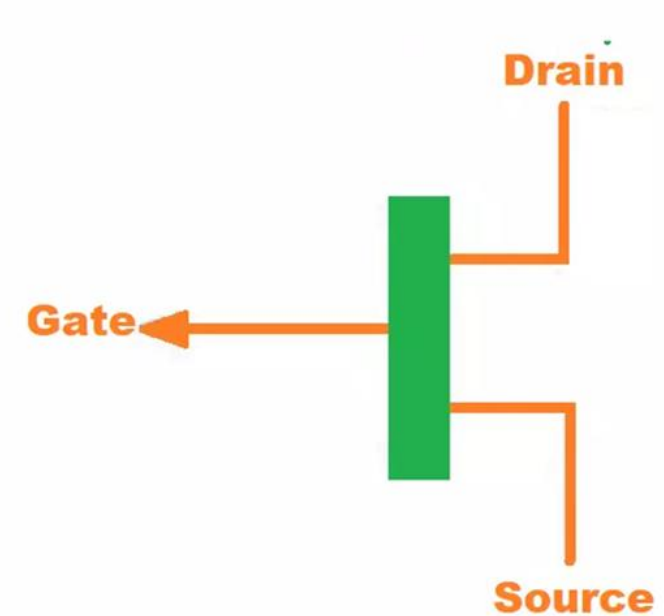


$V_{\text{kapu}} > 0$ → áram folyik

$V_{\text{kapu}} \leq 0$ → nem folyik áram



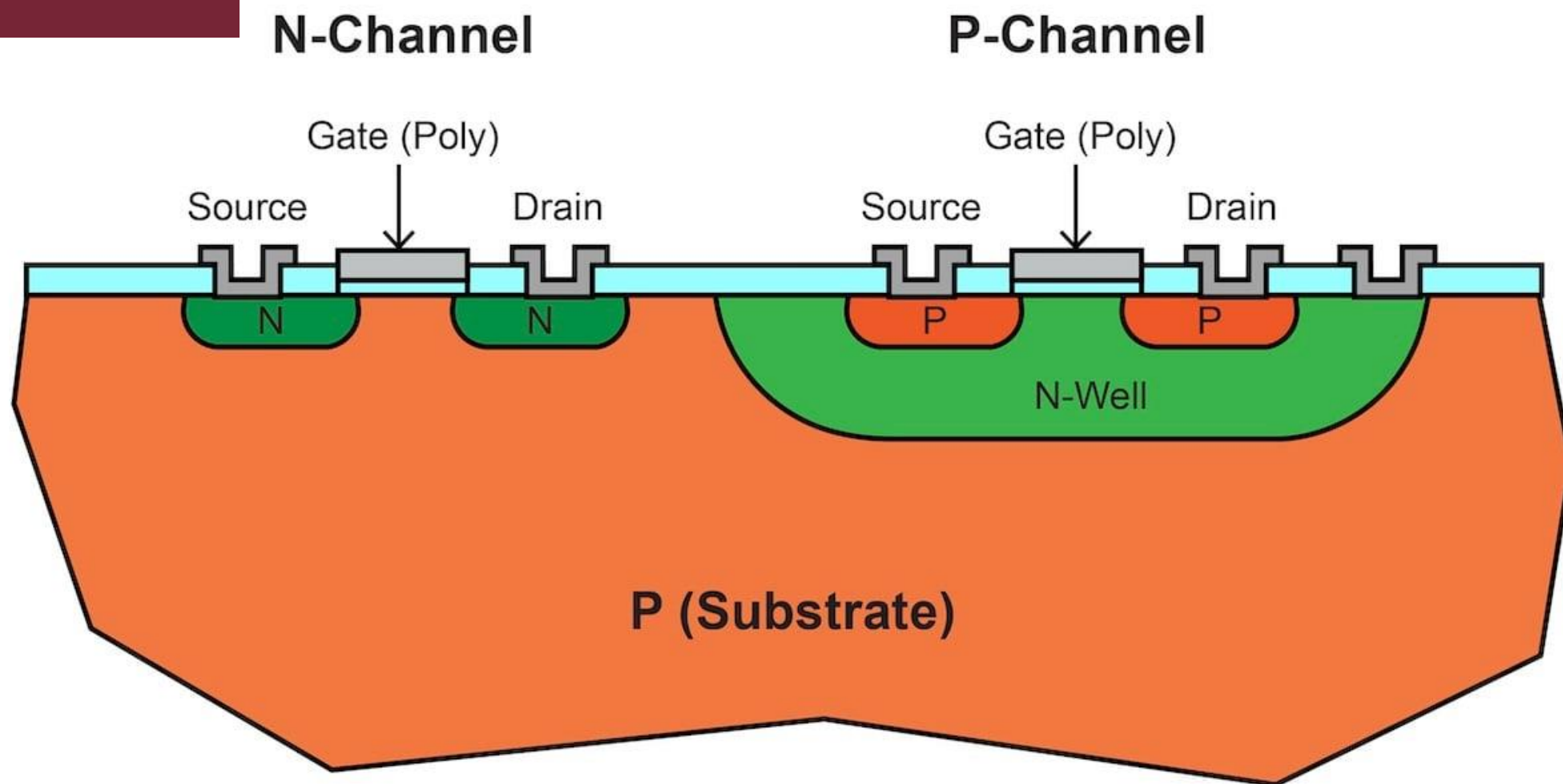
N-Channel



P-Channel

Symbol of Field Effect transistor

NMOS és PMOS



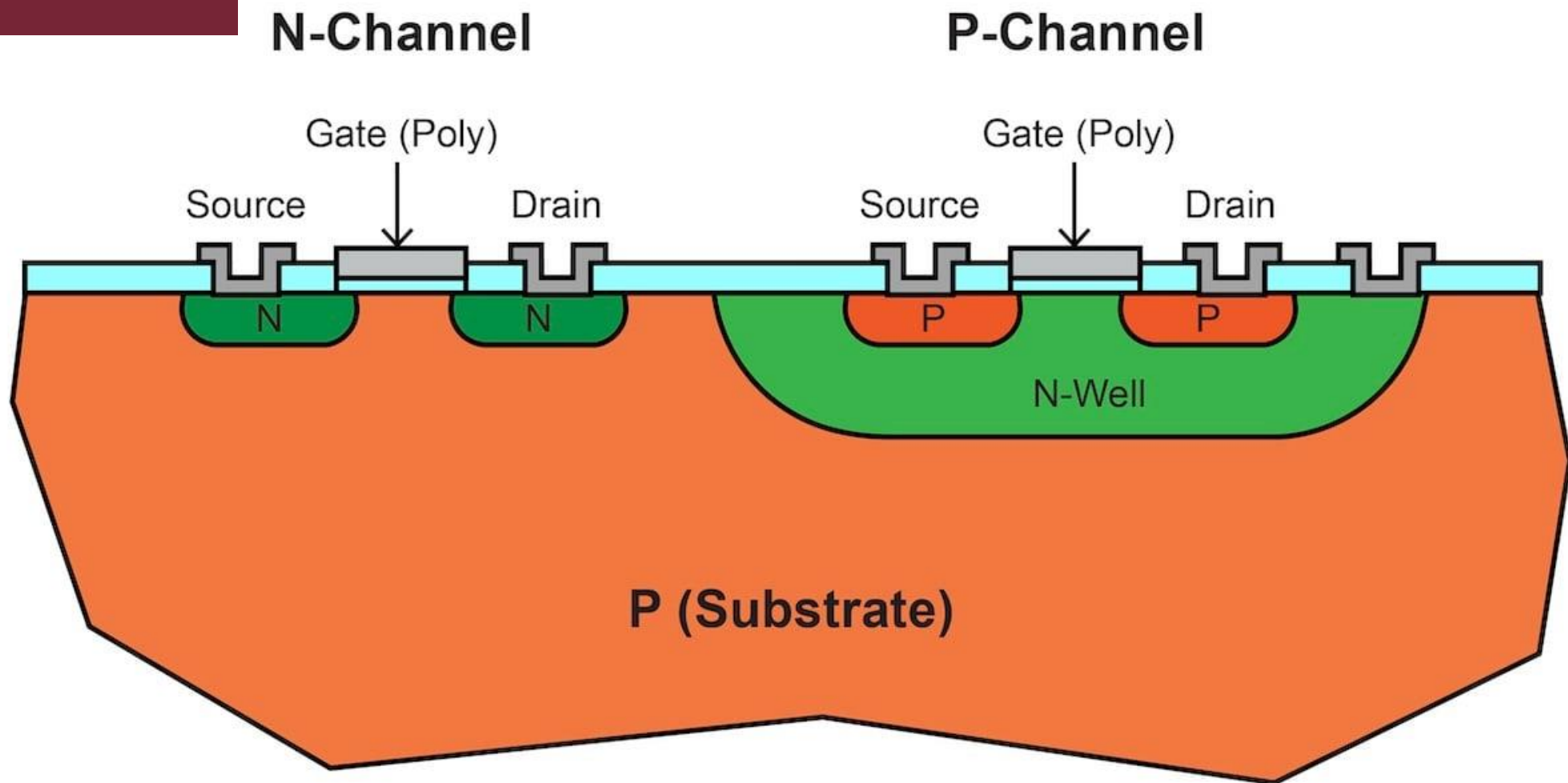
NMOS és PMOS

NMOS:

- N csatorna
- $V_{\text{kapu}} > 0$ nyit

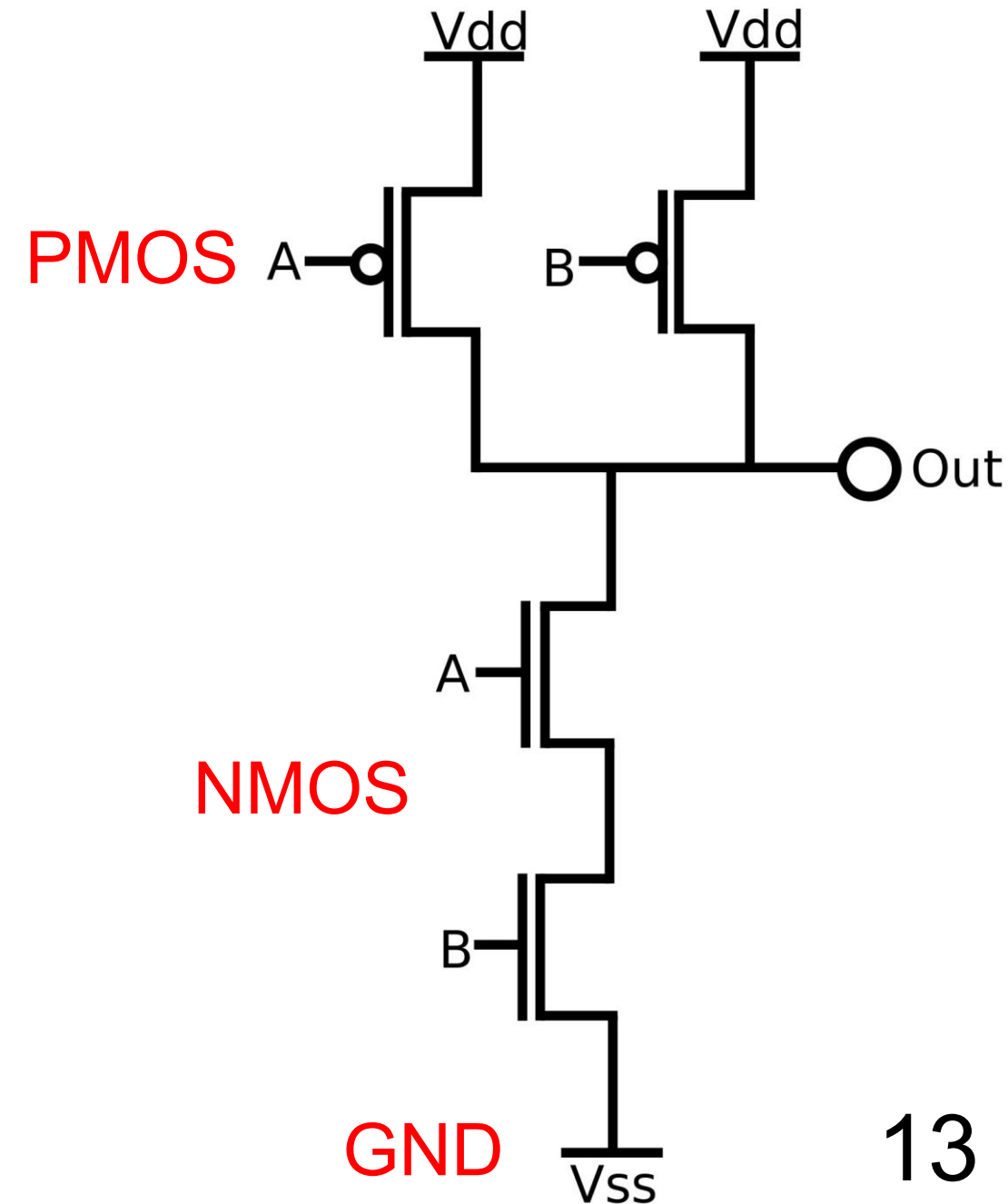
PMOS:

- P csatorna
- $V_{\text{kapu}} < 0$ nyit



Tranzisztor (FET)

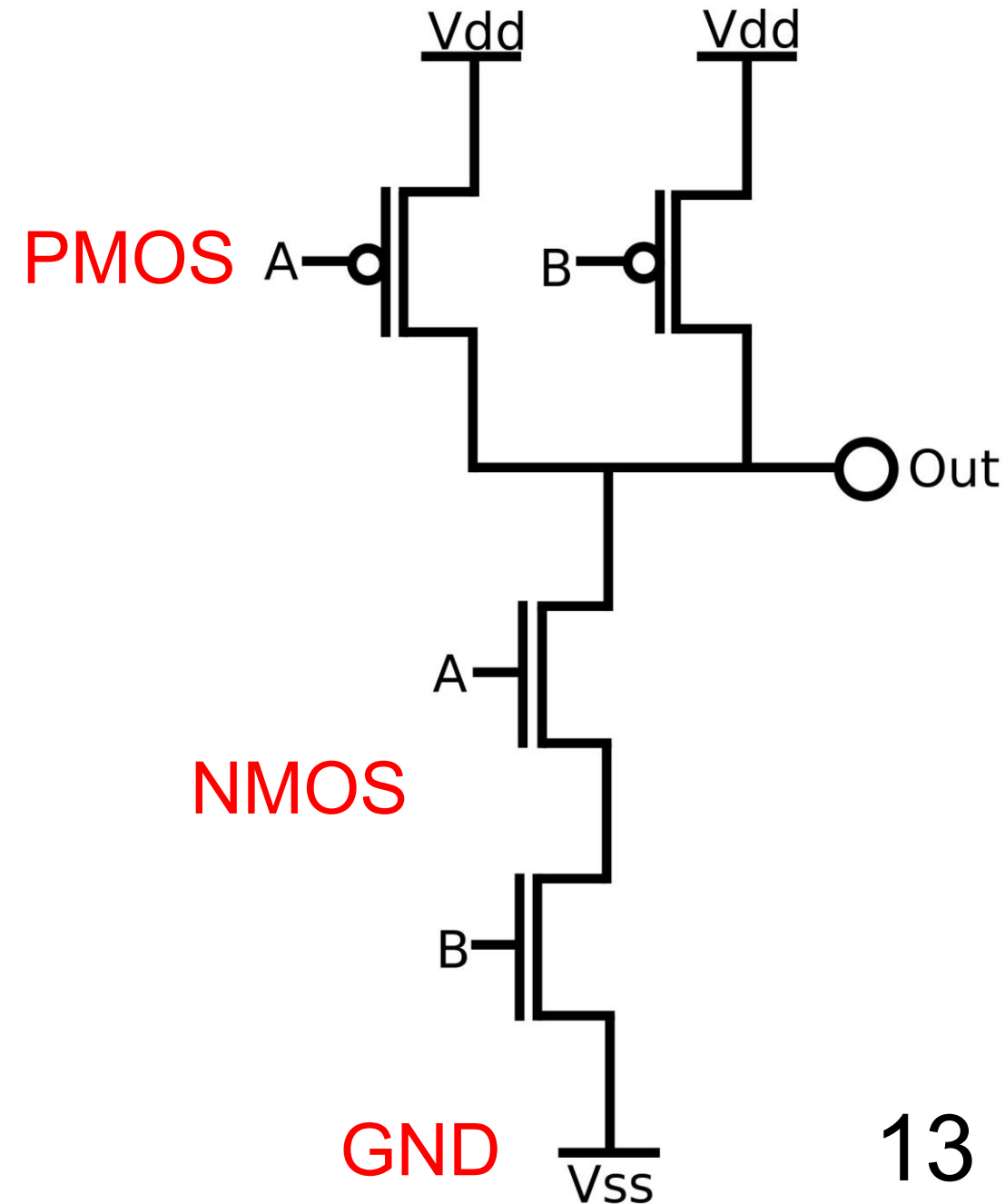
Input		Output	
A	B	AND	NAND
0	0	0	1
0	1	0	1
1	0	0	1
1	1	1	0



Tranzisztor (FET)

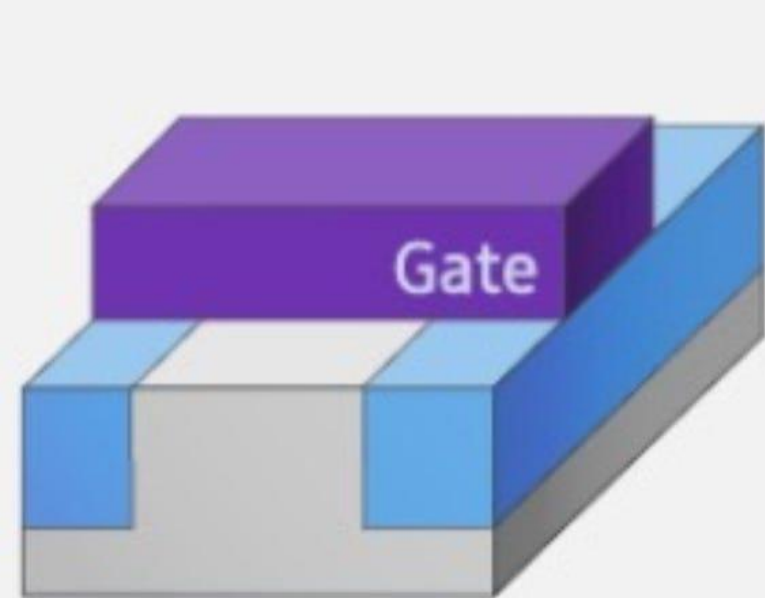
Input		Output	
A	B	AND	NAND
0	0	0	1
0	1	0	1
1	0	0	1
1	1	1	0

Nem folyik áram, feszültség
tárolja az információt!

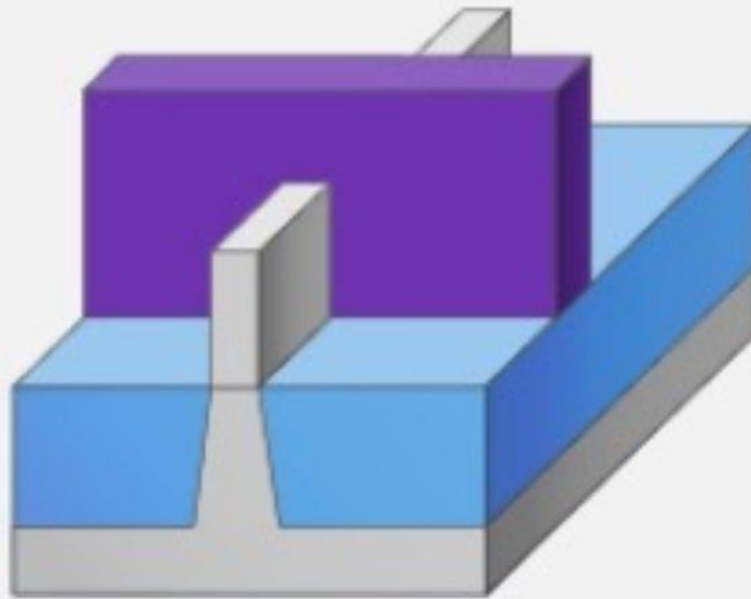


Tranzisztor (FET)

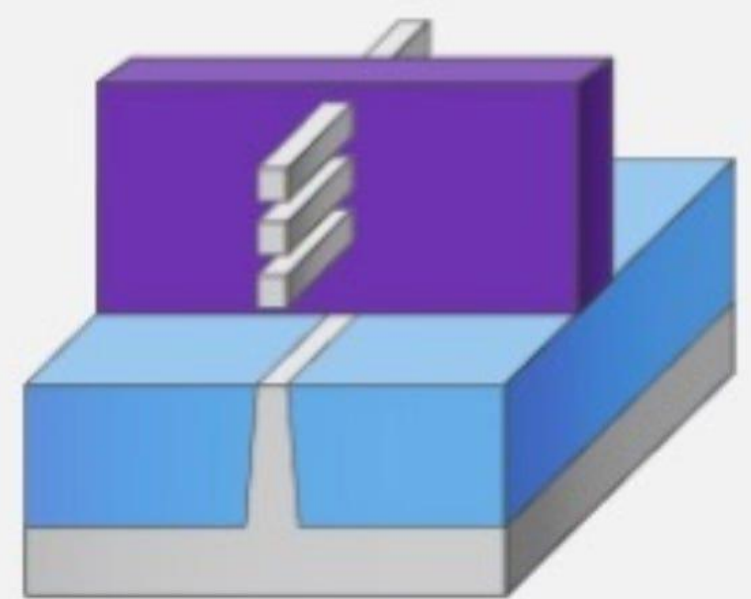
Többet és többet!



Planar FET



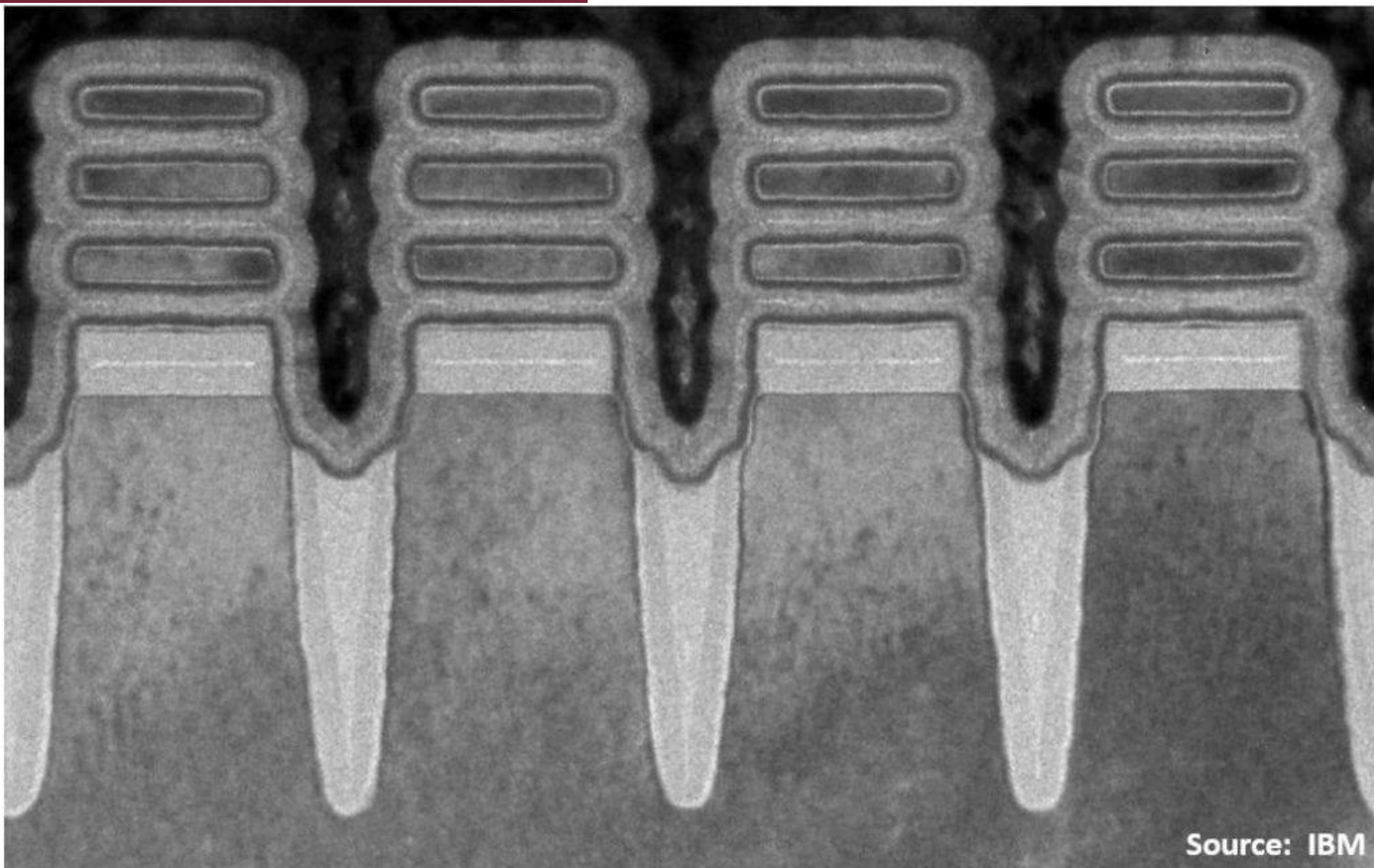
FinFET



GAAFET
(Nanowire)

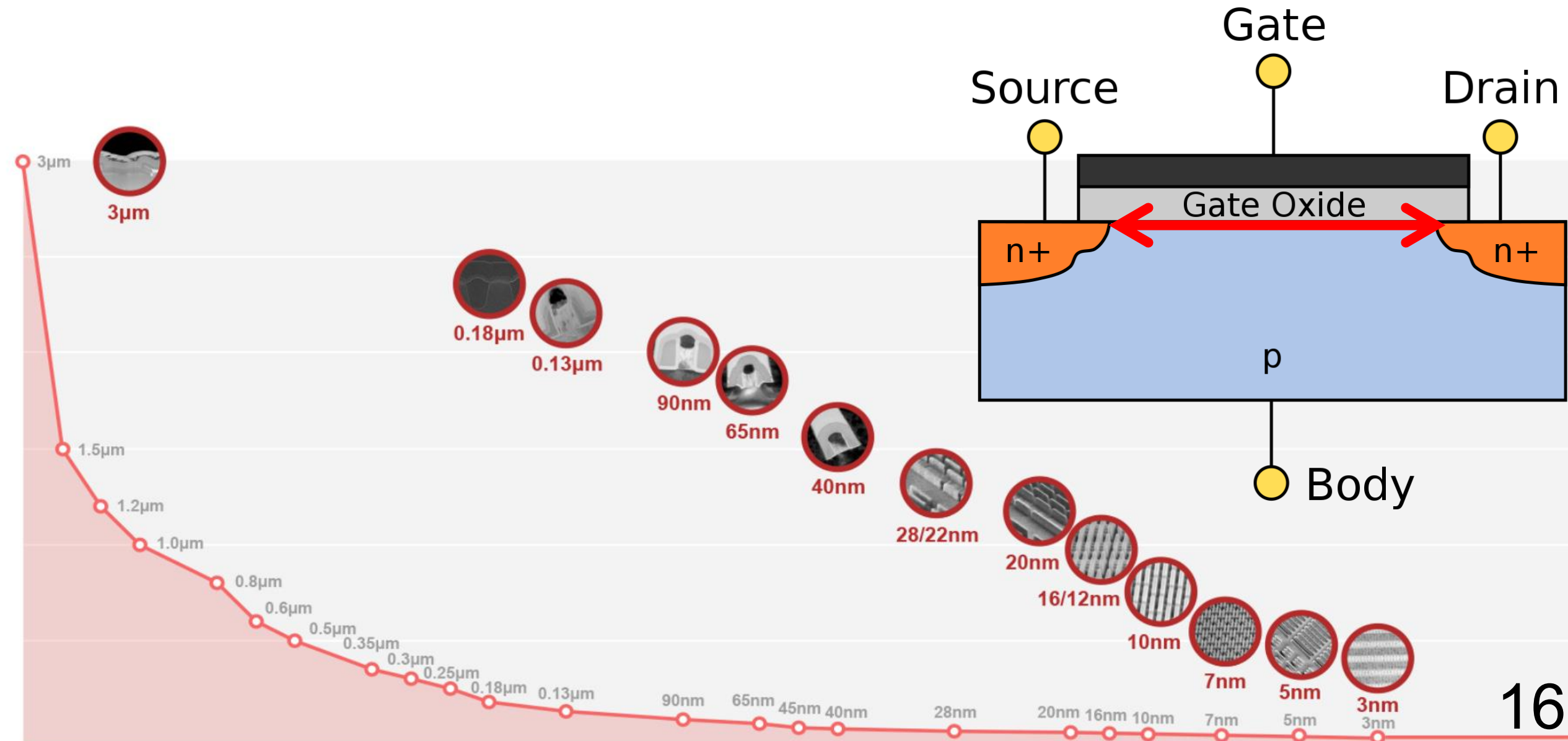
2011 Intel

2025 TSMC

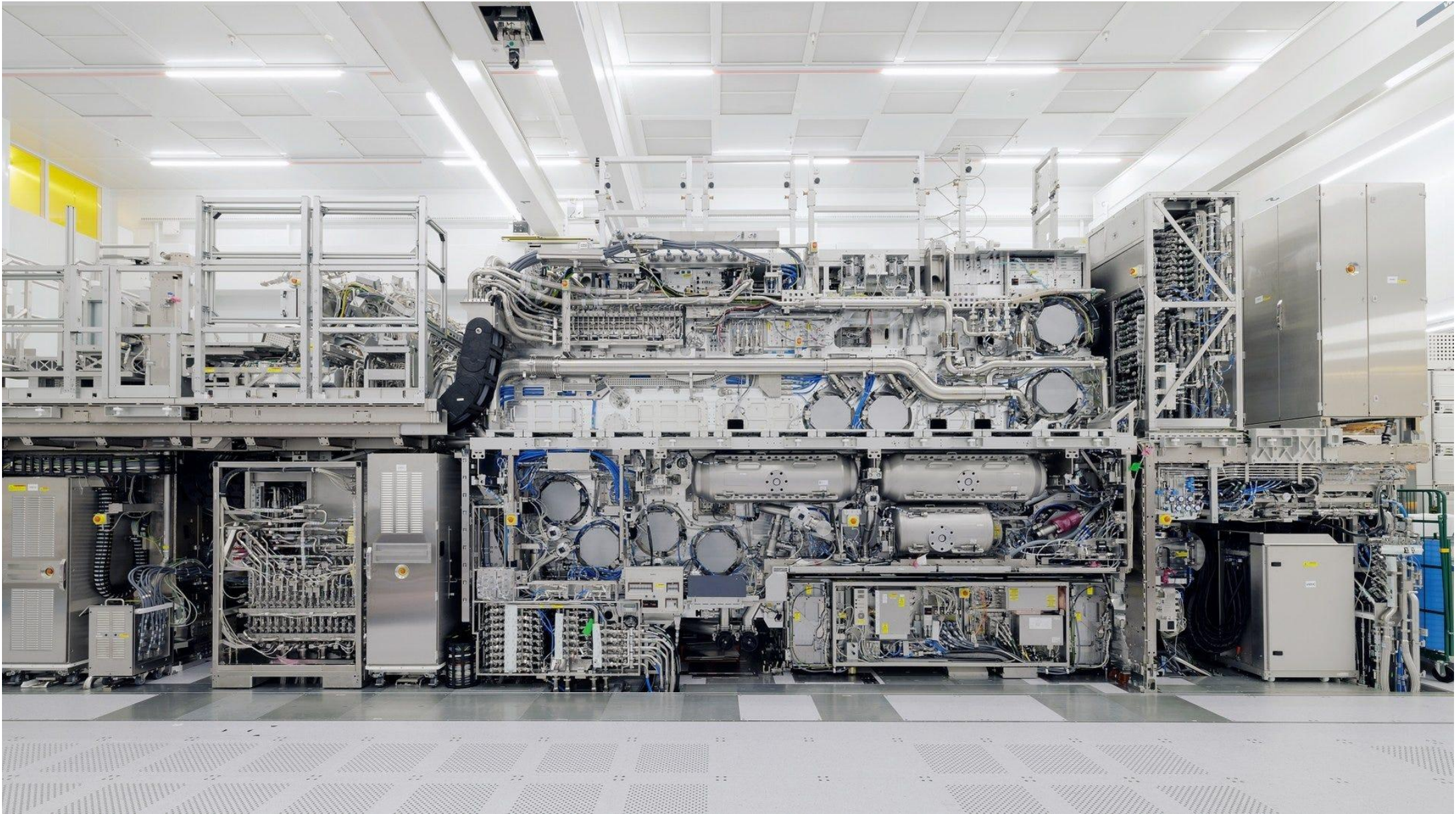


Tranzisztor (FET)

- 12 nm = 80 db atom

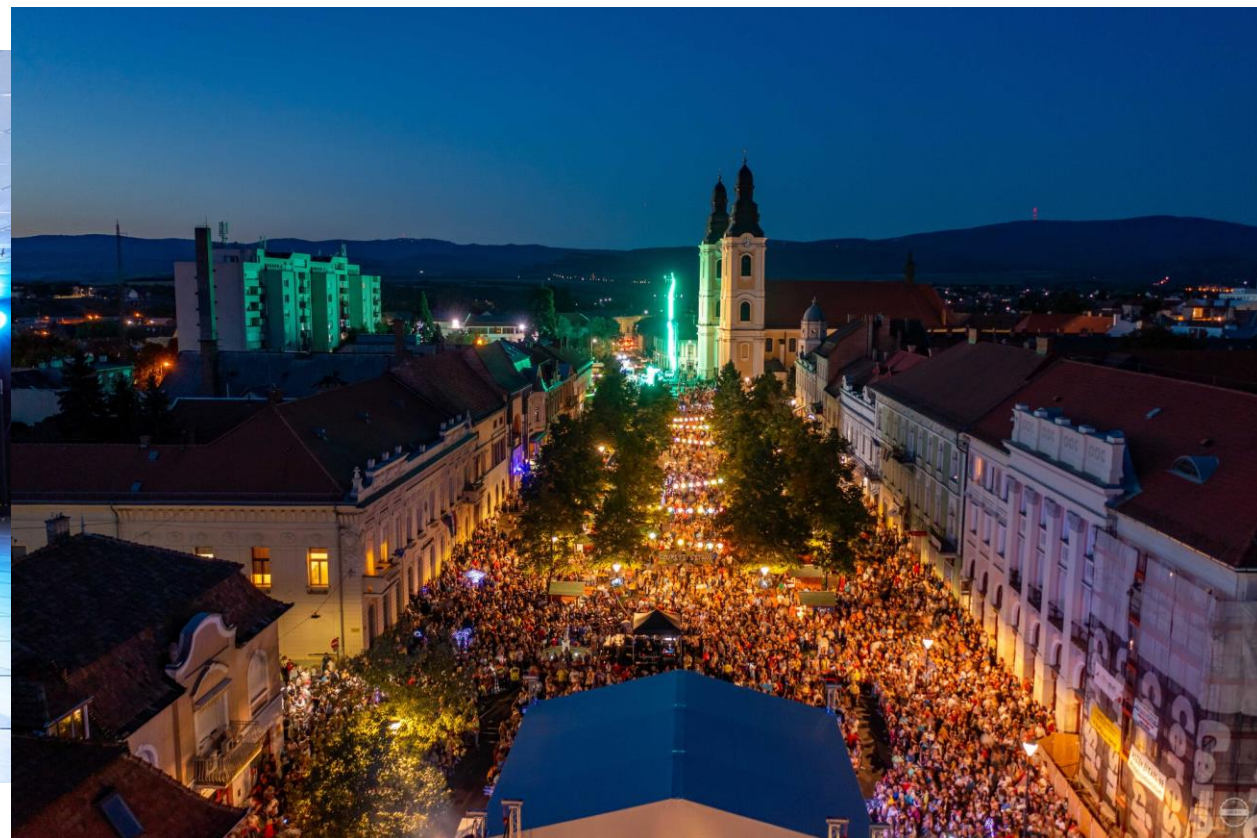


Tranzisztor (FET)



Tranzisztor (FET)

- El Capitan 30 MW, Gyöngyös 17 MW



Tranzisztor (FET)

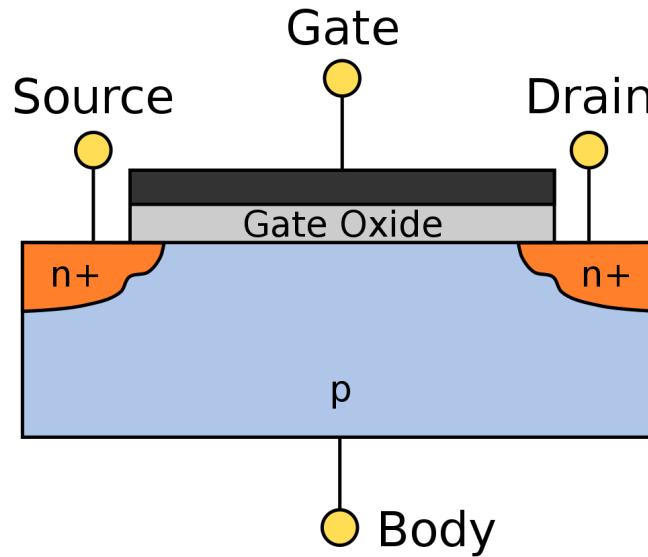
- El Capitan 30 MW, Gyöngyös 17 MW



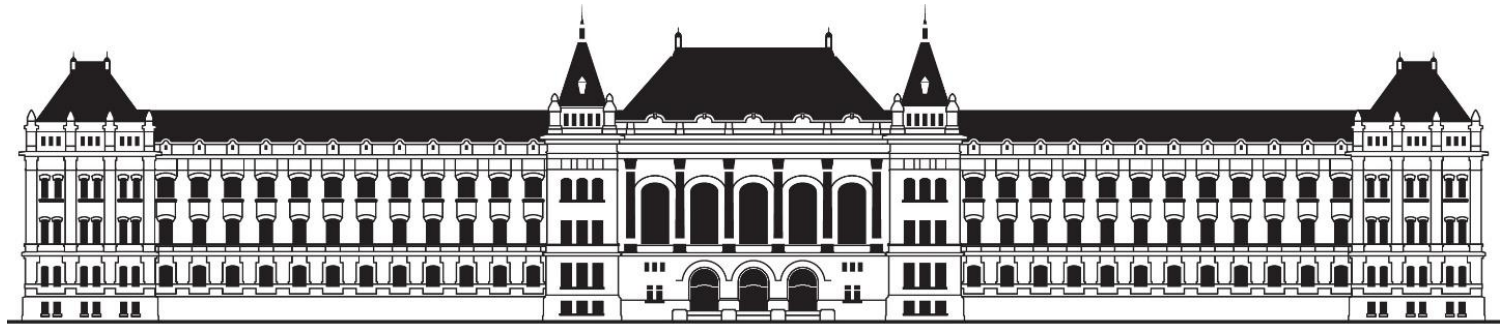
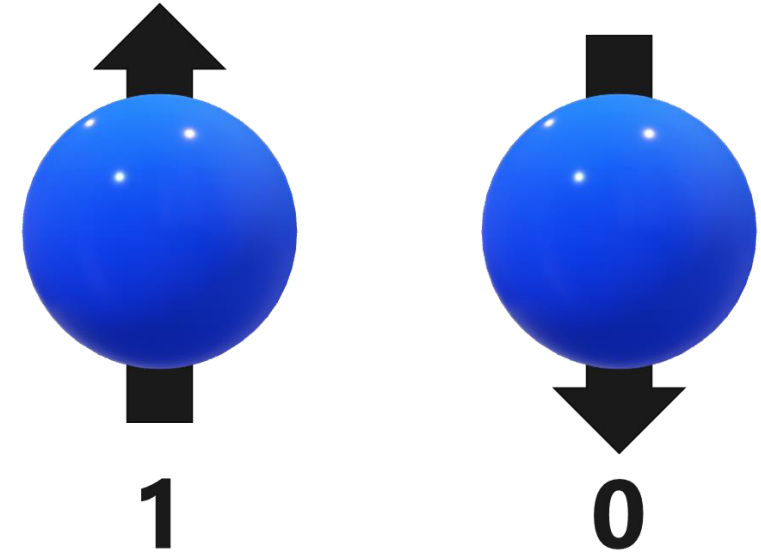
Merre tovább? Szupravezetés, kvantummechanika

Merre tart az elektronika? II.

Kupás Lőrinc Pál
2025.07.11.



Electron Spin (Up and Down)



M Ű E G Y E T E M 1 7 8 2

Szupravezetés

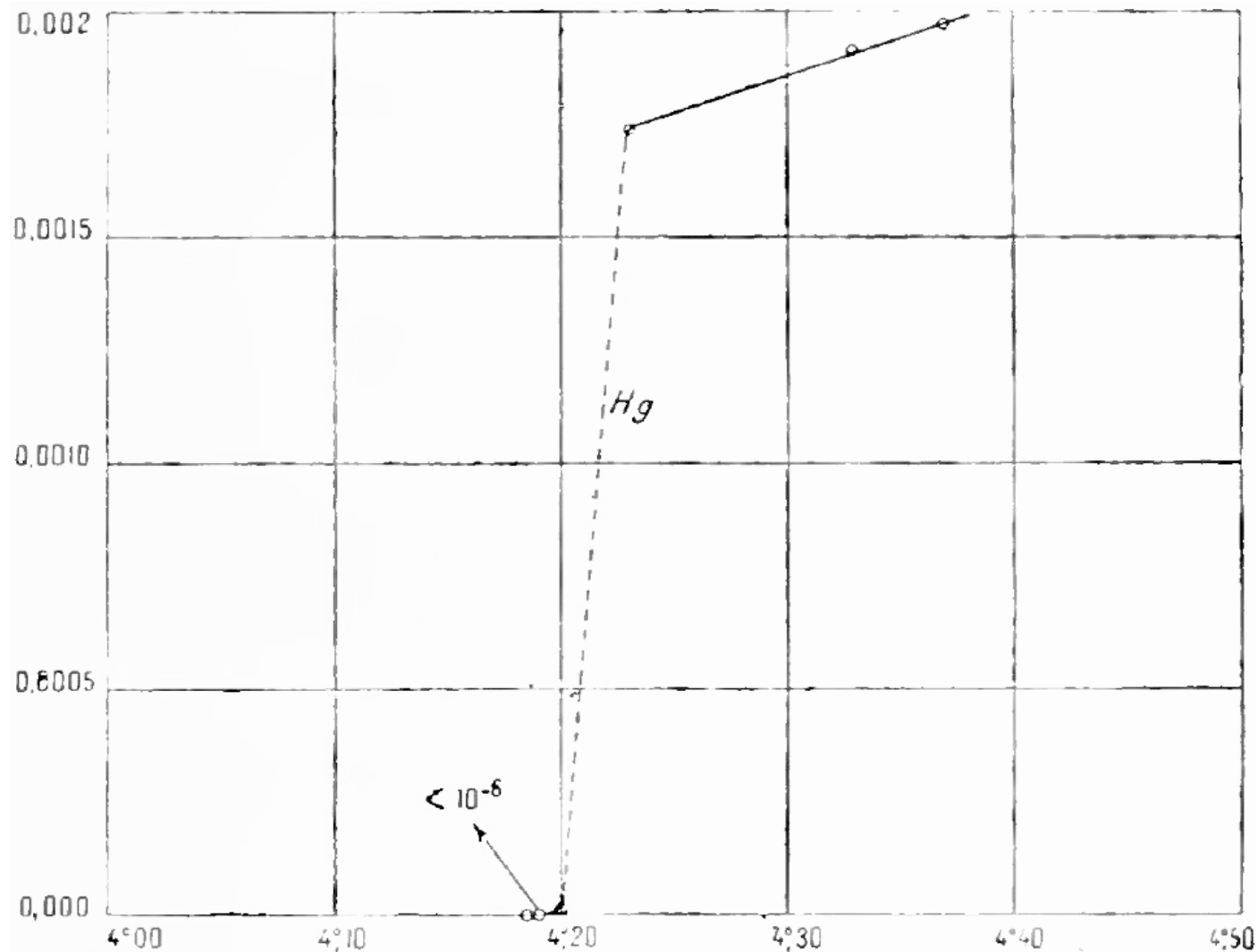


H. Kamerling

Szupravezetés



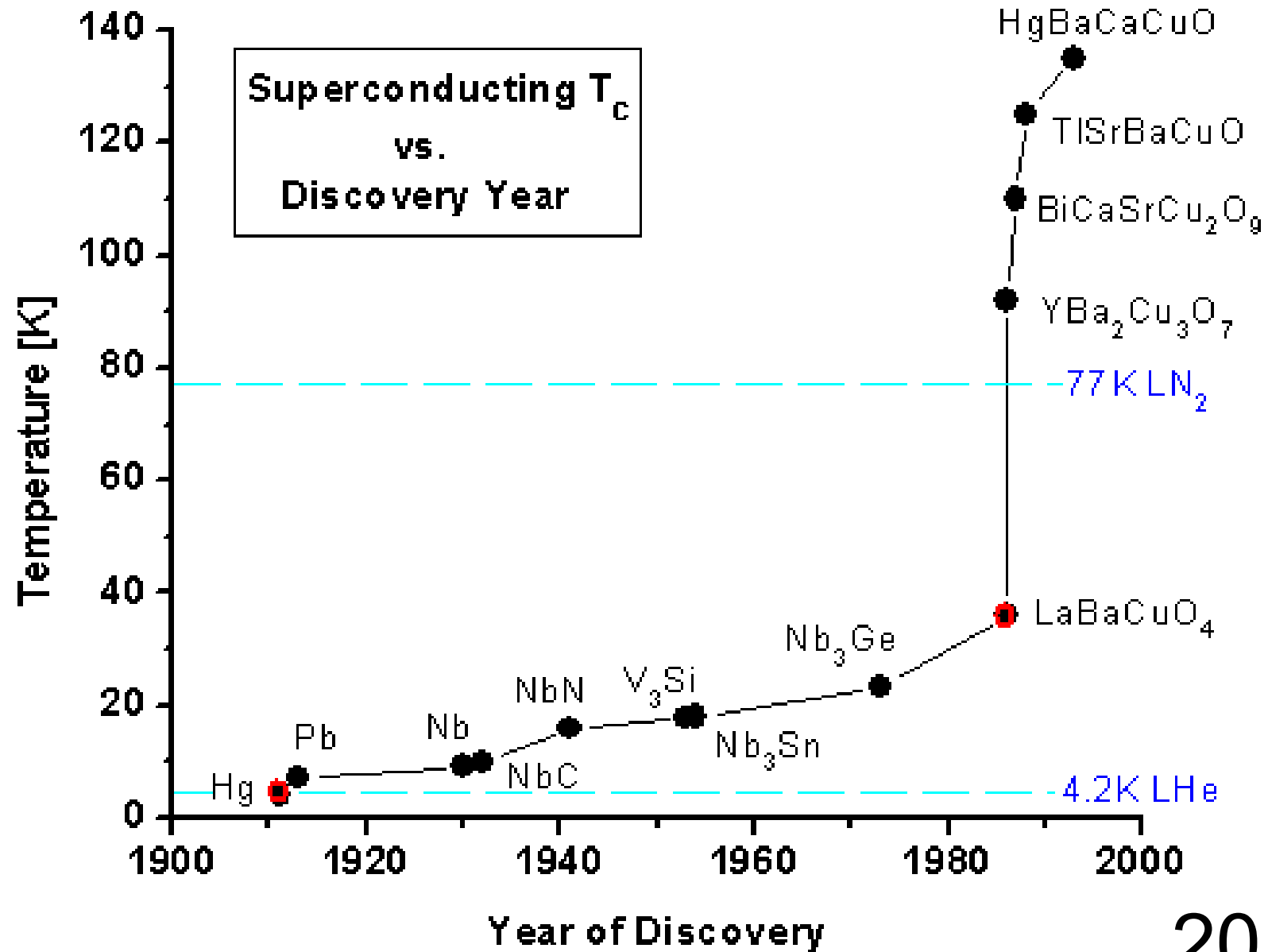
Heike Kamerlingh Onnes



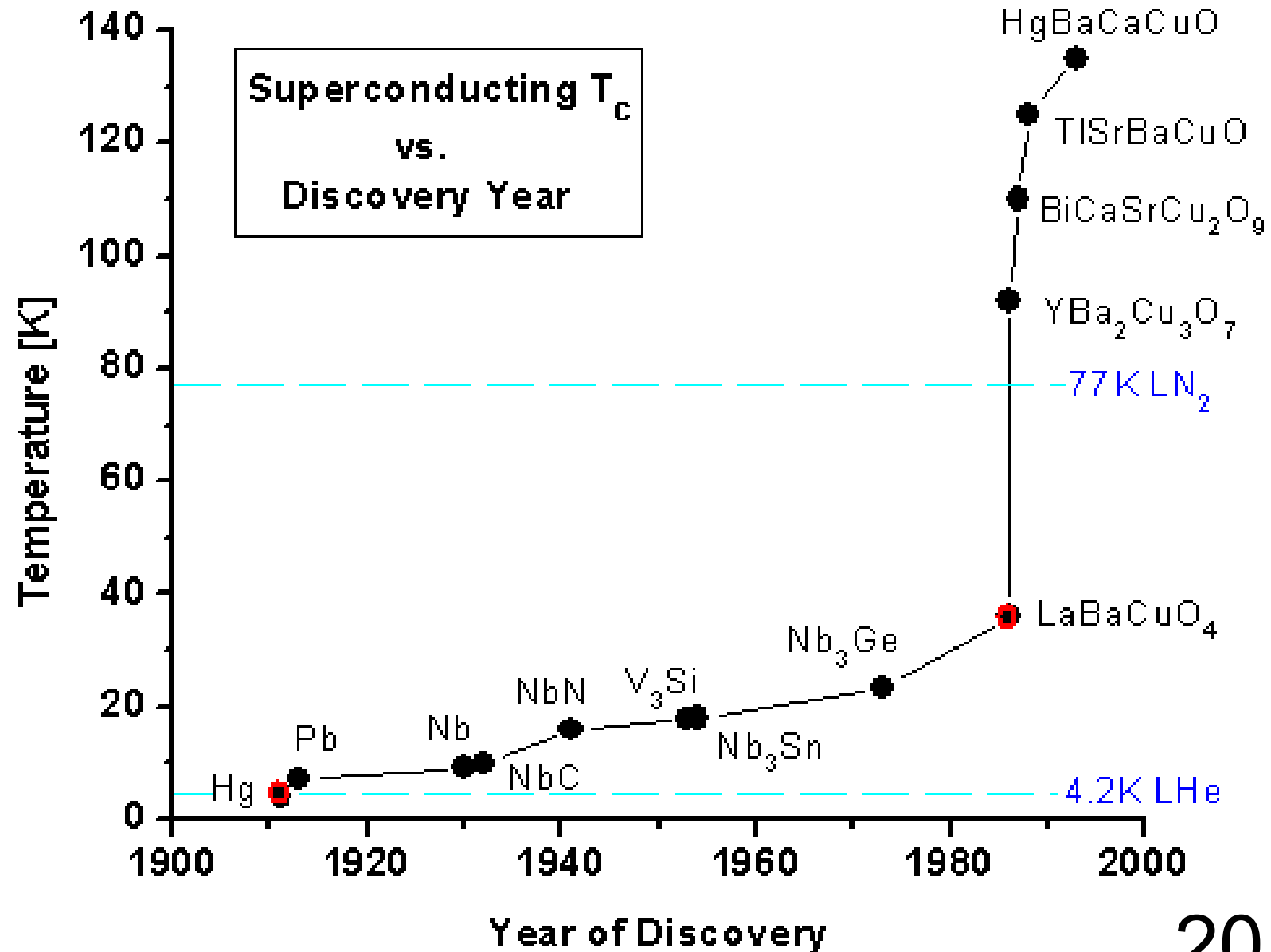
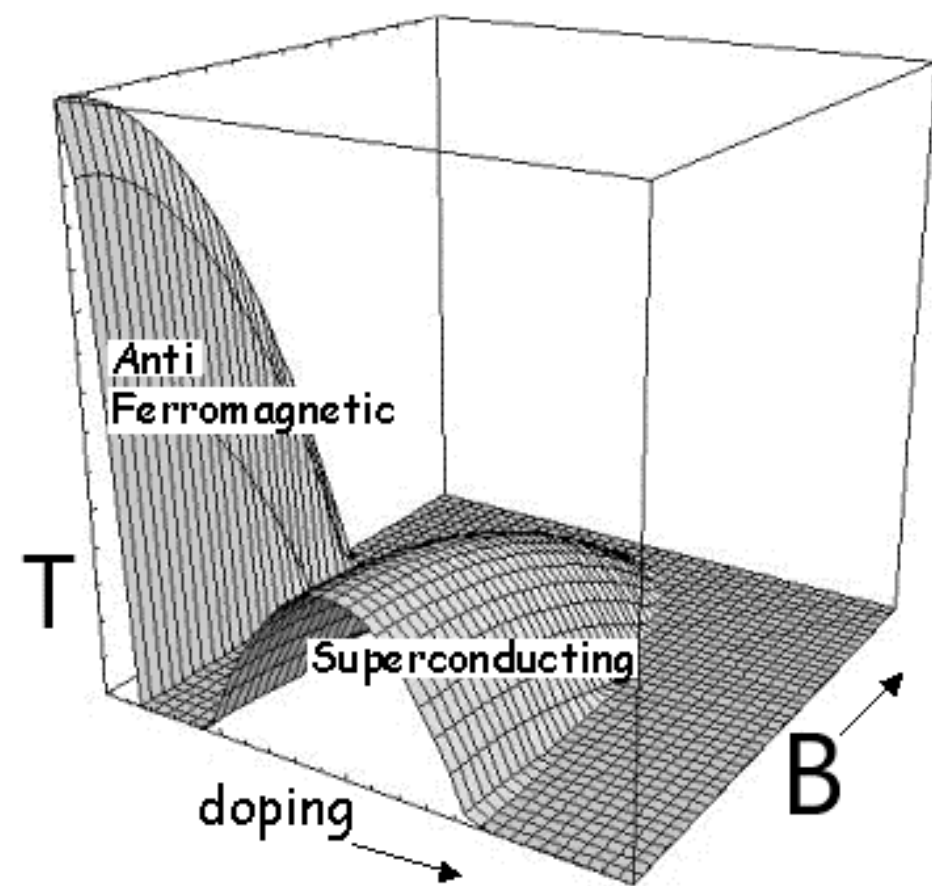
1908: Folyékon hélium előállítása

1911: Szilárd higany ellenállása vs hőmérséklet

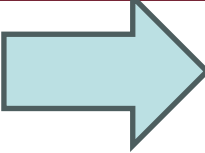
1913: Nobel-díj



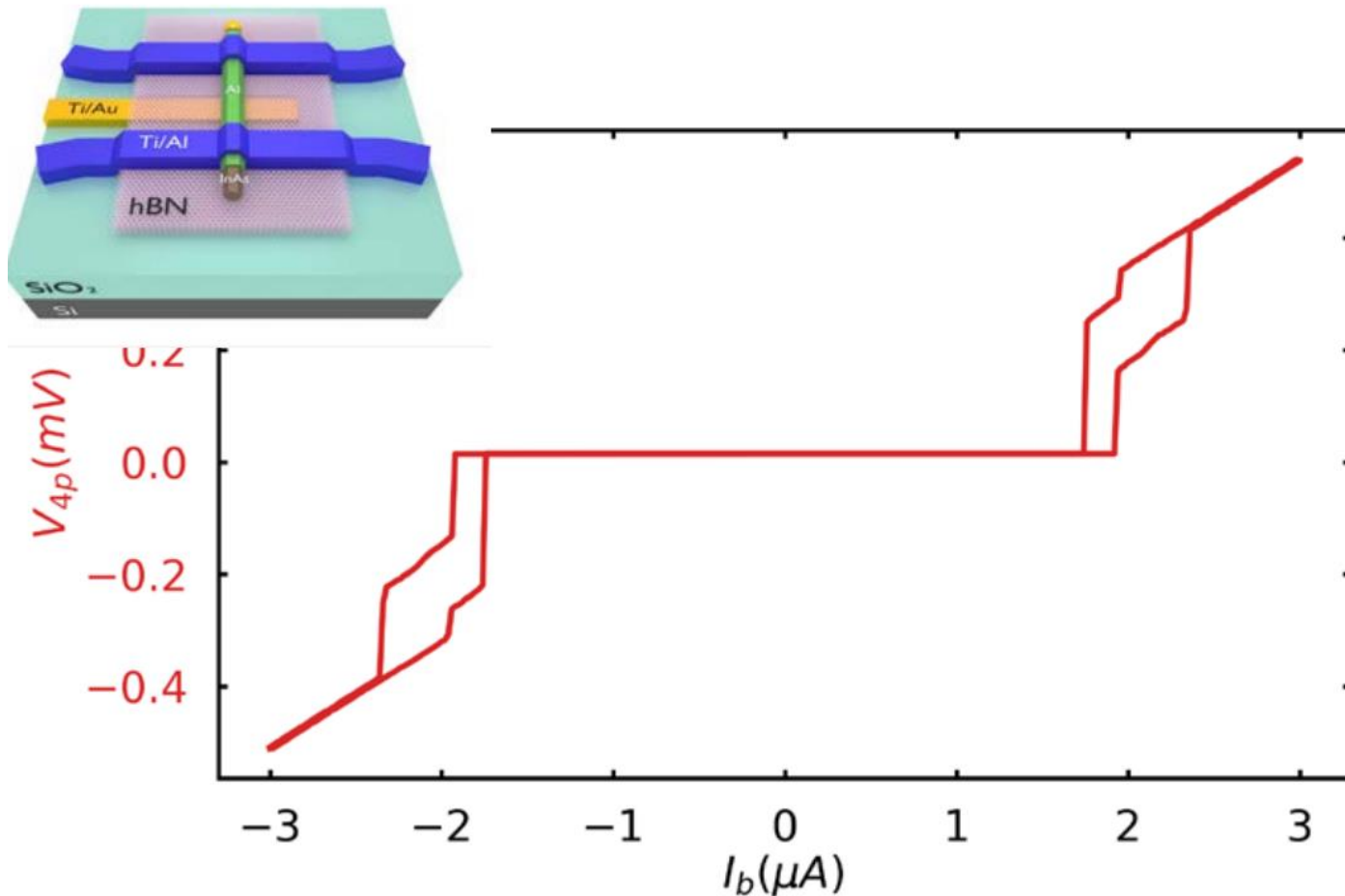
Szupravezetés



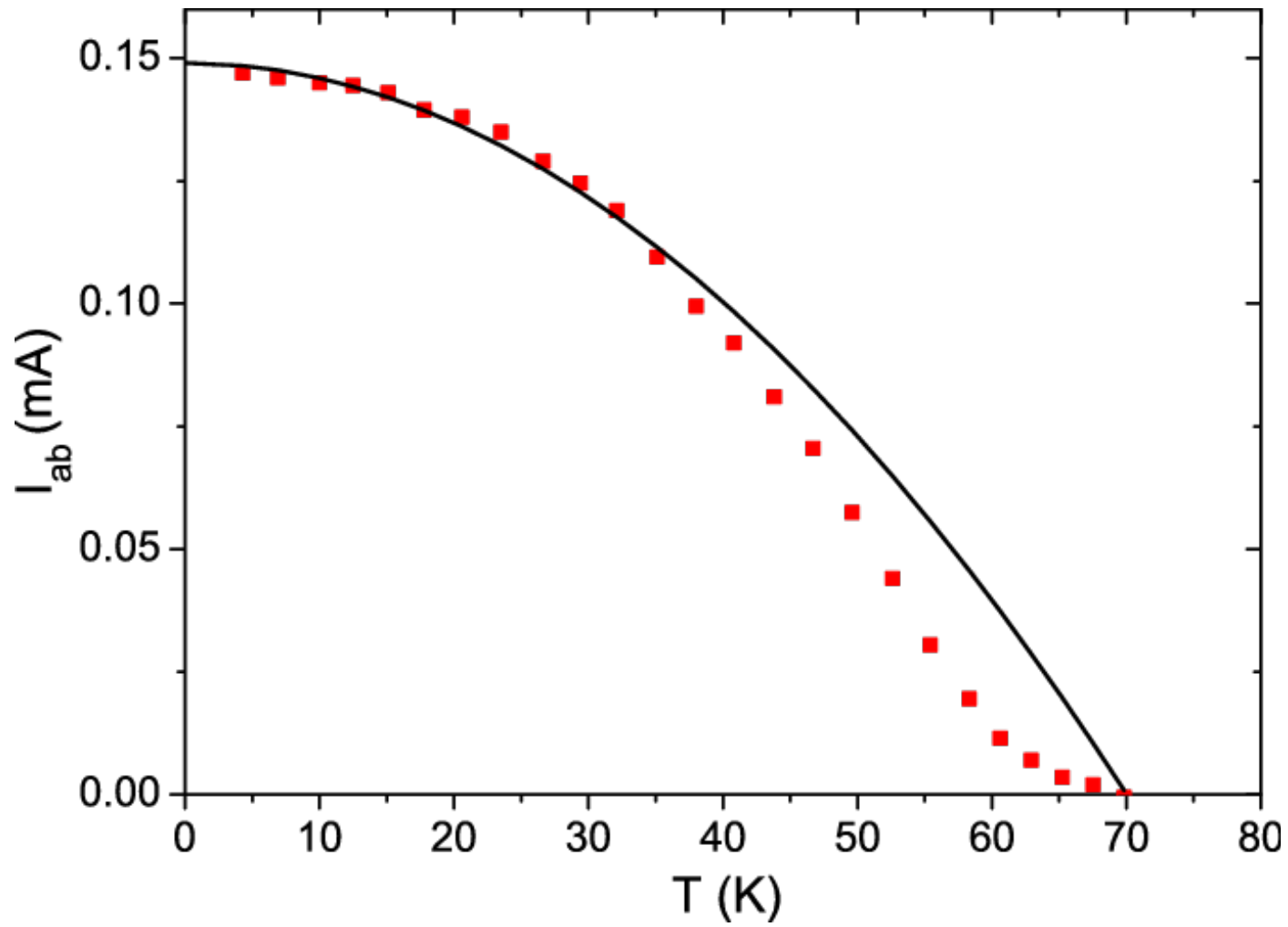
Kontroll paraméterek

Két állapot: szupra vagy normál  bit?

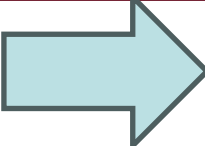
DC áram



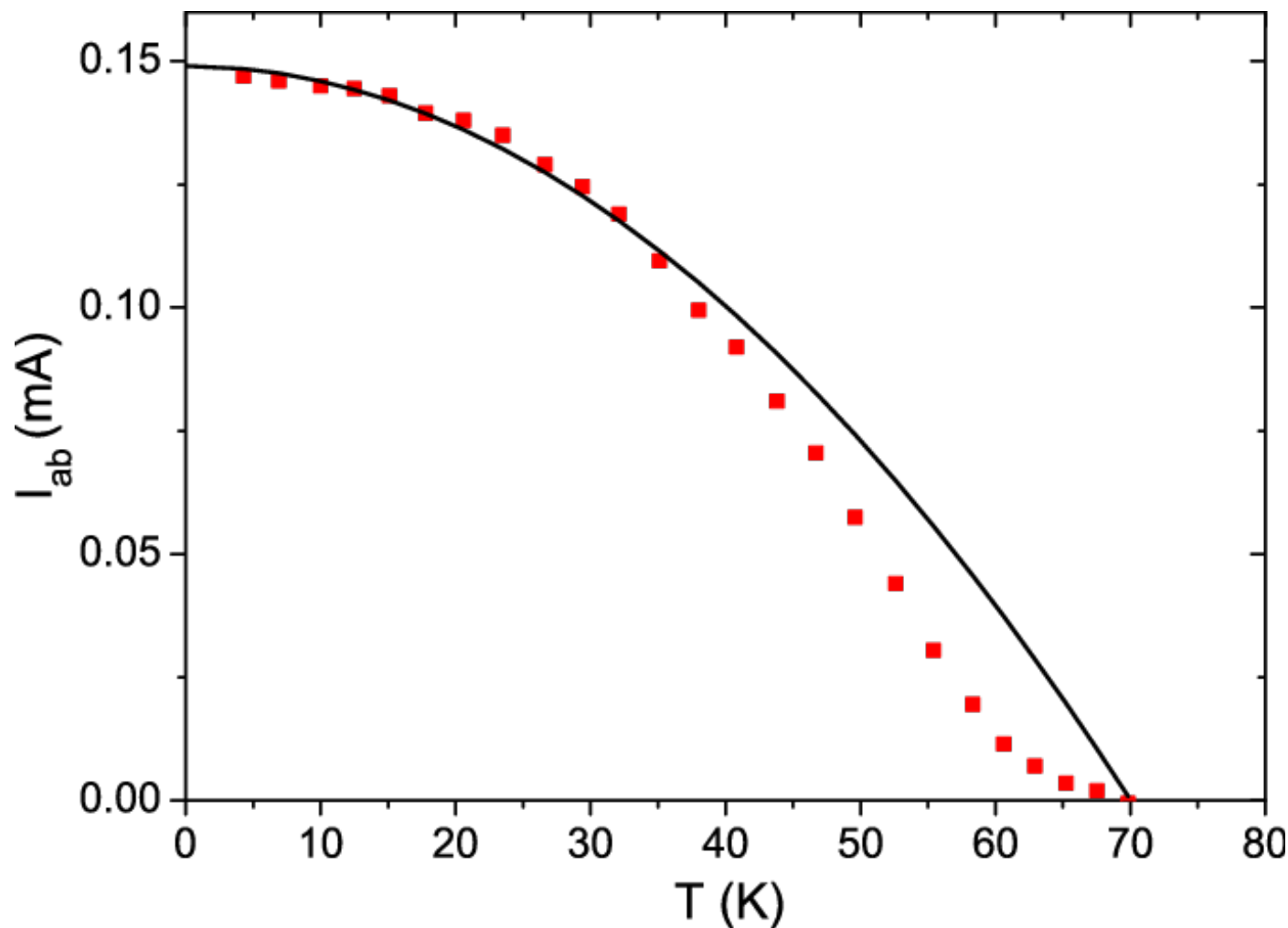
DC áram



Kontroll paraméterek

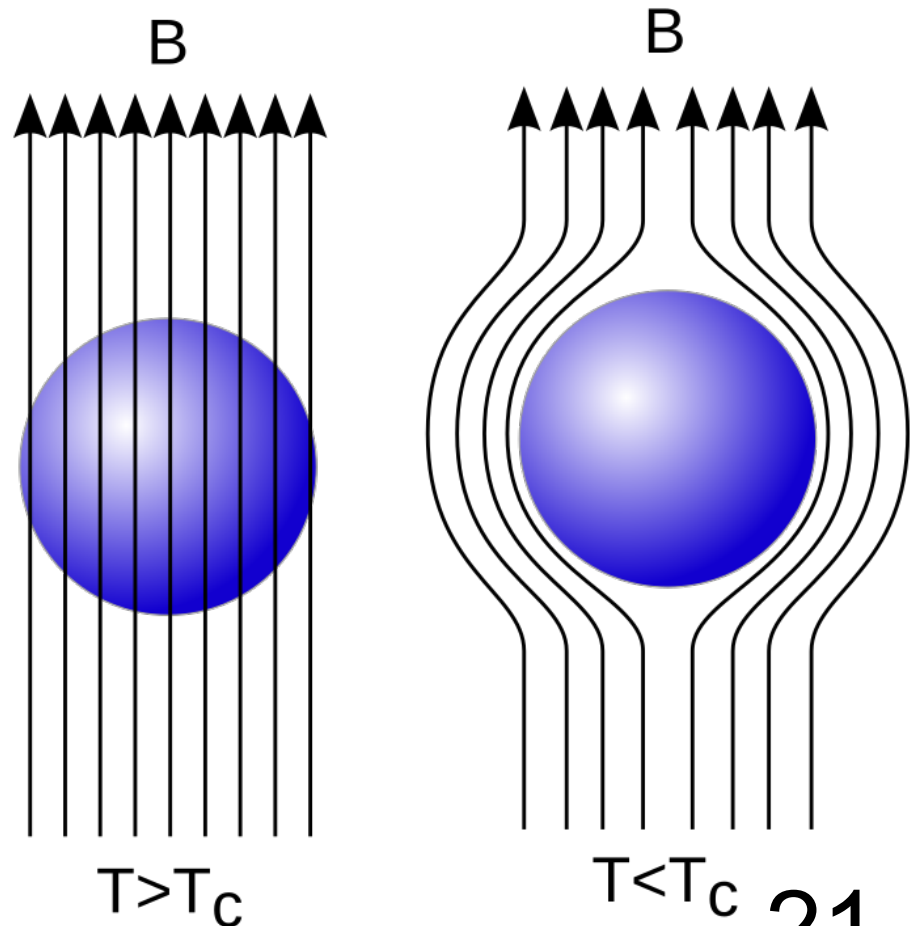
Két állapot: szupra vagy normál  bit?

DC áram

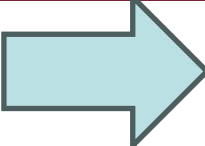


Mágneses tér

Meissner effektus

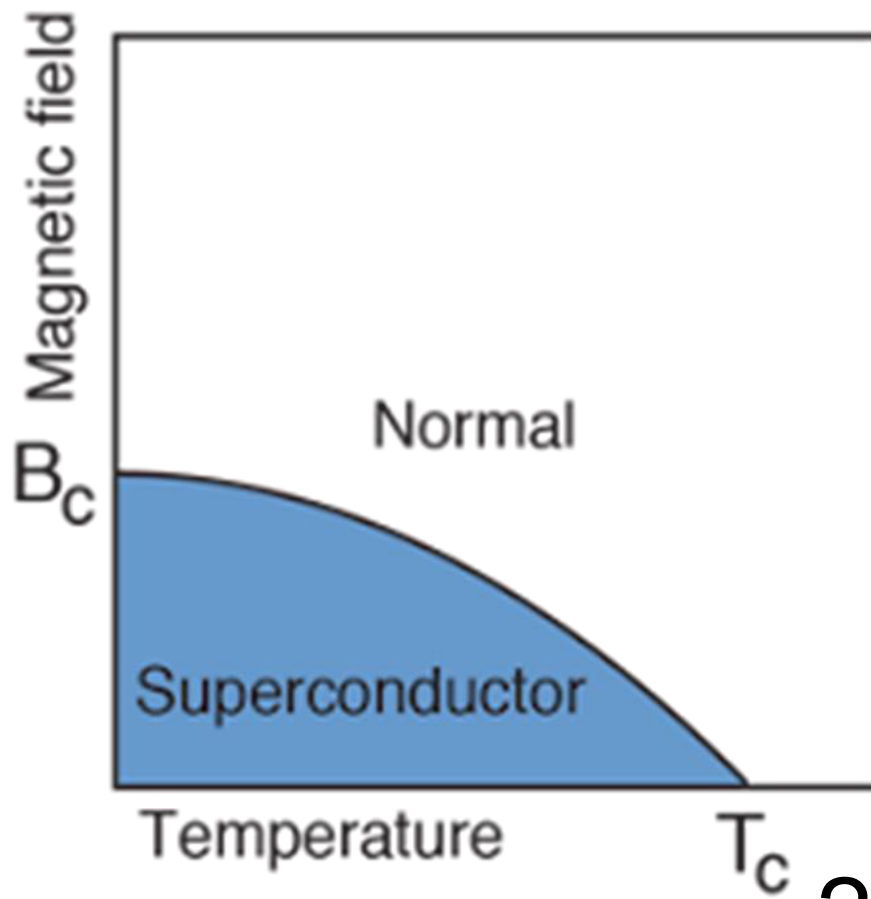
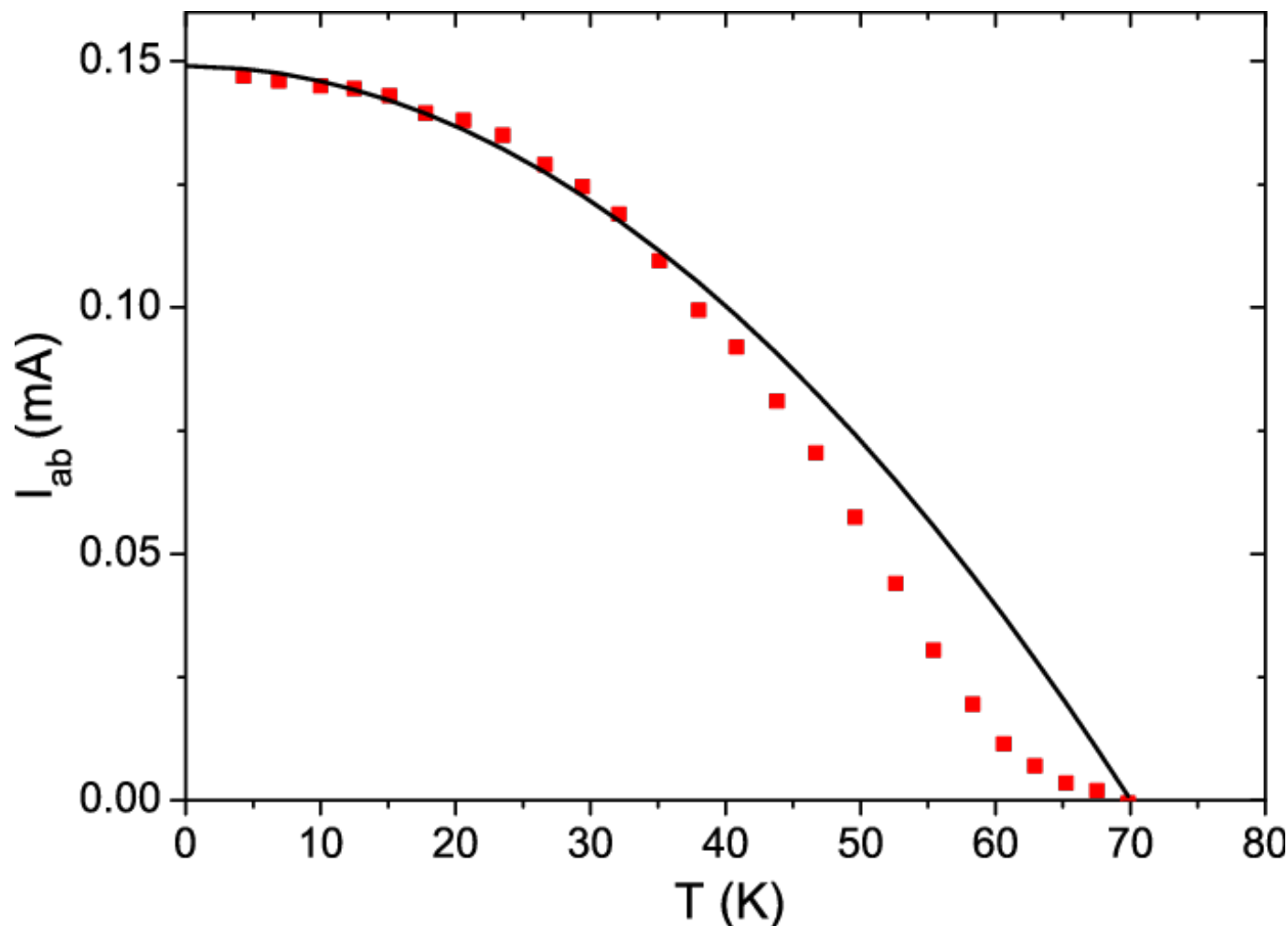


Kontroll paraméterek

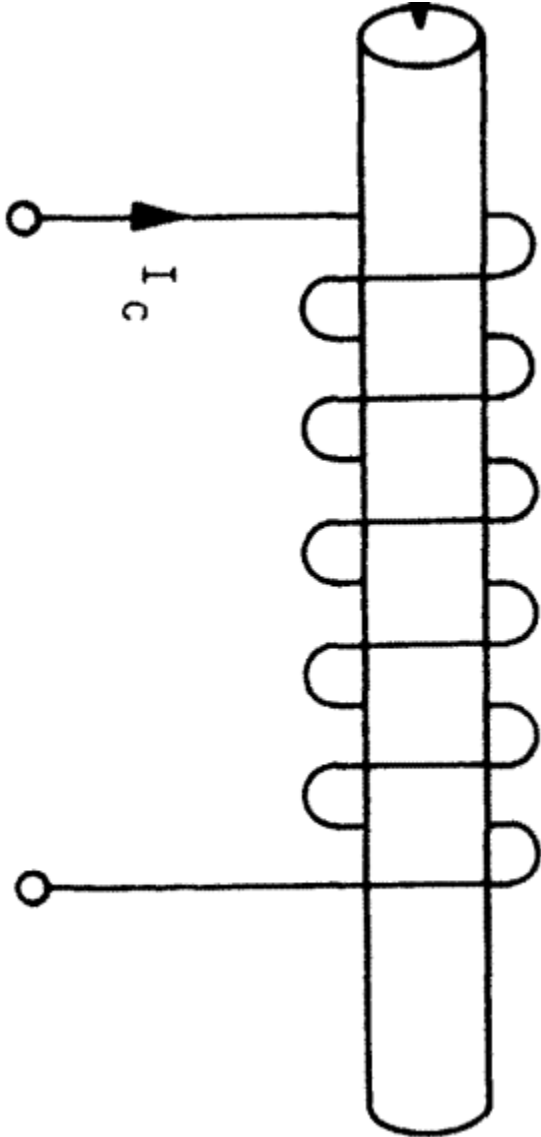
Két állapot: szupra vagy normál  bit?

Mágneses tér
Meissner effektus

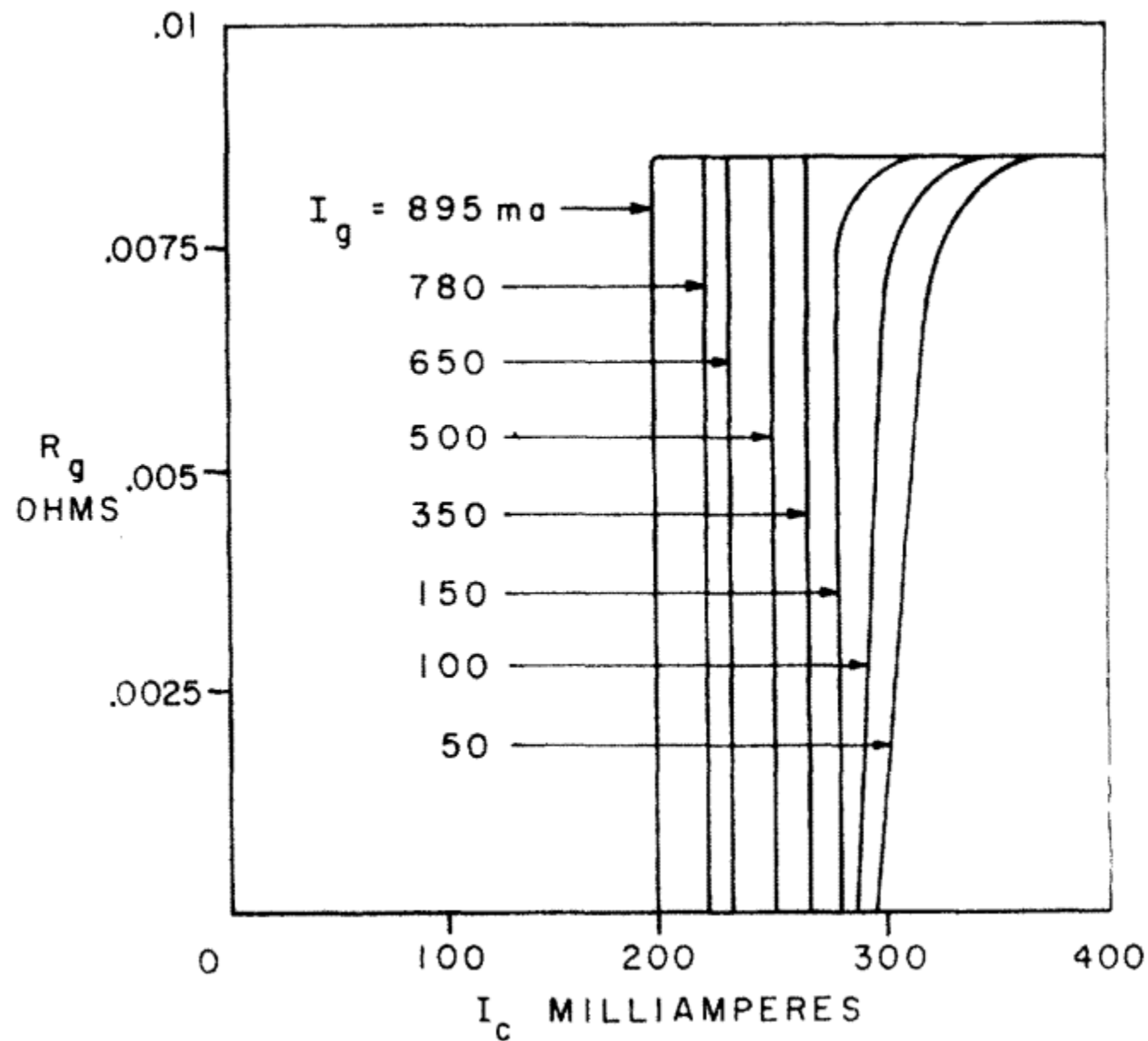
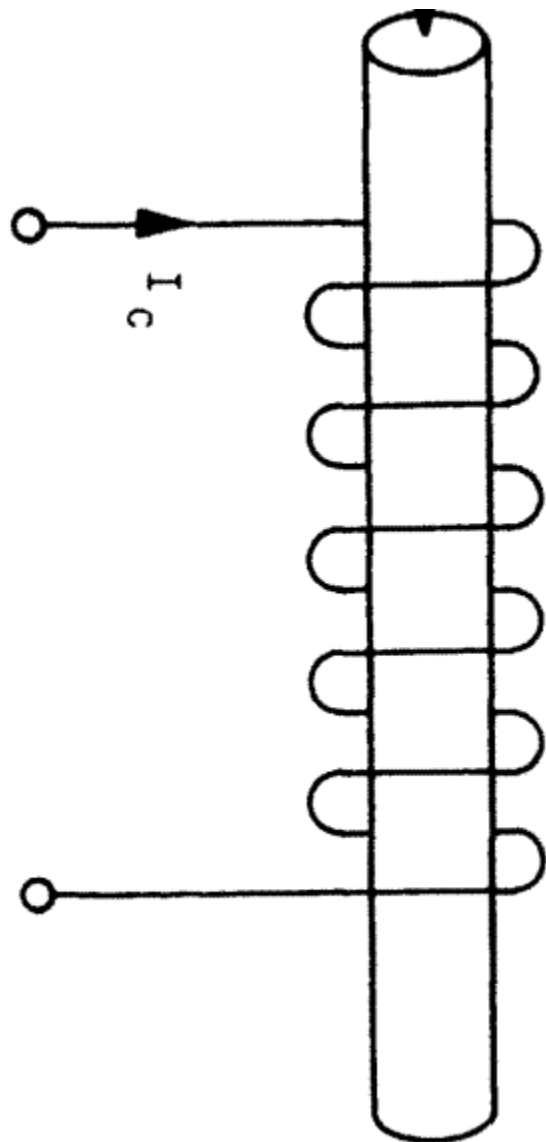
DC áram



Crytron 1956



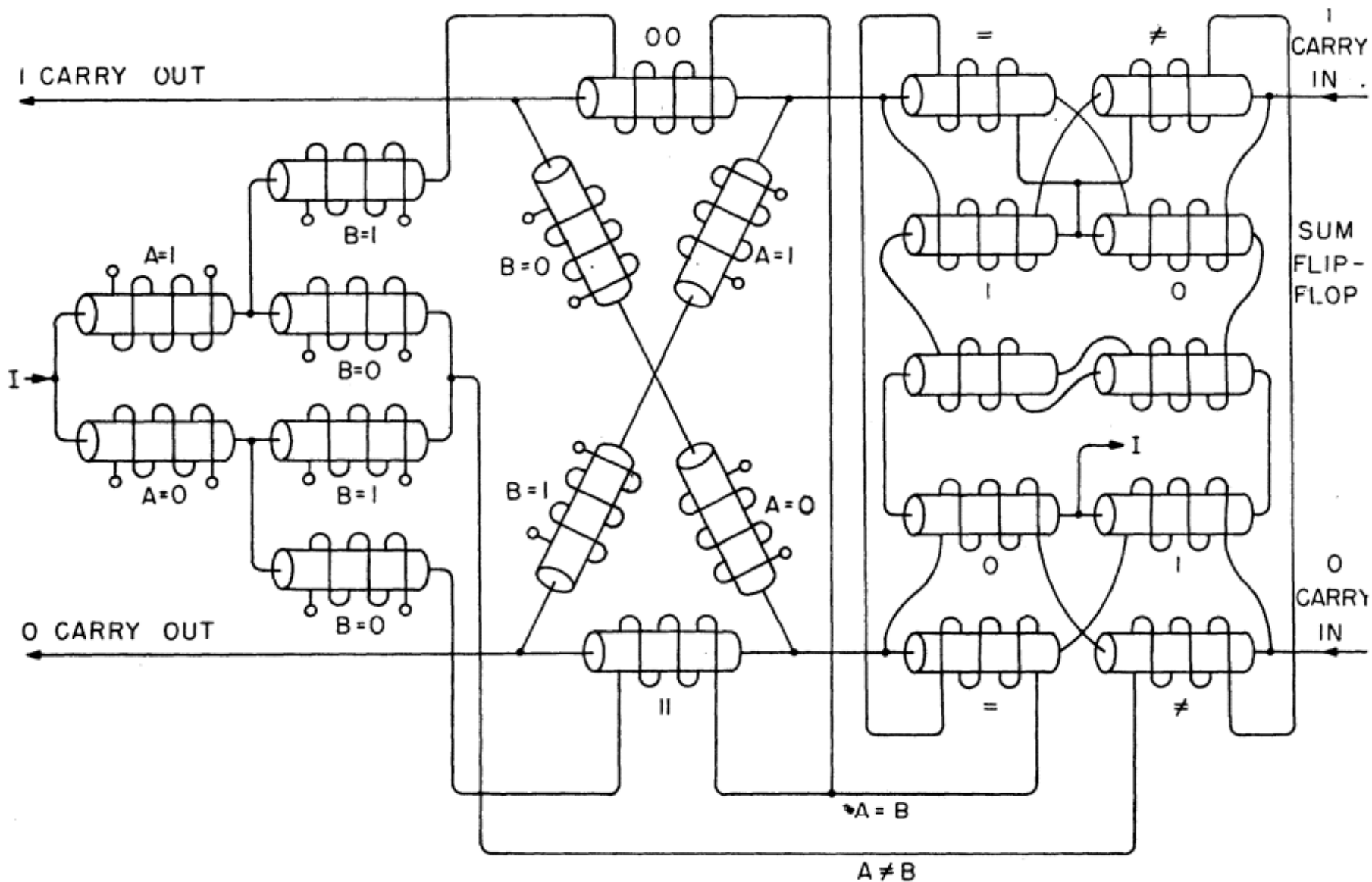
Crytron 1956



Szupravezető kapcsolók

Crytron 1956

Bináris akkumulátor
fázis



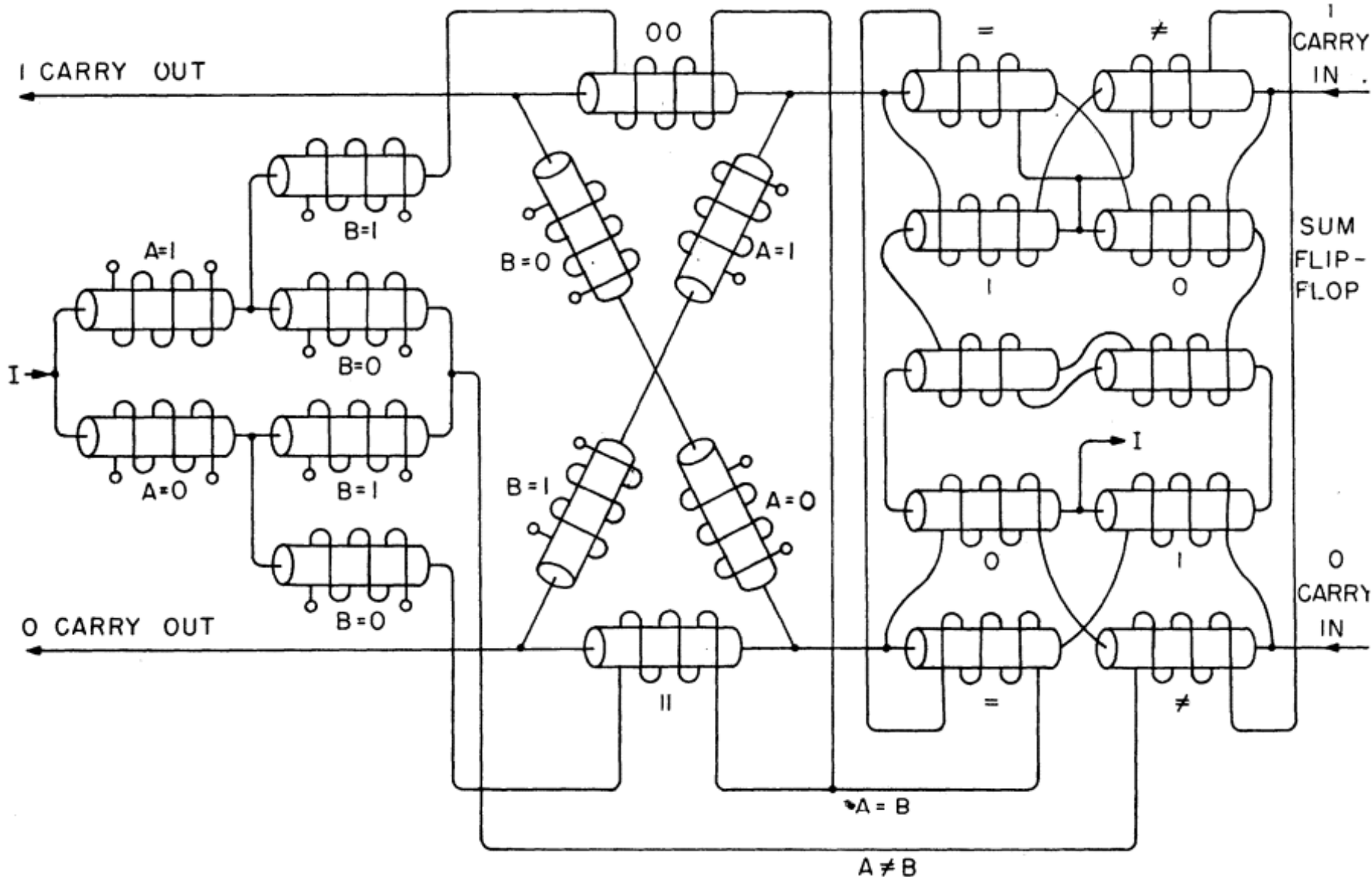
Szupravezető kapcsolók

Crytron 1956

Bináris akkumulátor
fázis

Probléma:

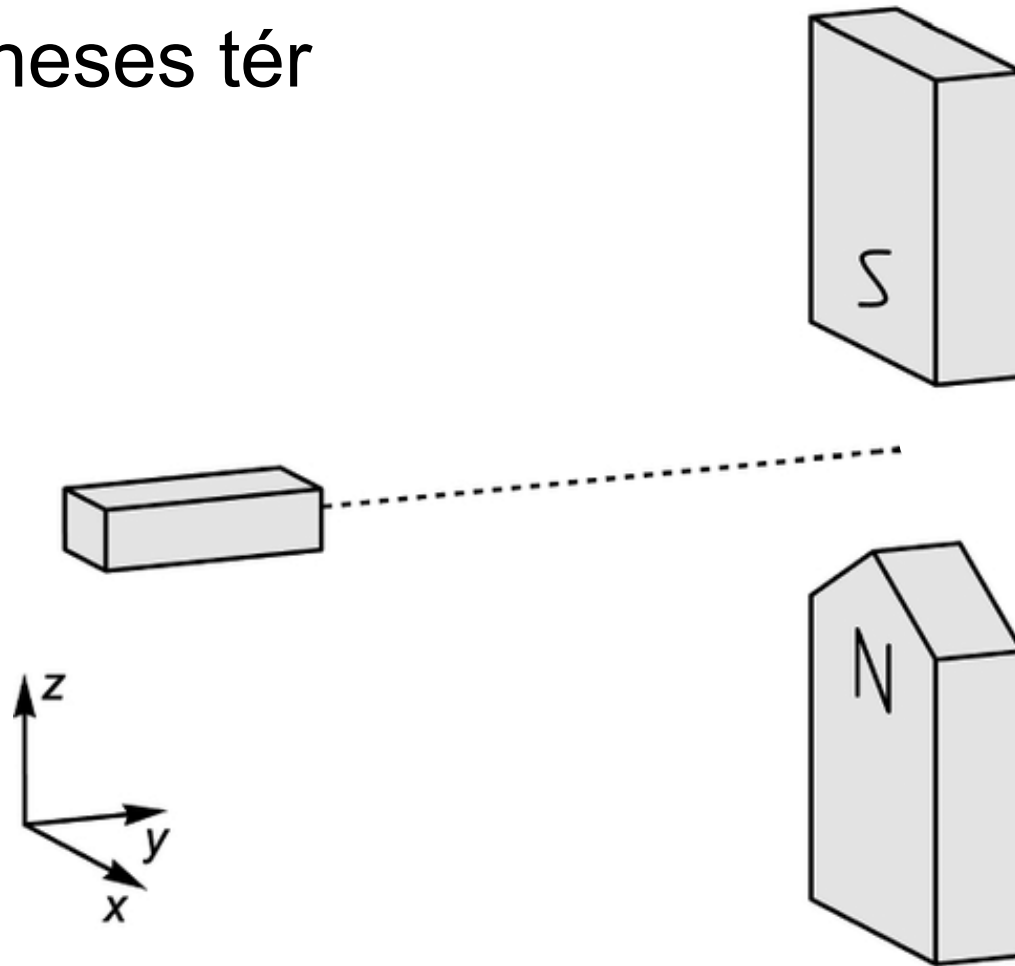
- Skálázhatóság
- Zajszűrés
- Sebesség



Bit = elektron?

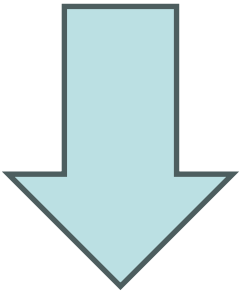
- Inhomogén mágneses tér
- Elektronsugár

Stern - Gerlach kísérlet 1922

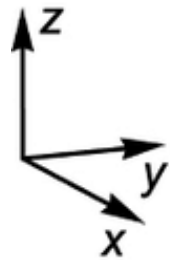


Bit = elektron?

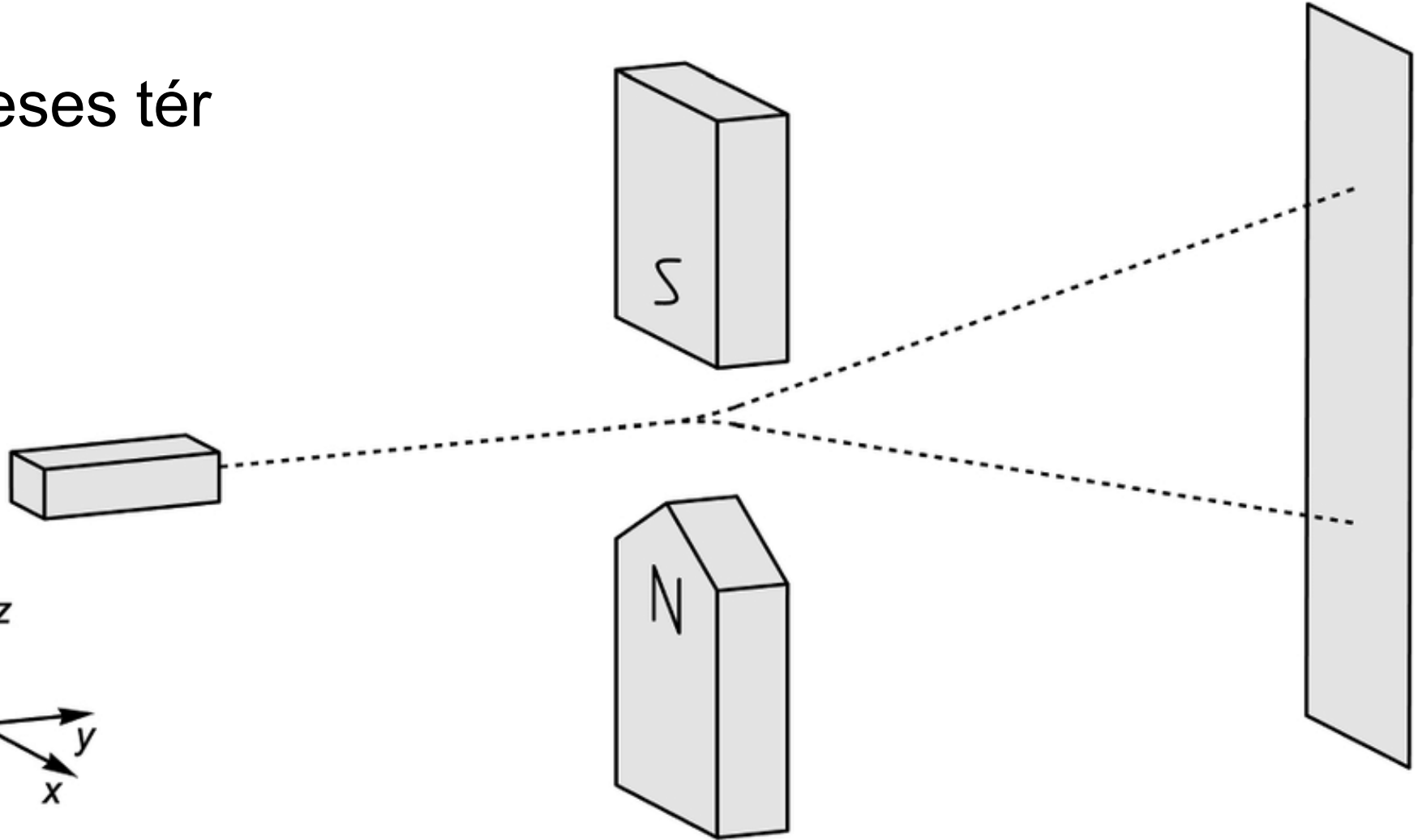
- Inhomogén mágneses tér
- Elektronsugár
- Szétválasztás



Lehetséges bit!

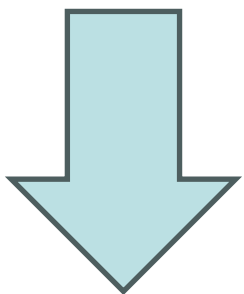


Stern - Gerlach kísérlet 1922



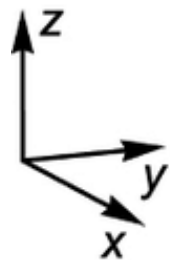
Bit = elektron?

- Inhomogén mágneses tér
- Elektronsugár
- Szétválasztás

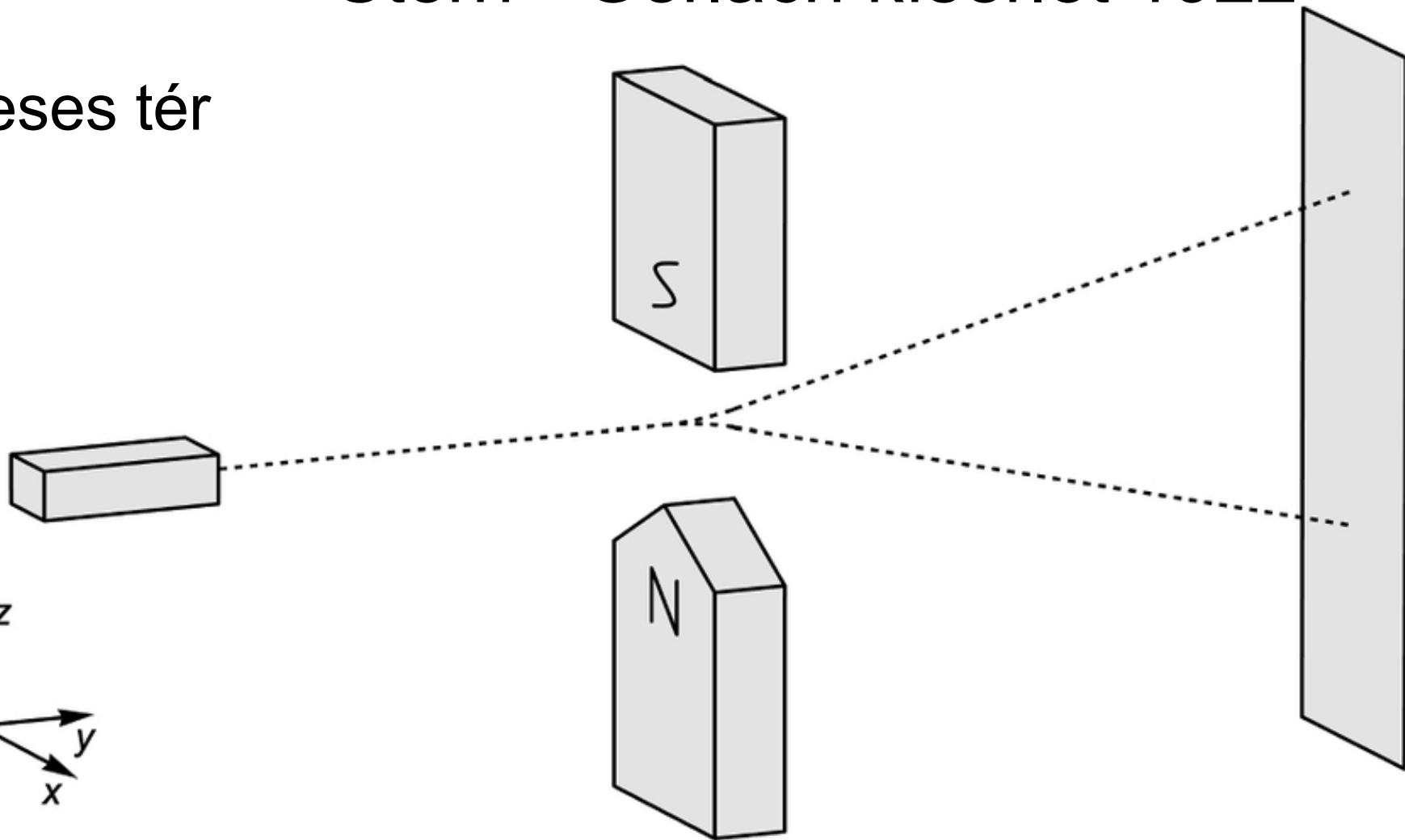


Lehetséges bit!

1. Kérdés: Miért?

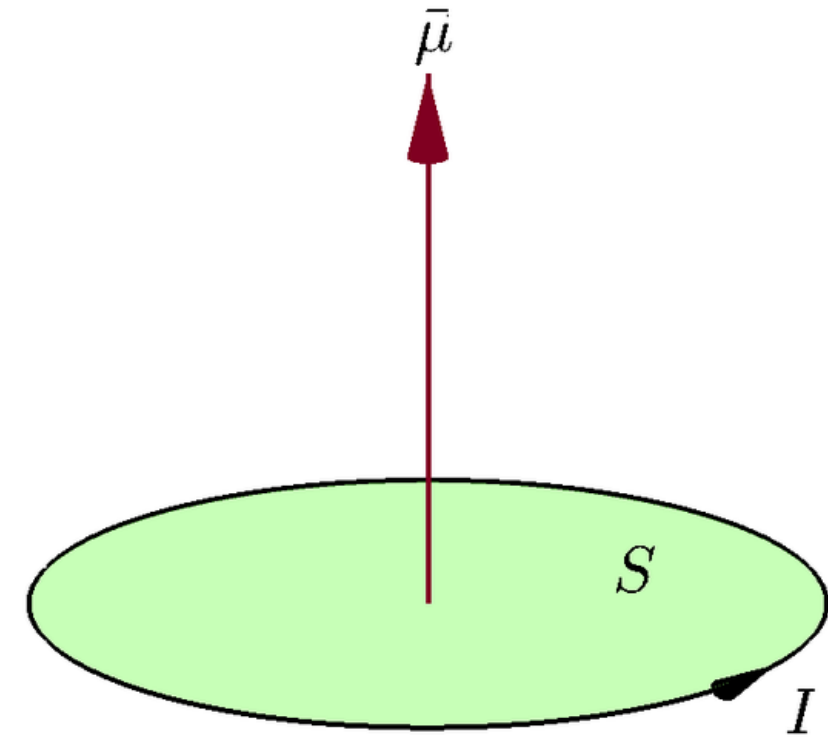


Stern - Gerlach kísérlet 1922



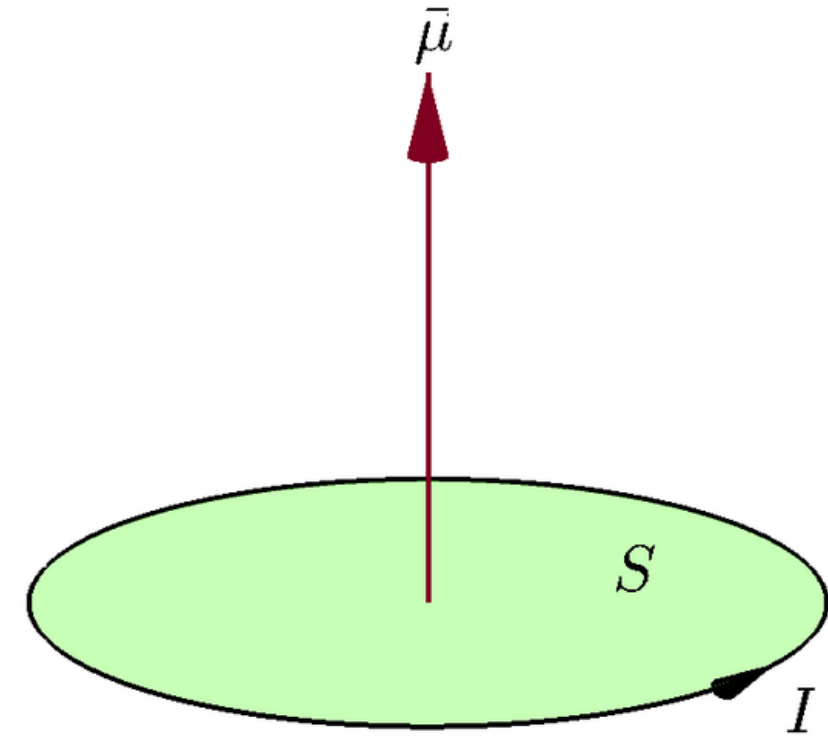
Mágneses dipólmomentum

- Inhomogén mágneses térben folyó áramra erő hat



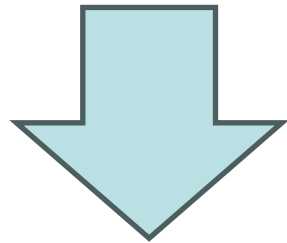
Mágneses dipólmomentum

- Inhomogén mágneses térben folyó áramra erő hat
- Dipólmomentum arányos az impulzusmomentummal



Mágneses dipólmomentum

- Inhomogén mágneses térben folyó áramra erő hat
- Dipólmomentum arányos az impulzusmomentummal



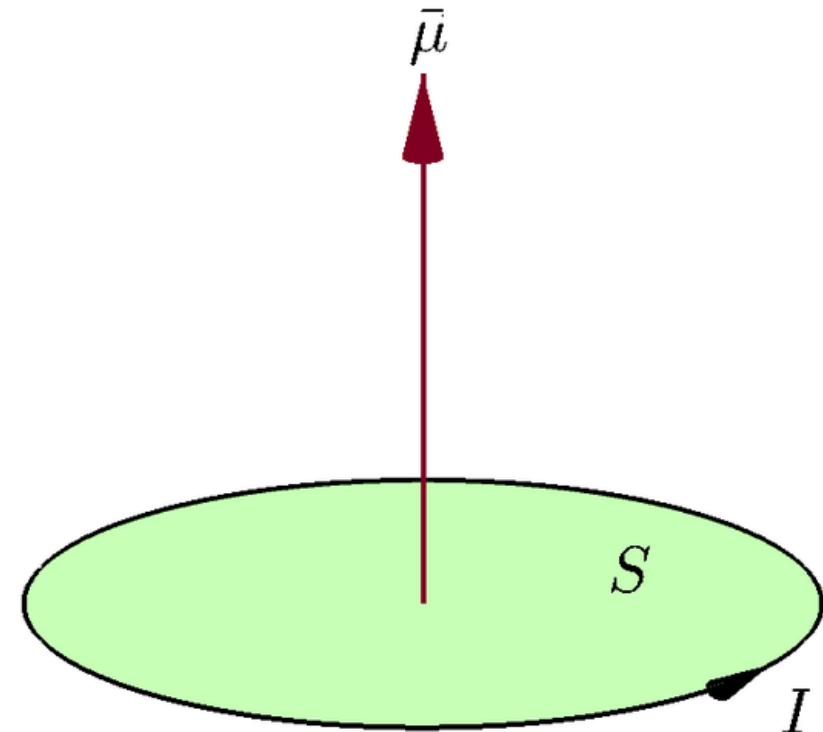
Electron Spin (Up and Down)



1

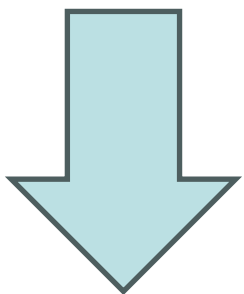


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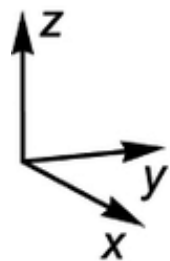
Bit = elektron?

- Inhomogén mágneses tér
- Elektronsugár
- Szétválasztás

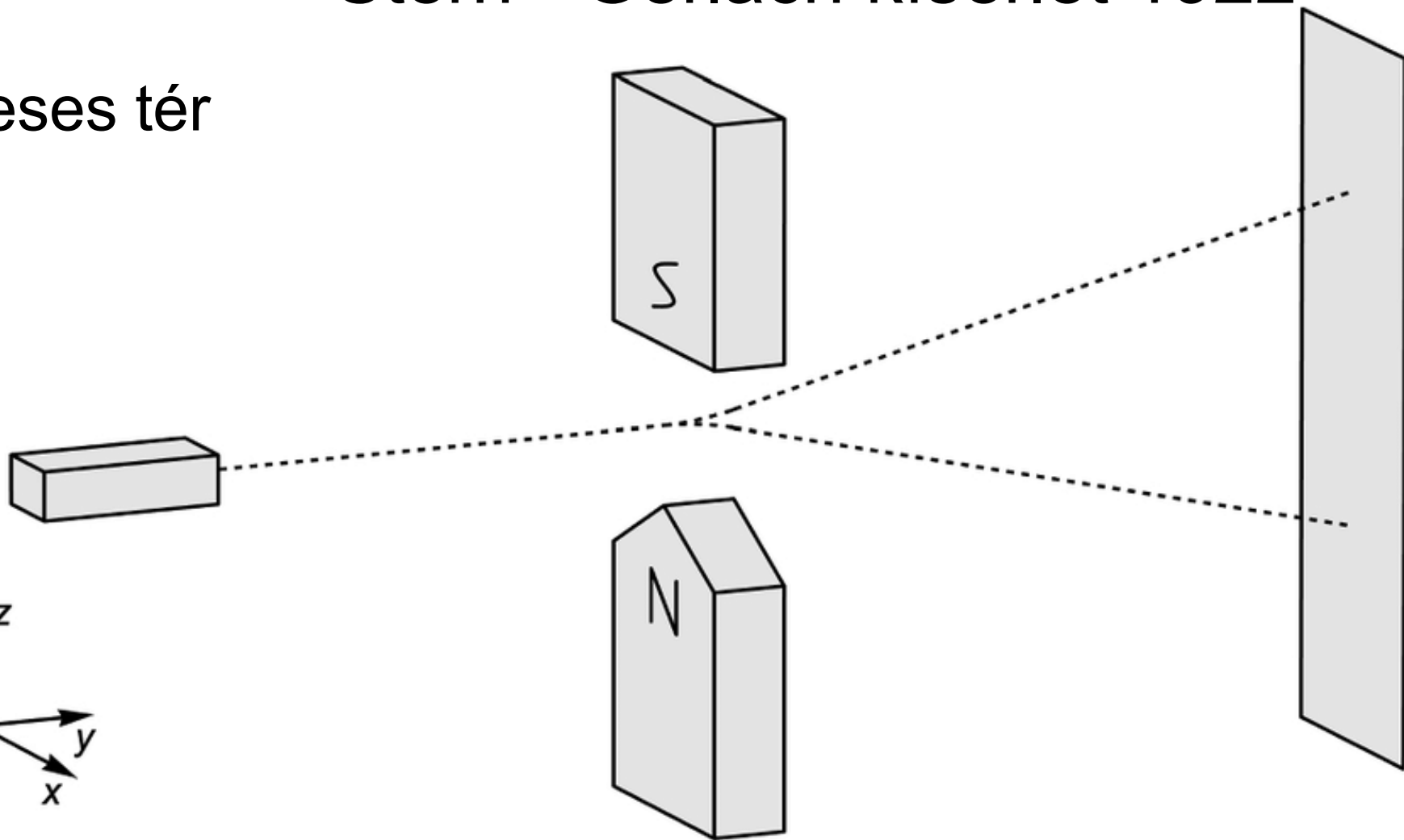


Lehetséges bit!

1. Kérdés: Miért?
2. Kérdés: Hogyan kapcsolom?

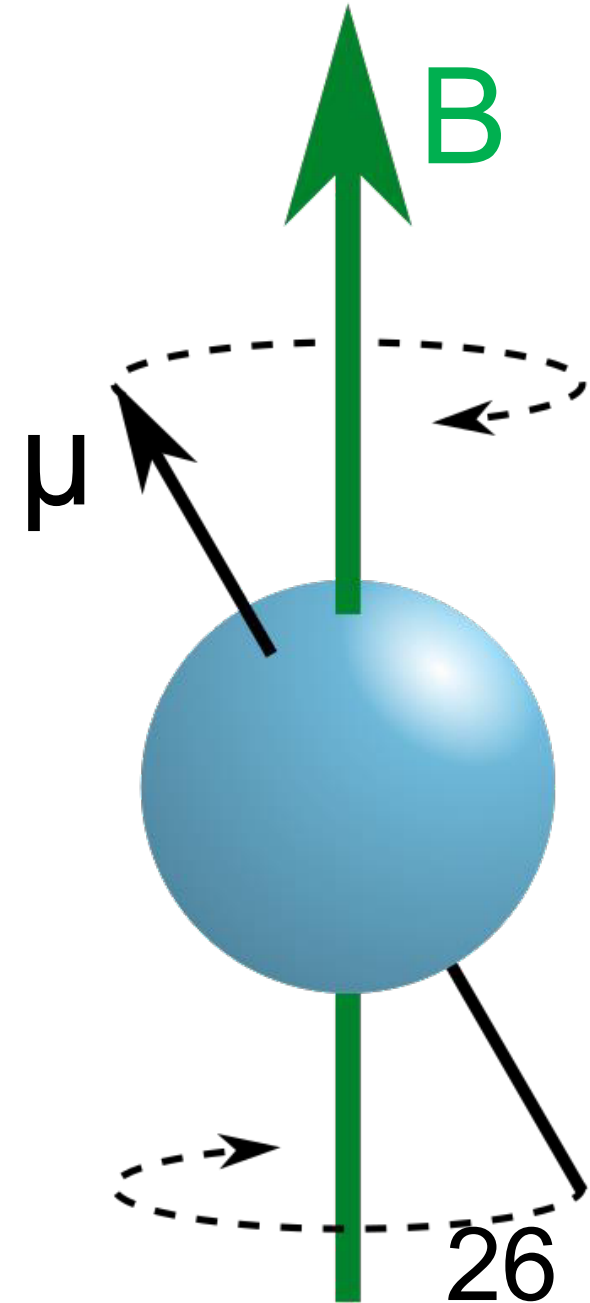


Stern - Gerlach kísérlet 1922



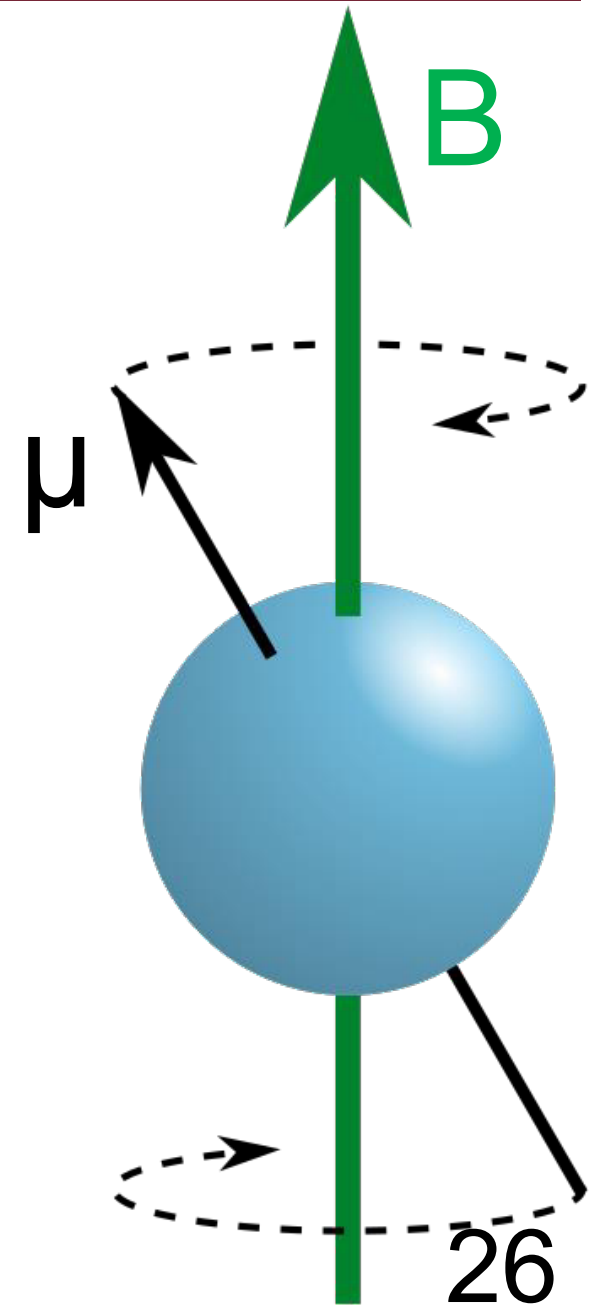
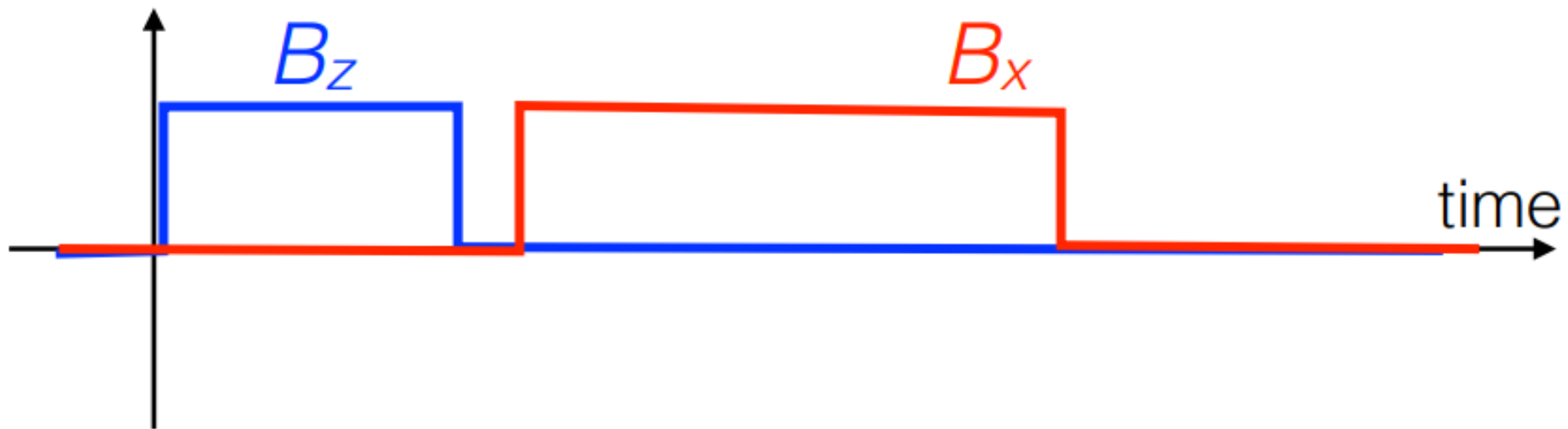
Mágneses dipólmomentum

- Dipólmomentum mágneses térben precesszál
- z és x irányú mágneses impulzusok



Mágneses dipólmomentum

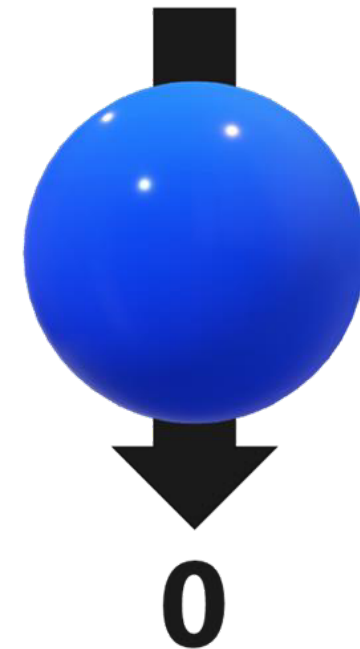
- Dipólmomentum mágneses térben precesszál
- z és x irányú mágneses impulzusok



Kvantumbit

- 2 diszkrét spinállapot! Miért?

Electron Spin (Up and Down)

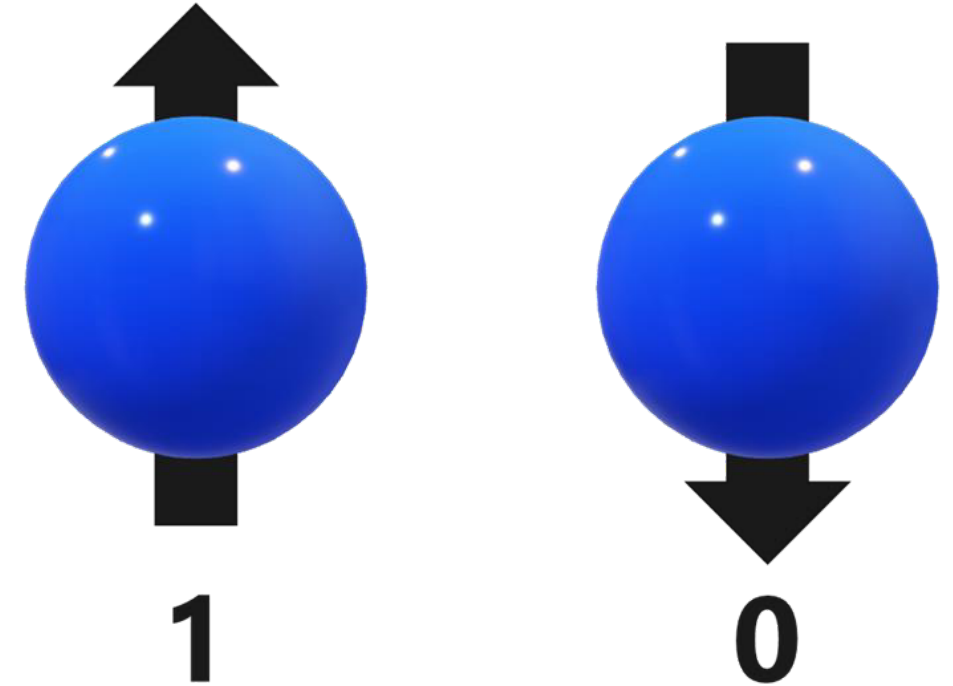


Kvantumbit

- 2 diszkrét spinállapot! Miért?

1. $\psi = \alpha_0|0\rangle + \alpha_1|1\rangle$
2. $|0\rangle$: $P_0 = |\alpha_0|^2$
3. $|1\rangle$: $P_1 = |\alpha_1|^2 = 1 - P_0$

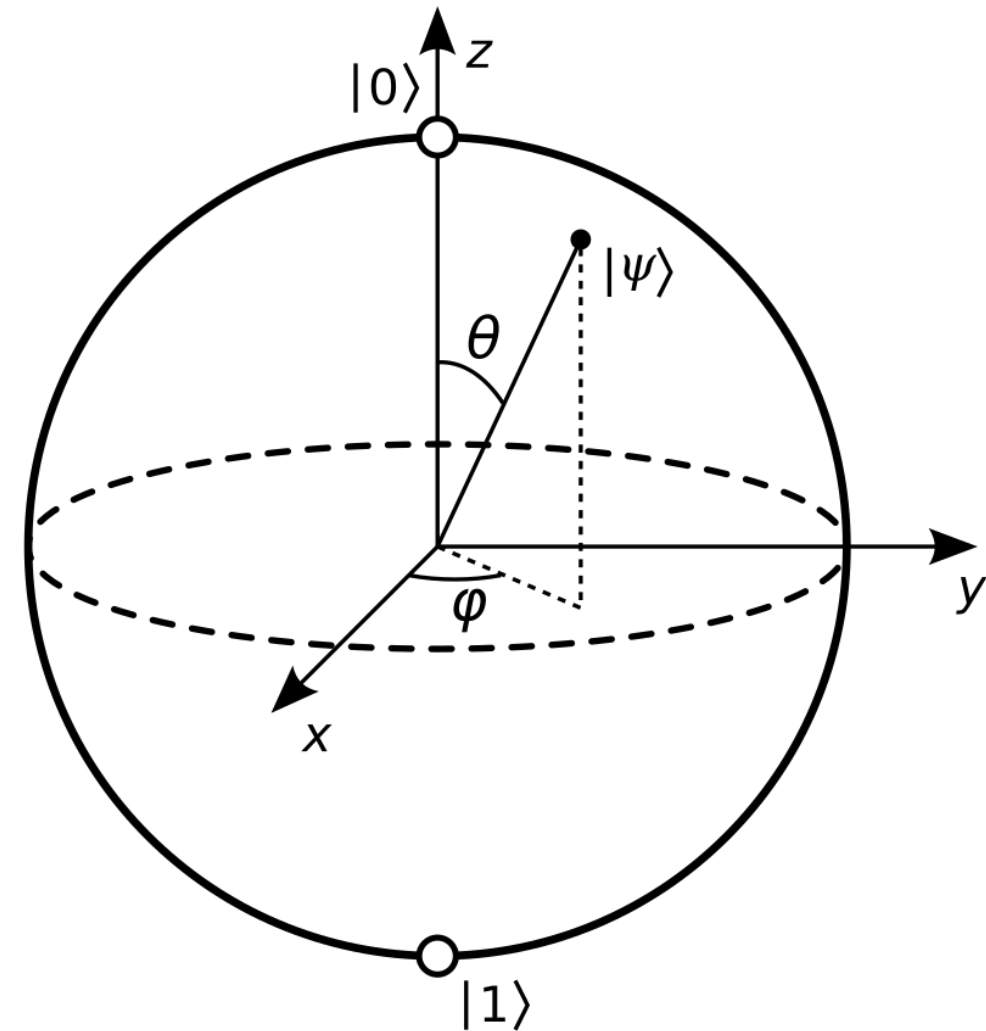
Electron Spin (Up and Down)



Kvantumbit

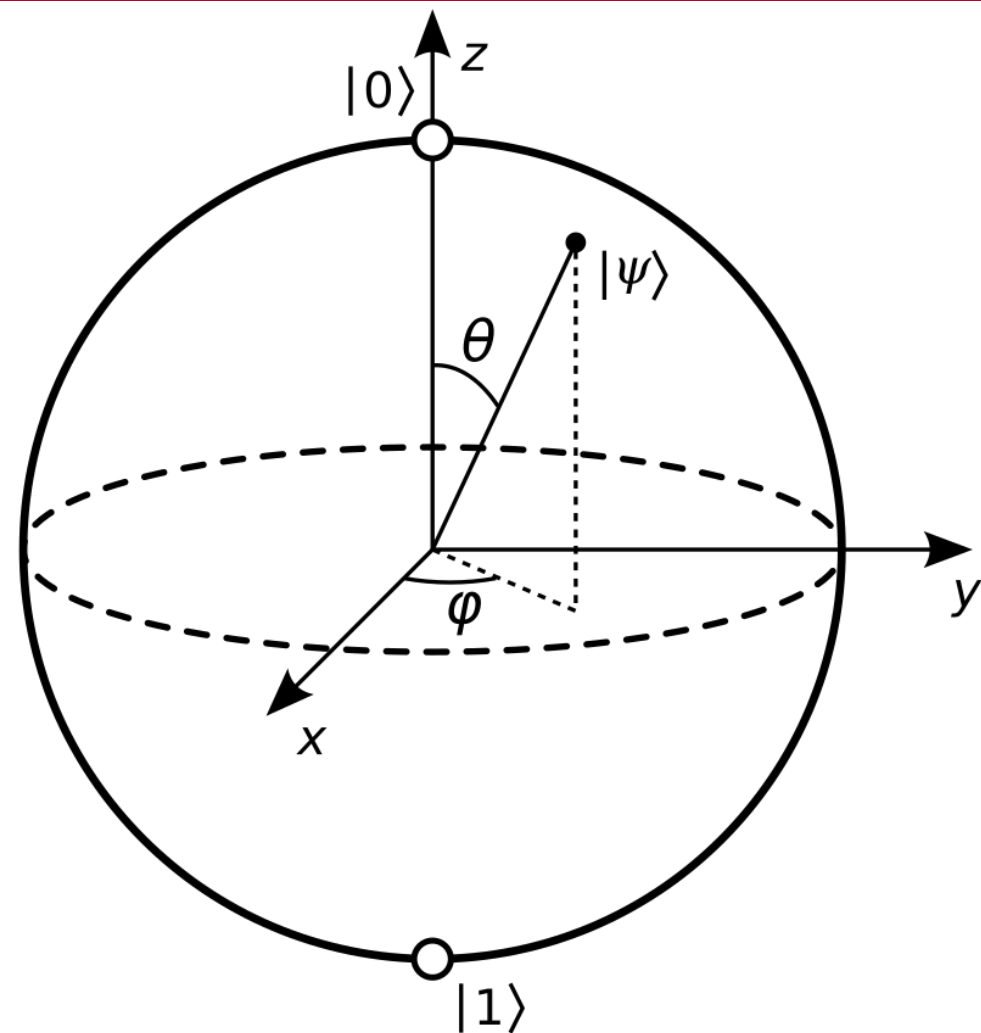
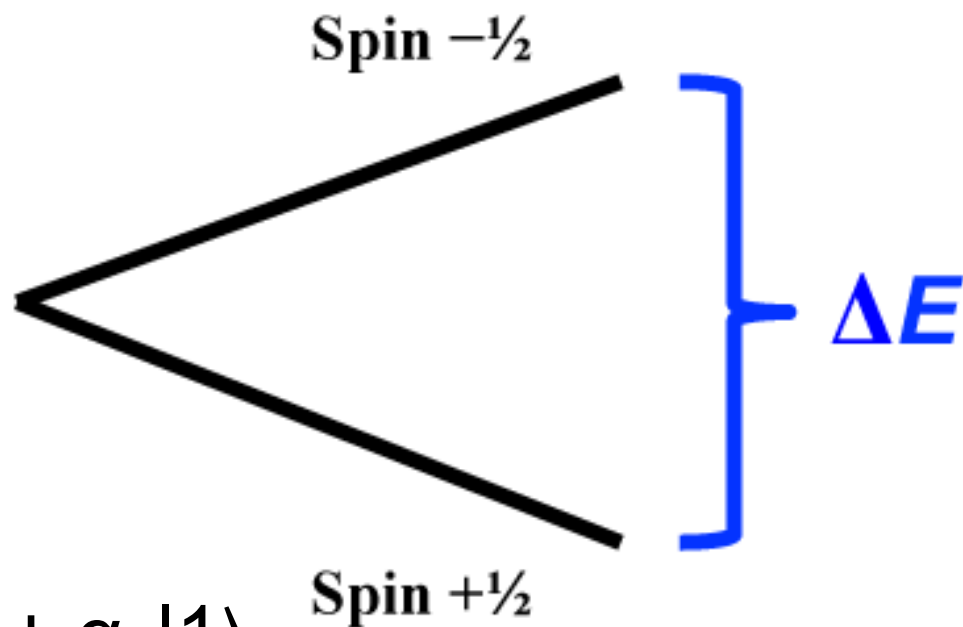
- 2 diszkrét spinállapot! Miért?

1. $\psi = \alpha_0|0\rangle + \alpha_1|1\rangle$
2. $|0\rangle$: $P_0 = |\alpha_0|^2$
3. $|1\rangle$: $P_1 = |\alpha_1|^2 = 1 - P_0$
4. $\alpha_0 = \cos(\theta/2)$
5. $\alpha_1 = \exp(i \times \phi) \times \sin(\theta/2)$



Kvantumbit

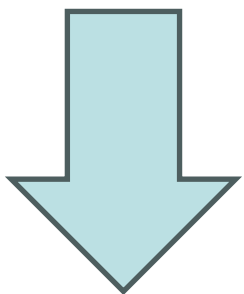
- 2 diszkrét spinállapot! Miért?



1. $\psi = \alpha_0|0\rangle + \alpha_1|1\rangle$
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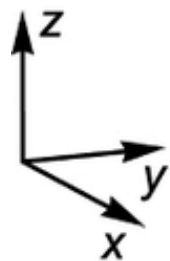
Bit = elektron?

- Inhomogén mágneses tér
- Elektronsugár
- Szétválasztás

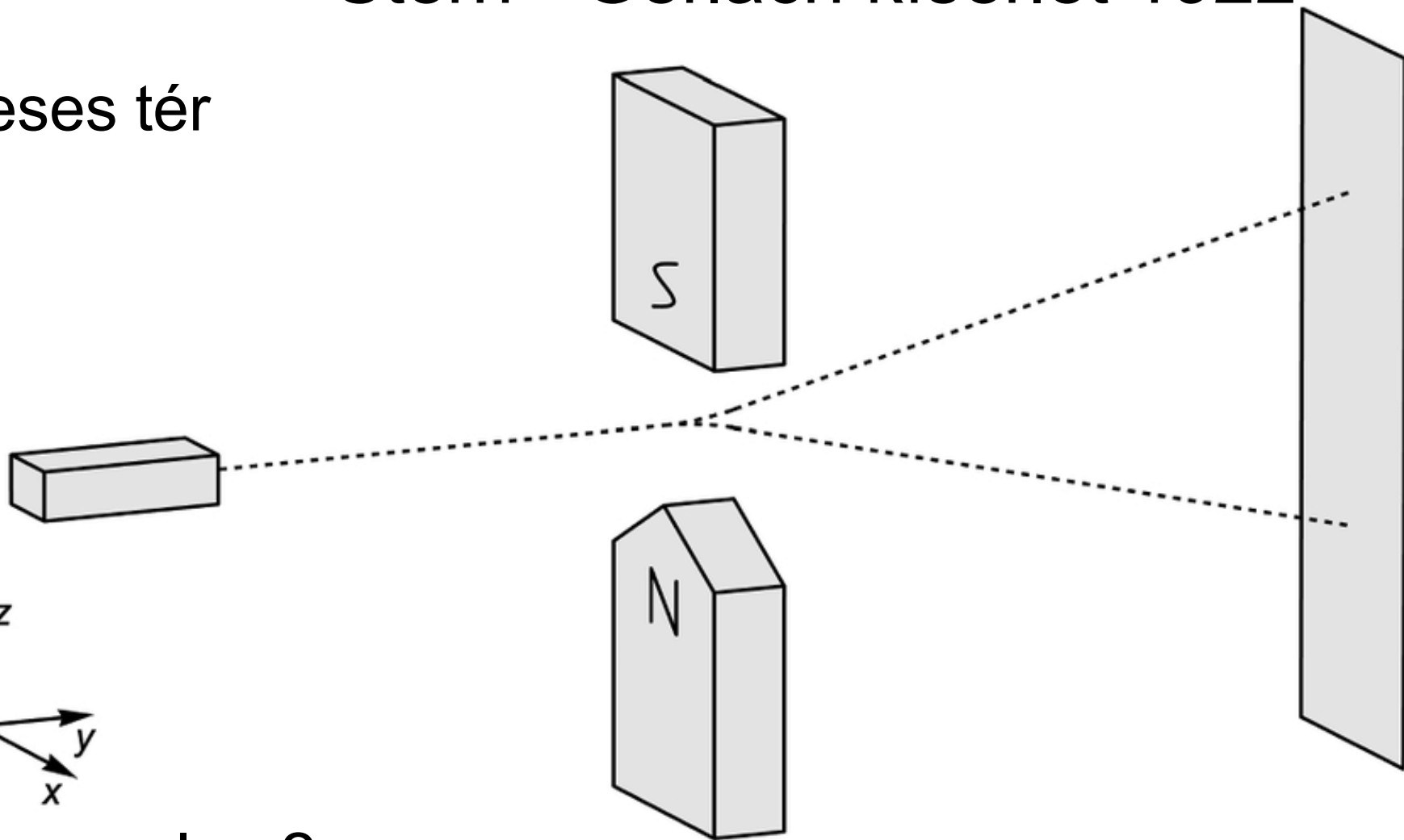


Lehetséges bit!

1. Kérdés: Miért?
2. Kérdés: Hogyan kapcsolom?
3. Hogyan olvasom ki?

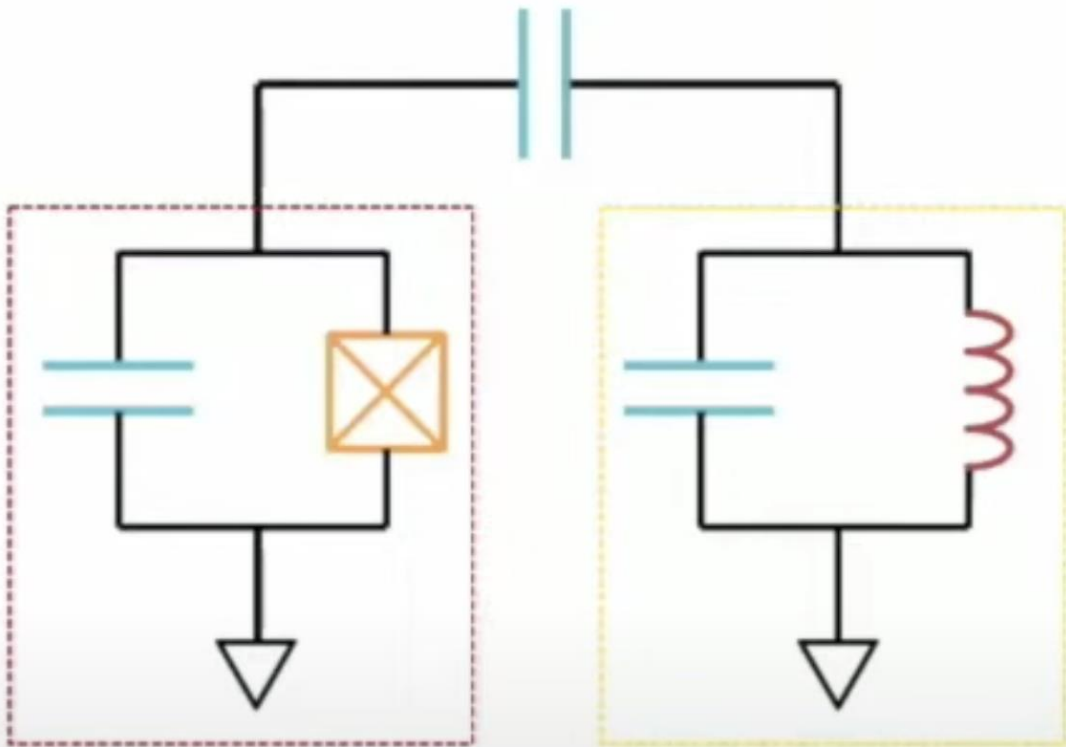


Stern - Gerlach kísérlet 1922



Kiolvasás

- Kvantumbit csatolva egy rezonátorhoz

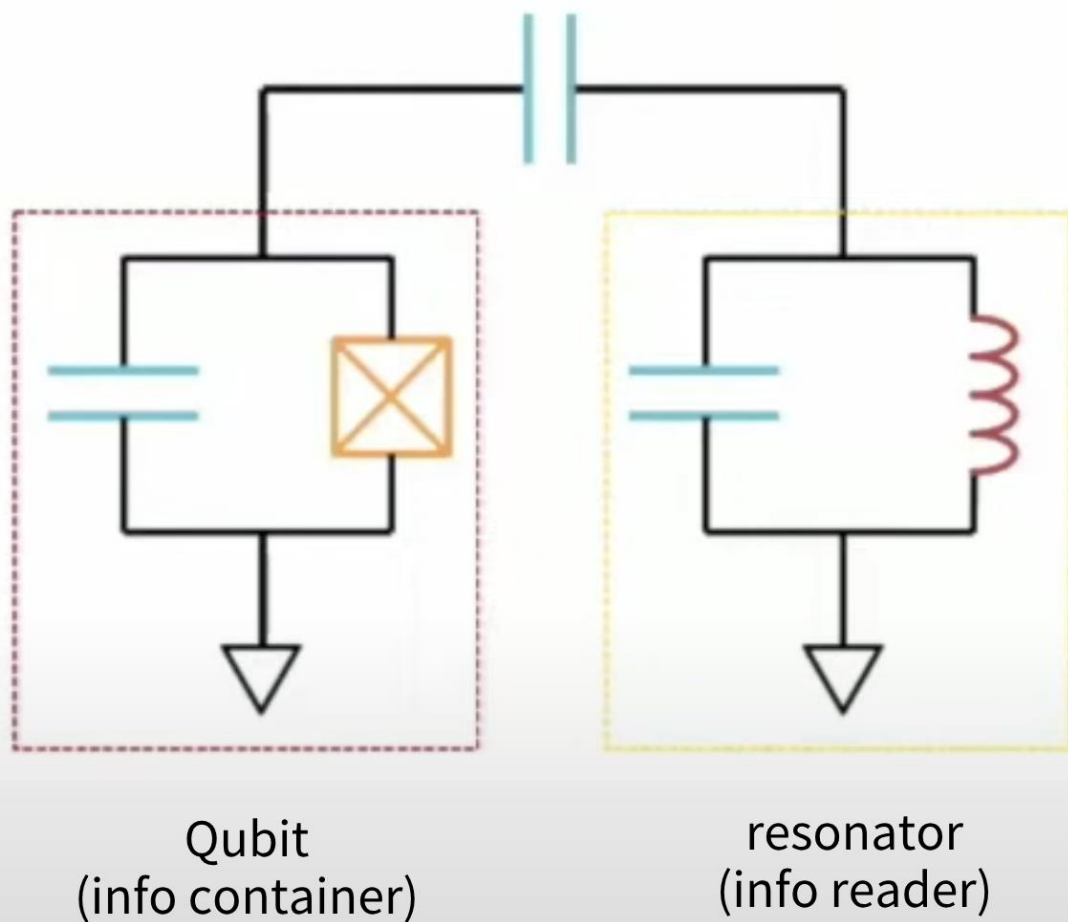


Qubit
(info container)

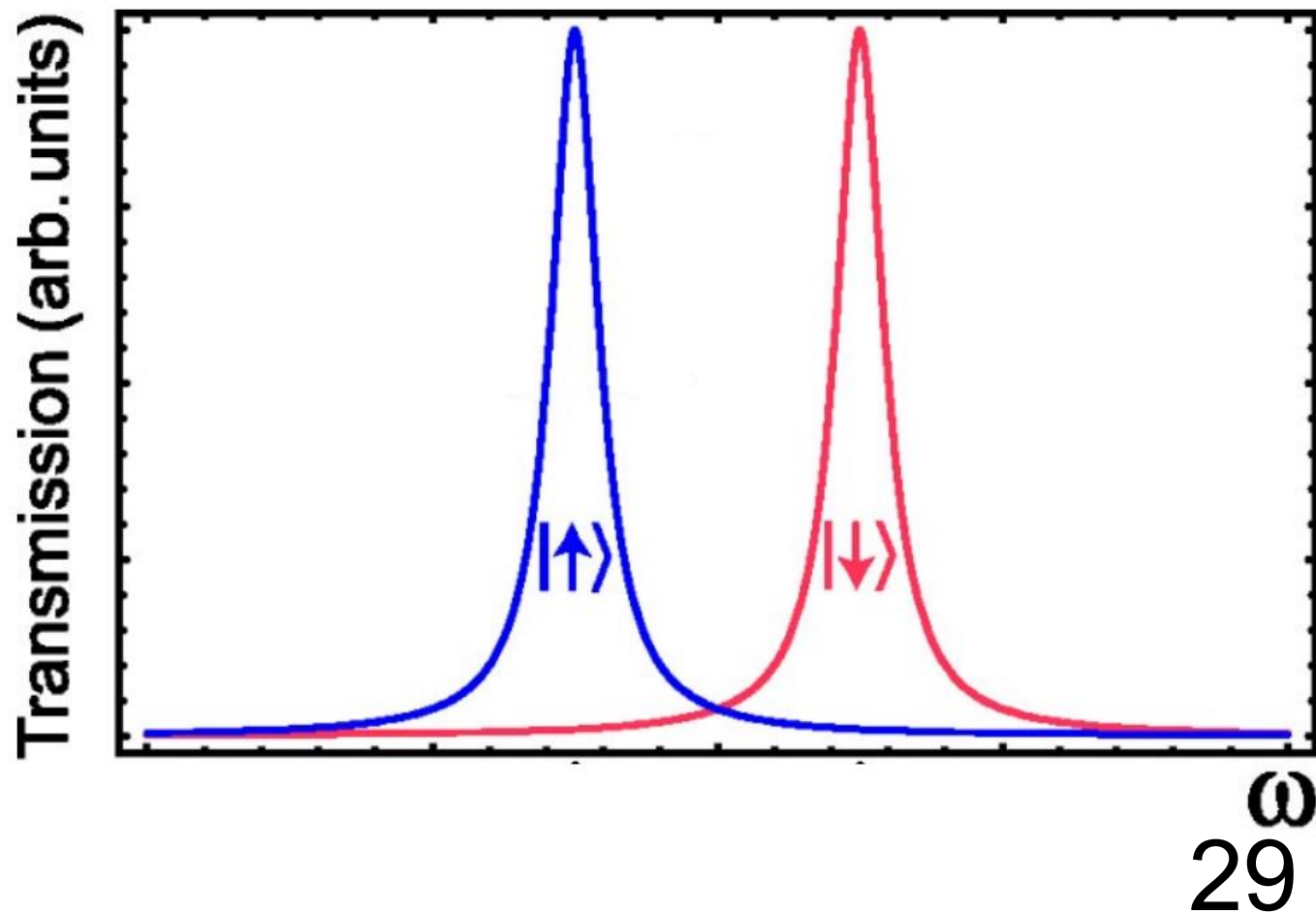
resonator
(info reader)

Kiolvasás

- Kvantumbit csatolva egy rezonátorhoz



- Kvantumbit állapota megjelenik a rezonanciafrekvenciában



Miért jó a kvantumbit?

- $f: \{0,1\} \rightarrow \{0,1\}$ függvény
- 4 lehetséges opció f -re

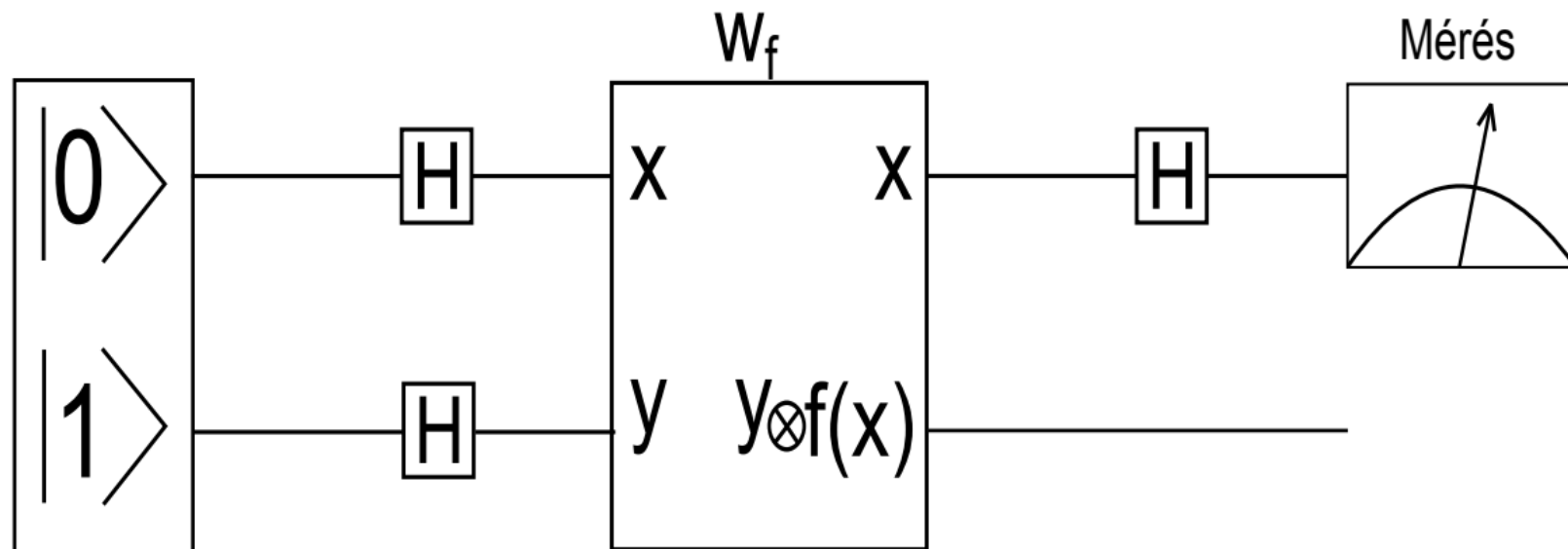
constant (value = 1)	constant (value = 0)
$0 \rightarrow 1$	$0 \rightarrow 0$
$1 \rightarrow 1$	$1 \rightarrow 0$
balanced (NOT)	balanced (<i>id.</i>)
$0 \rightarrow 1$	$0 \rightarrow 0$
$1 \rightarrow 0$	$1 \rightarrow 1$

Döntsük el hogy f konstans vagy kiegyensúlyozott a leghatékosabban!
Megoldás: f -et kiértékelem 0 és 1 bemenettel

Miért jó a kvantumbit?

$f = 0$	$f = 1$
$00 \rightarrow 00$	$00 \rightarrow 01$
$01 \rightarrow 01$	$01 \rightarrow 00$
$10 \rightarrow 10$	$10 \rightarrow 11$
$11 \rightarrow 11$	$11 \rightarrow 10$
$f = id.$	$f = NOT$
$00 \rightarrow 00$	$00 \rightarrow 01$
$01 \rightarrow 01$	$01 \rightarrow 00$
$10 \rightarrow 11$	$10 \rightarrow 10$
$11 \rightarrow 10$	$11 \rightarrow 11$

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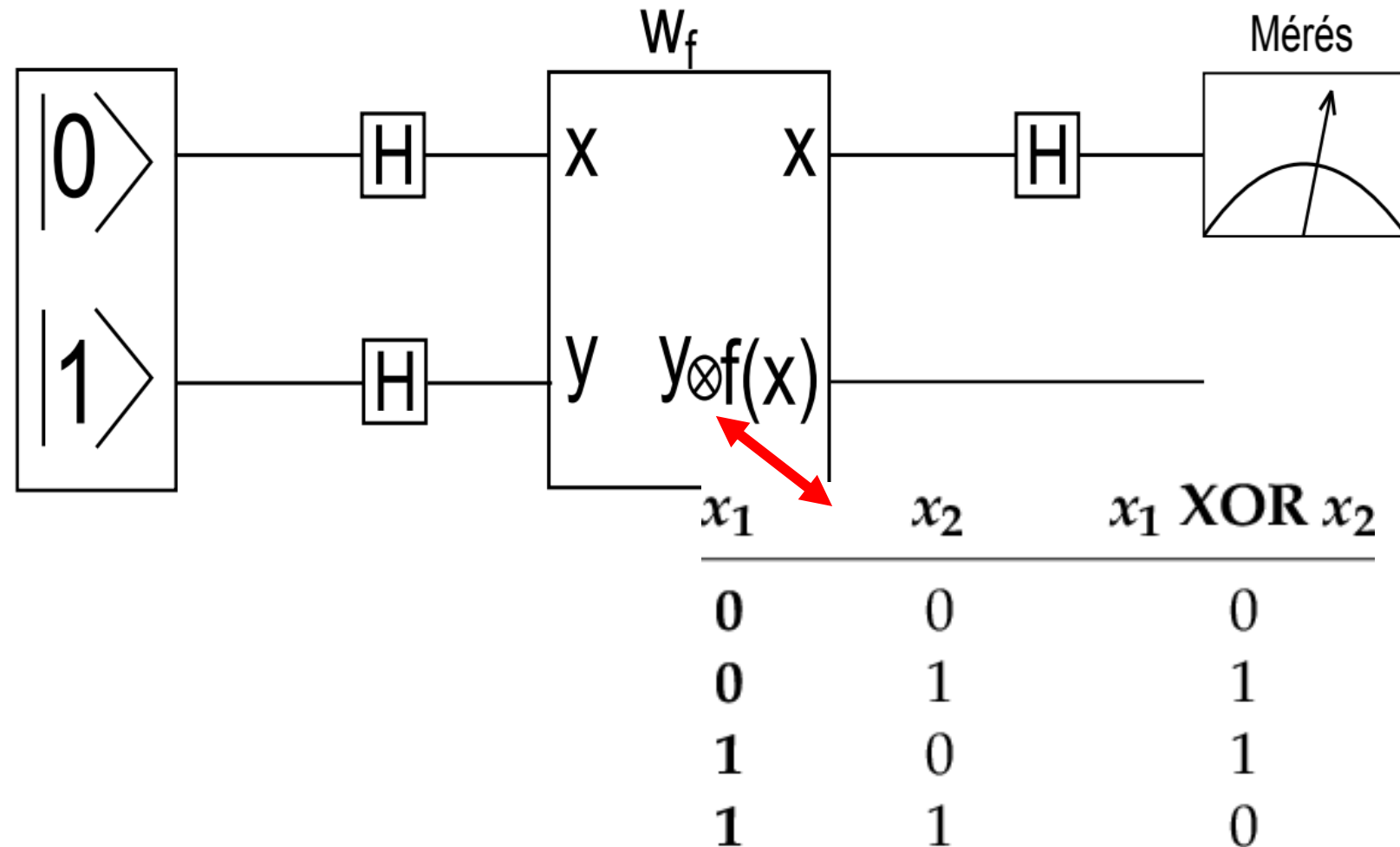


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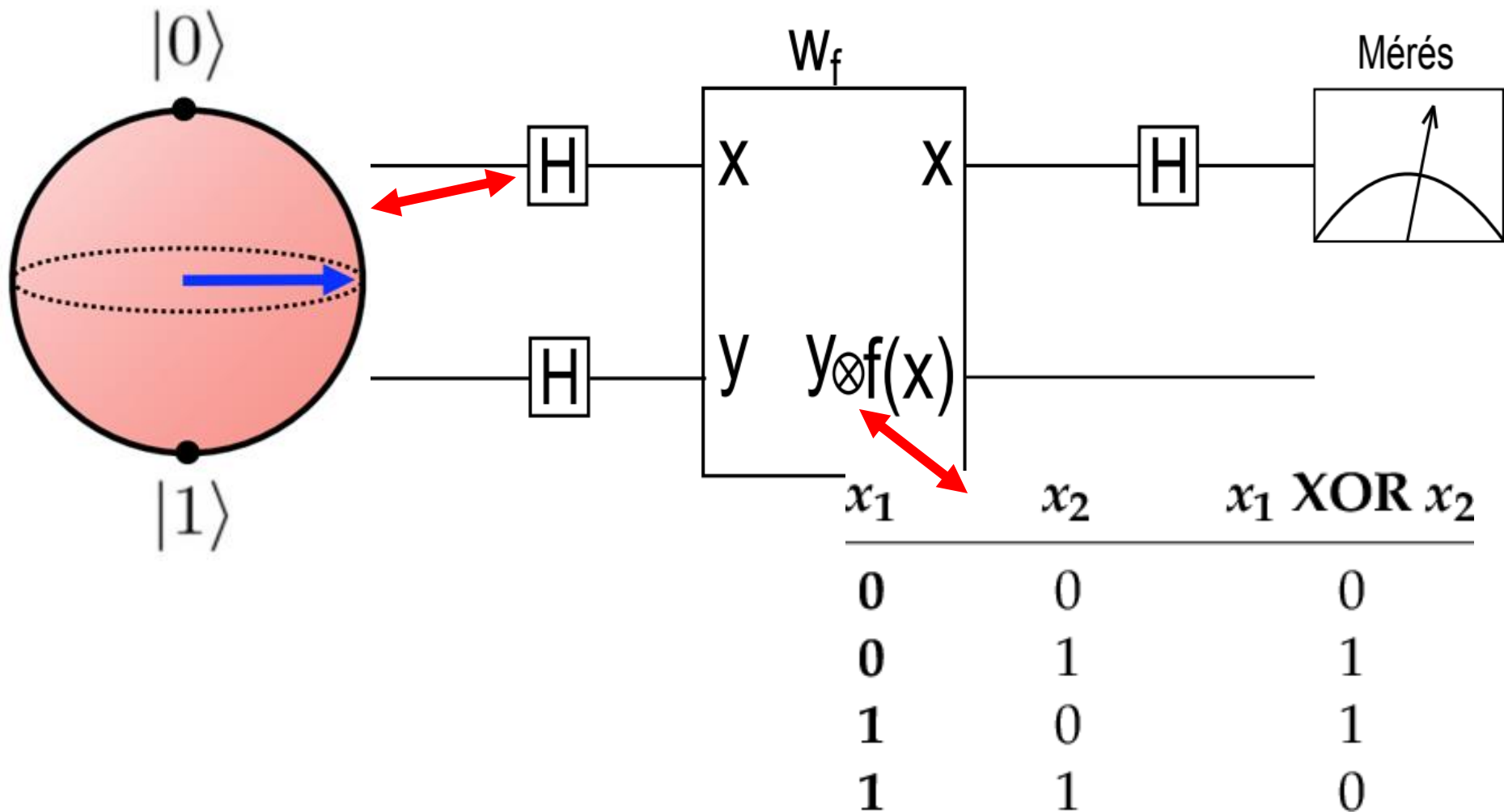


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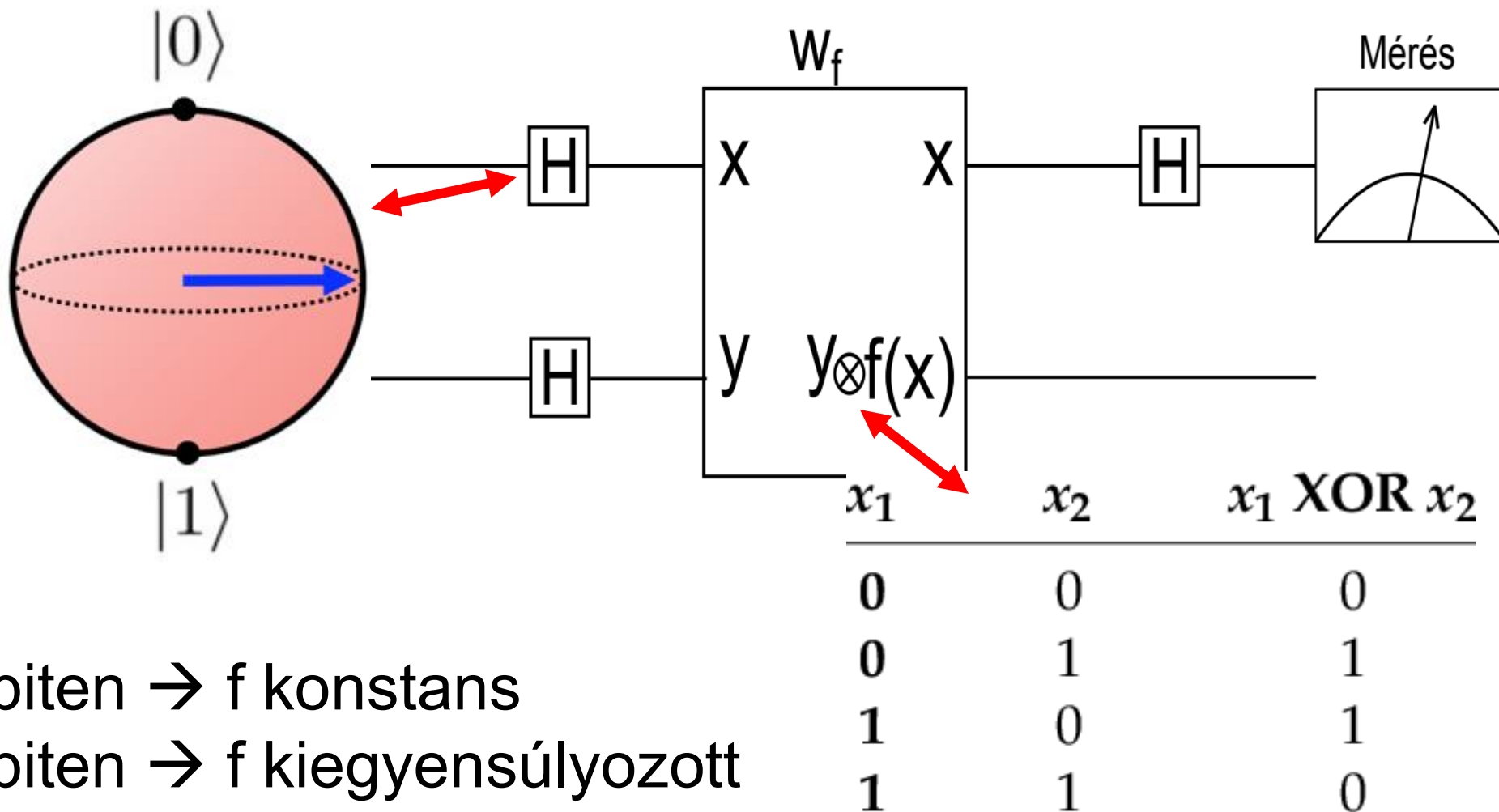


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0-t mérek az 1. qubiten $\rightarrow$ f konstans

1-t mérek az 1. qubiten $\rightarrow$ f kiegyensúlyozott

Egyszer kell kiértékelni $f(x)$ -et

Miért jó a kvantumbit?

Általánosított probléma:

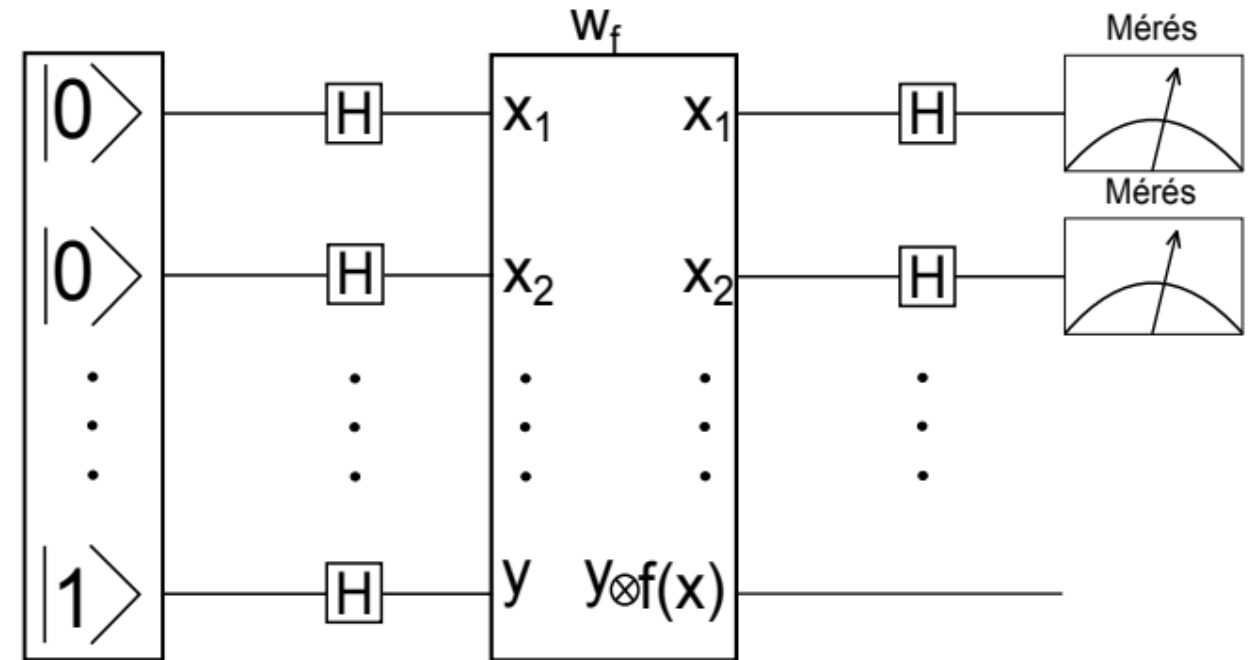
- $f: \{0,1\}^n \rightarrow \{0,1\}$ kiegyensúlyozott vagy konstans függvény
- $2^{n-1}+1$ kiértékelés klasszikusan

Miért jó a kvantumbit?

Általánosított probléma:

- $f: \{0,1\}^n \rightarrow \{0,1\}$ kiegyensúlyozott vagy konstans függvény
- $2^{n-1}+1$ kiértékelés klasszikusan
- Kvantum:

$$\begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_N \\ y \end{pmatrix} \xrightarrow{W_f} \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_N \\ y \oplus f(x_1, x_2, \dots, x_N) \end{pmatrix}$$

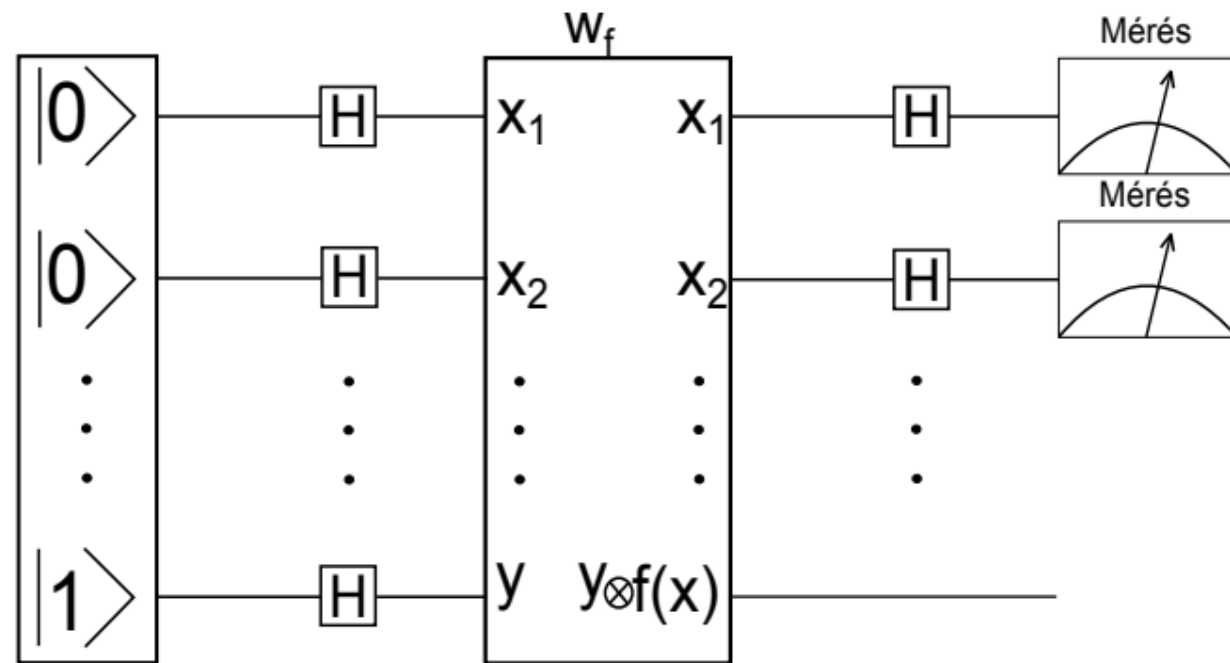


Miért jó a kvantumbit?

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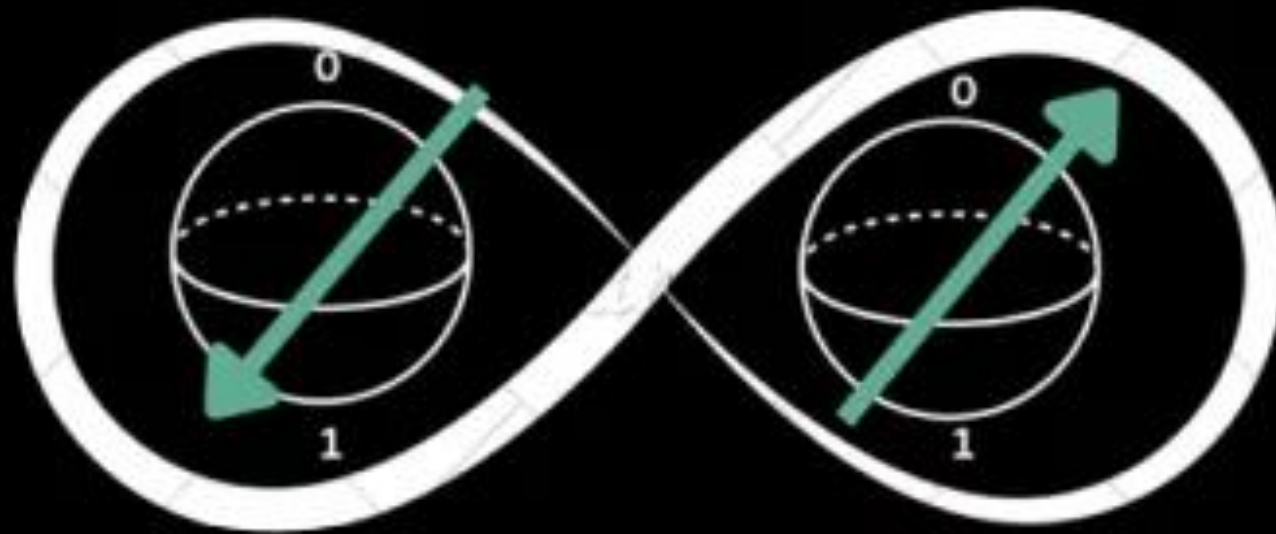
Minden mérés eredménye 0 $\rightarrow$ f konstans

Nem minden mérés eredménye 0 $\rightarrow$ f kiegyensúlyozott

f-et csak egyszer kell kiértékelni!

Miért jó a kvantumbit?

ENTANGLEMENT

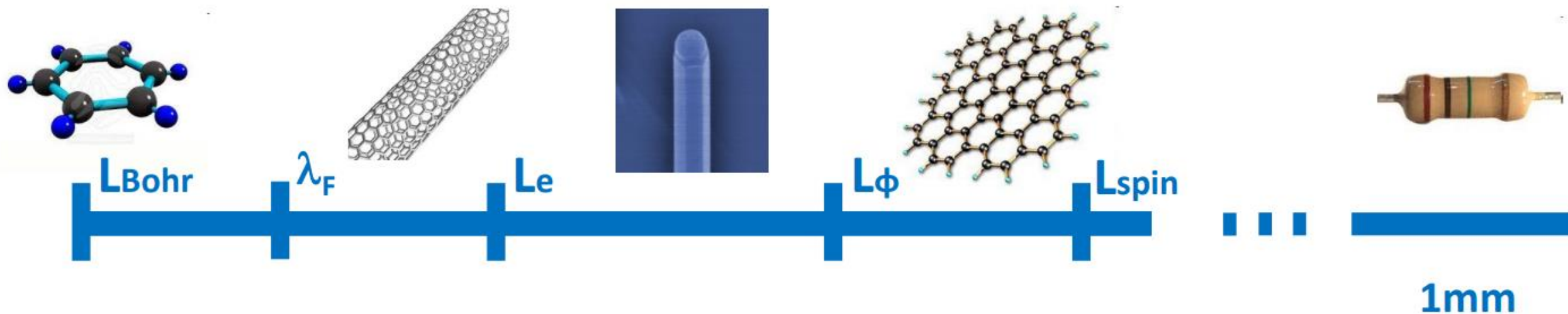


Miért jó a kvantumbit?

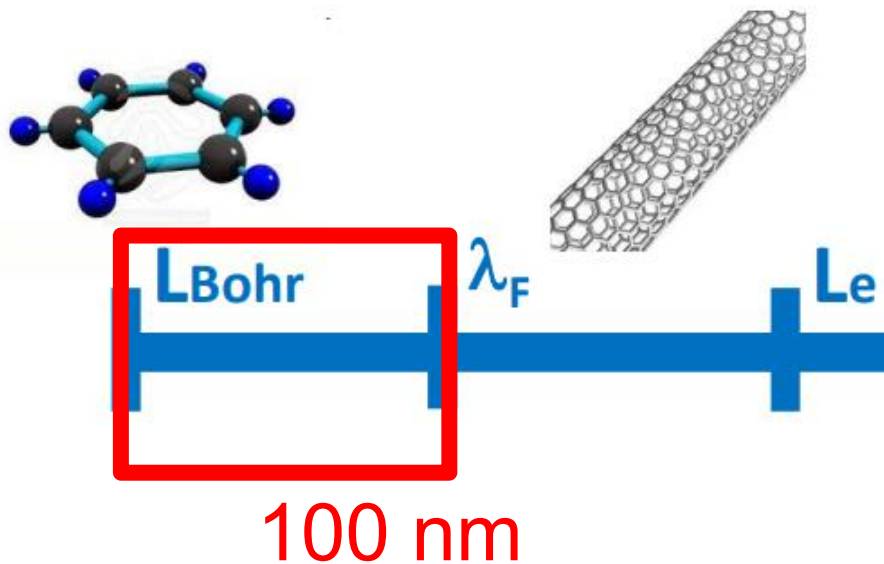
ENTANGLEMENT



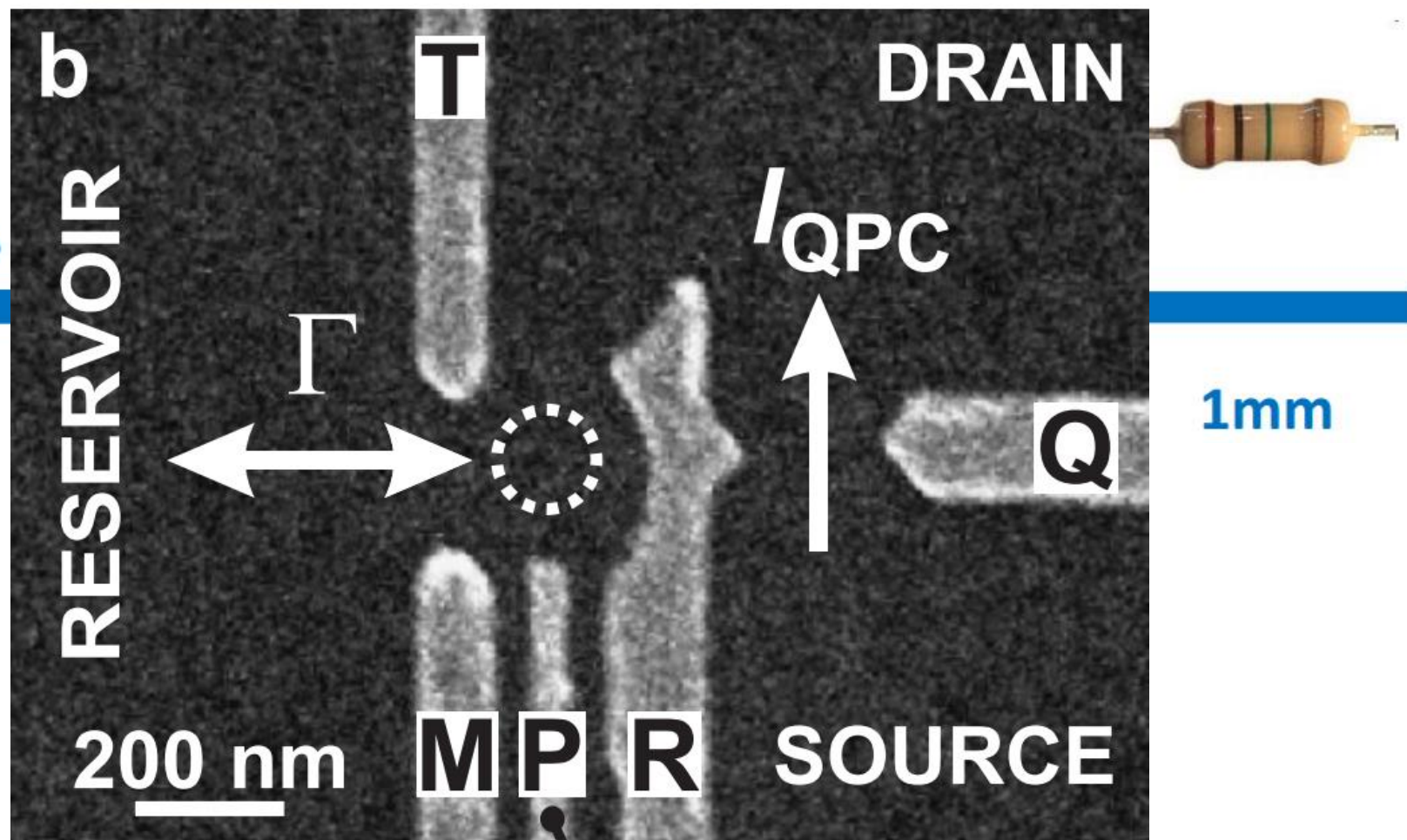
Mi a baj?



Mi a baj?

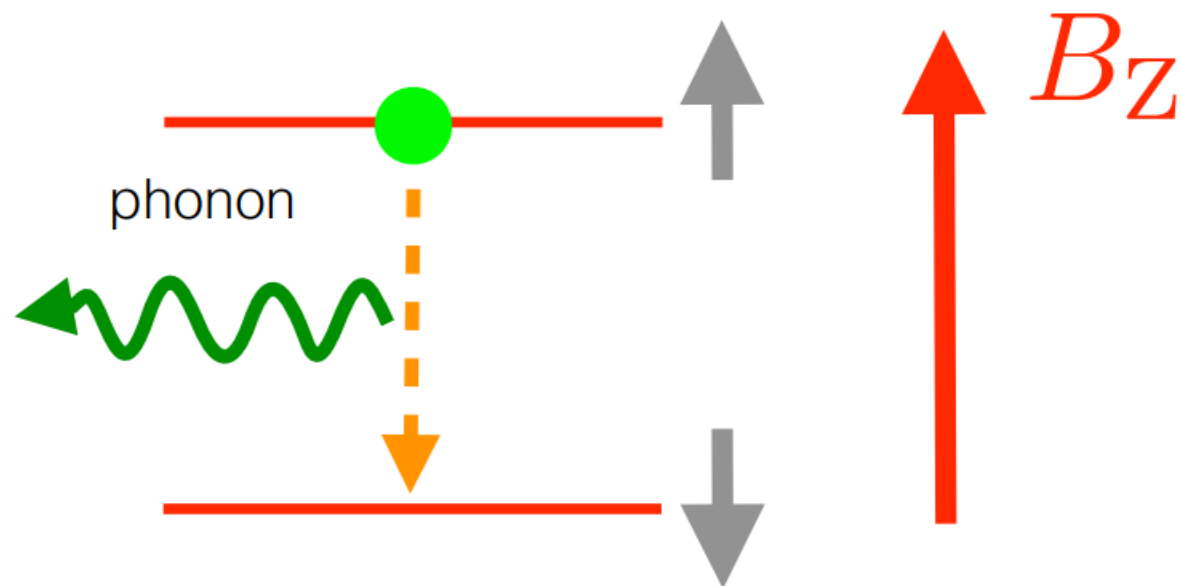


- Kvantum mechanika: méret és hőmérséklet!



Mi a baj?

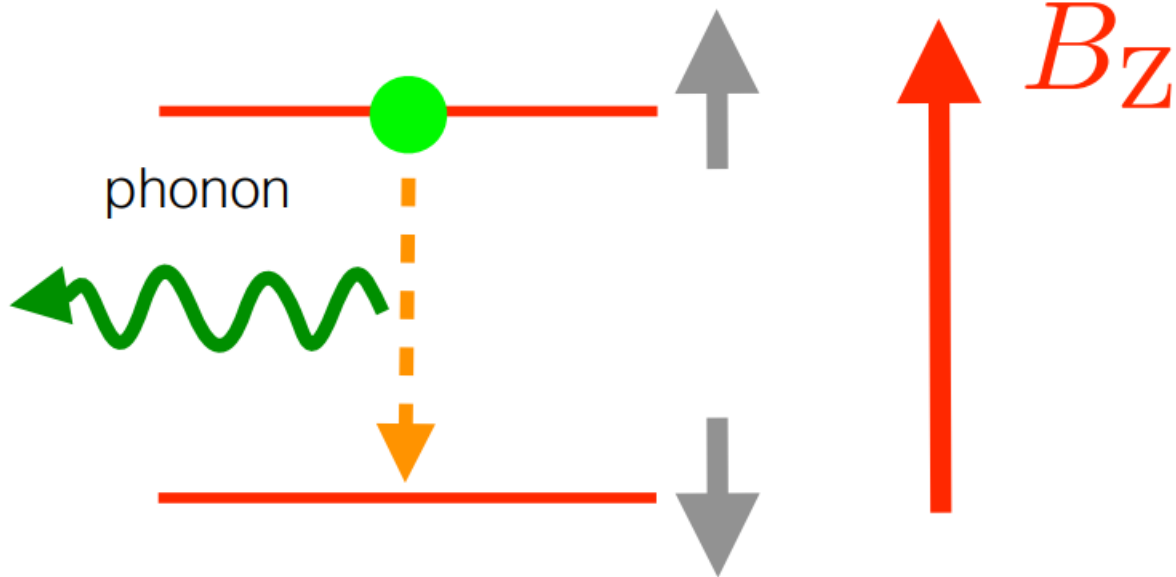
Relaxáció



$$T_1 = 1\text{s};$$

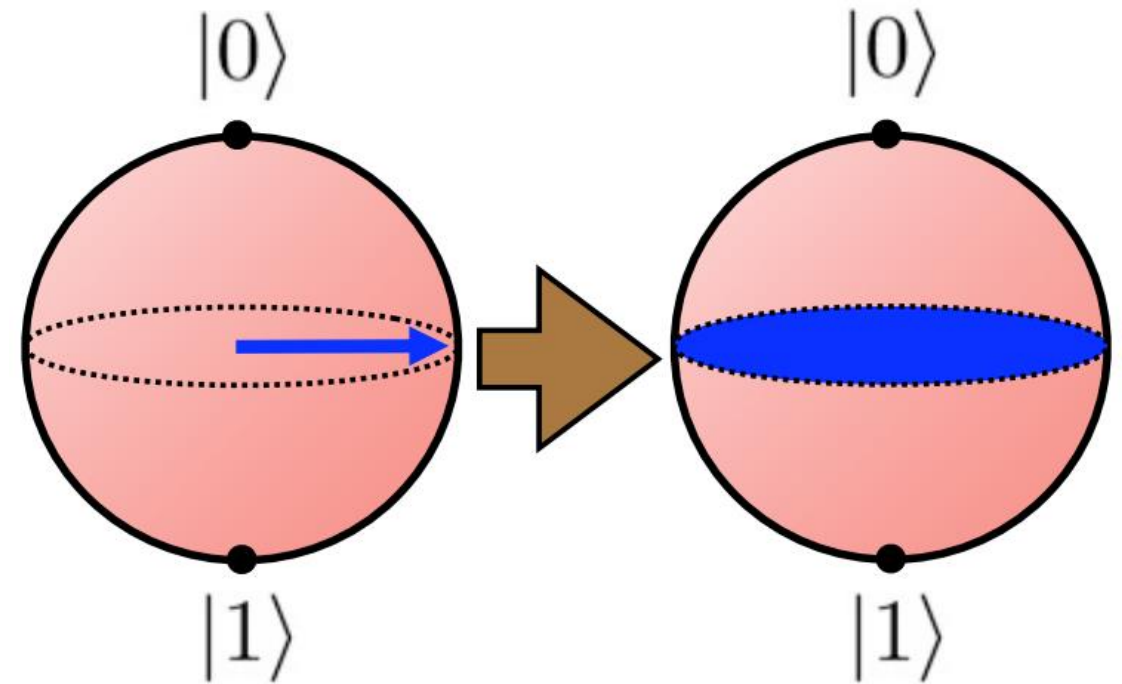
Mi a baj?

Relaxáció



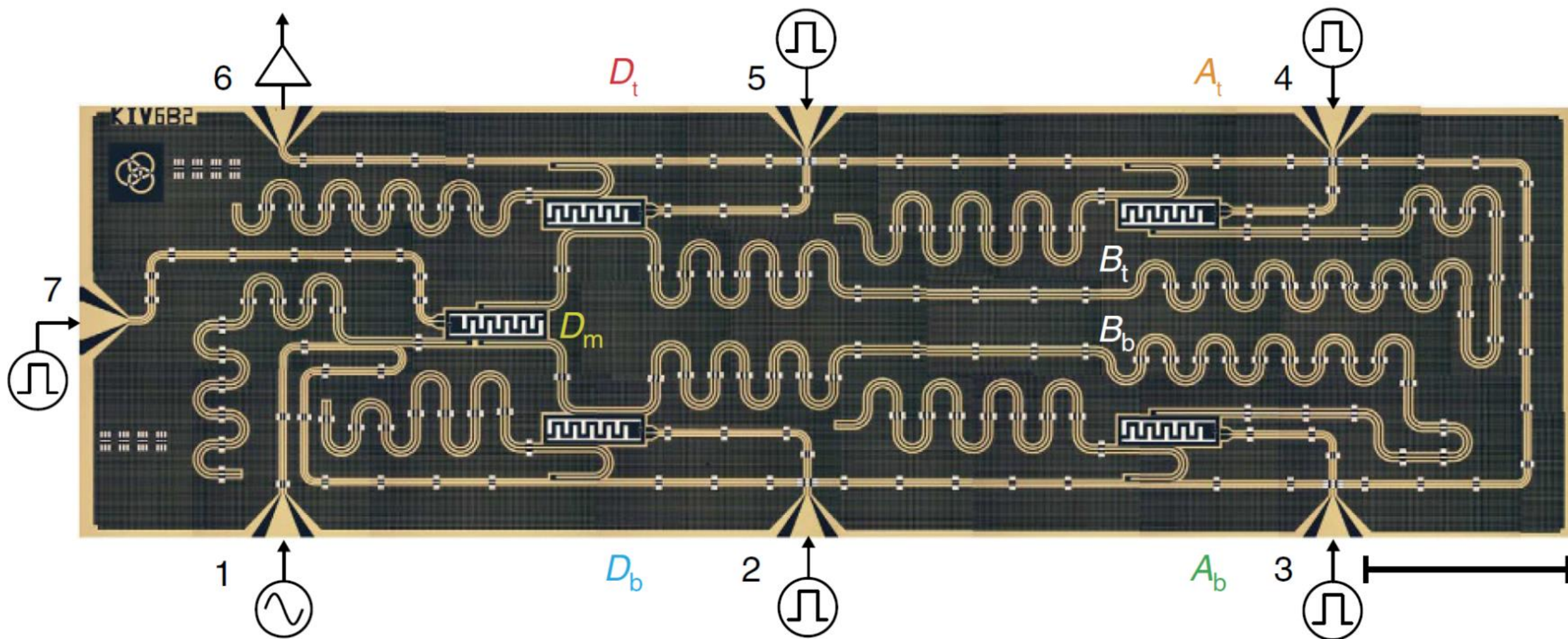
$$T_1 = 1\text{s}; T_2 = 1\text{ms}$$

Fázisdekoherencia



$$\bar{p}_x(t) = e^{-(t/T_2^*)^2}$$

Hol tartunk?



Hol tartunk?

IBM Quantum (USA), Google Quantum (USA),
Rigetti Computing (USA), IQM (Finnország),
stb.



Radiance

Advanced superconducting computer with 20, 54 and 150 high-fidelity qubits, designed for HPCs.

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