ON THE PECULIAR BEHAVIOUR OF NEUTRONS VIA NANO-STRUCTURES

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2-HISTORICAL BACKGROUND: FROM CHADWICK TO RAUCH

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4-NEUTRON TUNNELLING & NEUTRON LIFETIME

5-NEUTRON TRANSMISSION THROUGH ^{10}B !!!!

4-NEUTRON OPTICS & FORESIGHT: ESS

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MULTISKILLED Human Capital DEVELOPMENT-

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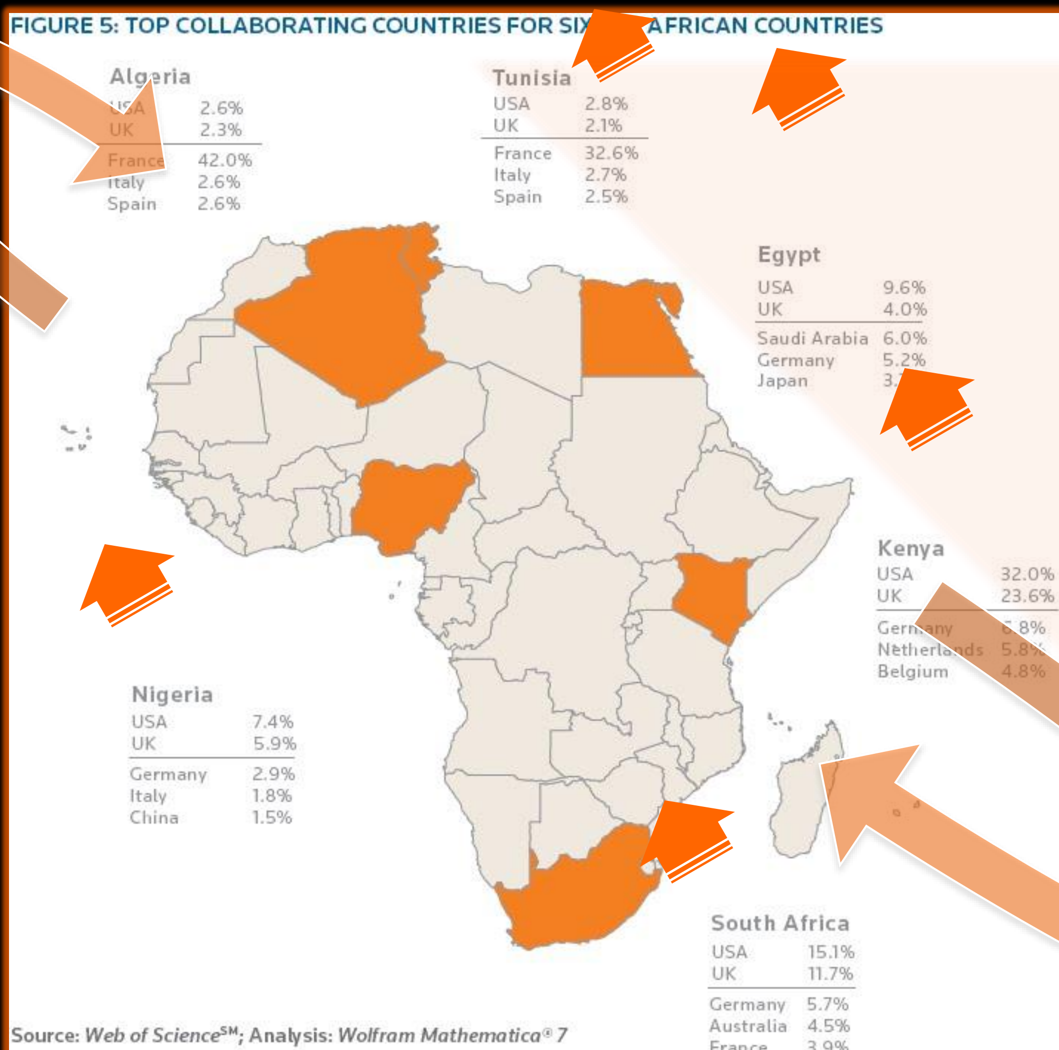

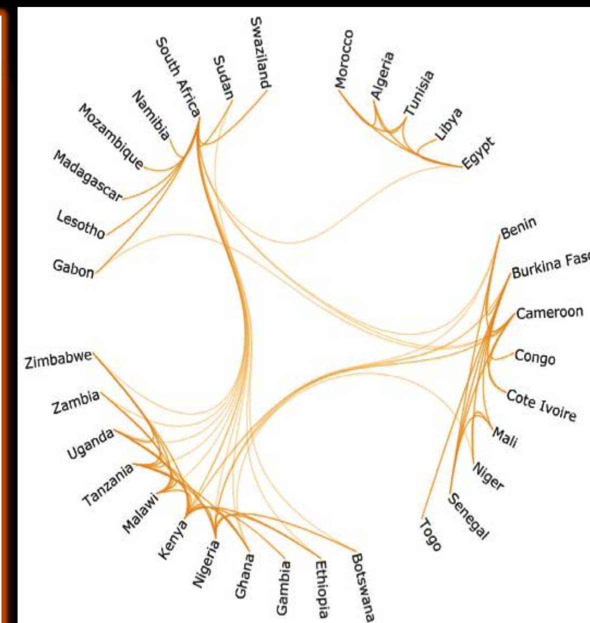

Source: OECD, Nature Publishing, World Economic Forum 2012

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Structural and optical properties of nano-structured tungsten-doped ZnO thin films grown by pulsed laser deposition

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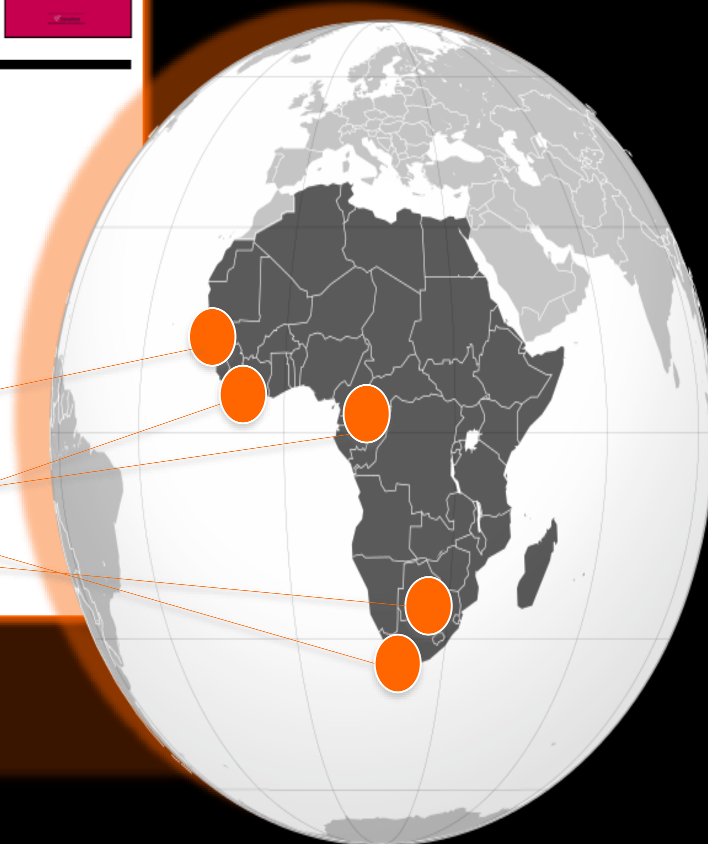


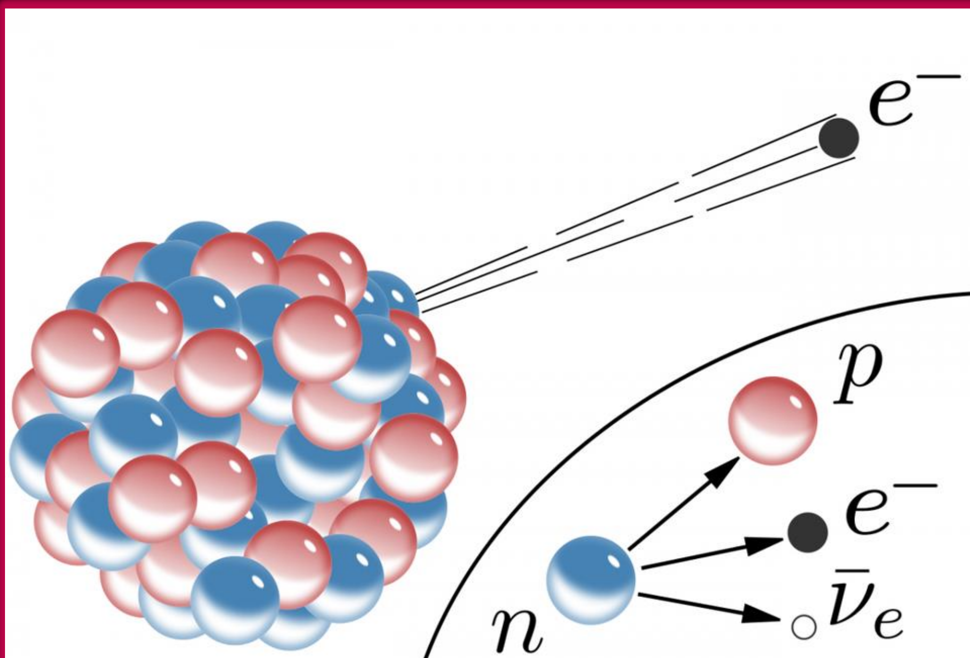
2-HISTORICAL BACKGROUND: FROM CHADWICK VIA FERMI TO RAUCH

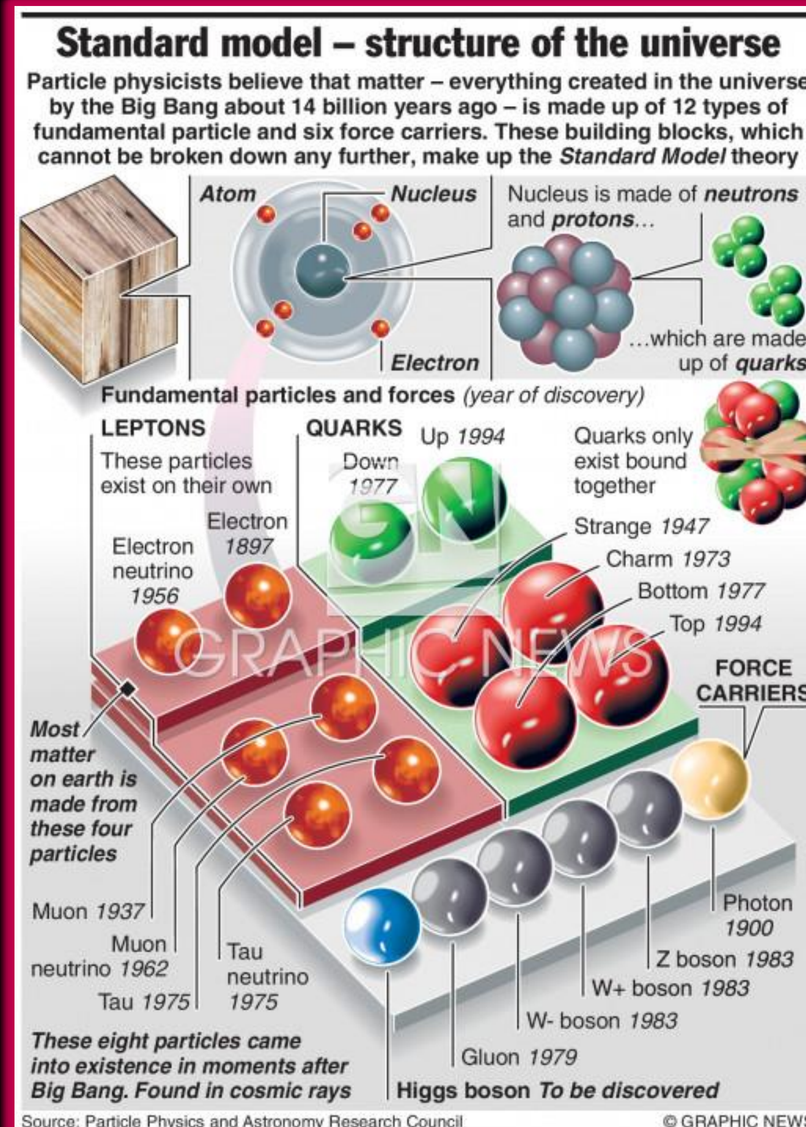
- Postulated 1920: Rutherford
- Confirmed 1923 : Chadwick
- Sensitive to the 4 forces
- Cornerstone for the Standard model

- Ideal QM tool / Wave-particle duality
- Total Reflection 1946
- Interferometry 1973
- Size: r_n~1F [area~ 10^{-25} cm^2=0.1 “barn”]

2-HISTORICAL BACKGROUND: GLUON NATURE

- Sensitive to the 4 forces
- Cornerstone of the Standard model
- Neutron decay

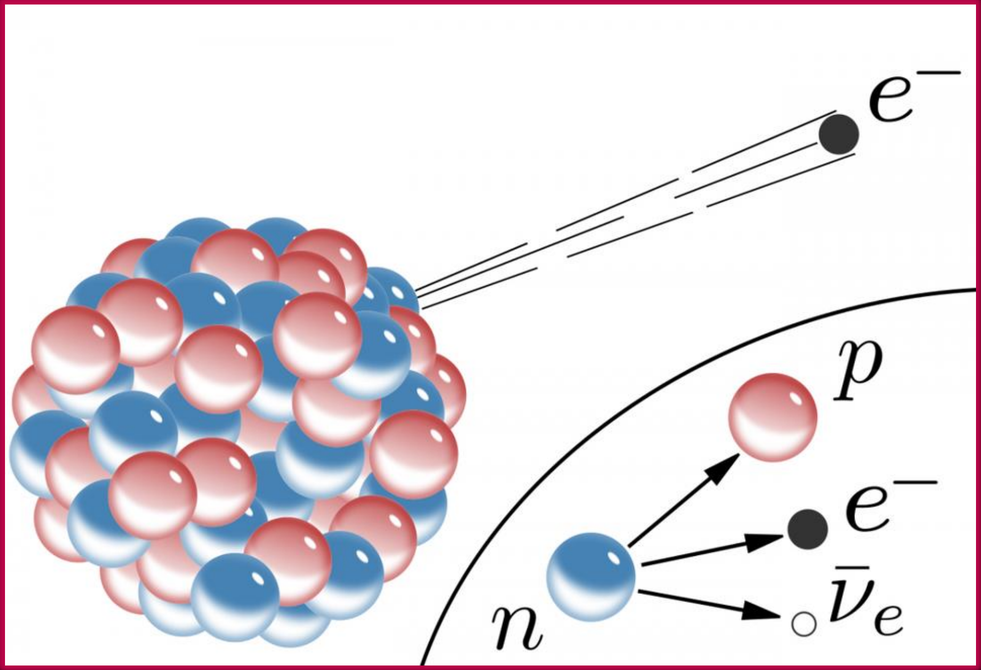


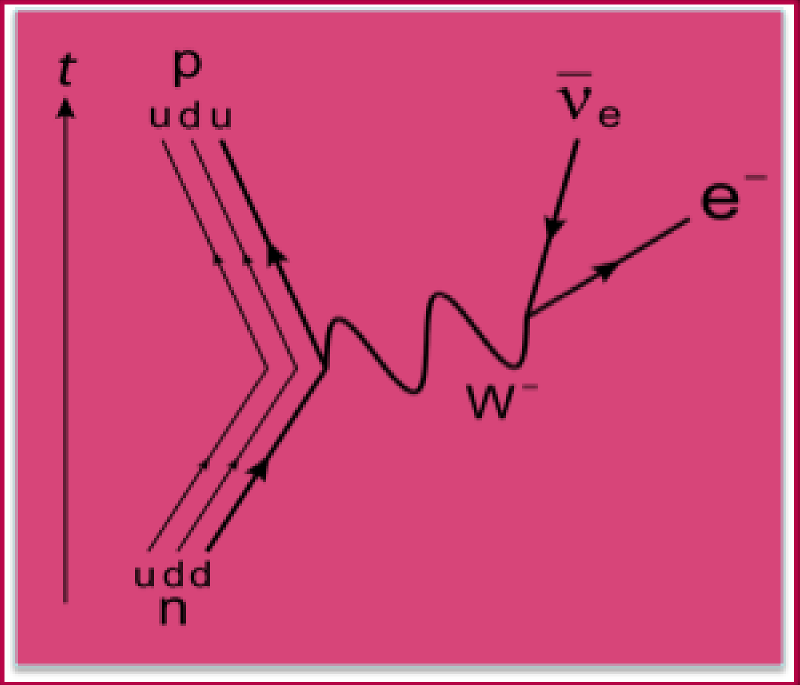


2-HISTORICAL BACKGROUND: GLUON NATURE

- Sensitive to 4 forces
- Cornerstone of the Standard model

- Neutron decay





2-HISTORICAL BACKGROUND: GLUON NATURE

- Cornerstone for the Standard model
- Lifetime: τ_n=885.7 +/- 0.8 s

PARTICLE PHYSICS

Physicists close in on neutron puzzle

Researchers are narrowing down their measurements of how long the subatomic particle survives on its own.

BY ALEXANDRA WITZE IN DENVER, COLORADO

Physicists are drawing nearer to answering a long-standing mystery of the Universe: how long a neutron lives.

Neutrons are electrically neutral particles that usually combine with protons to make up atomic nuclei. Some neutrons are not bound up in atoms; these free-floating neutrons decay radioactively into other particles in minutes.

But physicists can't agree on precisely how long it takes a neutron to die. Using one laboratory approach, they measure the average neutron lifetime as 14 minutes 39 seconds. Using a different approach, they get 8 seconds longer.

"We don't know why they're different," says Shannon Hoogerheide, a physicist at the National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland. "We really need to understand and eliminate this discrepancy." She and other scientists debated new ways to solve the problem this month at a meeting of the American Physical Society in Denver, Colorado.

Pinpointing the lifetime of a neutron is important for understanding how much hydrogen, helium and other light elements formed in the first few minutes after the Universe was born 13.8 billion years ago. Scientists also think that pinning down the neutron's lifetime would help to constrain measurements of other subatomic particles.

One way of clocking the neutron's lifespan is to put some of the particles in a bottle and count how many are left after a period of time. This 'bottle' method has been tried at several laboratories, including the Los Alamos National Laboratory in New Mexico[1] and the Institut Laue–Langevin in Grenoble, France. On average, they come up with a neutron lifetime of 14 minutes 39 seconds.

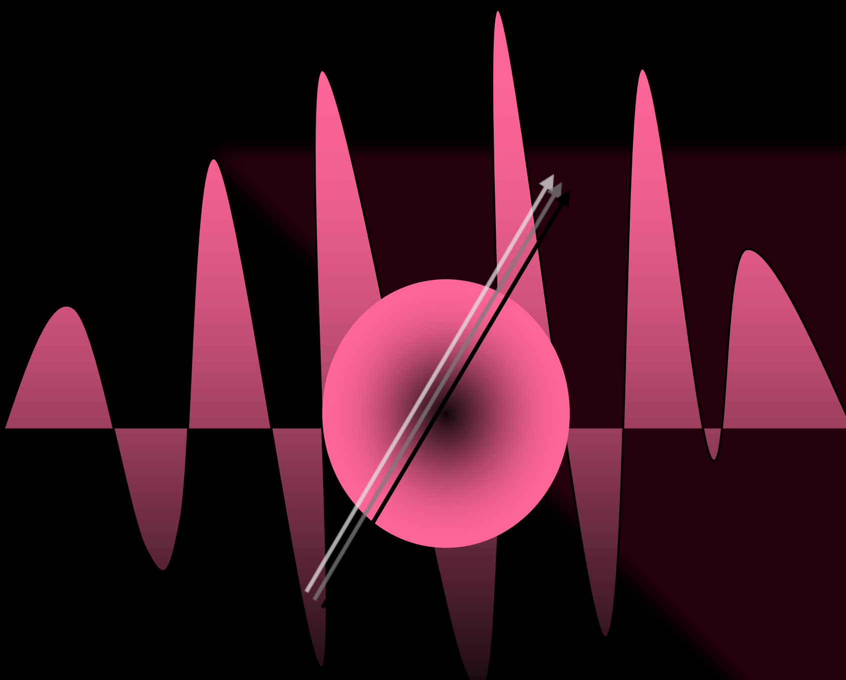
The other way is to feed neutrons into a detector that counts the protons created as the neutrons decay. This 'beam' method has been used at NIST and at the Japan Proton Accelerator Research Complex in Tokai. The Japanese work has just begun, but the NIST team reported in 2013 that its neutrons live eight seconds longer, on average, than those in the bottle method[2].

That's a big problem, because the beam and bottle measurements don't overlap, even when their margins of error are taken into account. So physicists have been looking for ways to explain why neutrons might be disappearing from bottles faster than from beams.

One possibility is that one of the two methods is doing something wrong. In that case, researchers might want to combine beam

2-HISTORICAL BACKGROUND: WAVE PARTICLE DUALITY

- Ideal Quantum Mechanics tool
- $\lambda = h/mv$

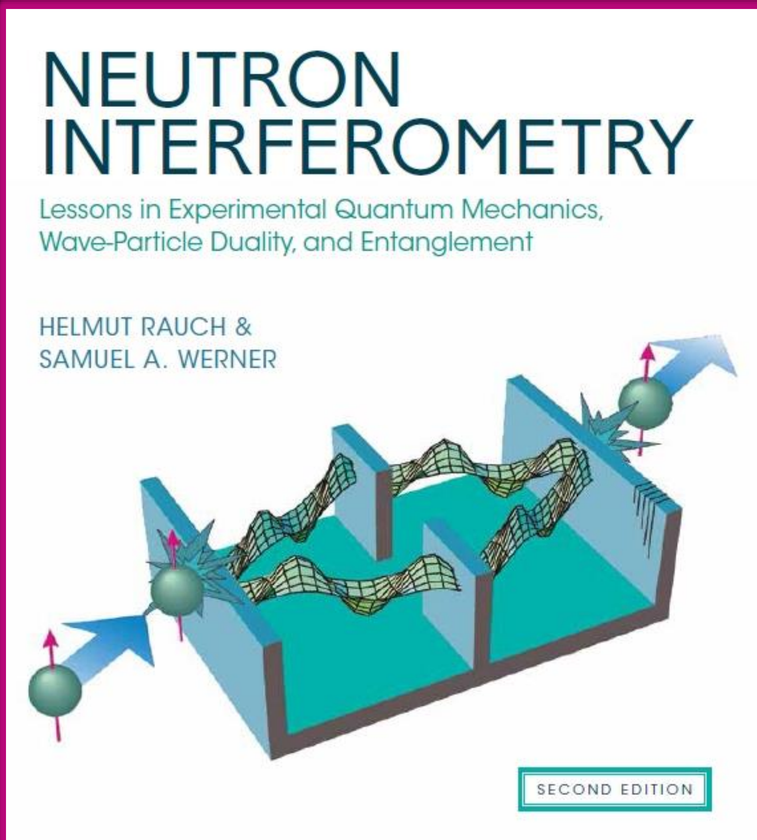


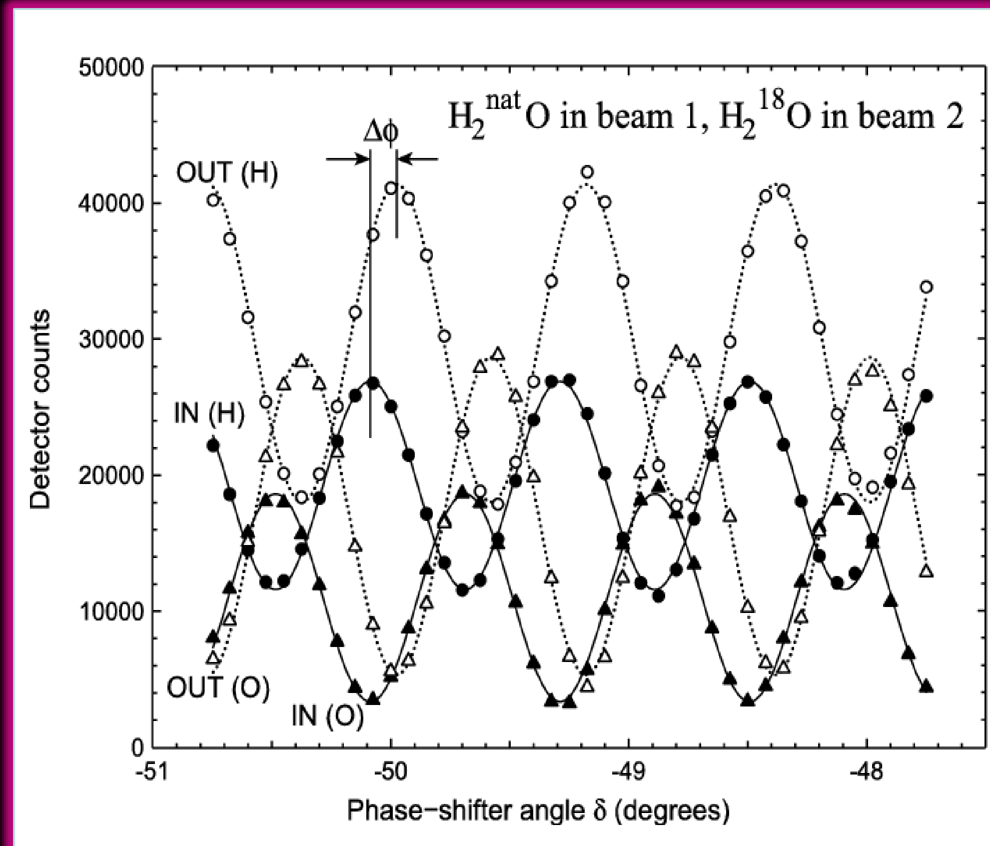
2-HISTORICAL GROUND: WAVE NATURE
WAVE PARTICLE DUALITY

- Total Reflection "Fermi, 1946",
- Polarization "Gukasov, 1954",
- Thin Film Interference "Maier-Leibnitz, 1962",
- Prism Deflection "Landkammer/ Korpiun, 1966",
- Neutron Interferometry "Rauch, 1973",
- Supermirrors "Mezei, 1978",
- Neutron Tunneling "Refl. mode, Steyerl, 1981",
- Sagnac Effect "Werner, 1985",
- Aharonov-Bohm Effect "Collela, 1993",
- Neutron Tunneling "Ref./Trans "Maaza & al, 1996",
- Neutron Goos-Hanschen"de Haan & al, 2010".
- Zeeman Tunneling "Ref. "Maaza & al, 1997"

2-HISTORICAL GROUND: WAVE NATURE
WAVE PARTICLE DUALITY

- Neutron Interferometry "H. Rauch, 1973",





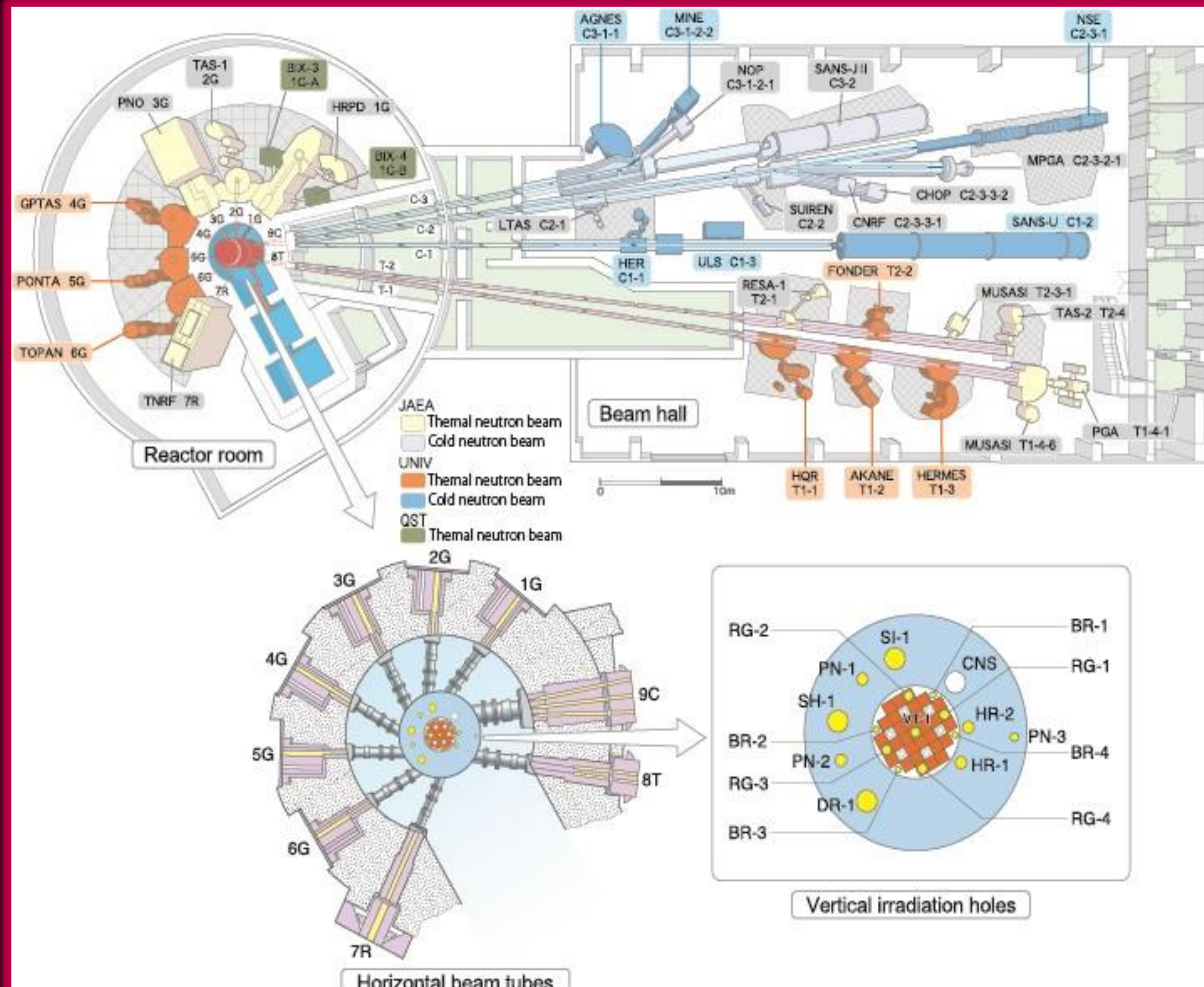
NEUTRON OPTICS: **THERMAL NEUTRONS**

Neutron energy	Energy range
0.0–0.025 eV	Cold neutrons
0.025 eV	Thermal neutrons
0.025–0.4 eV	Epithermal neutrons
0.4–0.5 eV	Cadmium neutrons
0.5–1 eV	Epi-Cadmium neutrons
1–10 eV	Slow neutrons
10–300 eV	Resonance neutrons
300 eV–1 MeV	Intermediate neutrons
1–20 MeV	Fast neutrons
> 20 MeV	Ultrafast neutrons

RESEARCH REACTORS: **THERMAL NEUTRON**

.Controlled

Fission + Thermalization + Moderation



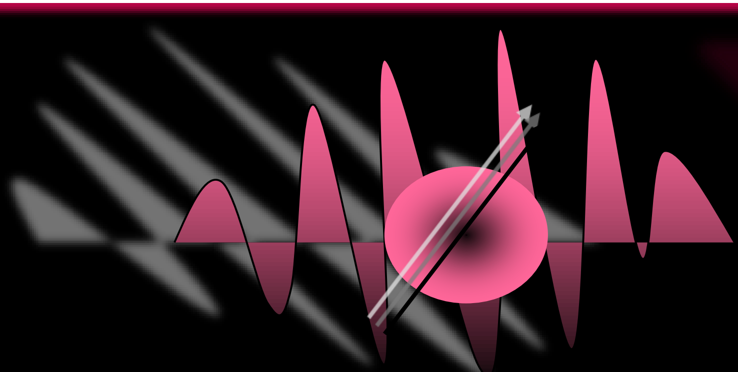
3-NEUTRON OPTICS :REFRACTIVE INDEX

WavePacket & Schrodinger Equation.

The de Broglie wave-particle duality [15] associates a wavevector, $\mathbf{k} = m\mathbf{v}/\hbar$, with a neutron propagating through a medium, where $\mathbf{v}$ is the neutron velocity, m its mass, and $\hbar = 1.05457\times10^{-34}$Js is the reduced Planck constant. The wavefunction can be represented as a 3D wavepacket (in Dirac notation),

$$|\Psi(t)\rangle = \int d\mathbf{k}\ \mu_{\mathbf{k}} e^{-i\omega_{\mathbf{k}} t}|\mathbf{k}\rangle, \tag{1.1}$$

with $\omega_k = E/\hbar$, where E is the energy, $\mu_{\mathbf{k}}$ is the probability amplitude. The state $|\mathbf{k}\rangle$ is a plane wave component with position representation $\psi_{\mathbf{k}} = \langle r|\mathbf{k}\rangle = e^{i\mathbf{k}\cdot\mathbf{r}}$, with wavevector $\mathbf{k} = k_x\hat{e}_x + k_y\hat{e}_y + k_z\hat{e}_z$ and $\mathbf{r} = x\hat{e}_x + y\hat{e}_y + z\hat{e}_z$.



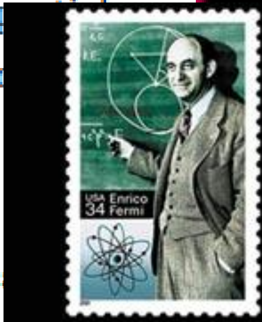
3-NEUTRON OPTICS :REFRACTIVE INDEX

The propagation of a neutron through a medium is governed by the matter-wave Schrödinger equation. In a time independent potential, under steady state conditions, the Schrödinger equation in the position representation is,

$$V(\mathbf{r}) = \sum_j \frac{2\pi\hbar^2}{m} b_j \delta(\mathbf{r} - \mathbf{r}_j),$$

$$\left[-\frac{\hbar^2}{2m}\nabla^2 + V(\mathbf{r})\right]\Psi(\mathbf{r}) = E\Psi(\mathbf{r}),$$

where $V(\mathbf{r})$ is the potential energy of the particle, and E is the total energy of the p
The equation can be written in a form that is similar to the Helmholtz equation in c
optics as,



$$\nabla^2\Psi(\mathbf{r}) + K(\mathbf{r})^2\Psi(\mathbf{r}) = 0,$$

with $K(\mathbf{r}) = \sqrt{2m[E - V(\mathbf{r})]}/\hbar$ is the medium dependent wavevector. $V(\mathbf{r})$ c
various forms including electromagnetic, gravitational, and nuclear. Of interest to us is the nuclear and magnetic interaction which will be explored in the next section in detail. One common way to characterize them is via the refractive index, defined as [2, 3],

$$n \equiv \frac{K(\mathbf{r})}{k} = \sqrt{\frac{2m[E - V(\mathbf{r})]}{2mE}} \simeq 1 - \frac{\overline{V}}{2E},$$

$$V(\mathbf{r}) = \sum_j \frac{2\pi\hbar^2}{m} b_j \delta(\mathbf{r} - \mathbf{r}_j),$$

where $k = \sqrt{2mE\hbar^{-2}}$ is the wavevector in free space. The approximation in Eq. (1.7) is valid for thermal neutrons as the potential $V(\mathbf{r})$ can be expressed in a form equal to the optical potential, $\overline{V}$, which for most materials is of the order $10^{-5}eV$.

3-NEUTRON OPTICS :REFRACTIVE INDEX

$$V_O = \frac{2\pi\hbar^2}{m} N\bar{b}, \text{ where } N\bar{b} = \sum_j b_j \delta(\mathbf{r} - \mathbf{r}_j). \tag{1.9}$$

$N\bar{b}$ is the local mean scattering length density, which represents the response of the overall system as multiple copies of a single atom of the same kind. Generally, $\bar{b}$ is complex with typical values in the femtometre scale. Moreover, this value leads to a scattering cross-section defined as $\bar{\sigma}_s = 4\pi|\bar{b}|^2$ and an absorption cross-section defined as $\bar{\sigma}_a = 4\pi \mathsf{Im}[b]^2 k^{-1}$, where $\mathsf{Im}[\bar{b}]$ is the imaginary component.

When a neutron beam is shined on an absorbing target of effective thickness D, the intensity of transmitted neutron is related to the incident intensity, I_0, by [19],

$$I = I_0 e^{-\bar{\sigma}_a N D}. \tag{1.10}$$

Materials with high $\bar{\sigma}_a$ including lead, cadmium, gadolinium, are commonly used as neutron absorbers. For most materials, $\mathsf{Re}[\bar{b}] > 0$, with the few exceptions of ^{2}H, ^{48}Ti, and ^{62}Ni

The general form of the complex refractive index from a spin-independent scattering material is [3, 2],

$$n \equiv 1 - \frac{\lambda^2 N}{2\pi} \sqrt{\bar{b}^2 - \left(\frac{\bar{\sigma}_r}{2\lambda}\right)^2} + i\frac{\bar{\sigma}_r N \lambda}{4\pi}, \tag{1.11}$$

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3-NEUTRON OPTICS :REFRACTIVE INDEX

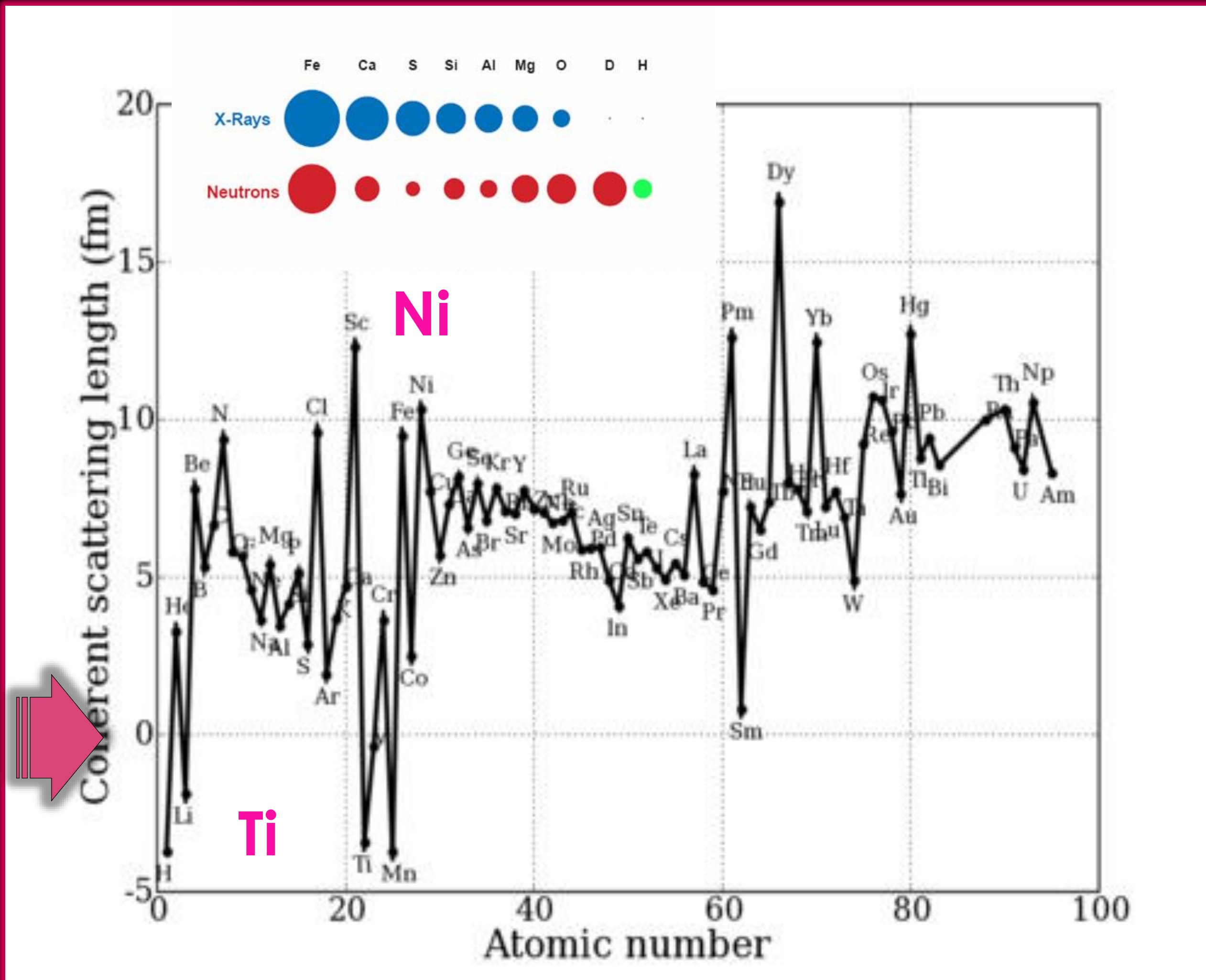
bNi= +10.31
b^{58}Ni= +14.41

bTi= - 3.438
b^{48}Ti= - 6.08

bV= -0.3824
bMn= -3.73

bDy= -+16.92

σ_aDy= -+994.13



3-NEUTRON OPTICS :REFRACTIVE INDEX

Table 1. **Neutron scattering lengths and cross sections of the elements and their isotopes.**

Column	Symbol	Unit	Quantity
1			element
2	Z		atomic number
3	A		mass number
4	$I(p)$		spin (parity) of the nuclear ground state
5	c	%	natural abundance (For radioisotopes the half-life is given instead.)
6	b_c	fm	bound coherent scattering length
7	b_i	fm	bound incoherent scattering length
8	s_c	barn[1]	bound coherent scattering cross section
9	s_i	barn	bound incoherent scattering cross section
10	s_s	barn	total bound scattering cross section
11	s_a	barn	absorption cross section for 2200 m/s neutrons[2]

(1) 1 barn = 100 fm²

(2) E = 25.30 meV, k = 3.494 Å⁻¹, l = 1.798 Å

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Chalk River, Ontario, Canada K0J 1J0

	Z	A	$I(\pi)$	c	b_c	b_i	σ_c	σ_i	σ_s	σ_a
H	1				−3.7390(11)		1.7568(10)	80.26(6)	82.02(6)	0.3326(7)
		1	1/2(+)	99.985	−3.7406(11)	25.274(9)	1.7583(10)	80.27(6)	82.03(6)	0.3326(7)
		2	1(+)	0.015	6.671(4)	4.04(3)	5.592(7)	2.05(3)	7.64(3)	0.000519(7)
		3	1/2(+)	(12.32 a)	4.792(27)	−1.04(17)	2.89(3)	0.14(4)	3.03(5)	0
He	2				3.26(3)		1.34(2)	0	1.34(2)	0.00747(1)
		3	1/2(+)	0.00014	5.74(7)	−2.5(6)	4.42(10)	1.6(4)	6.0(4)	5333.(7.)
					−1.483(2)i	+2.568(3)i				
		4	0(+)	99.99986	3.26(3)	0	1.34(2)	0	1.34(2)	0
Li	3				−1.90(2)		0.454(10)	0.92(3)	1.37(3)	70.5(3)
		6	1(+)	7.5	2.00(11)	−1.89(10)	0.51(5)	0.46(5)	0.97(7)	940.(4.)
					−0.261(1)i	+0.26(1)i				
		7	3/2(−)	92.5	−2.22(2)	−2.49(5)	0.619(11)	0.78(3)	1.40(3)	0.0454(3)
Be	4	9	3/2(−)	100	7.79(1)	0.12(3)	7.63(2)	0.0018(9)	7.63(2)	0.0076(8)
B	5				5.30(4)		3.54(5)	1.70(12)	5.24(11)	767.(8.)
					−0.213(2)i					
		10	3(+)	20.0	−0.1(3)	−4.7(3)	0.144(8)	3.0(4)	3.1(4)	3835.(9.)
					−1.066(3)i	+1.231(3)i				
		11	3/2(−)	80.0	6.65(4)	−1.3(2)	5.56(7)	0.21(7)	5.77(10)	0.0055(33)
C	6				6.6460(12)		5.550(2)	0.001(4)	5.551(3)	0.00350(7)
		12	0(+)	98.90	6.6511(16)	0	5.559(3)	0	5.559(3)	0.00353(7)
		13	1/2(−)	1.10	6.19(9)	−0.52(9)	4.81(14)	0.034(11)	4.84(14)	0.00137(4)

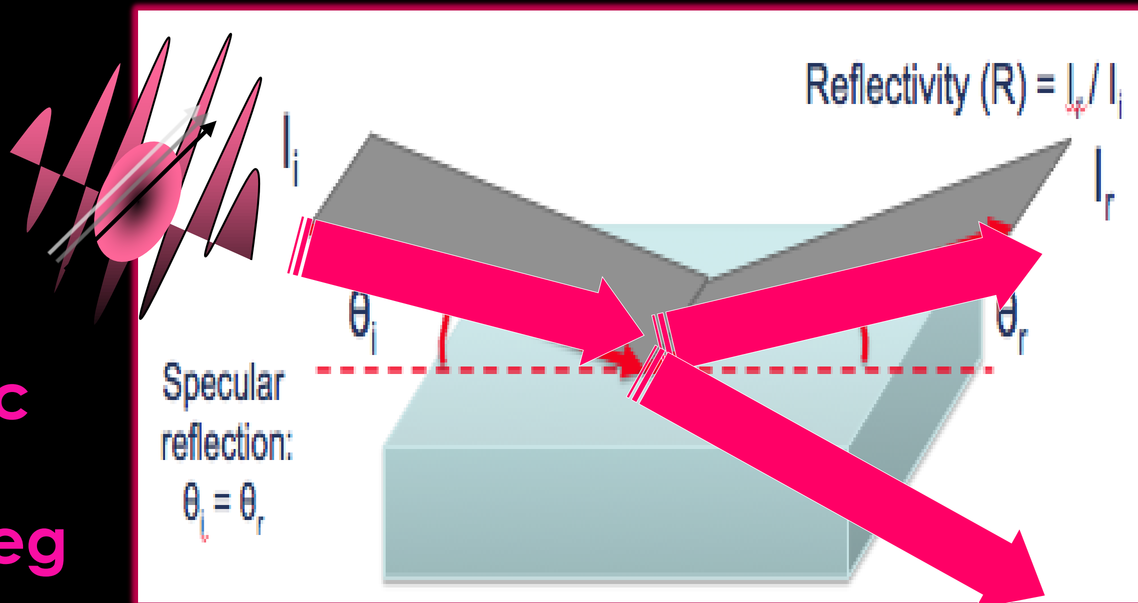
3-NEUTRON OPTICS :REFRACTIVE INDEX

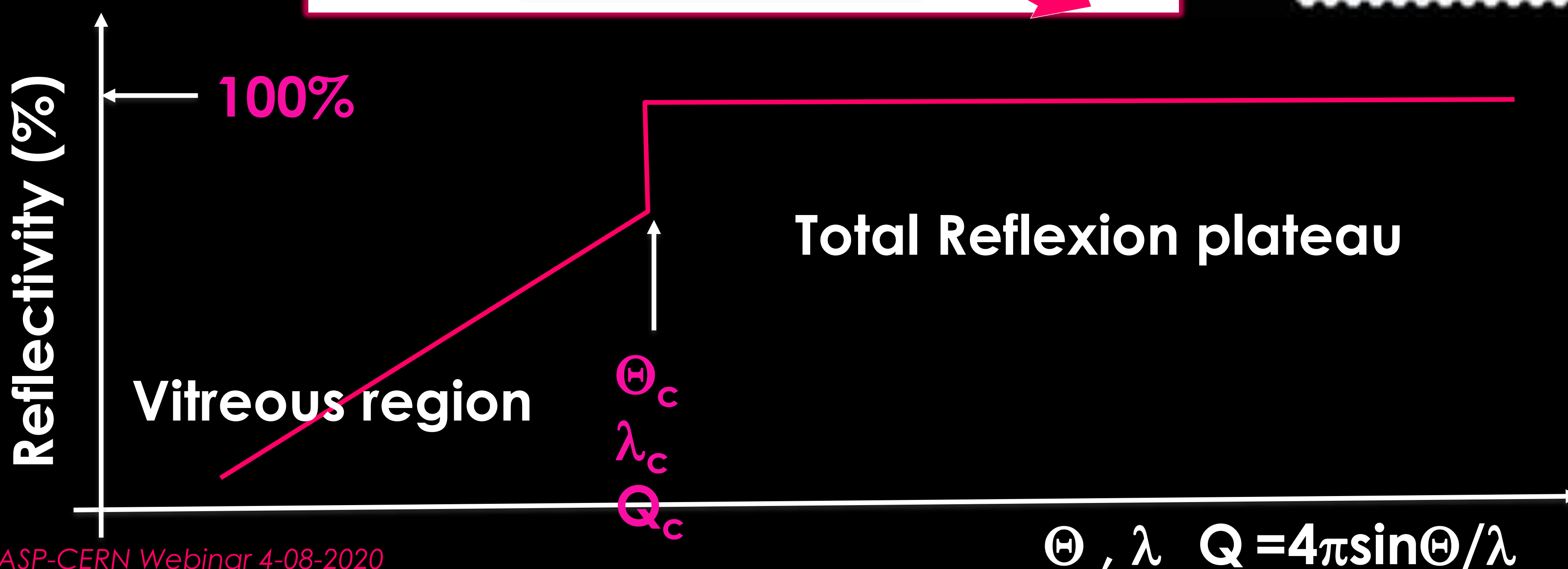
	Z	A	I(π)	c	b_c	b_i	σ_c	σ_i	σ_s	σ_a
Ti	22				−3.438(2)		1.485(2)	2.87(3)	4.35(3)	6.09(13)
		46	0(+)	8.2	4.93(6)	0	3.05(7)	0	3.05(7)	0.59(18)
		47	5/2(−)	7.4	3.63(12)	−3.5(2)	1.66(11)	1.5(2)	3.2(2)	1.7(2)
		48	0(+)	73.8	−6.08(2)	0	4.65(3)	0	4.65(3)	7.84(25)
		49	7/2(−)	5.4	1.04(5)	5.1(2)	0.14(1)	3.3(3)	3.4(3)	2.2(3)
		50	0(+)	5.2	6.18(8)	0	4.80(12)	0	4.80(12)	0.179(3)
V	23				−0.3824(12)		0.01838(12)	5.08(6)	5.10(6)	5.08(4)
		50	6(+)	0.250	7.6(6)		7.3(1.1)	0.5(5) E	7.8(1.0)	60.(40.)
		51	7/2(−)	99.750	−0.402(2)	6.35(4)	0.0203(2)	5.07(6)	5.09(6)	4.9(1)
Mn	25	55	5/2(−)	100	−3.73(2)	1.79(4)	1.75(2)	0.40(2)	2.15(3)	13.3(2)
Fe	26				9.45(2)		11.22(5)	0.40(11)	11.62(10)	2.56(3)
		54	0(+)	5.8	4.2(1)	0	2.2(1)	0	2.2(1)	2.25(18)
		56	0(+)	91.7	9.94(3)	0	12.42(7)	0	12.42(7)	2.59(14)
		57	1/2(−)	2.2	2.3(1)		0.66(6)	0.3(3) E	1.0(3)	2.48(30)
		58	0(+)	0.3	15.(7.)	0	28.(26.)	0	28.(26.)	1.28(5)
Ni	28				10.3(1)		13.3(3)	5.2(4)	18.5(3)	4.49(16)
		58	0(+)	68.27	14.4(1)	0	26.1(4)	0	26.1(4)	4.6(3)
		60	0(+)	26.10	2.8(1)	0	0.99(7)	0	0.99(7)	2.9(2)
		61	3/2(−)	1.13	7.60(6)	±3.9(3)	7.26(11)	1.9(3)	9.2(3)	2.5(8)
		62	0(+)	3.59	−8.7(2)	0	9.5(4)	0	9.5(4)	14.5(3)
		64	0(+)	0.91	−0.37(7)	0	0.017(7)	0	0.017(7)	1.52(3)

3-NEUTRON OPTICS :TOTAL REFLECTION

V_{Fermi} ≈ 10^{-5} eV, n ≈ 1

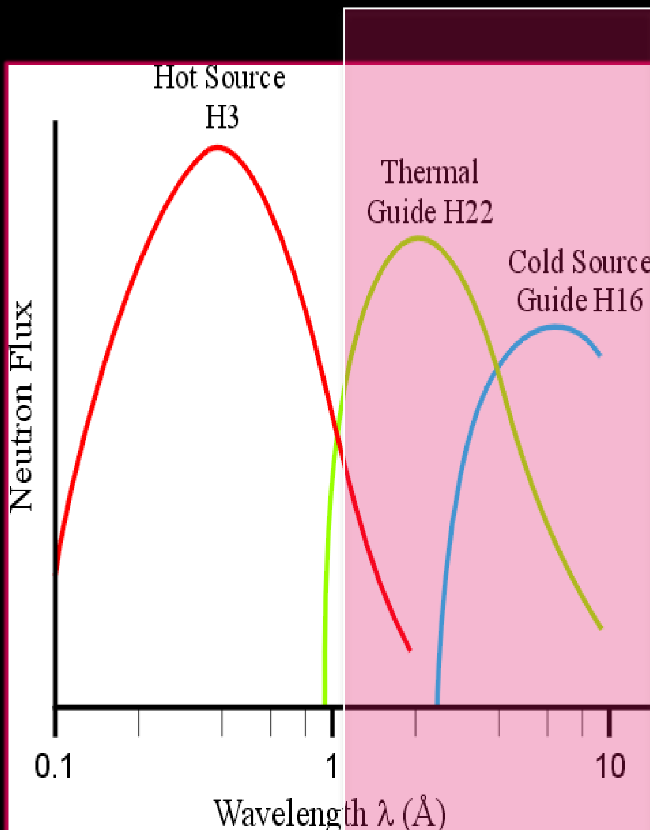
Grazing incidence
Θ_i ≈ 1 Deg

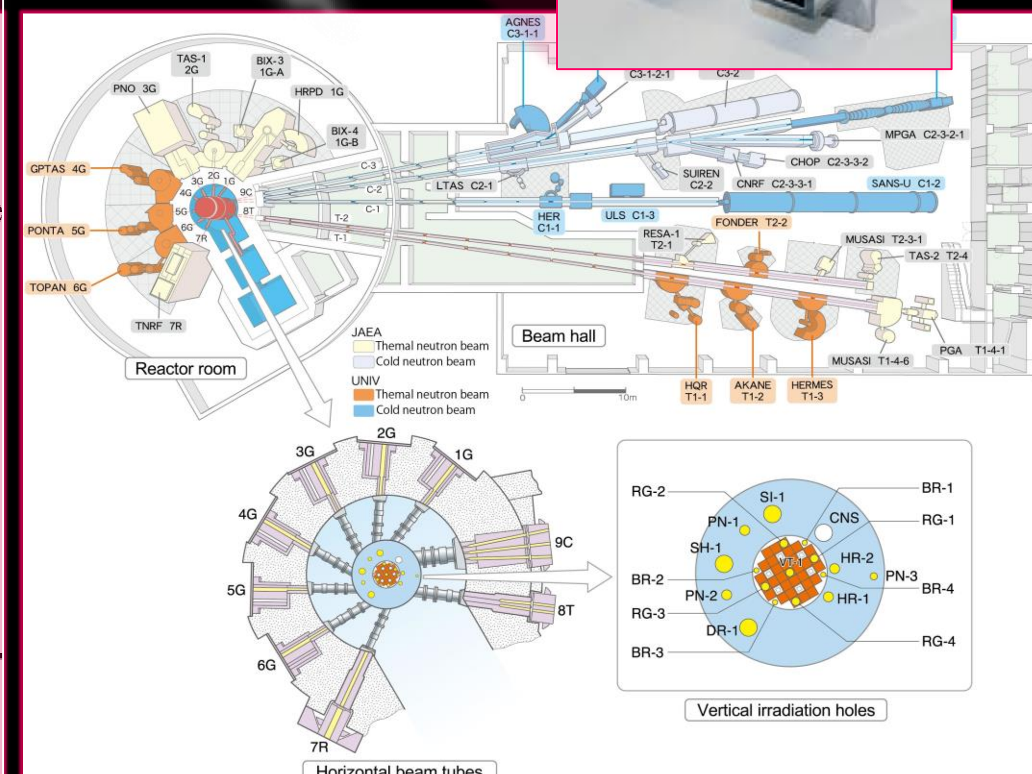




3-NEUTRON OPTICS :TOTAL REFLECTION

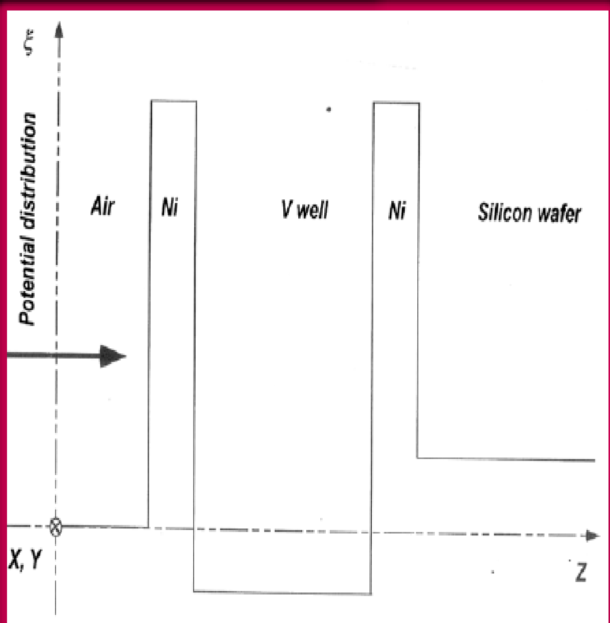
- Quantum Mechanics governed phenomena
- Maximize the reactor capabilities via n-guides

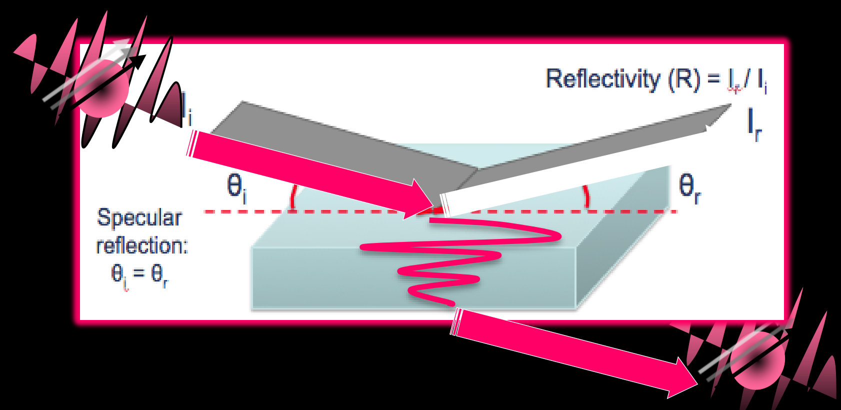




4-NEUTRON TUNNELING:NEUTRON LIFETIME

- 200 Å Ni-1000 Å ^{nat}V-200Å Ni /0.1 mmSilicon
- D_r =200 Å Ni D_S=1000 Å ^{nat}V Θi =0.5 deg
- Fabry-Perot structure (FPResonance Equation).

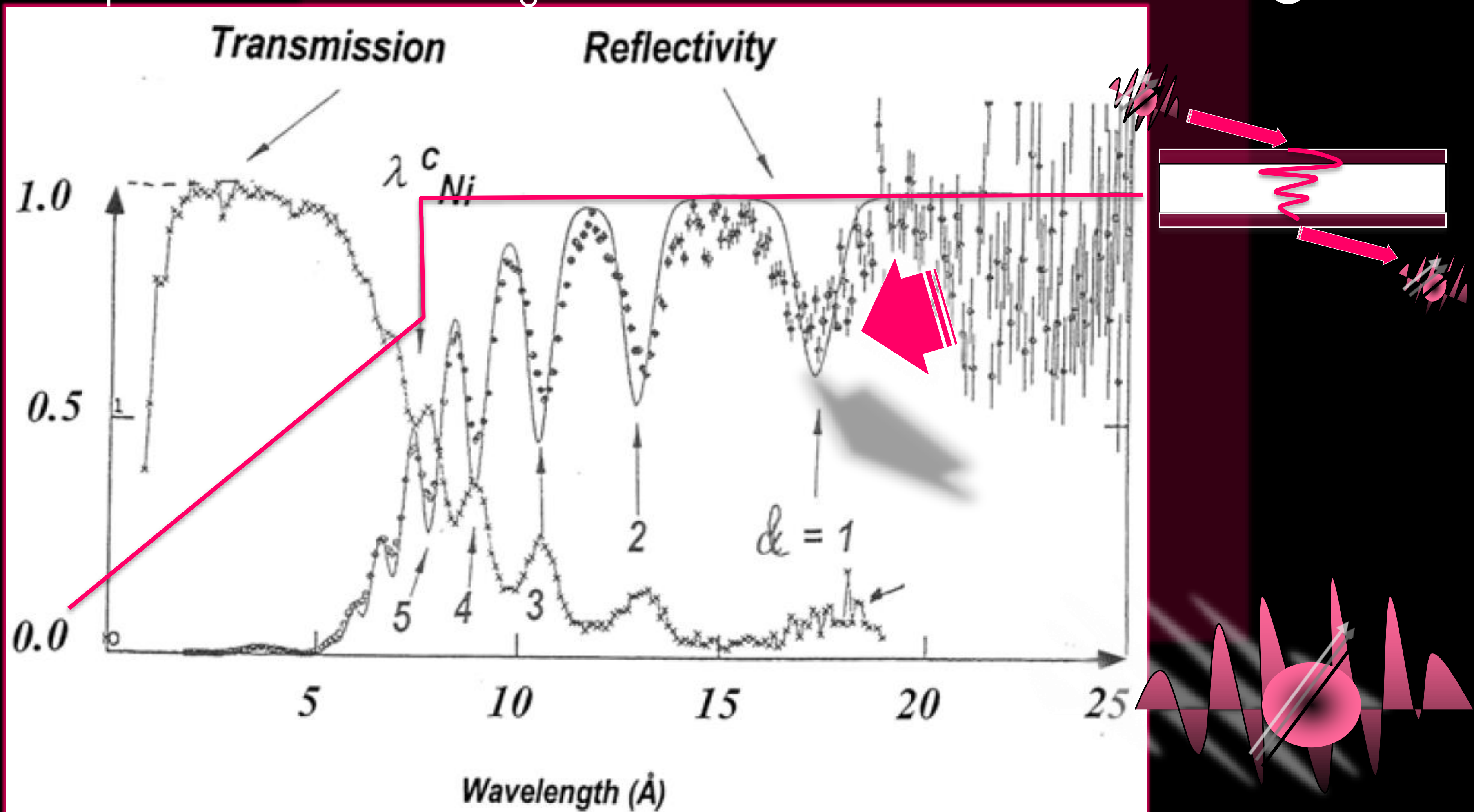




$$\tanh(2\pi x_{\pm} D_r) = \tan(2\Phi_{\pm}) / \tan(2\pi D_s / \Lambda)$$

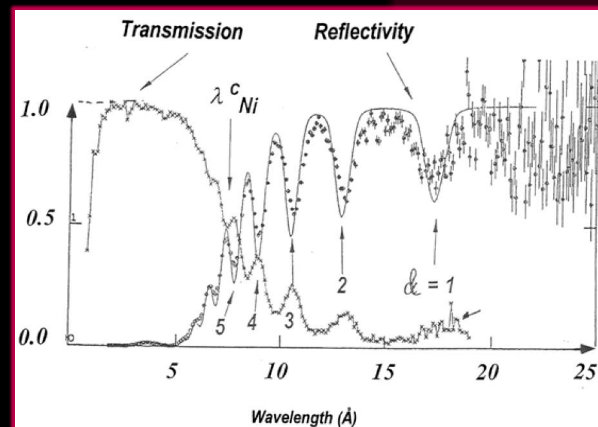
4-NEUTRON TUNNELING:NEUTRON LIFETIME

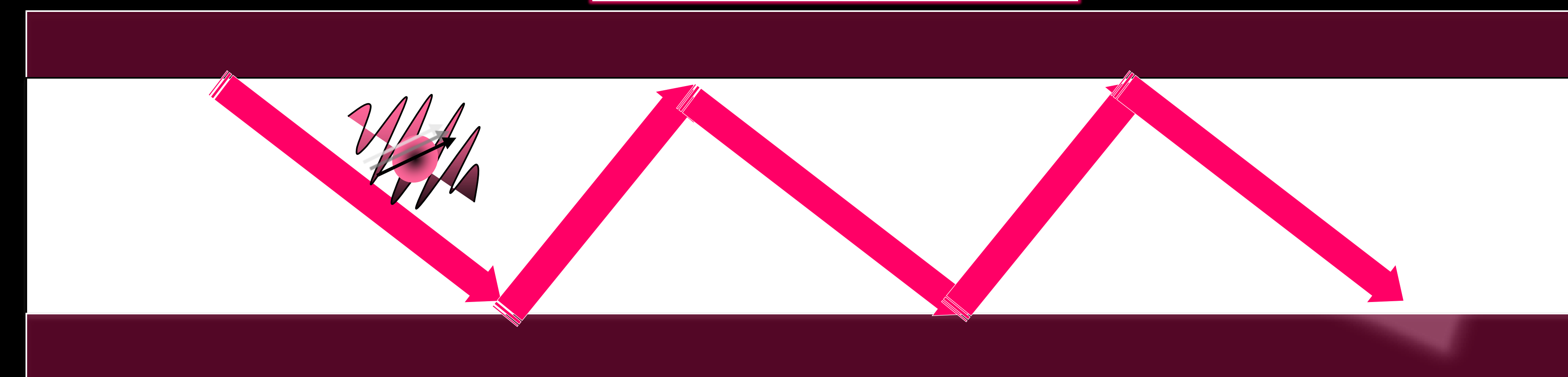
- 200 Å Ni-1000 Å ^{nat}V-200Å Ni /0.1 mmSilicon
- D_r =200 Å Ni D_S=1000 Å ^{nat}V Θi =0.5 deg



4-NEUTRON TUNNELING:NEUTRON LIFETIME

- Resonance modes: 5 modes
- D_r =200 Å Ni
- D_S=1000 Å ^{nat}V
- Θi =0.5 deg

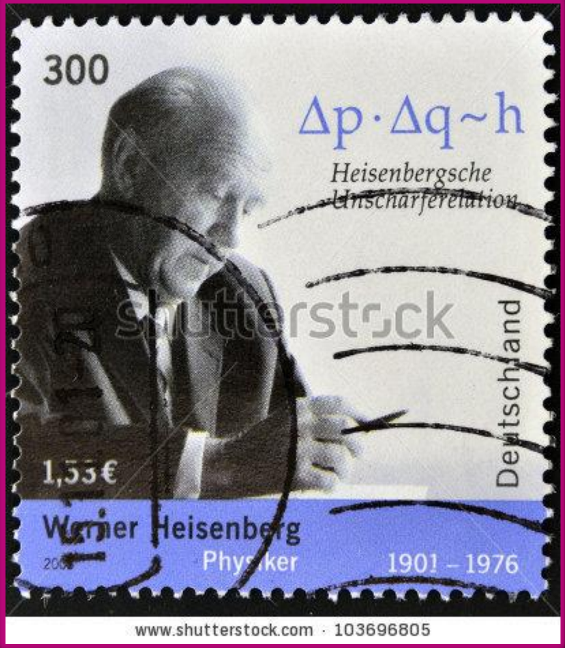


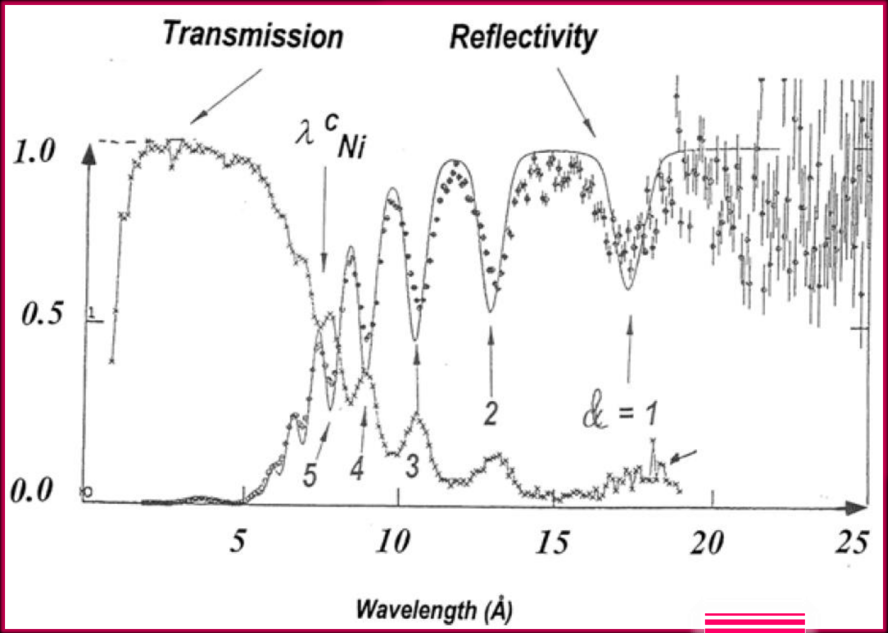


$$\tau \approx m/hk\Delta k$$

4-NEUTRON TUNNELING:NEUTRON LIFETIME

- 200 Å Ni-1000 Å ^{nat}V-200Å Ni /0.1 mmSilicon
- D_r =200 Å Ni D_S=1000 Å ^{nat}V Θi =0.5 deg



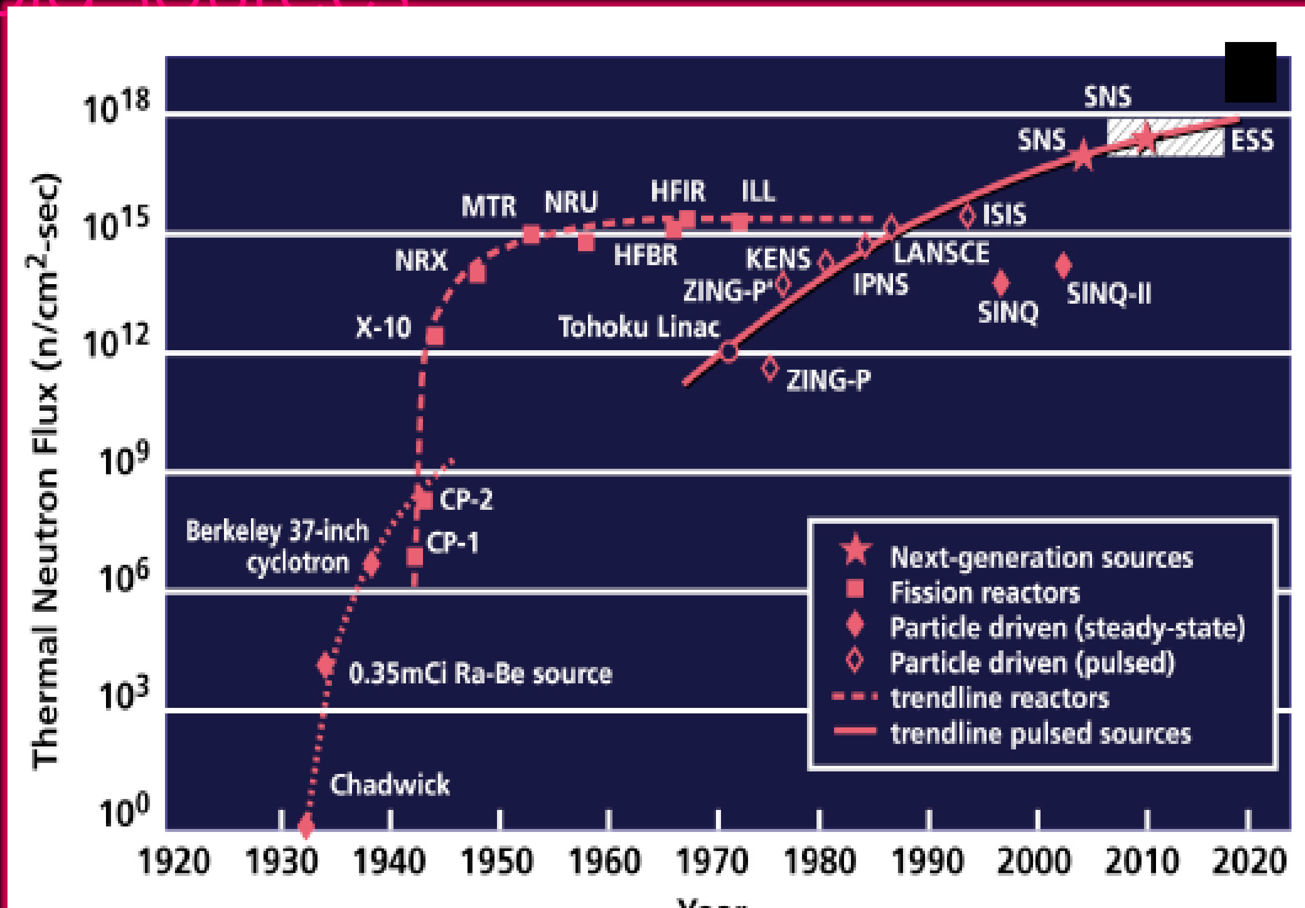


Resonance Order	λ_r (Å)	$\Delta\lambda_r$ (Å)	k_r (10^{-3}Å^{-1})	Δk_r (10^{-4}Å^{-1})	τ, (ms)
1	17.38	1.09	5.05	3.17	0.99
2	12.99	0.85	6.75	4.42	0.53
3	10.56	0.73	8.31	5.74	0.33
4	9.02	0.61	9.73	6.58	0.25
5	7.87	0.61	11.15	8.64	0.16

$$\tau \approx m/hk\Delta k$$

4-FORESIGHT:NEUTRON LIFETIME

- Reactors are limited by heat removed from core
- Pulsed sources have not reached yet that limit
- High flux cold sources



$$\tau \approx m/hk\Delta k$$

4-FORESIGHT:NEUTRON LIFETIME

- Cornerstone for the Standard model
- Lifetime: τ_n=885.7 +/- 0.8 s

PARTICLE PHYSICS

Physicists close in on neutron puzzle

Researchers are narrowing down their measurements of how long the subatomic particle survives on its own.

BY ALEXANDRA WITZE IN DENVER, COLORADO

Physicists are drawing nearer to answering a long-standing mystery of the Universe: how long a neutron lives.

Neutrons are electrically neutral particles that usually combine with protons to make up atomic nuclei. Some neutrons are not bound up in atoms; these free-floating neutrons decay radioactively into other particles in minutes.

But physicists can't agree on precisely how long it takes a neutron to die. Using one laboratory approach, they measure the average neutron lifetime as 14 minutes 39 seconds. Using a different approach, they get 8 seconds longer.

"We don't know why they're different," says Shannon Hoogerheide, a physicist at the National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland. "We really need to understand and eliminate this discrepancy." She and other scientists debated new ways to solve the problem this month at a meeting of the American Physical Society in Denver, Colorado.

Pinpointing the lifetime of a neutron is important for understanding how much hydrogen, helium and other light elements formed in the first few minutes after the Universe was born 13.8 billion years ago. Scientists also think that pinning down the neutron's lifetime would help to constrain measurements of other subatomic particles.

One way of clocking the neutron's lifespan is to put some of the particles in a bottle and count how many are left after a period of time. This 'bottle' method has been tried at several laboratories, including the Los Alamos National Laboratory in New Mexico[1] and the Institut Laue–Langevin in Grenoble, France. On average, they come up with a neutron lifetime of 14 minutes 39 seconds.

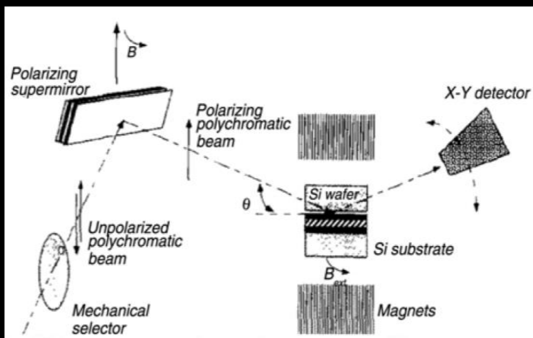
The other way is to feed neutrons into a detector that counts the protons created as the neutrons decay. This 'beam' method has been used at NIST and at the Japan Proton Accelerator Research Complex in Tokai. The Japanese work has just begun, but the NIST team reported in 2013 that its neutrons live eight seconds longer, on average, than those in the bottle method[2].

That's a big problem, because the beam and bottle measurements don't overlap, even when their margins of error are taken into account. So physicists have been looking for ways to explain why neutrons might be disappearing from bottles faster than from beams.

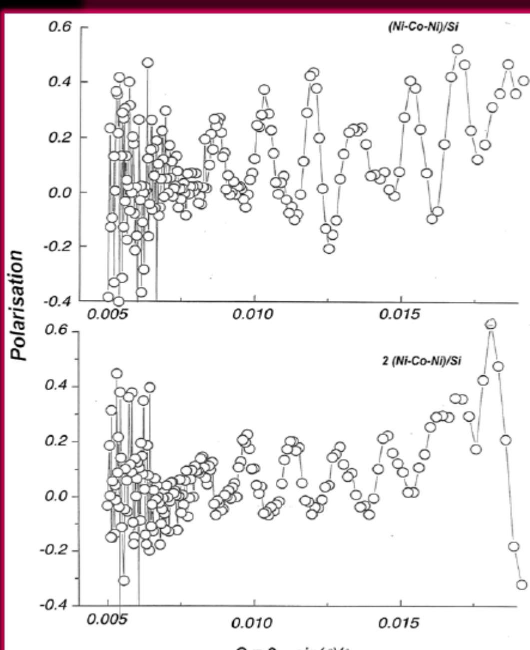
One possibility is that one of the two methods is doing something wrong. In that case, researchers might want to combine beam

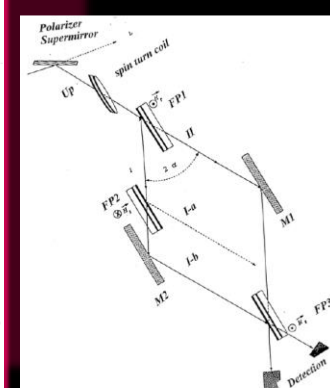
4-FORESIGHT:NEUTRON LIFETIME

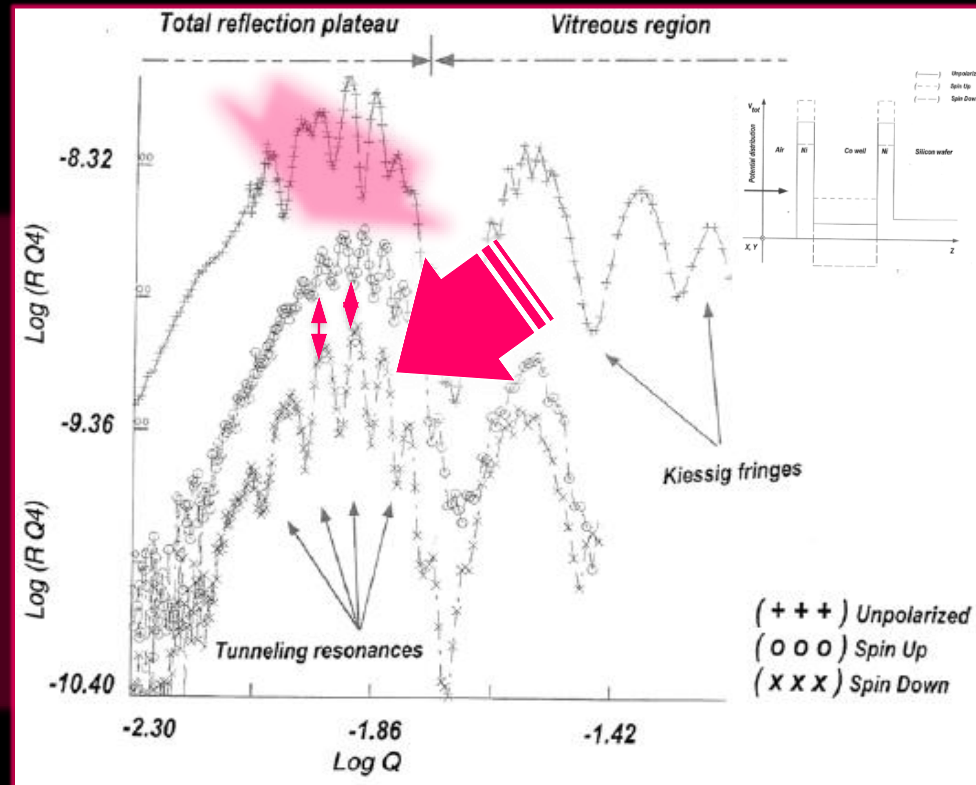
ZEEMAN-BEAM POLARIZATION



$$Q_{r\pm} = (l\pi - \varphi_{\pm})/D_s$$







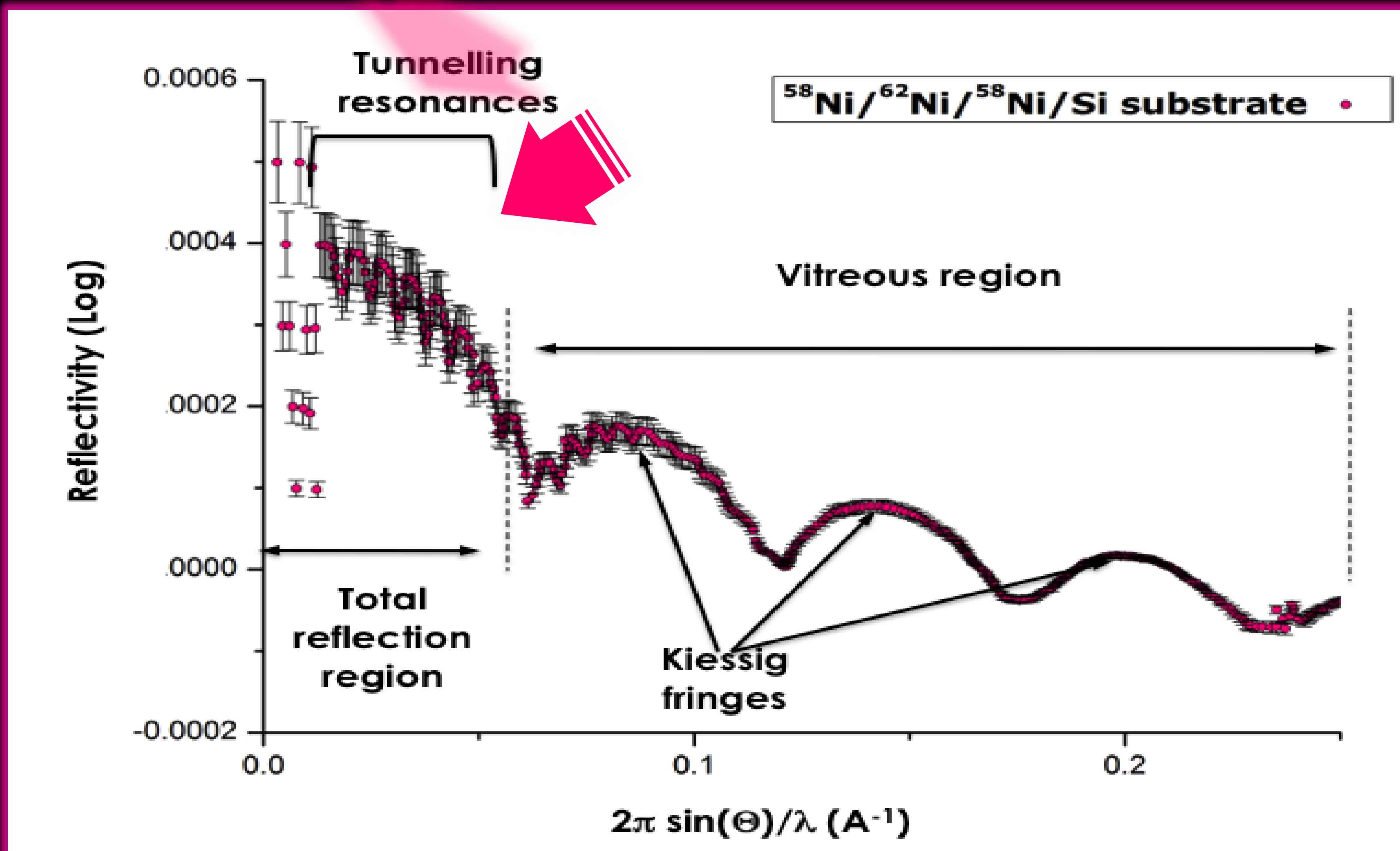
Resonance order l	1	2	3	4	5	6	7
$Q_{r\pm}$ (10^{-2}Å^{-1})	0.92	1.04	1.14	1.29	1.45	1.57	1.69
Q_{r+} (10^{-2}Å^{-1})	0.96	1.05	1.15	1.25	1.37	1.49	1.62
Q_{r-} (10^{-2}Å^{-1})	0.69	0.87	1.03	1.19	1.36	1.52	1.71
$\Delta Q_{r\pm}$ (10^{-2}Å^{-1})	0.05	0.02	0.07	0.06	–	–	–
ΔQ_{r+} (10^{-2}Å^{-1})	0.04	0.04	0.04	0.05	0.05	0.04	–
ΔQ_{r-} (10^{-2}Å^{-1})	0.07	0.05	0.06	0.06	0.06	0.05	–
$R_{r\pm}$ (%)	46.8	53.3	40.0	30.3	16.6	7.7	0
R_{r+} (%)	94.5	85.7	74.7	60.6	41.2	16.6	0
R_{r-} (%)	41.2	53.3	28.3	13.7	10.5	6.8	2.4

Maaza et al, Phys. Lett. A & Phys. Reports

4-FORESIGHT:NEUTRON LIFETIME

ISOTOPICAL EFFECT

$$Q_{r\pm} = (l\pi - \varphi_{\pm})/D_s$$



Maaza et al, MRS Advances2019

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4-LITERATURE:NEUTRON LIFETIME

Physics Reports 514 (2012) 177–198

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Nano-structured Fabry–Pérot resonators in neutron optics & tunneling of neutron wave-particles

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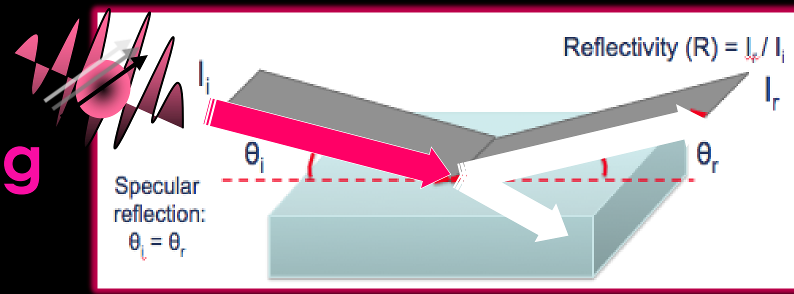
5-NEUTRON TUNNELING:TRANSPARENT BORON GATES

$\Theta_i \approx 1$ **Deg**



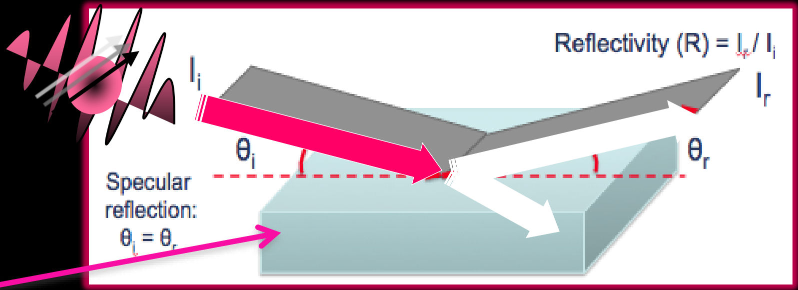
Neutron capture

□ Most important neutron absorbers: ^{10}B as $^{10}B_4C$ in control rods, or Boric acid as a coolant water additive in PWRs. □ □

□ Other important neutron absorbers that are used in nuclear reactors Xe, Cd, Hf, Gd, Co, Sm,, Dy, all of which usually consist of mixtures of various isotopes—some of which are excellent neutron-absorbers. These also occur in combinations such as Mo_2B_5, HfB_2, TiB_2,

5-NEUTRON TUNNELING:TRANSPARENT BORON GATES

$\Theta_i \approx 1$ Deg



Absorbing slab

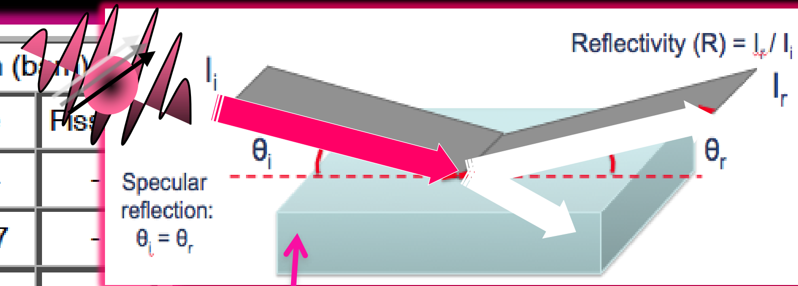
R=0%, T=0% A=100% Neutron capture

Isotope	absorption cross-section - [barns]	yield as fission product and by product decay [%]	half-life
Xe-135	2,700,000	6.4	9.1 hours
Gd-157	250,000	0.01	stable
Gd-155	61,000	0.08	stable
Sm-149	42,000	1.1	stable
Cd-113	20,000	0.01	nearly stable
Sm-151	10,000	0.6	90 years
Eu-151	7,700	0.6	nearly stable
B-10	3,800	< 0.0001	stable

5-NEUTRON TUNNELING: TRANSPARENT BORON GATES

$\Theta_i \approx 1$ Deg

		Thermal cross section (barn)			Fast cross section (barn)		
		Scattering	Capture	Fission	Scattering	Capture	Fission
Moderator	^{1}H	20	0.2	-	4	0.00004	-
	^{2}H	4	0.0003	-	3	0.000007	-
	^{12}C	5	0.002	-	2	0.00001	-
Structural materials, others	^{197}Au	8.2	98.7	-	4	0.08	-
	^{90}Zr	5	0.006	-	5	0.006	-
	^{56}Fe	10	2	-	20	0.003	-
	^{52}Cr	3	0.5	-	3	0.002	-
	^{59}Co	6	37.2	-	4	0.006	-
	^{58}Ni	20	3	-	3	0.008	-
	^{16}O	4	0.0001	-	3	0.00000003	-
Absorber	^{10}B	2	200	-	2	0.4	-
	^{113}Cd	100	30,000	-	4	0.05	-
	^{135}Xe	400,000	2,000,000	-	5	0.0008	-
	^{115}In	2	100	-	4	0.02	-
Fuel	^{235}U	10	99	583[5]	4	0.09	1
	^{238}U	9	2	0.00002	5	0.07	0.3
	^{239}Pu	8	269	748	5	0.05	2



B4C:

^{nat}B:

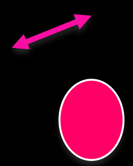
20% ^{10}B

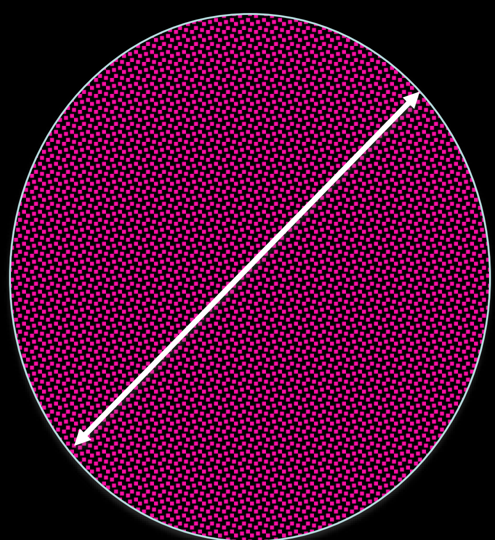
80% ^{11}B

Neutron capture

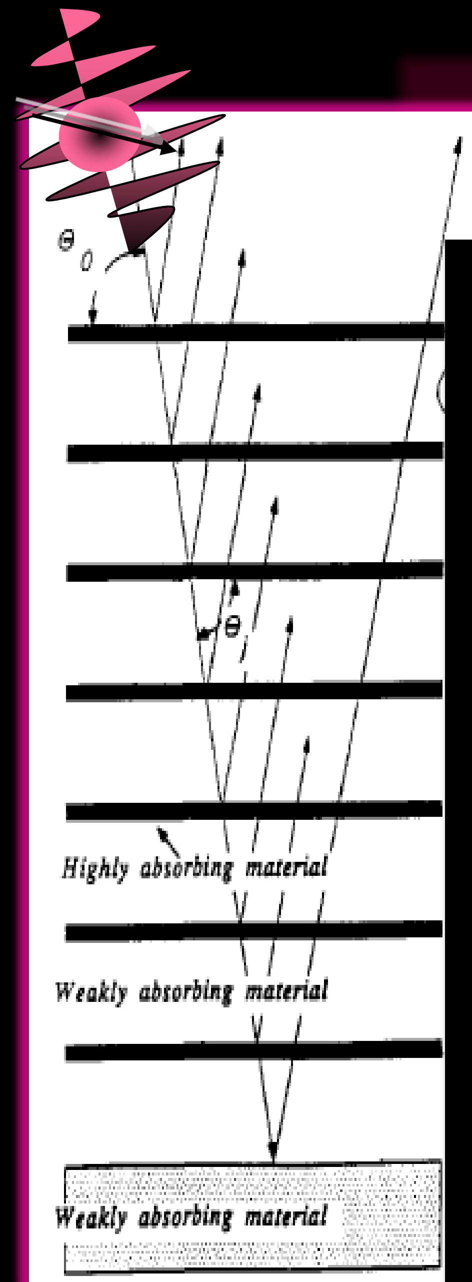
5-NEUTRON TUNNELING:TRANSPARENT BORON GATES

Neutron
0.2 barn





^{10}B
200 barns



D_{Ti}= 12 nm
D_{B4C}= 2 nm
(a)9 bilayers
(b)25 ……..
(c)50 ……..

5-NEUTRON TUNNELING:TRANSPARENT BORON GATES

Водородные бомбы с использованием принципа атомного обжатия. Опытное устройство для проверки принципа атомного обжатия РДС-37.

Преимущество водородных бомб не реализуется без достаточного сжатия легкого ядерного горючего (в 10–20 раз). Энергии обычных взрывчатых веществ не достаточно для осуществления такого сжатия. Многочисленные изыскания, проводившиеся в КБ-11 в 1951–55 гг. не привели к решению проблемы создания мощных, экономичных и транспортабельных водородных бомб, обжимаемых обычными ВВ.

При габаритах порядка РДС-6с такие водородные бомбы оказываются даже не более экономичными, чем атомные бомбы на принципе цепной реакции.

Для получения высоких ...
использовать совершенно но...
обжатие», т.е. сжатие водород...
гии взрыва вспомогательной а...
В 1951, 1952 и 1954 гг. в С...
пытаний водородных бомб, в т...
была испытана бомба мощност...
1954 г. была испытана транс...
ностью 14 млн тонн. Столь вы...
нашему мнению, с большой ...
тельствуют о применении атом...
Расчет мощности опытн...
проведенный на электронной ...
лении прикладной математики...
1,9 млн тонн.

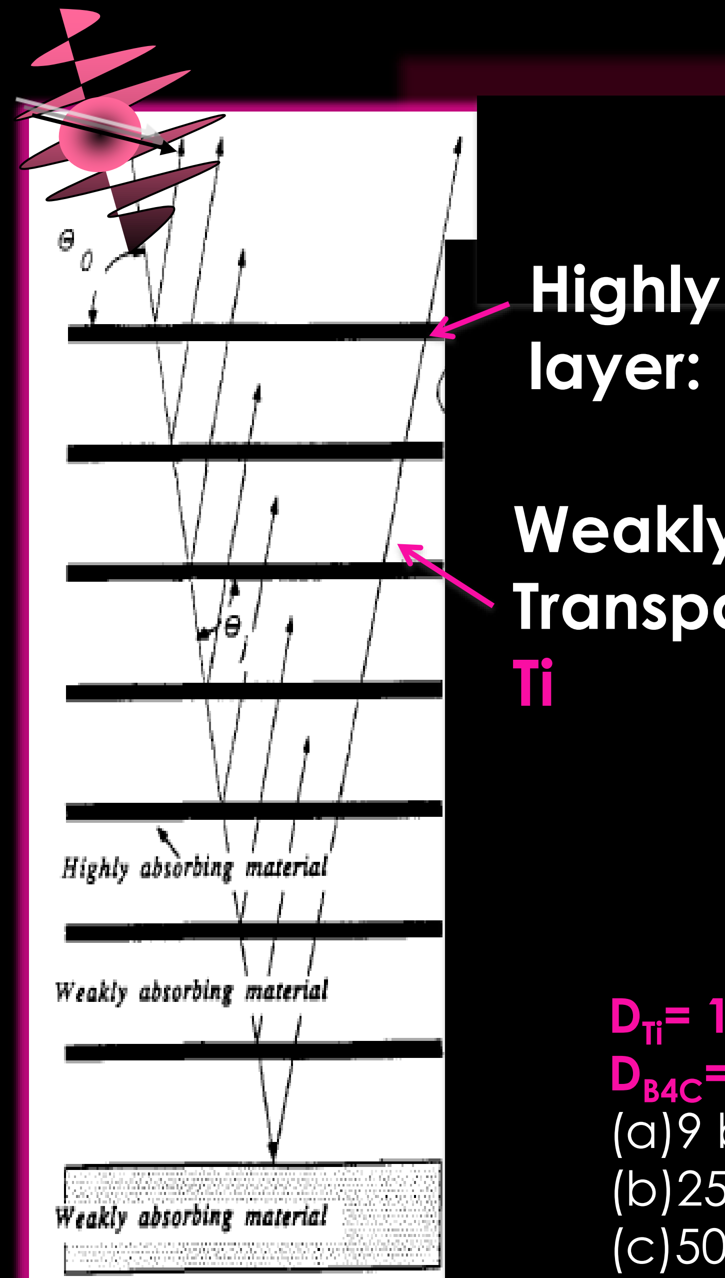
Zeldovich-Vinogradov equation (X-Rays)

$$\Gamma = \frac{\Delta t_H}{\Delta t_H + \Delta t_L} = \frac{\Delta t_H}{d} \qquad (4.7)$$

$$\tan(\pi\Gamma_{opt}) = \pi\left[\Gamma_{opt} + \frac{\beta_L}{\beta_H - \beta_L}\right] \qquad (4.8)$$

(Vinogradov and Zeldovich, 1977)
(also see Borrmann, 1941)

- Sharp interfaces needed for scattering
- Thin high-Z layer to minimize absorption
- Low-Z layer best as a "spacer"



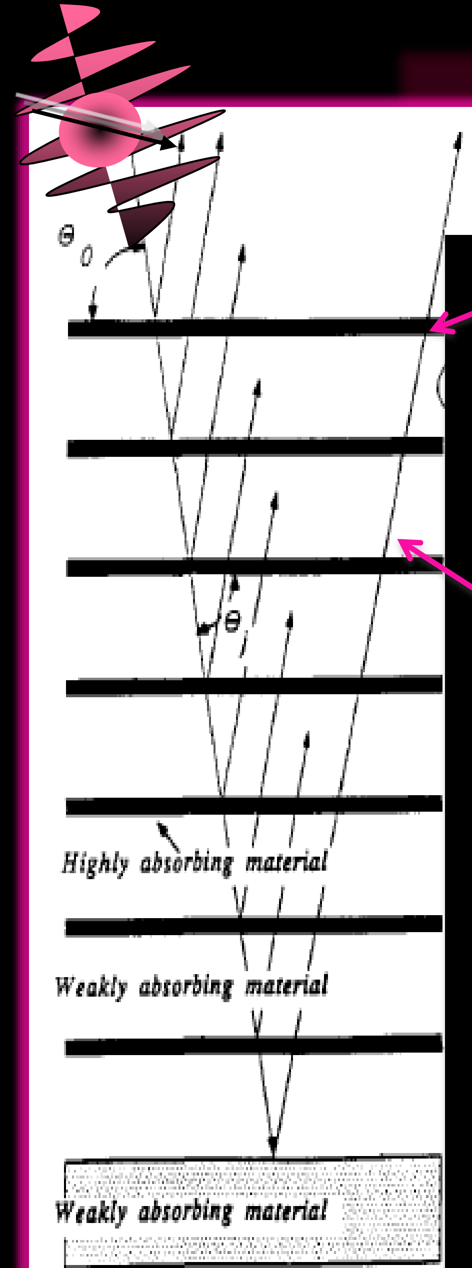
Highly Absorbing layer: B4C

Weakly Absorbing Transparent layer: Ti

D_{Ti}= 12 nm
D_{B4C}= 2 nm
(a)9 bilayers
(b)25 ……..
(c)50 ……..

5-NEUTRON TUNNELING:TRANSPARENT BORON GATES

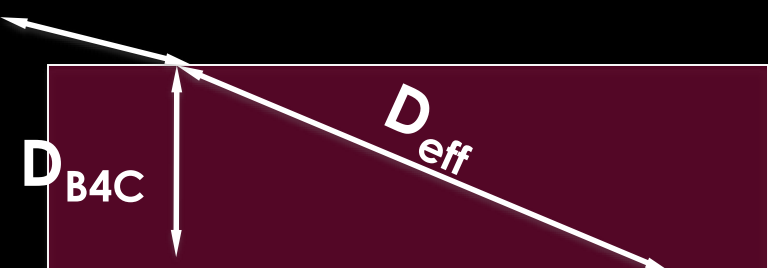
Zeldovich-Vinogradov equation (X-Rays)



Highly Absorbing layer: B4C

Weakly Absorbing Transparent layer: Ti

$\Theta_i \approx 1$ Deg



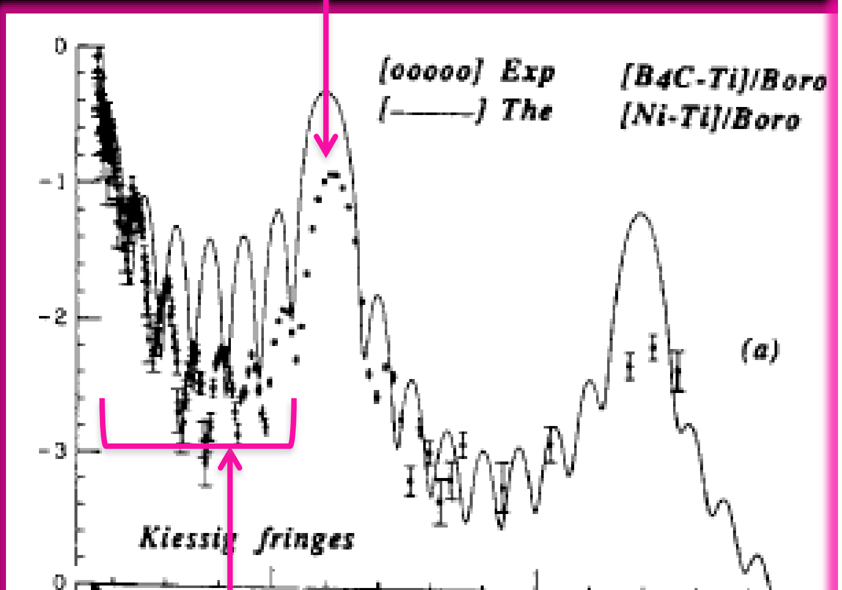
$D_{eff} \approx D_{B4C}/\sin\Theta$

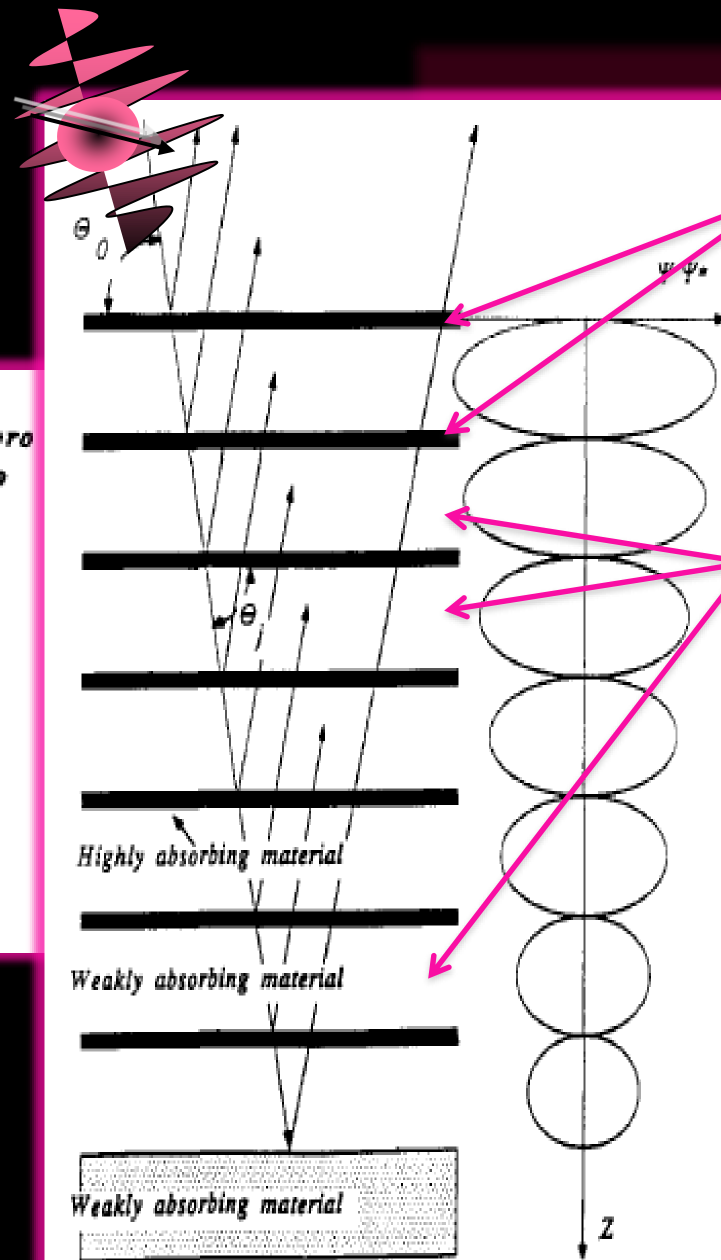
$D_{eff} \approx 200nm \approx 10^5 F$

D_{Ti}= 12 nm
D_{B4C}= 2 nm
(a)9 bilayers
(b)25 ....
(c)50 ....

5-NEUTRON TUNNELING:TRANSPARENT BORON GATES

1st order Bragg Peak
Periodicity interference
R=12.4 %





Highly Absorbing layer: B4C

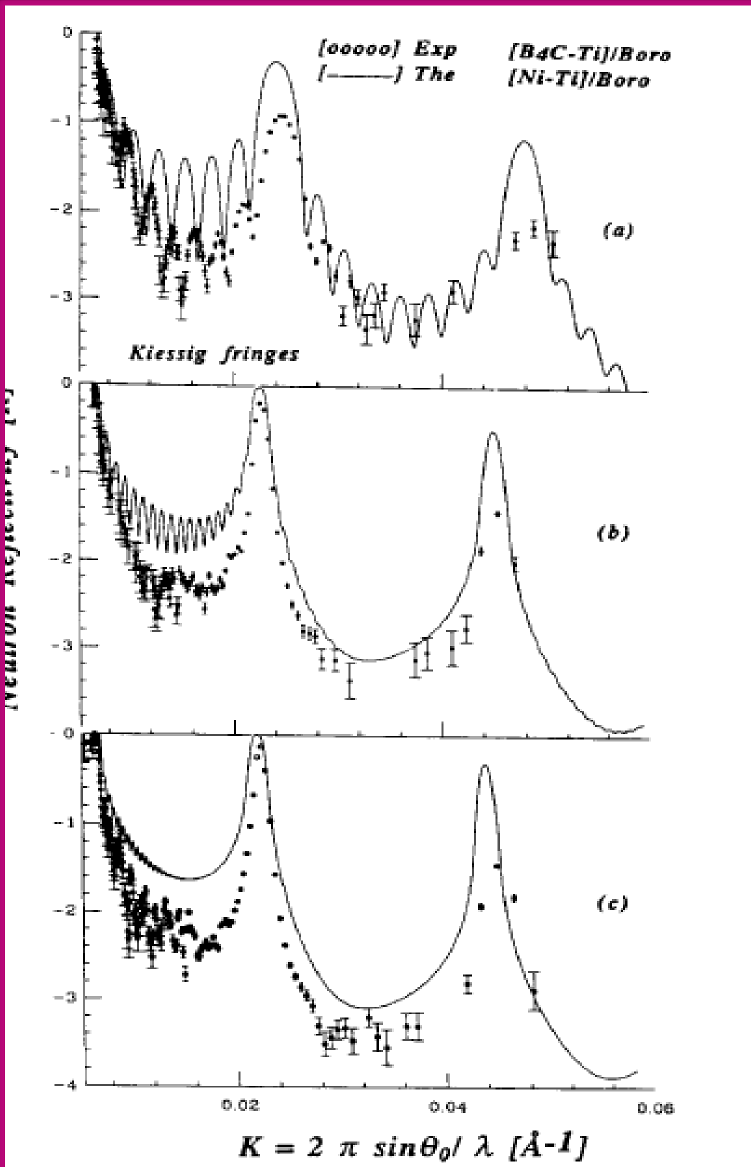
Weakly Absorbing Transparent layer: Ti

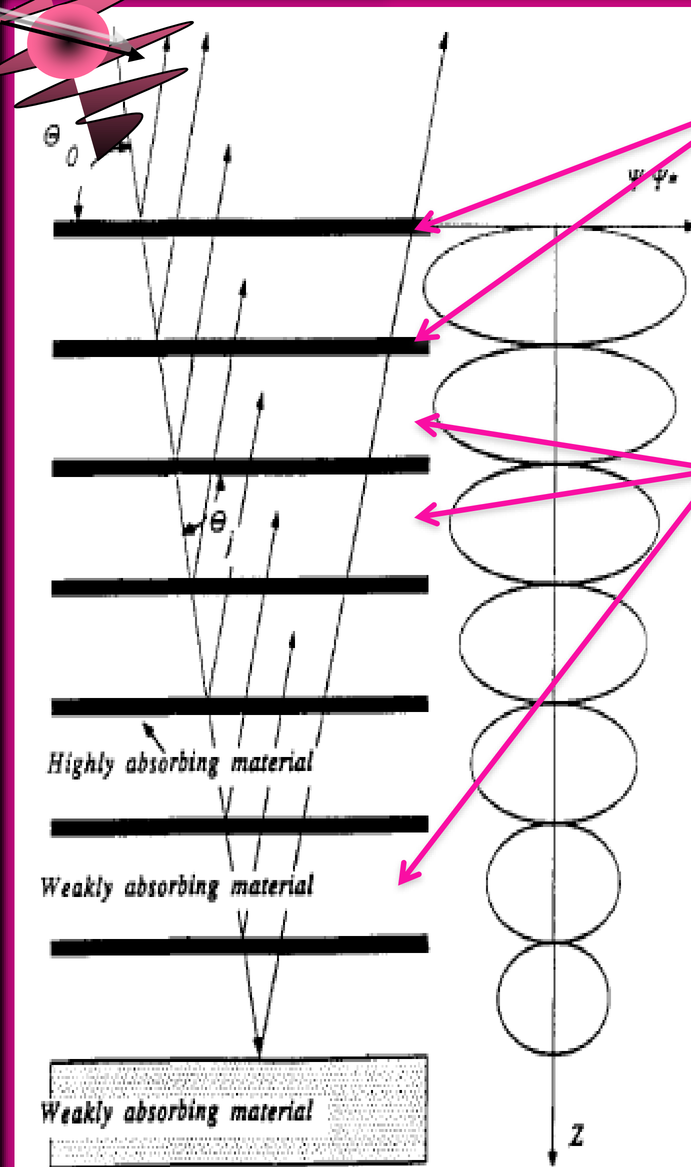
Kiessig Fringes: Air-ML & ML-Substrate interference

D_{Ti}= 12 nm
D_{B4C}= 2 nm
(a)9 bilayers
(b)25 ……..
(c)50 ……..

5-NEUT TUNNELING:TRANS BORON GATES

1st order Bragg Peak: R=12.4 % (a),60.6%(b), 73.5%(c)



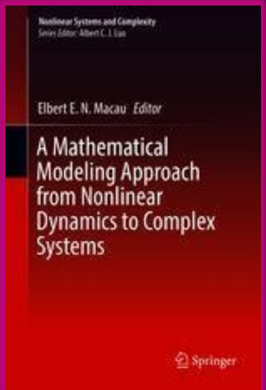


Highly Absorbing layer: B4C

Weakly Absorbing Transparent layer: Ti

D_{Ti}= 12 nm
D_{B4C}= 2 nm
(a)9 bilayers
(b)25 ……..
(c)50 ……..

5-NEUT TUNNELING:TRANS BORON GATES



Водородные бомбы с использованием принципа атомного обжатия. Опытное устройство для проверки принципа атомного обжатия РДС-37.

Преимущество водородных бомб не реализуется без достаточного сжатия легкого ядерного горючего (в 10–20 раз). Энергии обычных взрывчатых веществ не достаточно для осуществления такого сжатия. Многочисленные изыскания, проводившиеся в КБ-11 в 1951–55 гг. не привели к решению проблемы создания мощных, экономичных и транспортабельных водородных бомб, обжимаемых обычными ВВ.

При габаритах порядка РДС-6с такие водородные бомбы оказываются даже не более экономичными, чем атомные бомбы на принципе цепной реакции.

Для получения высоких показателей необходимо использовать совершенно новый принцип — «атомное обжатие», т.е. сжатие водородной бомбы за счет энергии взрыва вспомогательной атомной бомбы.

В 1951, 1952 и 1954 гг. в США был проведен ряд испытаний водородных бомб, в том числе, 1 ноября 1952 г. была испытана бомба мощностью 3,5 млн тонн и 1 марта 1954 г. была испытана транспортабельная бомба мощностью 14 млн тонн. Столь высокие характеристики, по нашему мнению, с большой определенностью свидетельствуют о применении атомного обжатия.

Расчет мощности опытного устройства РДС-37, проведенный на электронной машине «Стрела» Отделения прикладной математики МИАН СССР, дал цифру 1,9 млн тонн.

Monochromation and apodization with Ti–B_4C multilayers in neutron optics†

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THANK YOU, NDIALIVUHA CHUKRAN, MERCI,DANKE

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