Selected problems of the UCN Optics

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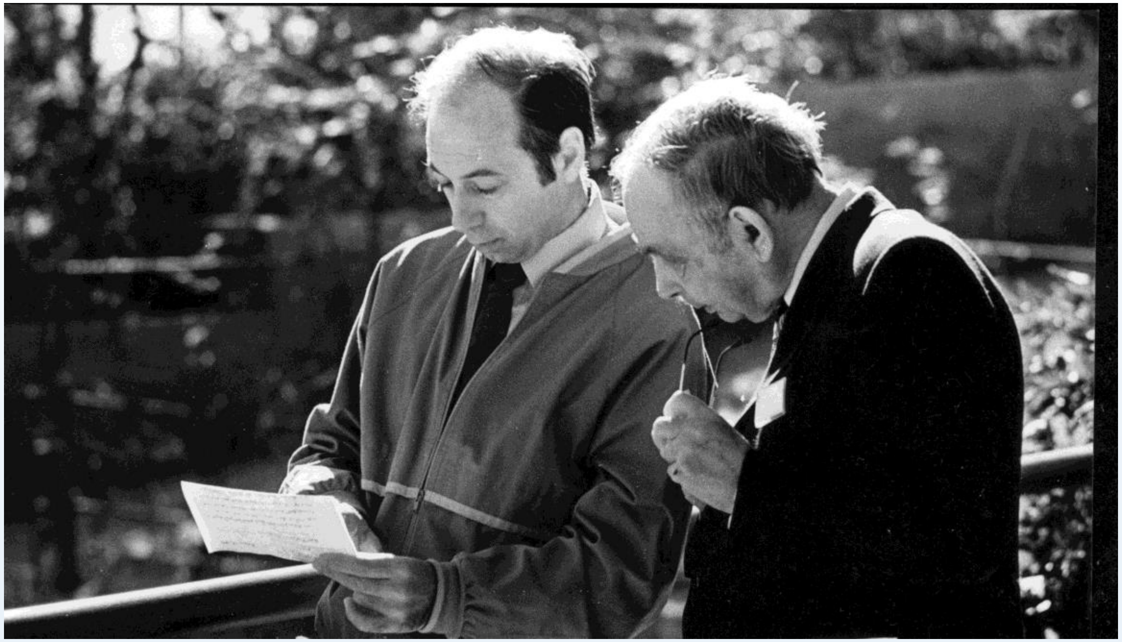


To the 110-th anniversary of I.M. Frank

Outline

- **Refractive index and dispersion law for neutron waves**
- **Neutron speed in matter**
- **Neutron microscopy**
- **Neutron waves in an accelerating matter**

Refractive index and dispersion law for the neutron waves

Neutron optics and "potential" dispersion law

Dispersion law $k^2 = k_0^2 - 4\pi N b$ $\quad b = b' + ib''$ $\quad b'' << b'$ $\quad \frac{b''}{b'} \approx 10^{-4} - 10^{-5}$

Refraction index $n = \frac{k}{k_0}$ $\quad n^2 = 1 - \frac{4\pi N}{k_0^2} b$

$k_{0\perp} \le k_b = (4\pi N |b|)^{1/2}$ → *Total reflection*

$|k_0| \le k_b \Rightarrow UCN$

$$\boxed{k_\perp^2 = k_{0\perp}^2 - 4\pi N b \quad (b = const)}$$ → *Optical properties of an object practically not depend on the longitudinal component of k*

I.M.Frank, 1974

$$\boxed{U = \frac{2\pi\hbar^2}{m} N b = const}$$ $\rightleftarrows$ $u = \frac{2\pi\hbar^2}{m} b\,\delta(\vec{r} - \vec{r}_j)$

Dispersion law zoo

$$k_1^2 = k_0^2 + 4\pi N C f_0 \qquad C = \begin{cases} C = \dfrac{1}{1-(4\pi/3)N\alpha} & \textit{for light} \\ C = 1 \ \ (f_0 = -b) & \textit{for neutrons} \end{cases}$$

Lax, 1951

$$n^2 = 1 - \frac{4\pi N}{k_0^2}(C' - iC'')(b' - ib'') \qquad b''/b' \approx 10^{-4}\text{-}10^{-5} \qquad C''b' \cong b''$$

I.M.Frank, 1974

$$n^2 = 1 - \frac{4\pi N}{k_0^2}(C' - iC'')(b' - ib'')$$

$C' \approx 1 + 2\pi N b' a^2$ $\quad ka \to 0$ *V.F.Sears,1982*

$C'' \approx \pi N b' k a^3$ $\quad$ a – ***interatomic distance***

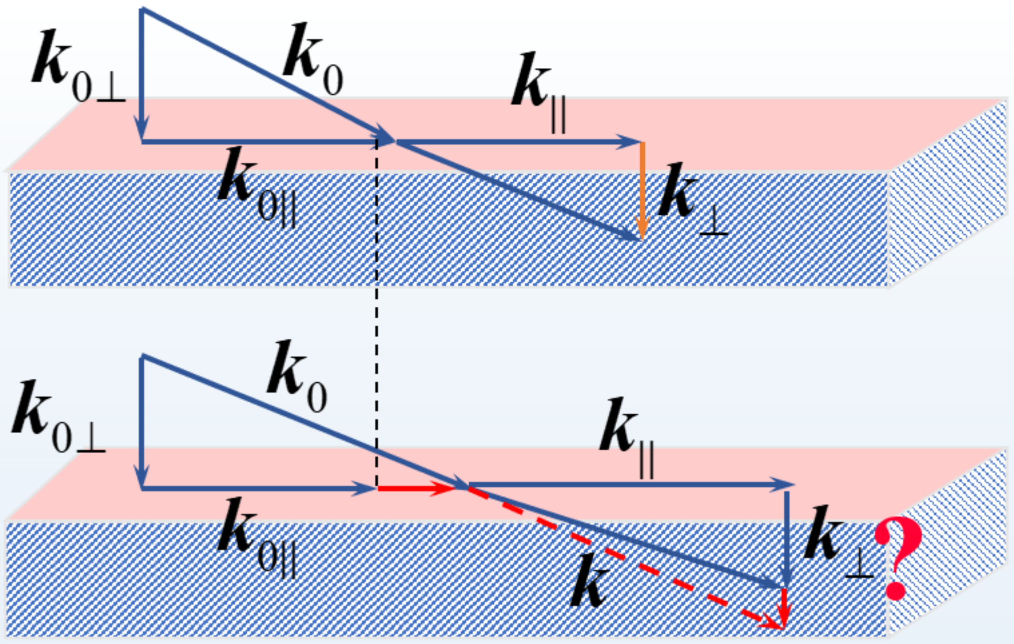
$$n^2 = 1 - \frac{4\pi N b}{k_0^2}\left\{1 + \left(4\pi N b / n k_0^2\right)\int_o^\infty dx e^{iy} \sin(nx)\left[g(x/k_0) - 1\right]\right\}^{-1}$$

M. Warner & J.E Gubernatis, 1985

$k_0 \le 4\pi N b a$ (super slow neutrons) $\cancel{n^2 = 1 - \dfrac{4\pi N}{k_0^2} b}$ $\quad \cancel{u = \dfrac{2\pi\hbar^2}{m} b\,\delta(\vec{r} - \vec{r}_j)}$

Unknown dispersion law and small corrections at the region of UCN. *V.G.Nosov & A.I.Frank, 1991*

Specific feature of the potential dispersion law



$$k_{II}^2 = k_{0\,II}^2$$

$$k^2 = k_0^2 - \chi^2; \qquad \chi^2 = 4\pi N b$$

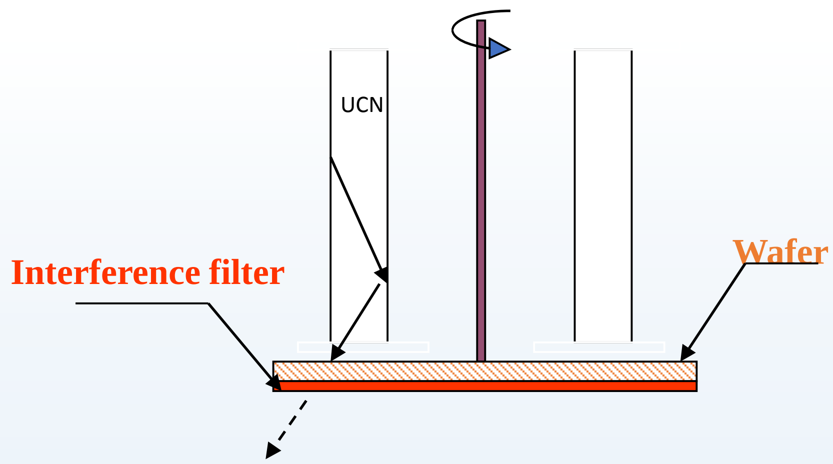
$$k_{\perp}^2 = k_{0\perp}^2 - \chi^2; \qquad b = const$$

I.M.Frank, 1974

$$k^2 = k_0^2 - \chi^2 + \varepsilon\left(k_0^2\right); \qquad \chi^2 = 4\pi N b$$

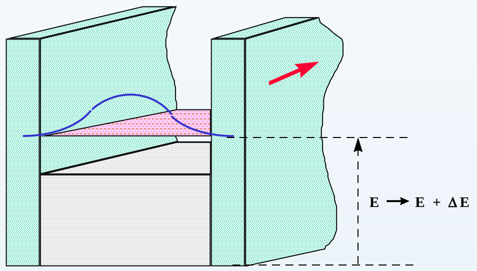
$$k_{\perp}^2 = k_{0\perp}^2 - \chi^2 + \varepsilon\left(k_0^2\right);$$

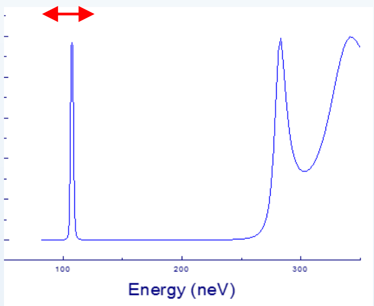
First attempt of the testing the UCN dispersion law with rotating interference filter

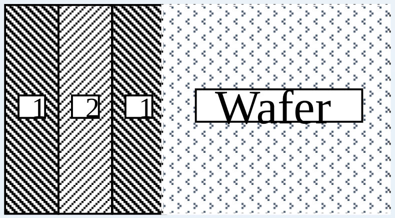


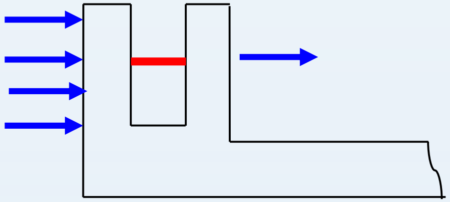
$$k^2 = k_0^2 - 4\pi N b + \varepsilon\left(k_0^2\right)$$

$$k_\perp^2 = k_{0\perp}^2 - 4\pi N b + \varepsilon\left(k_0^2\right)$$







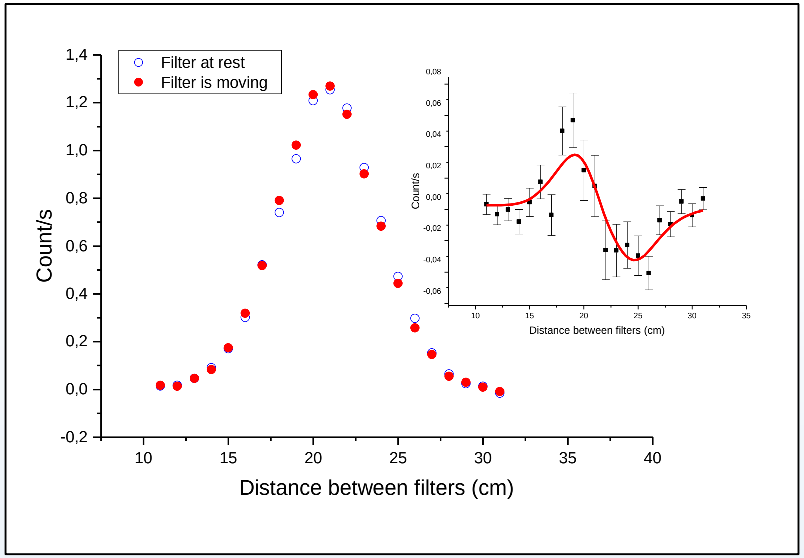


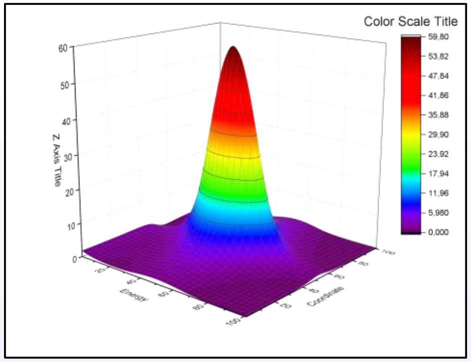
If the case of deviation from the potential dispersion law $(\varepsilon \neq 0)$ *the position of the resonance and correspondently the spectrum of transmitted neutrons will shifted when sample would rotating*

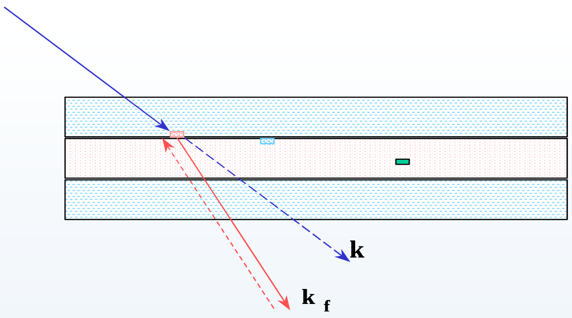
$$U_{1,2} = \frac{2\pi\hbar^2}{m}(Nb)_{1,2}$$

A.I.Frank, V.G.Nosov, 1995

Unexpected result and possible explanation



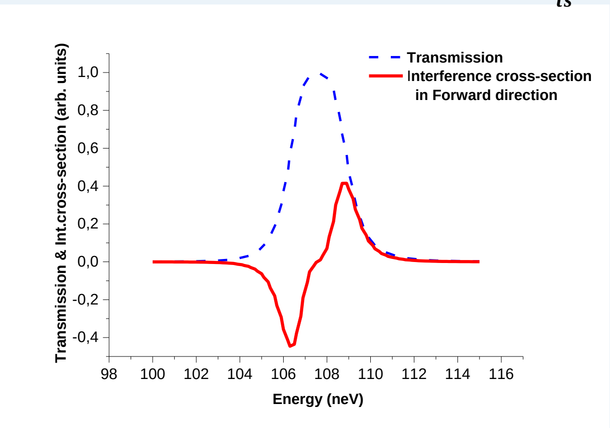




$$f\left(k',k\right) = -\frac{m}{2\pi\hbar^2}\int \tilde{\Psi}_f\left(\vec{r}\right)V_1\left(\vec{r}\right)\Psi\left(\vec{r}\right)d\vec{r}$$

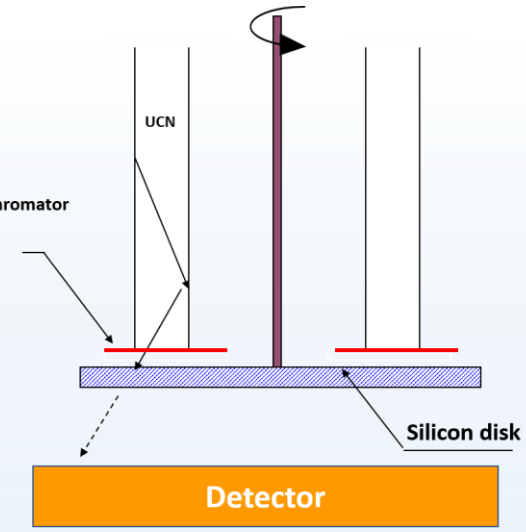
$$\sigma_{ts} = -\frac{4\pi}{k}\, Im\left\{T^* f\left(k_t,k_t\right)\right\}$$

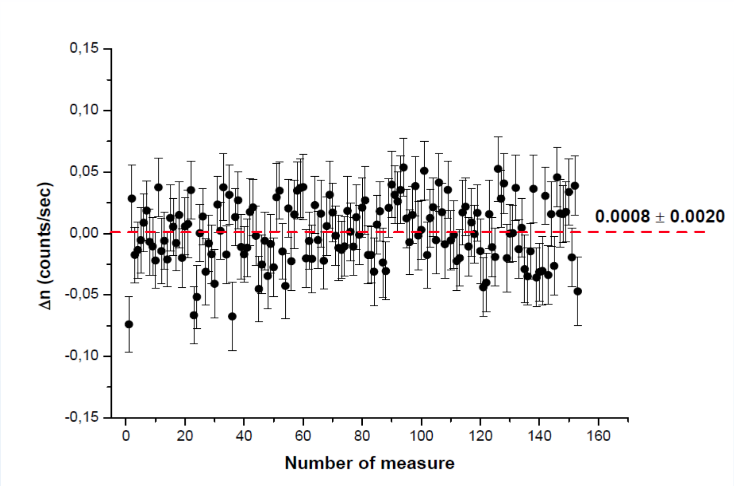
1. *In the resonant conditions the amplitude of neutron scattering at roughness's rises by some orders of magnitude*
2. *Transmitted wave and forward scattered wave are interferes.*
3. *The phase of the transmitted wave changes its sign in the resonance*



I.V.Bondarenko et al, 1998
A.I.Frank et.al, 1999

Test the UCN dispersion law with rotating sample





$$v_x = 6 \Leftrightarrow 36\ m/s$$

$$\Delta n/n = (0.6 \pm 1.4) \times 10^{-3}$$

$$\delta J' = \leq 3 \times 10^{-3} \quad if \quad \delta W = 0$$

$$U = V - iW = \frac{2\pi\hbar^2}{m} N\left(1 + J' + iJ''\right)\left(b' - ib''\right)$$

$$\delta J'' = \leq 3 \times 10^{-8} \quad if \quad \delta V = 0$$

G.V. Kulin et al, 2014
A.I. Frank, 2016

FLNP

Discussion I

1. The theory predicts that dispersion law have to differs from the potential forms at least for the cold neutrons.
2. This prediction was not yet verified by experiment.
3. For the case of UCN only one experiment was performed to confirm the model of effective potential.
4. Any data concerning the existence of the super slow neutron still absent.

Neutron speed in matter

First experimental demonstration of distinctions between the neutron speed in matter and the speed in vacuum

$$\boxed{n = \frac{k}{k_0}} \qquad n = \sqrt{1 - \frac{4\pi N}{k_0^2} b}$$

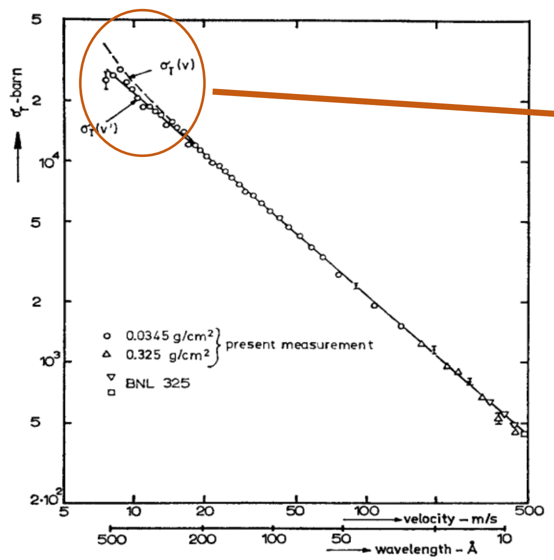
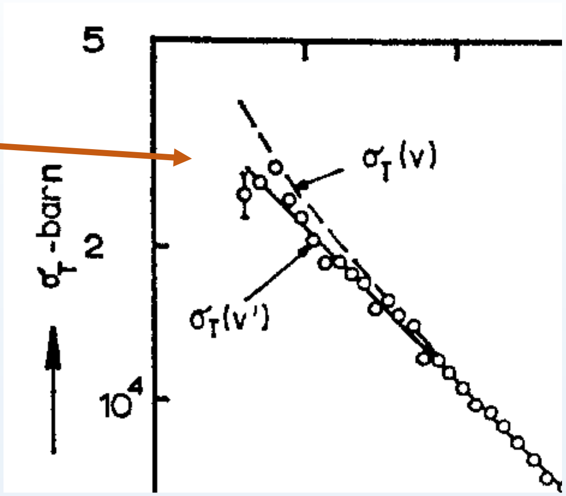


Fig. 2. Total cross-section of 2 gold foils versus neutron velocity in vacuo (v) and insi the sample (v'); at temperatures 80 and 299 °K



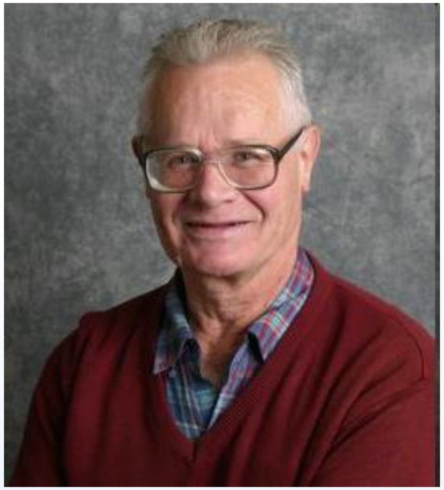
$$v = n v_0$$

In experiment of A. Steyerl (1972) it was shown that transmission of this film for very cold neutrons corresponds to the $\sigma \propto \frac{1}{n v_0}$ **but not to** $\sigma \propto \frac{1}{v_0}$

Albert Steyerle, Alushta, 1974

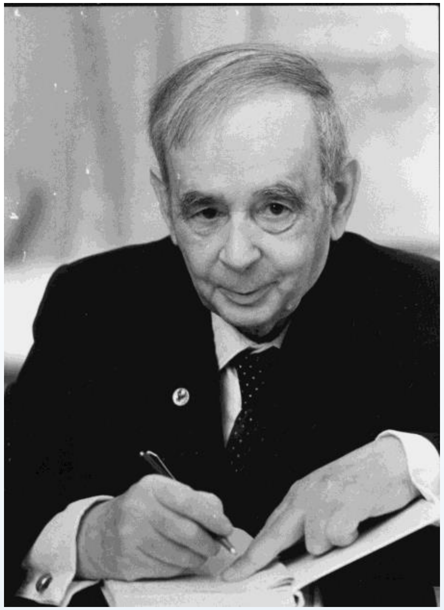
I.M.Frank's speech dedicated to F.L.Shapiro. Alushta, 6 April, 1974

Concerning the neutron speed in a matter (1974-2008)



Over the long period of almost 40 years of common research interests, starting from the early days of ultracold neutrons at Dubna and Garching, I remember just one incidence where I am afraid I did not understand Ilya Mikhailovich. That is when he summarized our work at Garching as “confirmation of the 1/v law”. This was surprising to us since we had never doubted that the 1/v law for neutron reaction processes should be valid even at the lowest energies, as long as a refractive correction to neutron velocity inside the medium is applied. I wish I had asked him what he meant.

A.Steyerl, 2008



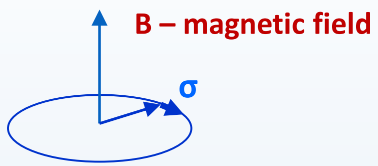
«Фотон в среде очевидно не является свободной частицей. Распространение волны получается в результате когерентного сложения волн отдельных атомов. Таким образом, для возникновения волны существенно коллективное движение, происходящее в атомах среды. Это характерное свойство не частицы, а квазичастицы (например, аналогично фононам)»

И.М.Франк, 1978

Direct measure of neutron speed in matter

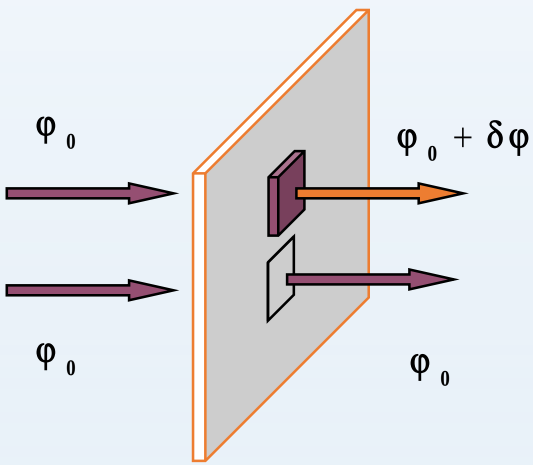
Delay time in a refractive sample

$$\Delta t = \frac{L}{n v_0} - \frac{L}{v_0} = \frac{L}{v_0}\left(\frac{1-n}{n}\right)$$



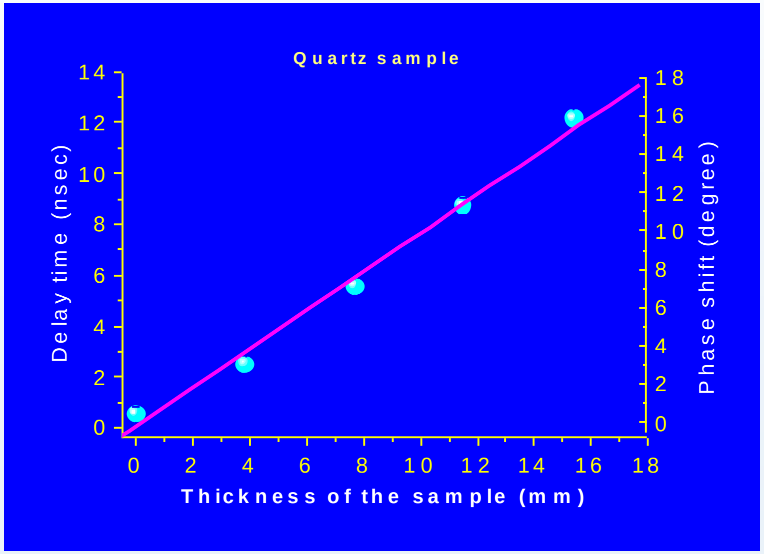
$$\delta\varphi = \Delta t \cdot \omega_L \qquad \omega_L = \frac{2\mu B}{\hbar}$$

Precession (Larmor) frequency



$\lambda = 18.85$ Å

$v \approx 210\ m/s$



$$\delta t_{min} = 3.7 \times 10^{-10}\ \mathbf{sec} \qquad \mathbf{t} \approx 1.7 \times 10^{-2}\ \mathbf{sec}$$

A.I. Frank et al, 2002

Neutron speed in matter and another feature of the potential dispersion law

In general case dispersion law may be represent as $k = F(k_0^2)$

It was shown recently that in this case $\boxed{v = \frac{\hbar}{2m}(F')^{-1}}$ *and* $\mathbf{v} \neq n\mathbf{v}_0$ (?)

$k = nk_0 \Rightarrow m^*\mathbf{v} = nm\mathbf{v}_0$

$v = \frac{\hbar k}{m^*} = nv_0 \frac{m}{m^*}$

$m^* = 2mkF'$

$\frac{1}{\mathbf{m}^*} = \frac{\partial^2 \mathbf{E}}{\partial \mathbf{p}^2}$

Generally speaking neutron inside a refractive matter is not a particle

but a quasi particle

Concerning the negative neutron effective mass at Bragg diffraction see Zeilinger A. et al. *Phys. Rev.Lett.* **57,** 3089 (1986)

Putting $\mathbf{v} = n\mathbf{v}_0$ we arrive immediately to $\boxed{k^2 = k_0^2 + \chi^2}$ $\boxed{m^* = m}$

A.I. Frank, 2018

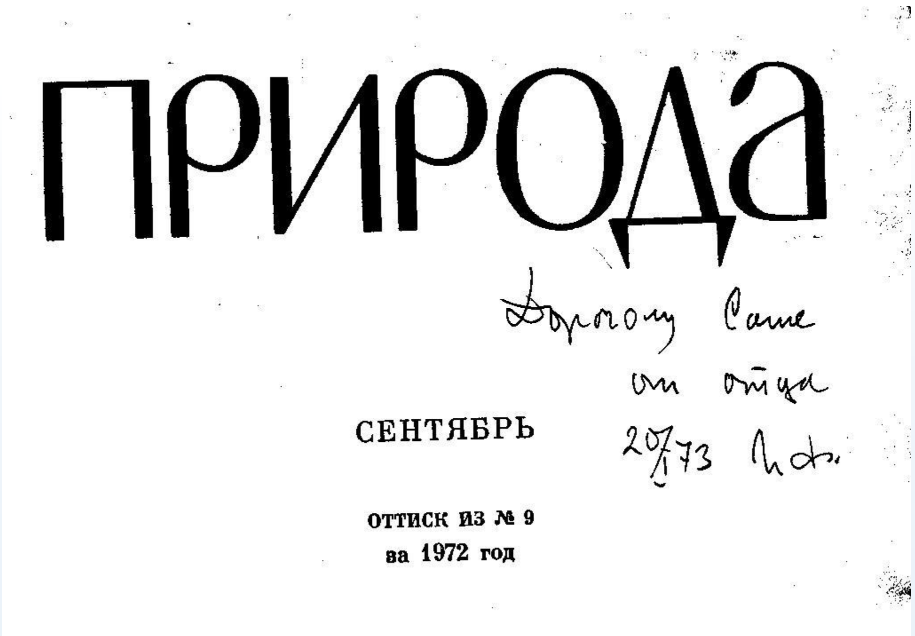
Potential dispersion law $k^2 = k_0^2 - 4\pi\rho b$

Discussion II

1. Neutron speed in a refractive matter differs from the speed in vacuum
2. Direct measurement of neutron speed in matter was performed, but only in one experiment.
3. The relation $v = n v_0$ is correct only in the case of the potential dispersion law.
4. Deviation from the relation $v = n v_0$ in refractive media was not yet observed

Technical UCN optics and the problem of neutron microscopy

UCN and neutron microscopy


ПРИРОДА

Дорогому Саше от отца 20/I 73

СЕНТЯБРЬ

ОТТИСК ИЗ № 9
за 1972 год

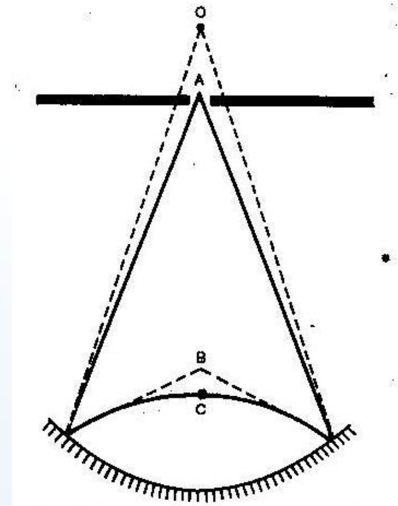


Рис. 7. Простейшая схема опыта для получения оптического изображения отражением ультрахолодных нейтронов от вогнутого зеркала. Через небольшое отверстие А ультрахолодные нейтроны падают на вогнутое зеркало. Но за счет силы тяжести их пути изгибаются так, как если бы они шли по прямой из О. По той же причине они соберутся не в оптическом фокусе В, а в нижележащей точке С.

Мне думается, что получение оптического изображения с помощью отражения и преломления очень медленных нейтронов — опыт настолько существенный, что его обязательно необходимо выполнить. Ведь в отдаленной перспективе можно мечтать о том, что оптика очень медленных нейтронов когда-нибудь позволит создать нейтронный микроскоп.

И.М.Франк, 1972

Fermat principle in light and neutron optics

$$n(z) = \left(1 - \frac{2gz}{v_0^2}\right)^{1/2}, \quad v_0 = v\Big|_{z=0}$$

Письма в ЖЭТФ, том 28, вып.8, стр. 559 – 560 20 октября 1978 г.

О ПРИМЕНИМОСТИ ПРИНЦИПА ФЕРМА
К ОПТИКЕ УЛЬТРАХОЛОДНЫХ НЕЙТРОНОВ

И.М.Франк, А.И.Франк

Рассмотрен вопрос о применимости принципа Ферма к оптике ультрахолодных нейтронов (УХН), когда наличие гравитации существенно искривляет траектории нейтронов. Показано, что принцип Ферма вполне применим и в случае нейтронных волн

Fermat principle $\delta \int_A^B k\,dl = 0, \quad \text{or} \quad \delta \int_A^B n\,dl = 0$ **Minimality or stationarity of phases A→B,**

Optics

$$I = \int_A^B n\,dl = \int_A^B \frac{c}{v} dl = c\int_A^B dt, \qquad \delta I = 0,$$

Minimality or stationarity of the propagation time A→B

Massive particle

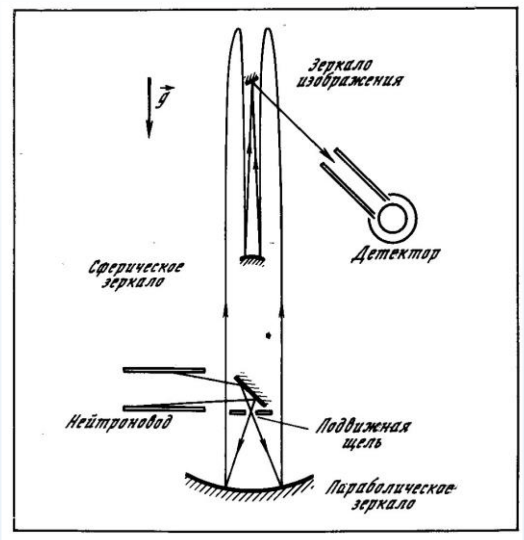
Phase stationarity → $\delta \int_A^B v\,dl = 0,$

Stationarity of the propagation time → $\delta \int_A^B \frac{dl}{v} = 0$

Achromatic imaging → isochronism + isophasality

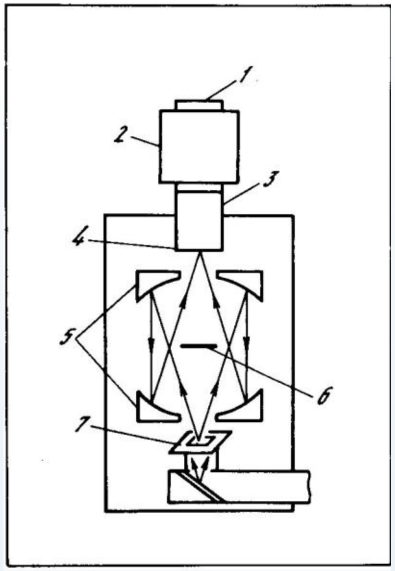
Neutron microscopes and UCN imaging

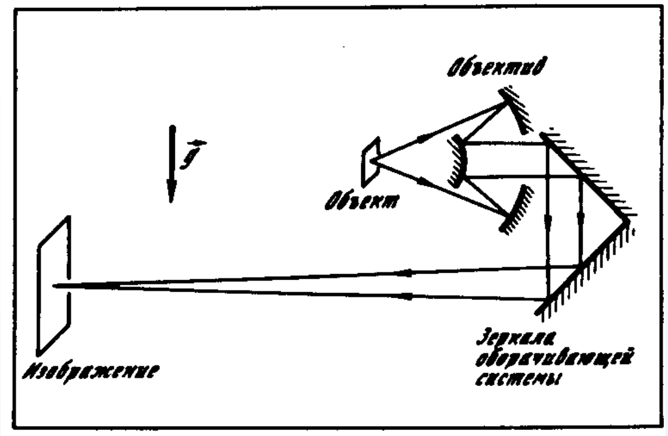
A.Steyerl et al, 1985



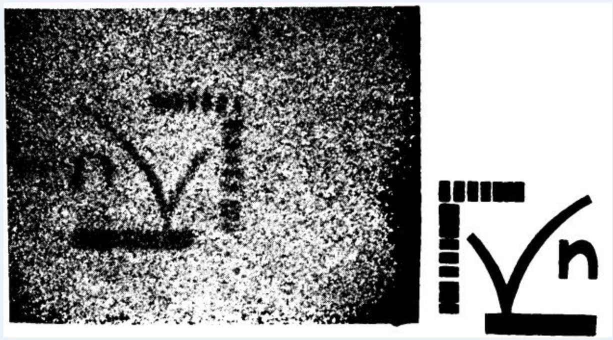
Resolution ≈ 10 μ

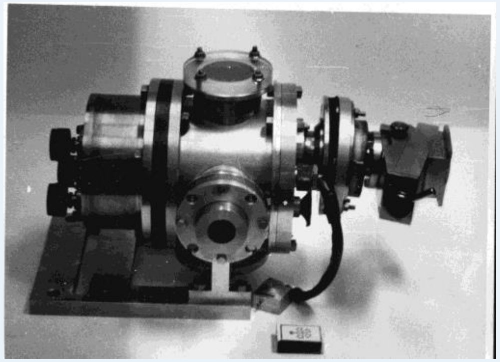
A.I.Frank and Kurchatov Inst. Group 1986- 90





Resolution ≈ 15 μ





The problem of phase contrast and Neutron Spin Interferometry

Refractive indexes of certain amino-acid resides and phase shifts for 1μ thick layer for neutrons with two velocities

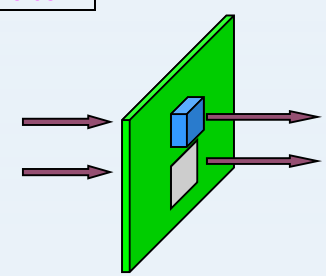
Amino acid	Chemical	Number of	V=5m/c				V=20m/c			
	Composition	exchanable	Refractiv index		Phase shift (radian)		Refractiv index		Phase shift	
		hydrogen atoms	Ordinary	Deuterated	**Ordinary**	**Deuterated**	Ordinary	Deuterated	**Ordinary**	**Deuterated**
Glycine	C_2NOH_3	1	0.692	0.408	**24.4**	**47**	0.984	0.974	**5.08**	**8.25**
Alanine	C_3NOH_5	1	0.801	0.642	**7.9**	**28.4**	0.988	0.981	**3.81**	**6.03**
Valine	C_5NOH_9	1	0.890	0.803	**8.7**	**15.6**	0.993	0.989	**2.21**	**3.49**
Leucine	C_6NOH_{11}	1	0.913	0.842	**6.9**	**12.53**	0.995	0.991	**1.59**	**2.86**
Phenilalanine	C_9NOH_9	1	0.770	0.701	**18.2**	**23.7**	0.987	0.984	**4.12**	**5.08**
Tyrosine	$C_9NO_2H_9$	2	0.733	0.577	**21.2**	**33.6**	0.985	0.979	**4.76**	**6.66**
Tryptophan	$C_{11}N_2OH_{10}$	2	0.702	0.563	**23.6**	**49.6**	0.984	0.978	**5.08**	**6.98**
Aspartic acid	$C_4NO_3H_4$	1	0.570	0.375	**34.1**	**49.6**	0.978	0.973	**8.57**	**8.57**
Glutamic acid	$C_5NO_3H_6$	1	0.738	0.564	**20.8**	**34.6**	0.986	0.978	**4.44**	**6.98**
Serine	$C_3NO_2H_5$	2	0.743	0.363	**20.4**	**50.5**	0.986	0.972	**4.44**	**8.88**
Threonine	$C_4NO_2H_7$	2	0.806	0.557	**15.4**	**35.14**	0.989	0.978	**3.49**	**6.98**
Asparagine	$C_4N_2O_2H_6$	3	0.699	0.169	**23.9**	**65.9**	0.984	0.969	**5.08**	**9.84**
Glutanine	$C_5N_2O_2H_8$	3	0.812	0.441	**14.9**	**44.3**	0.989	0.974	**3.49**	**8.25**
Lysine	$C_6N_2O_2H_{13}$	4	0.905	0.590	**7.54**	**32.5**	0.994	0.979	**1.9**	**6.66**
Arginine	$C_6N_4OH_{13}$	6	0.785	imaginary	**17.06**	**total reflec**	0.988	0.966	**3.8**	**10.8**
Methionine	C_5NOSH_9	1	0.891	0.820	**8.6**	**14.3**	0.993	0.984	**2.21**	**5.08**

$$\Psi = \frac{1}{\sqrt{2}} \begin{pmatrix} e^{ik_+ x} \\ e^{ik_- x} \end{pmatrix}$$

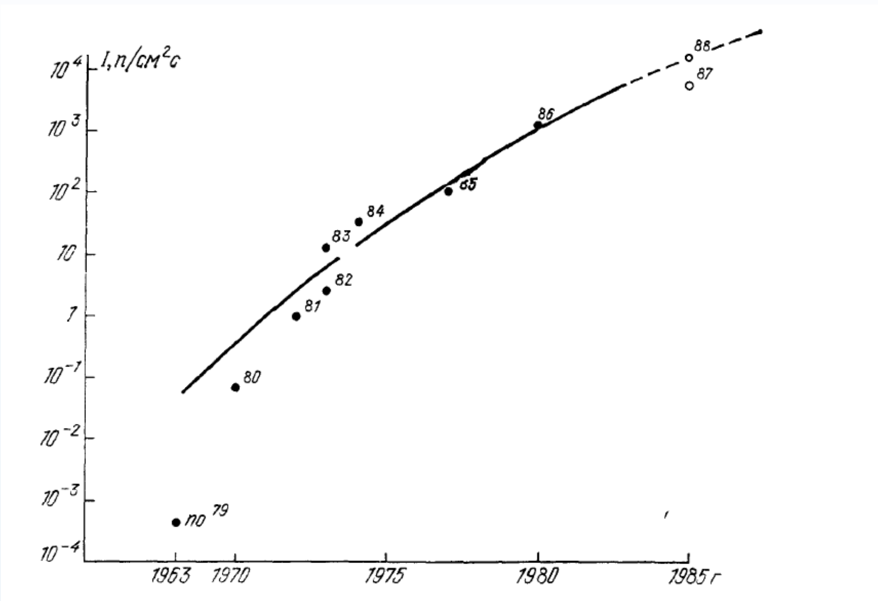
$$\varphi_\pm = k_\pm \left[1 - n\left(k_\pm\right) \right] d$$

$$\Delta\Phi = \omega_L \left(\frac{1-n}{n} \right) \frac{d}{v}$$

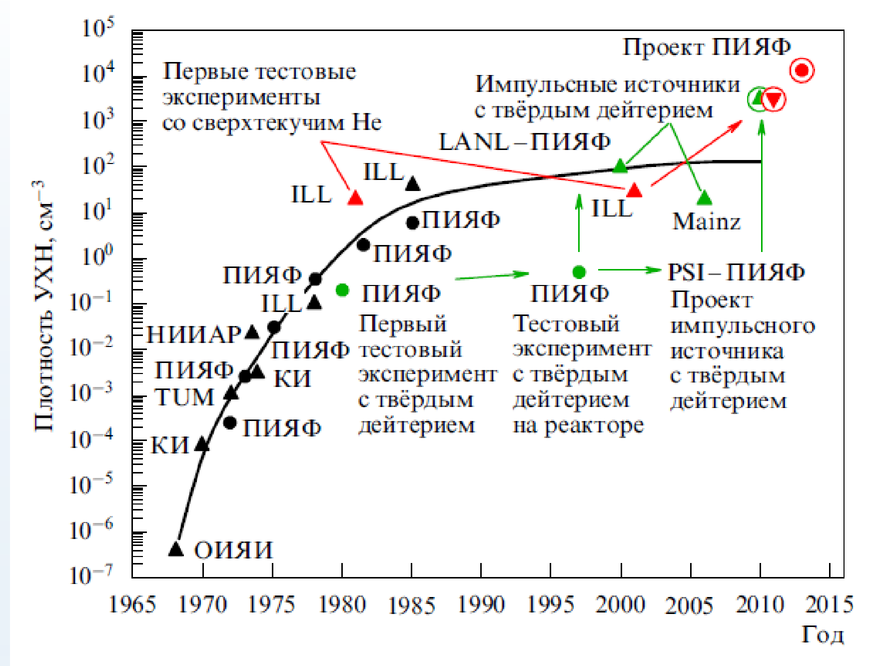
$$\boxed{\Delta\Phi \propto \lambda^3}$$



The problem of the UCN sources



A.I. Frank, Phys. Uspechy, 1987



A.P. Serebrov. Phys. Uspechy, 2015

Discussion III

1. Theoretical base for the neutron microscope was created in the end of the last century
2. A number of schemes of the NM were proposed and analyzed
3. The activity was stopped due to weak progress of the UCN sources

Не пора ли вернуться к этой проблеме?
Is it the time to turn back to this problem ?

Neutron waves in an accelerating matter

Transmission of wave through a refractive sample (sample in rest)

$$\psi = \exp\left[i\left(nk_0x - \omega_0 t\right)\right]$$

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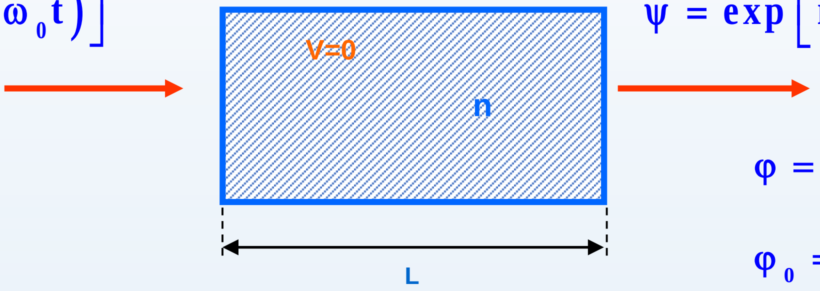


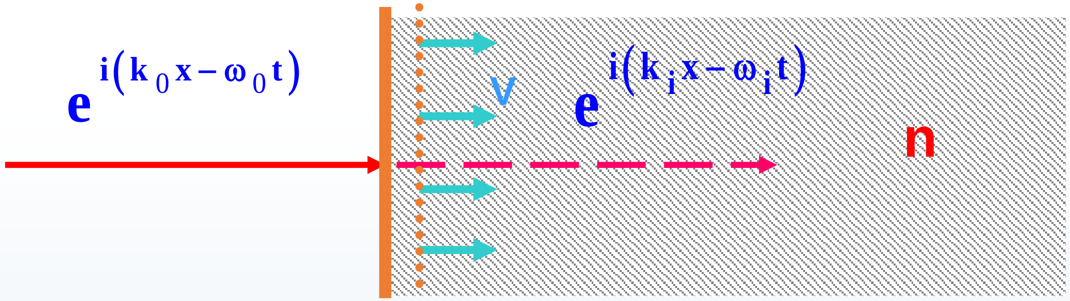
$$\psi = \exp\left[i\left(k_0x - \omega_0 t\right) + i\varphi\right]$$

$$\varphi = nk_0L$$

$$\varphi_0 = k_0L$$

After transmission through a stationary sample wave number is exactly equal to the initial one

Refraction of wave at the border of the moving matter



$$k_i = n k_0\left(1+\frac{1-n}{n}\frac{V}{v_0}\right)$$

$$\boxed{\omega_i = \omega_0 + (n-1)k_0 V}$$

Doppler shift

__Massive particle (neutron)__

$$k_0 = \frac{m v_0}{\hbar} \qquad (c \to v_0) \qquad \left(\frac{V}{v_0} << 1\right)$$

$$n \equiv n(k'_0) = n(k_0 - k_v)$$

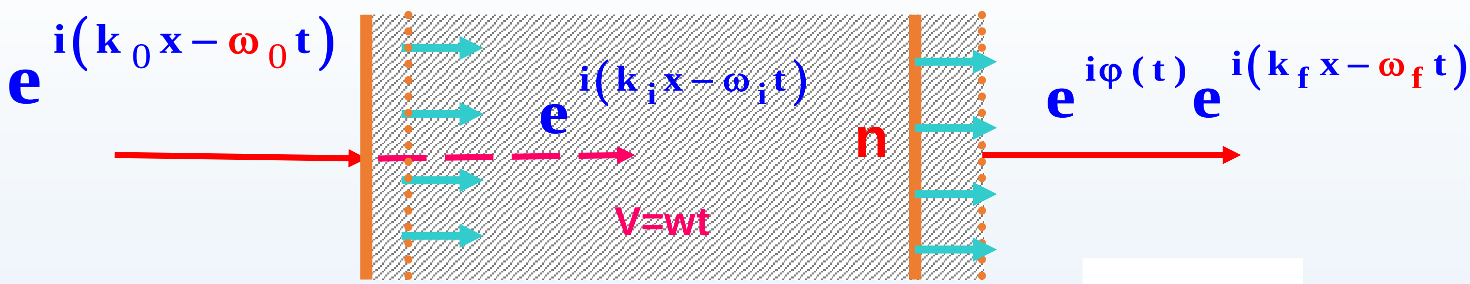
__Light__

$$k_0 = \frac{\omega_0}{c} \qquad \left(\frac{V}{c} << 1\right)$$

$$v_{ph} = \frac{c}{n} + v\left(1-\frac{1}{n^2}\right)$$

Fresnel drag

Transmission of wave through the sample moving with acceleration



$\omega_f \neq \omega_0$

For the motion with acceleration, two frequencies shift do not cancel because the velocity of the medium is not constant.

Differential Doppler effect- Accelerating Medium Effect

Neutrons

$$\boxed{\Delta E \simeq mwd\frac{1-n}{n}}$$

F. V. Kowalski, 1993; V.G.Nosov, A.I.Frank, 1998

Assumptions:

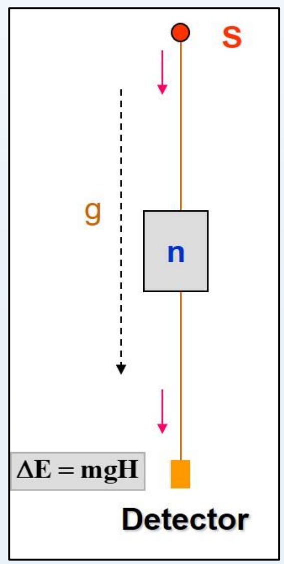
1) Model of effective optical is also valid in the case of accelerating matter
2) Quasi – classical approach is correct

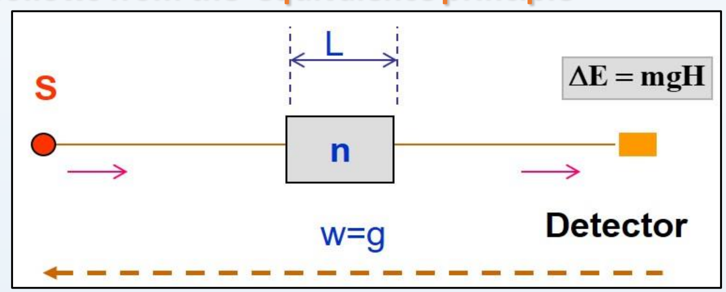
Light

$$\Delta\omega \cong \frac{\omega w d}{c^2}(n-1)$$

K. Tanaka, Phys. Rev. A 25, 385 (1982).

The same results follows from the equivalence principle





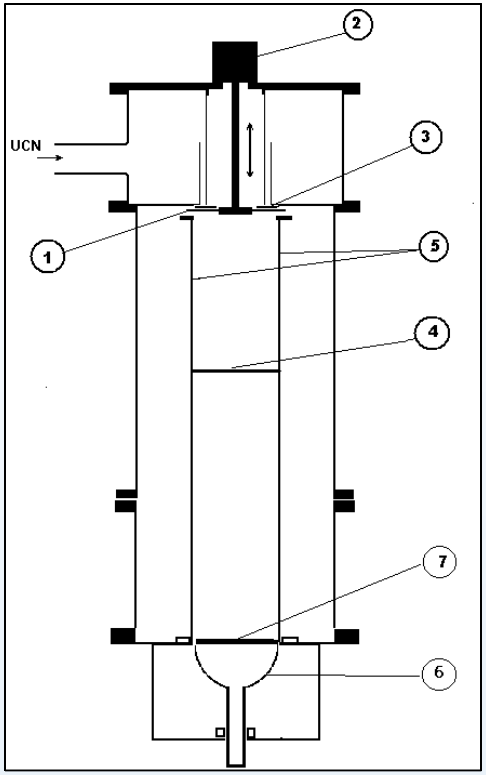
1. In both cases the energy, measured by the detector, must be the same due to the equivalence principle
2. Introduction of the refracting slab does not change the energy due to the energy conservation law (see left fg.)
3. Delay time due to refraction is $\Delta\tau$

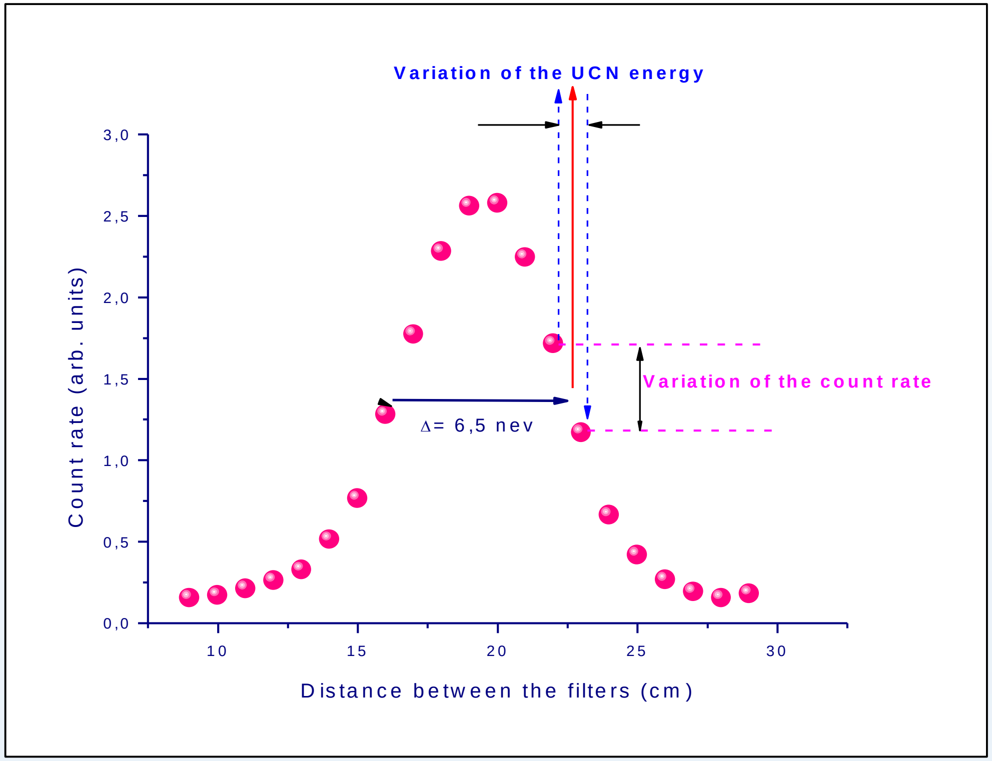
During this delay time the detector will continue to accelerate

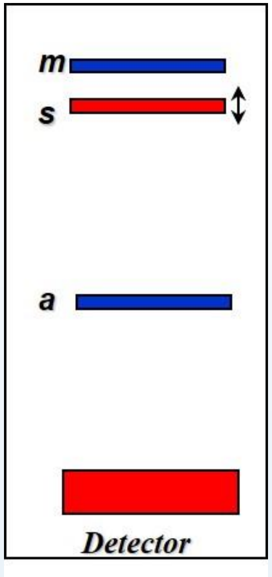
$\Delta v = w\Delta\tau$

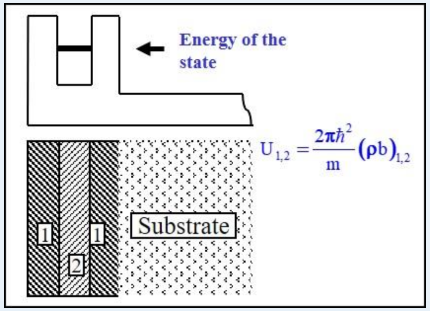
A.I. Frank, et al.,(2008)

Idea of the experiment





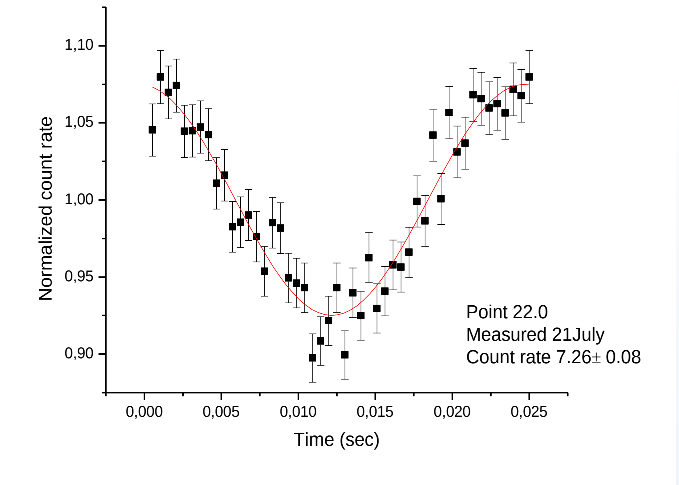


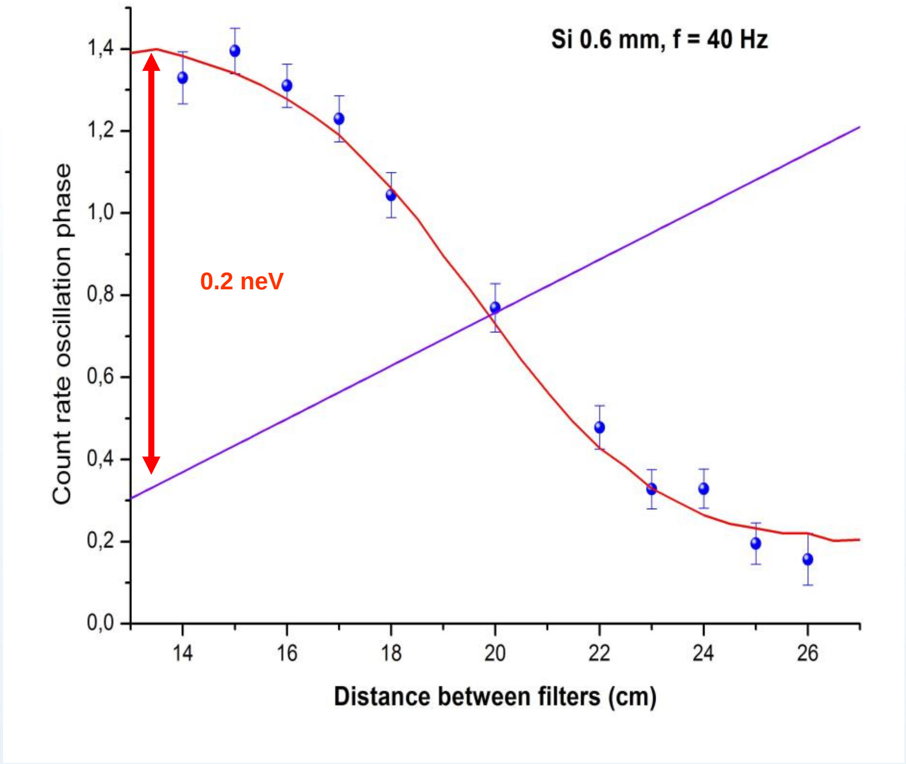


$\Delta E \approx (2\text{-}5)\times 10^{-10}$ eV

Periodically variation of the neutron energy, caused by the sample acceleration, leads to the periodical oscillation of the count rate

Oscillation of the count rate and experimental result





$$a \cong -A\Omega^2 \sin \Omega t \qquad V \cong A\Omega \cos \Omega t$$

$$f(t) = 1 + B \sin(\Omega t - \varphi)$$

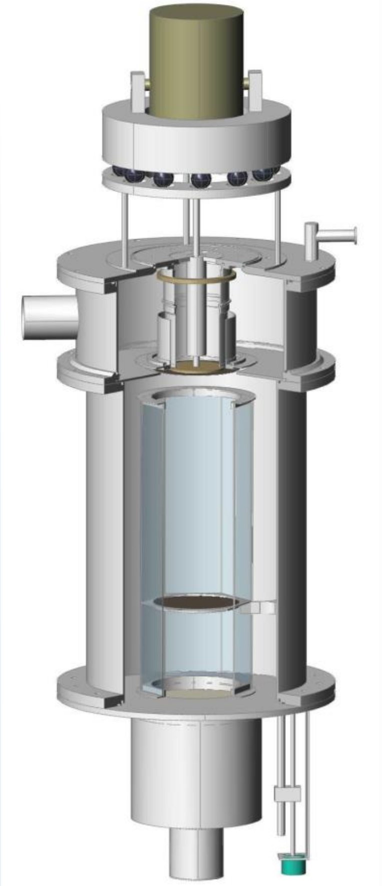
Frequency f = 40, 60 Hz
Oscillation period 0.025, 0.017 sec
Time of flight 0.11 sec

$$w_{max} = A\Omega^2 \approx 60 m/s^2$$

$$\Delta E \cong -K m A\Omega^2 L \left(\frac{1}{n} - 1 \right) \sin \Omega t$$

$$K = 0.94 \pm 0.06$$

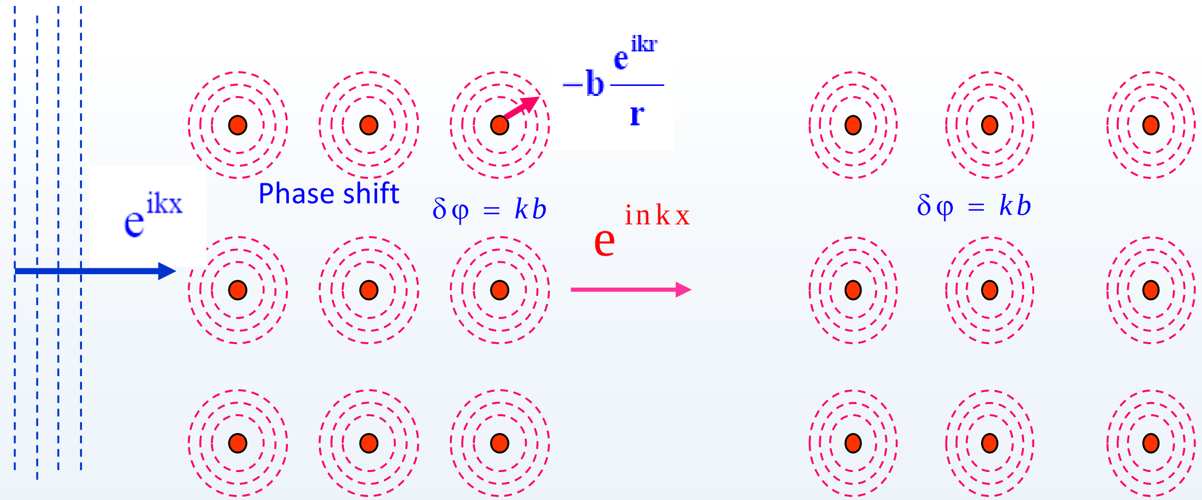
A.I. Frank, P.Geltenbort, G.V.Kulin, et al, Phys. At. Nuclei, 71 (2008) 1656.

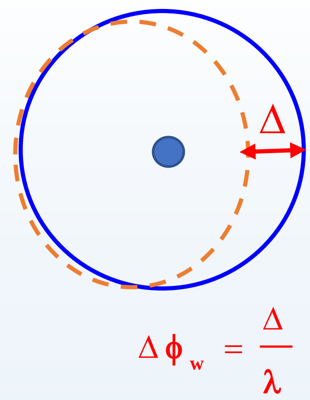


Dispersion law in the accelerating media: questions, hypothesis and possible experiments

Waves in accelerating matter

$$k^2 = k_0^2 - 4\pi\rho b \quad (??)$$





Matter in rest

Matter is moving with acceleration.
Non-inertial system

It is naturally to suppose that usual dispersion law is not valid in a non-inertial system

Where is the region of validity of the usual dispersion law?

To the estimation of the region of validity of the usual dispersion law

The hypothesis is that the usual dispersion law is valid when the phase distortion due to acceleration $\Delta\phi_w$ appeared at the interatomic distance d is much less than the phase shift kb due to scattering at the nuclei

$$\Delta\phi_w << \delta \cong kb$$

$$\Delta\phi_w = k\frac{mwx^2}{4E}$$

for x ≈ interatomic distance d

$$w << \frac{4Eb}{md^2}$$

$$\boxed{W_{crit} = E(ev)\cdot 8\times10^{14}\,cm/s^2}$$

For UCN E ≈ 100nev (UCN), b ≈ 5×10^-13^cm, d ≈ 5×10^-8^cm

$$W_{crit} = 8\times10^7\,cm/s^2 \approx 10^5\,g$$

A.I. Frank. (2014)

This hypothesis is not contradicts any experimental results

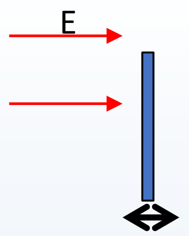
A theory of the neutron waves dispersion in accelerating media is absent

A possible strategy:

to perform experiment with accelerating matter and compare result with theoretical predictions based on the model of effective potential

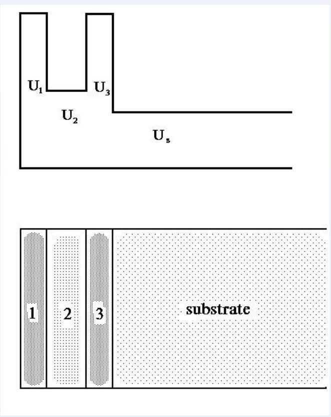
Possible experiments in geometry of transmission

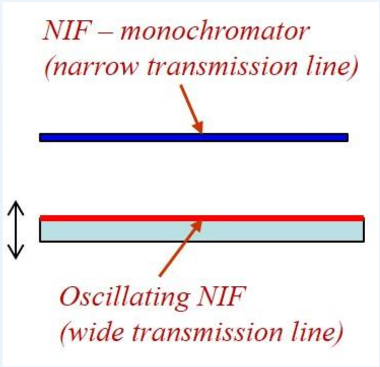
1. Transmission through barrier A. Pimpale, S. Holloway, R.J.Smith (1991)

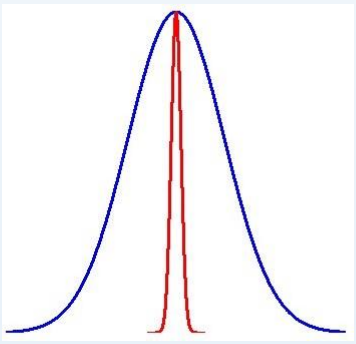


Observable effects are only when neutron energy is very close to the height of barrier (E~ U)

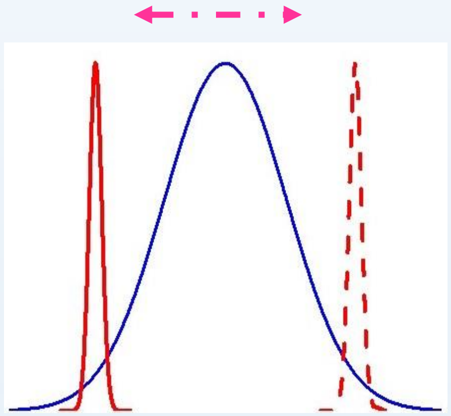
2. Transmission through oscillating NIF





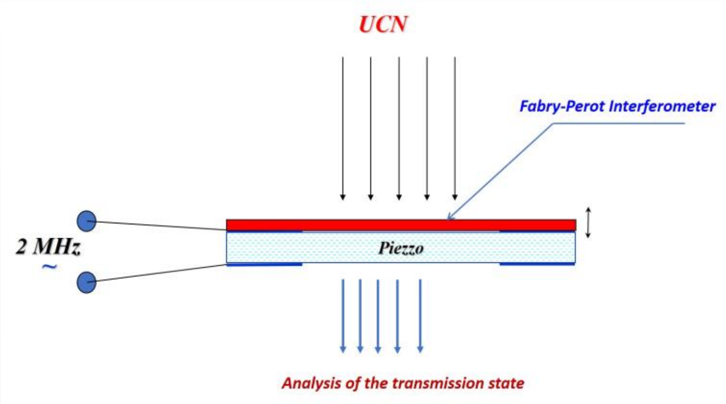


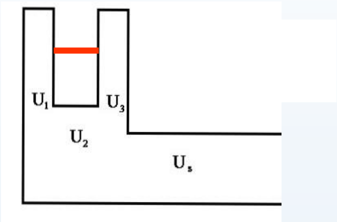
NIF in rest – transmission of the initial quasi-monochromatic beam

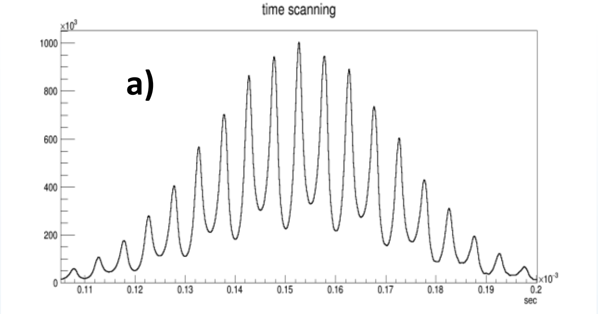


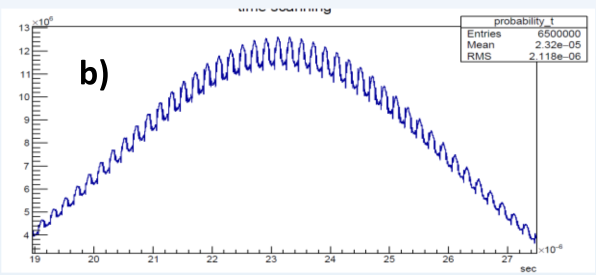
Oscillating NIF. In it reference the energy of the incoming beam is oscillating due to the Doppler effect. Transmitted beam is modulated in time

Proposed experiment. Oscillating Fabry-Perot (scheme of the experiment and quantum calculation)









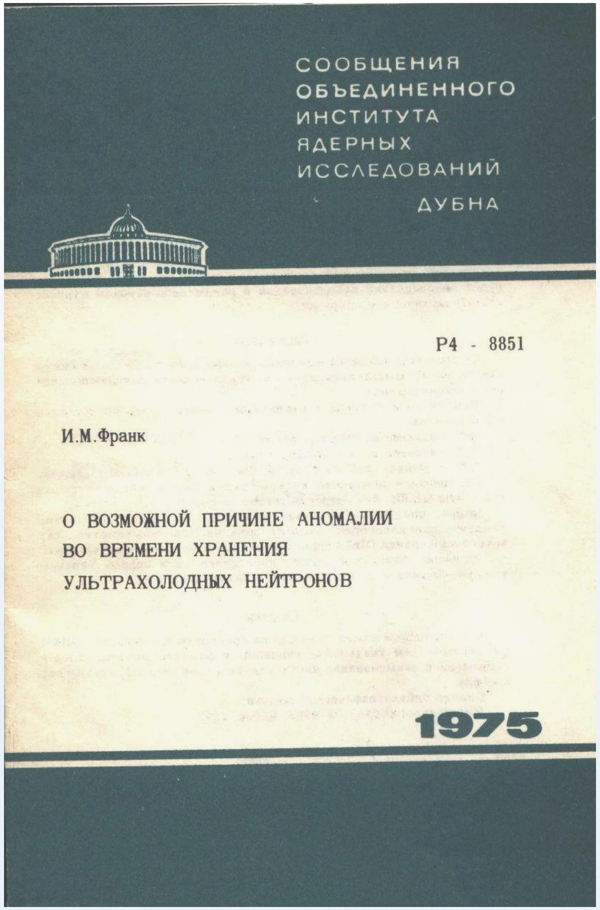
f =2.2 MHz
Amp = 5-6 nm

Acceleration $w \approx 10^5$ g≈ W_{crit}

Simulation of the wave packet transmission through the vibrating Fabry-Perot Interferometer f =100 kHz (a) and 5 MHz (b)

The project is in a progress

Neutron diffraction by surface wave



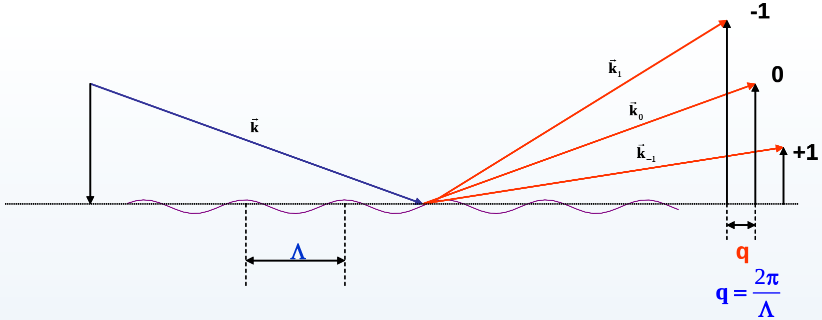
СООБЩЕНИЯ
ОБЪЕДИНЕННОГО
ИНСТИТУТА
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ
ДУБНА

Р4 - 8851

И.М.Франк

О ВОЗМОЖНОЙ ПРИЧИНЕ АНОМАЛИИ
ВО ВРЕМЕНИ ХРАНЕНИЯ
УЛЬТРАХОЛОДНЫХ НЕЙТРОНОВ

1975



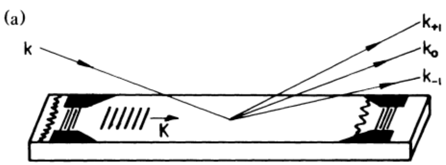
К 100-ЛЕТИЮ И.М.ФРАНКА

Об одной работе И.М.Франка

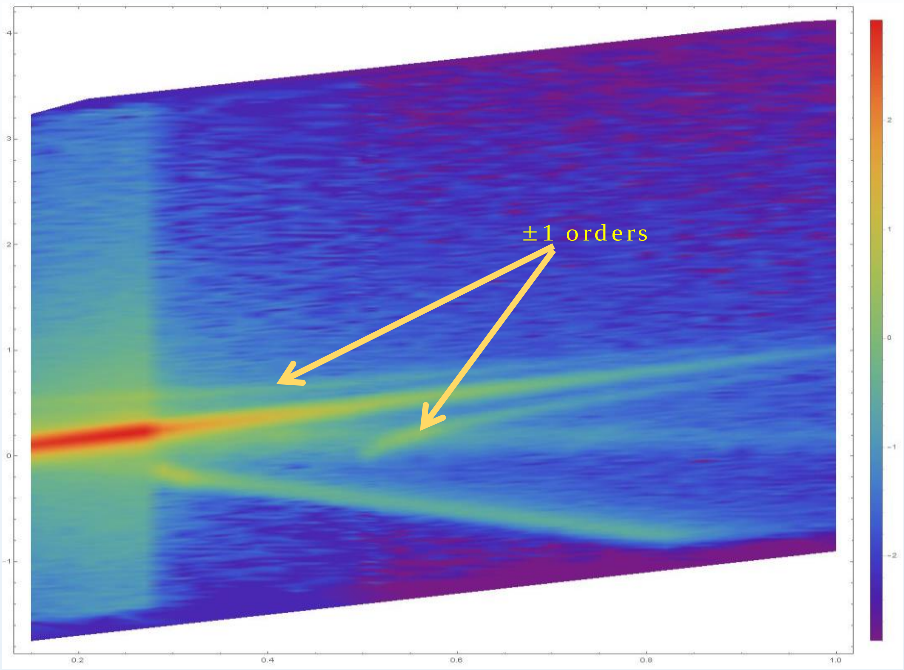
А.И.Франк,
доктор физико-математических наук
Объединенный институт ядерных исследований
Дубна

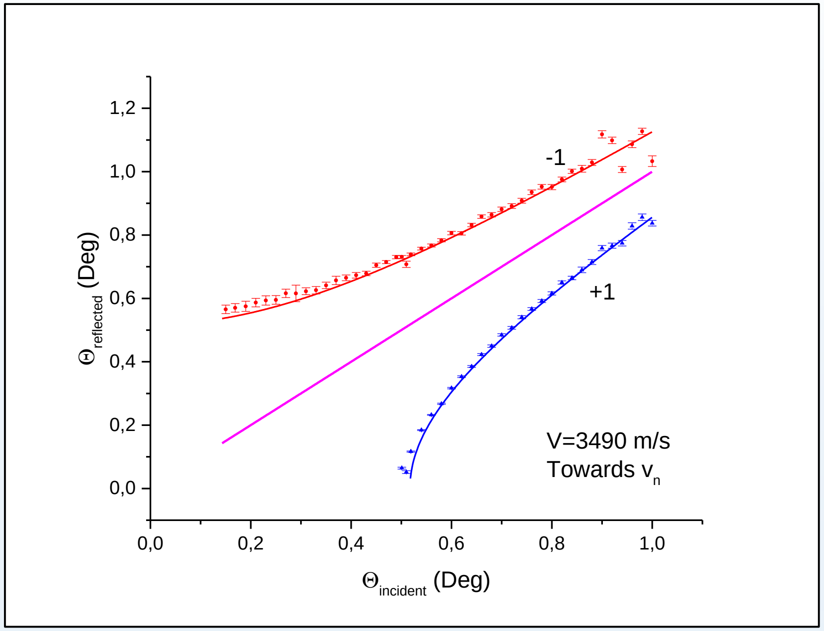
Так случилось, что круг моих научных интересов, с годами существенно менявшийся, со временем оказался тесно связанным с областью науки, развитие которой в значительной степени связано с именем И.М.Франка. Я имею в виду нейтронную оптику вообще и оптику очень медленных, так называемых ультрахолодных нейтронов, в частности. Какие-то из работ лаборатории уже в 1962 г. Вторым важнейшим обстоятельством было открытие так называемых ультрахолодных нейтронов (УХН), скорость которых столь мала, что они способны испытывать полное отражение от поверхности вещества при всех углах падения. Это замечательное свойство УХН было предсказано Я.Б.Зельдовичем в 1959 г. [1], а через 10 лет Ф.Л.Шапиро с сотатами. Здесь он увидел область, где сочетаются нейтронная ядерная физика, которой он отдал столько лет жизни, и так любимая им оптика. В апреле 1970 г. он сделал большой доклад, посвященный проблемам нейтронной оптики, на общем собрании Отделения ядерной физики Академии наук. Через два года на конференции в Будапеште он выступил с корот-

Neutron diffraction by surface acoustic waves



W.A.Hamilton et al, 1987



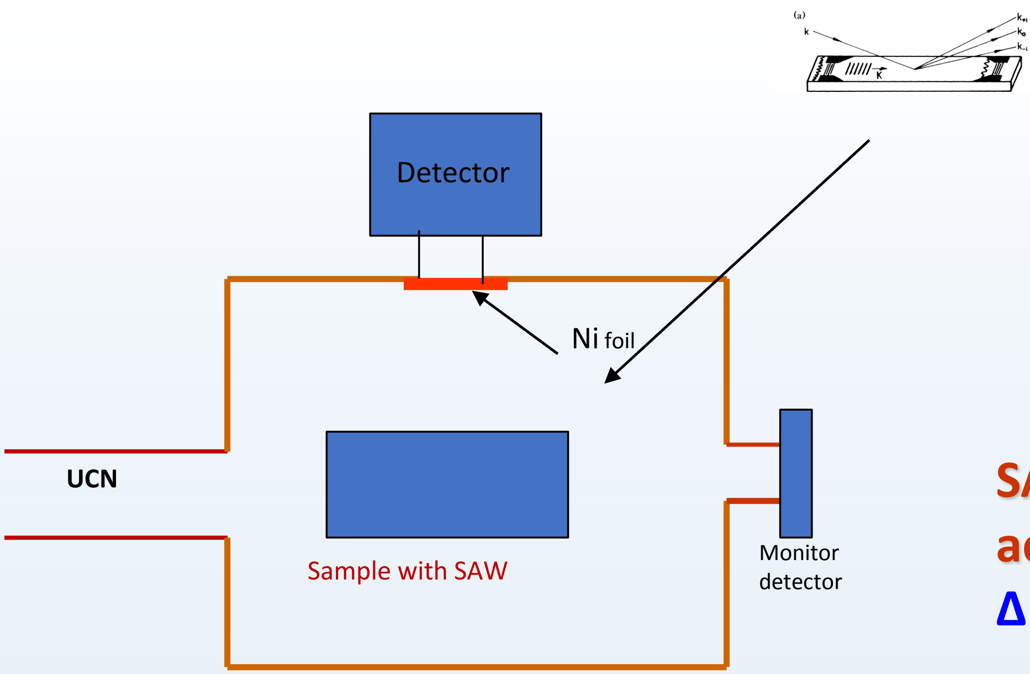


f = 60 MHz **Acceleration of surface ≈ $5x10^{10}$**

G. Kulin at al. ISINN 25 & ICNS2017

Cold neutrons: W_{crit} ≈ $3{\cdot}10^{12}$

UCN – SAW experiment



Cold Neutrons $W_{crit} \approx 3 \times 10^{12}$

UCN: $W_{crit} \approx 10^{8}$

SAW 30 MHz at $LiNiO_3$ surface

acceleration of surface $\approx 2\times 10^{10}$

$\Delta E \sim 100$ neV

The experiment is in progress just now.

The beam time at PF2 @ILL allocated for 5-27 October 2018

Conclusion

Нейтронная оптика и ультрахолодные нейтроны

Обзоры, доклады, научно-популярные статьи

Conclusion 2

Нам есть что делать в области фундаментальной нейтронной оптики

There is something to do in neutron optics

Acknowledgements

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Yu. Khaydukov

D. Roshchupkin, D. Irzhak

Thank you for your attention!