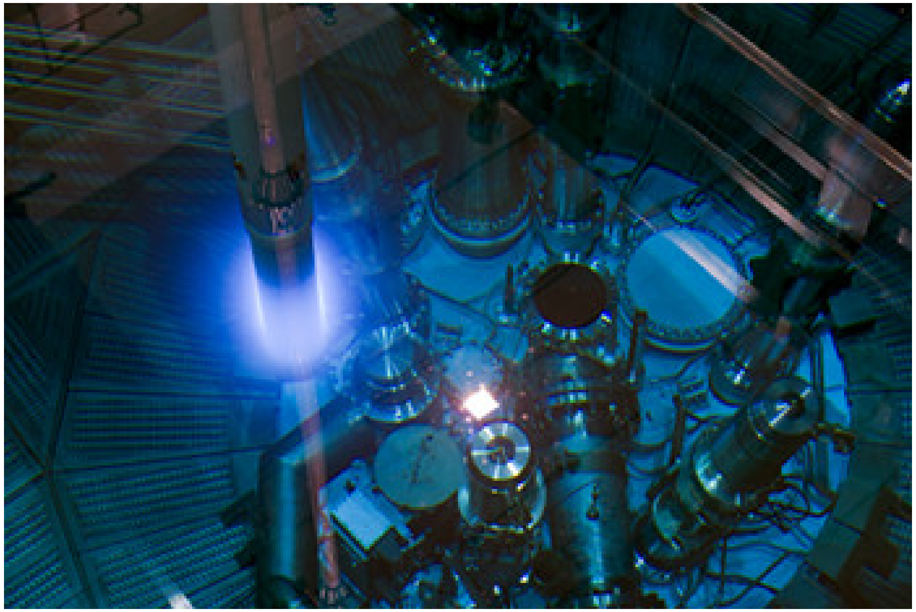
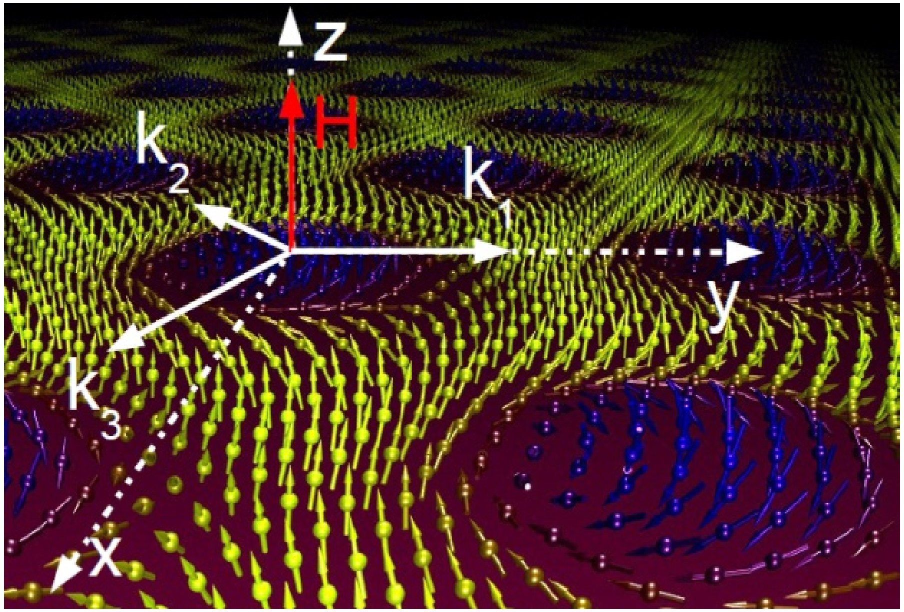
FRM II
Forschungs-Neutronenquelle
Heinz Maier-Leibnitz

MLZ
Heinz Maier-Leibnitz Zentrum

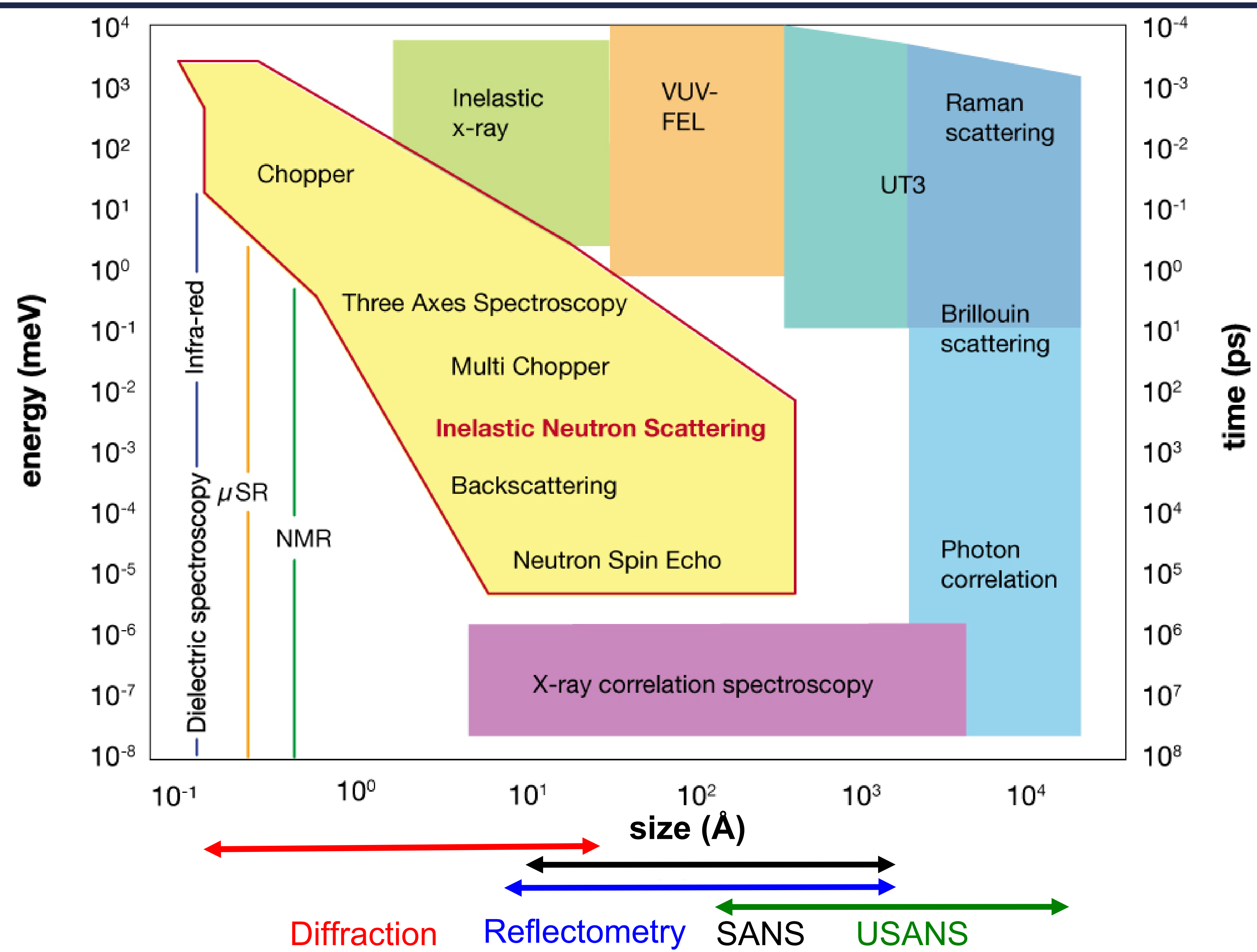
Physics with Neutrons I, WS 2015/2016





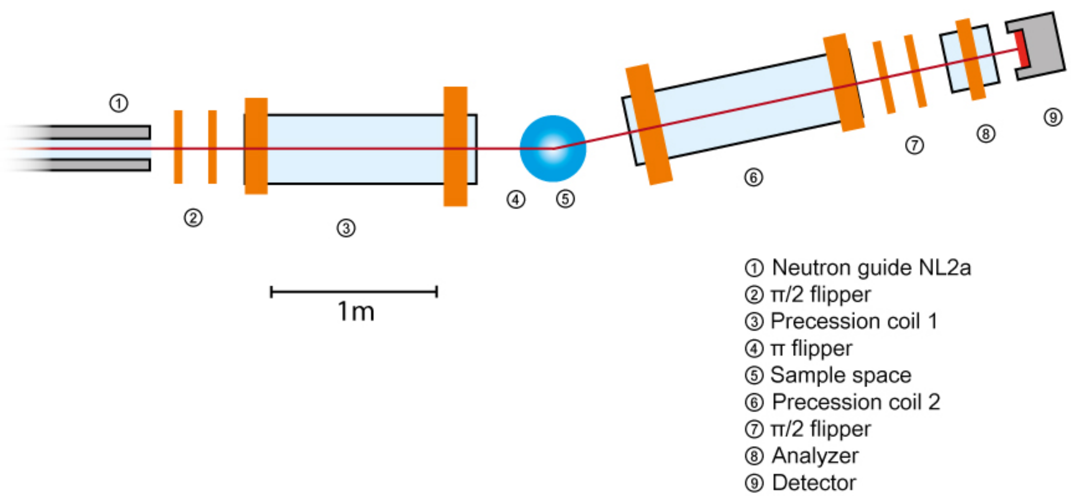
Lecture 4, 9.11.2015

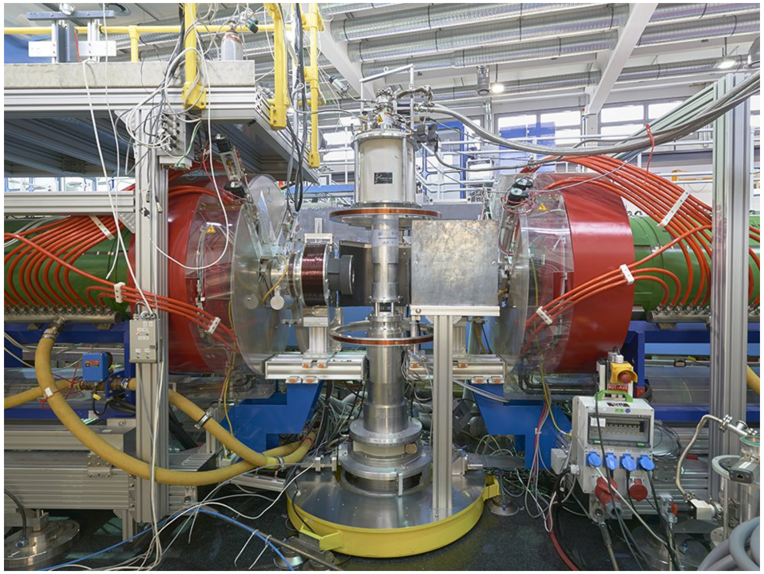
2.6. Overview on neutron instrumentation (Spectroscopy, inelastic)

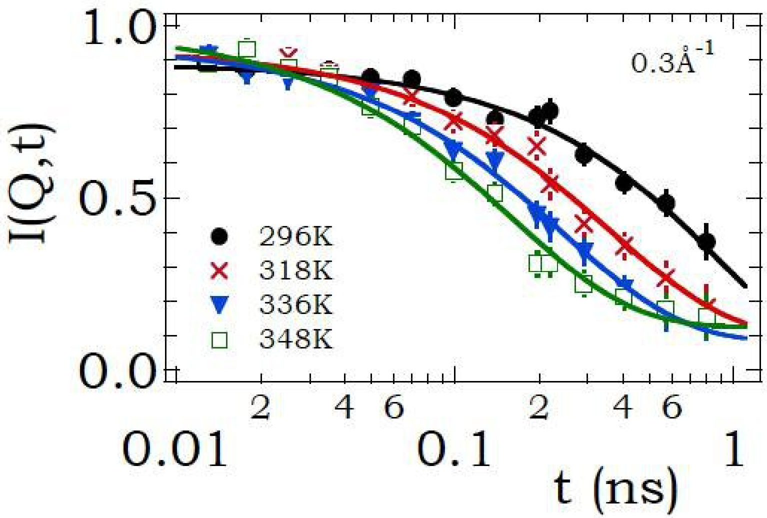


2.6. Overview on neutron instrumentation (inelastic scattering)

Spin echo (JNSE @ MLZ)



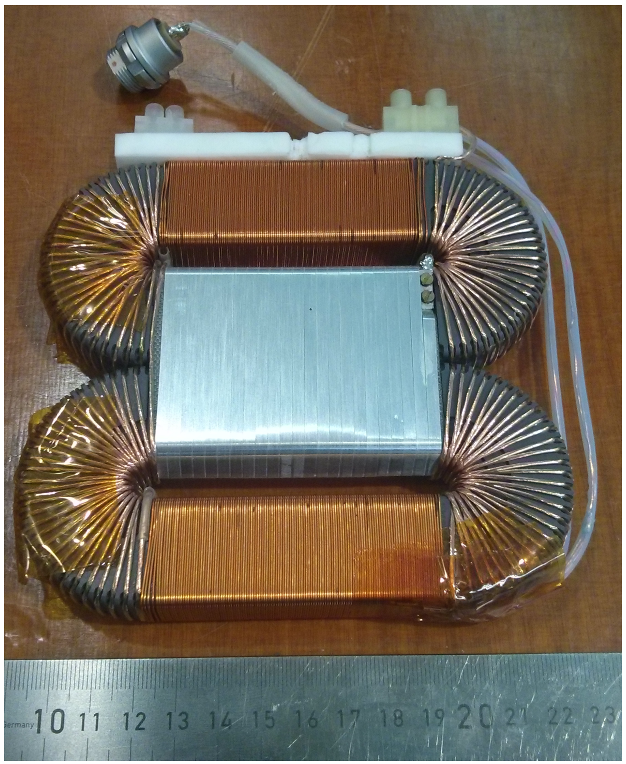


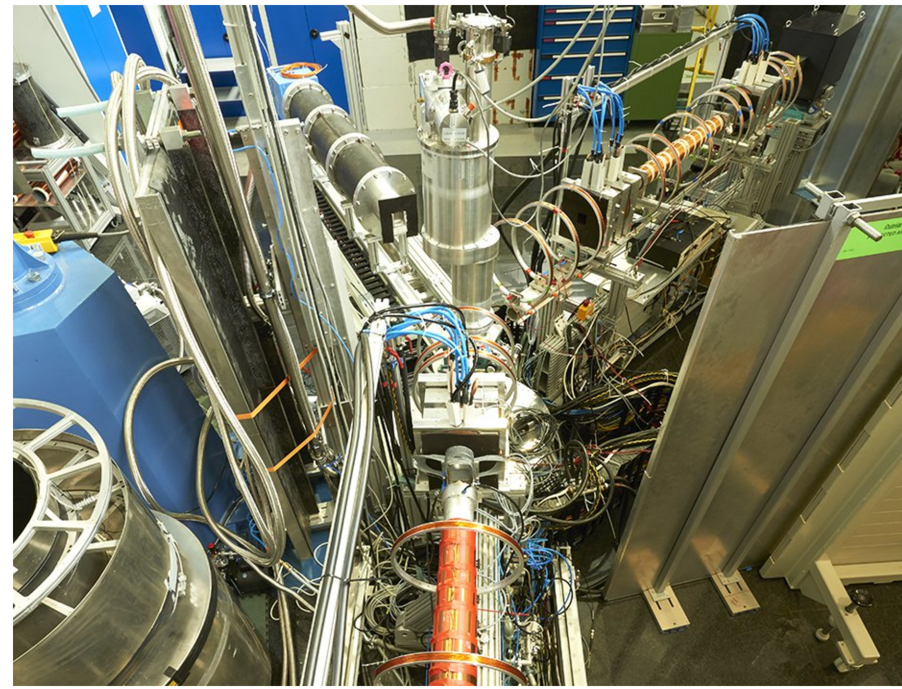


Neutron Spin Echo
Decoupling of wavelength spread and energy resolution
Use the Larmor precession of neutrons in magnetic field as a sort of „clock“ to encode the energy
Slow dynamics of soft matter /biological samples
Cosinus Fourier transform S($\boldsymbol{Q},\boldsymbol{\tau}$) of S($\boldsymbol{Q},\boldsymbol{\omega}$)
2ps<$\boldsymbol{\tau}$< 350ns
Momentum transfer $\boldsymbol{Q}$<1.5Å^{-1}

2.6. Overview on neutron instrumentation (inelastic scattering)

Resonance spin echo (RESEDA @ MLZ)





Neutron Spin Echo:
Static precession field.

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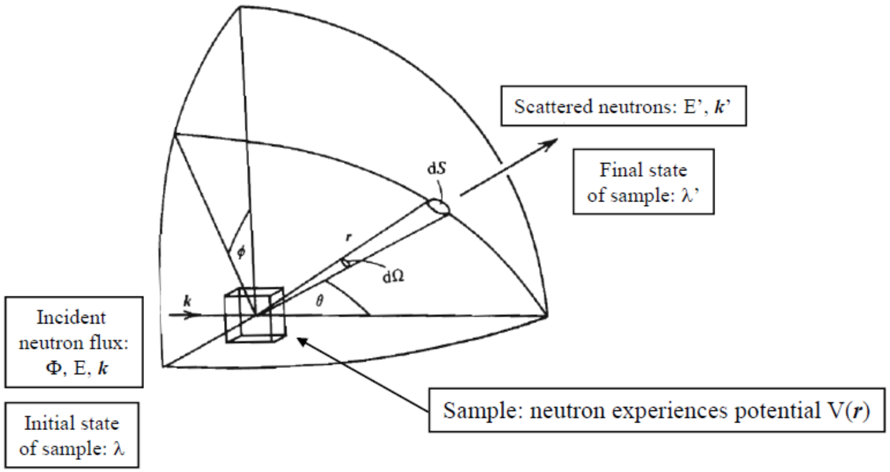
Neutron Resonance Spin Echo:
Two sychronized rotating HF fields separated by a zero field region!

Zero field is cheaper as compared to super-precise static fields

3.1 Definition of a scattering cross-section



Partial (double) differential cross-section

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}\Omega\mathrm{d}E'} = \frac{number\ of\ neutrons\ scattered\ into\ \mathrm{d}\Omega\ with\ final\ energy\ between\ E'\ and\ E'+\mathrm{d}E'}{incoming\ flux\ \Phi\ \mathrm{d}\Omega\mathrm{d}E'}$$

Differential cross-section

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \int_0^\infty \left(\frac{\mathrm{d}^2\sigma}{\mathrm{d}\Omega\mathrm{d}E'}\right)\mathrm{d}E'$$

Total scattering cross-section

$$\sigma_{tot} = \int_{all\ directions} \left(\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}\right)\mathrm{d}\Omega$$

3.1 Definition of a scattering cross-section

Scattering length:

Imaginary: Nuclear resonance, strong absorption, energy dependent

Real: energy independent

$$\sigma_{tot} = 4\pi b^2$$

Table 1.3 Values of scattering lengths

Nuclide	Combined spin	b/fm	Nuclide	Combined spin	b/fm
^{1}H	1	10.85	^{23}Na	2	6.3
	0	−47.50		1	−0.9
^{2}H	$\frac{3}{2}$	9.53	^{59}Co	4	−2.78
	$\frac{1}{2}$	0.98		3	9.91

The values for H, Na, and Co are from Koester (1977), Abragam *et al.* (1975), and Koester *et al.* (1974) respectively. The spin values refer to the nucleus–neutron system.

3.2 Fermis Golden Rule

Fermis Golden Rule for scattering process: Born approximation

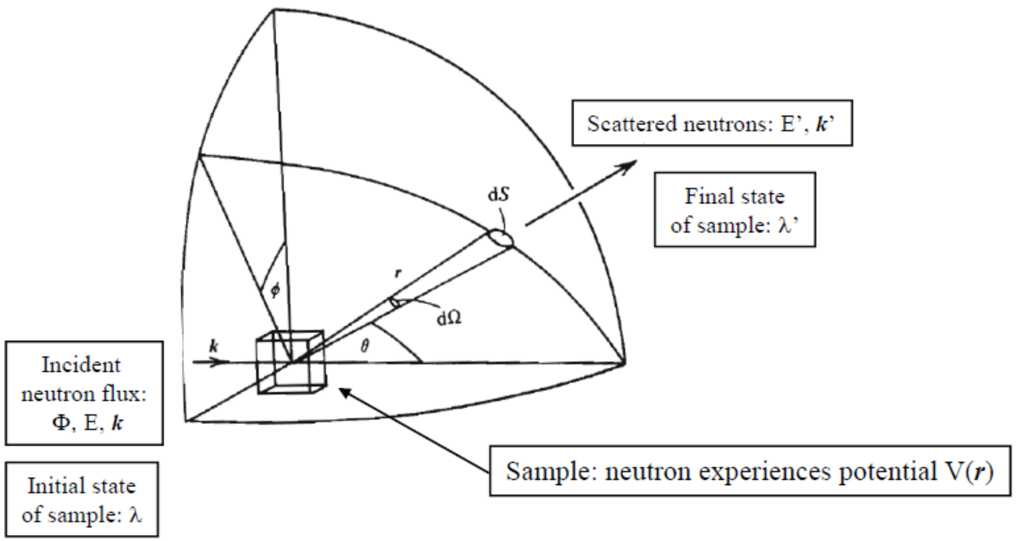
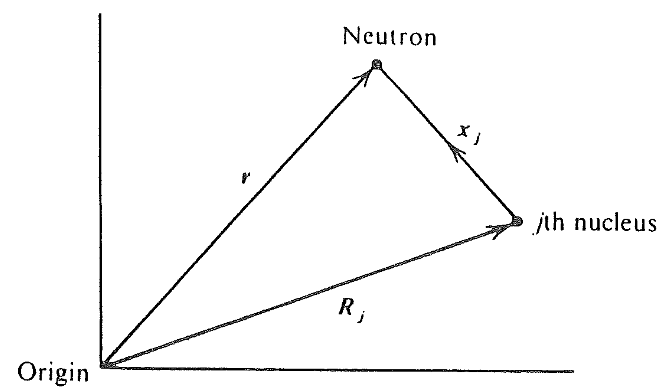


Fig. 2.1 Coordinates of nucleus and neutron.



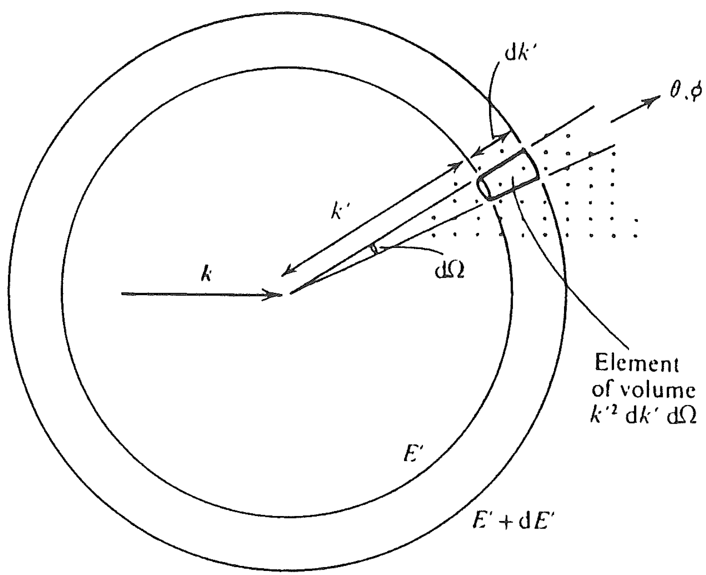
$$\left(\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}\right)_{\lambda\to\lambda'} = \frac{1}{\Phi}\frac{1}{\Omega}\sum_{k'\ in\ \mathrm{d}\Omega} W_{k,\lambda\to k',\lambda'}$$

$$\sum_{k'\ in\ \mathrm{d}\Omega} W_{k,\lambda\to k',\lambda'} = \frac{2\pi}{\hbar}\varrho_k \left|\langle k'\lambda' \left|V\right| k\lambda\rangle\right|^2$$

Challenge: Rewrite this mixed expression in terms of sample properties

3.2 Fermis Golden Rule

1st step: Box Normalization to calculate ρ_k



$$\left(\frac{d\sigma}{d\Omega}\right)_{\lambda\to\lambda'} = \underline{\frac{k'}{k}\left(\frac{m}{2\pi\hbar^2}\right)^2} \left|\langle k'\lambda'|V|k\lambda\rangle\right|^2$$

3.2 Fermis Golden Rule

2nd step: Energy conservation

$$\left(\frac{d^2\sigma}{d\Omega dE'}\right)_{\lambda\to\lambda'} = \frac{k'}{k}\left(\frac{m}{2\pi\hbar^2}\right)^2 \left|\langle k'\lambda'|V|k\lambda\rangle\right|^2 \underline{\delta(E_\lambda - E_{\lambda'} + E - E')}$$

$$\int \delta(E_\lambda - E_{\lambda'} + E - E') = 1$$

3rd step: Integration with respect to neutron coordinate r

$$\langle k'\lambda'|V|k\lambda\rangle = \sum_j V_j(\kappa)\langle\lambda'|e^{i\kappa R_j}|\lambda\rangle \quad , \quad \underline{V_j(\kappa) = \int V_j(x_j)\, e^{(i\kappa x_j)}\, dx_j} \, , \quad \kappa = k - k'$$

Interaction is Fourier transform of the potential function

3.2 Fermis Golden Rule

4th step: Ansatz: Delta function potential for single nucleus

$$V(r) = \alpha \delta(r)$$

Fermi pseudopotential:

$$V(r) = \frac{2\pi\hbar^2}{m} b \, \delta(r)$$