European Spallation Source

Niels Bech Christensen, Fysiklærerdag 2/10 2014

Outline

- Neutronens egenskaber
- Neutronproduktion, neutronoptik og lidt om hvordan ESS ændrer spillets regler
- Vekselvirkninger (neutroner vs røntgen)
- Eksempler på videnskab:
  - Imaging-teknikker
  - Krystalstruktur og spredningskontrast (H/D)
  - Magnetisk struktur
  - (Dynamik)

Neutronens egenskaber

Masse : $1.675\ 10^{-27}$ kg

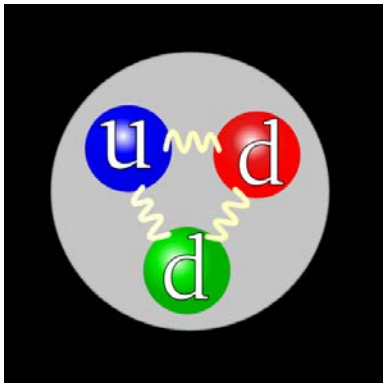
Ladning : 0 (no Coulomb)

$^{1}_{0}n \rightarrow {}^{1}_{0}p + e^{-} + \overline{\mu_e}$

Levetid: 886(1) sekunder

Spin : ½ (magnetisk)

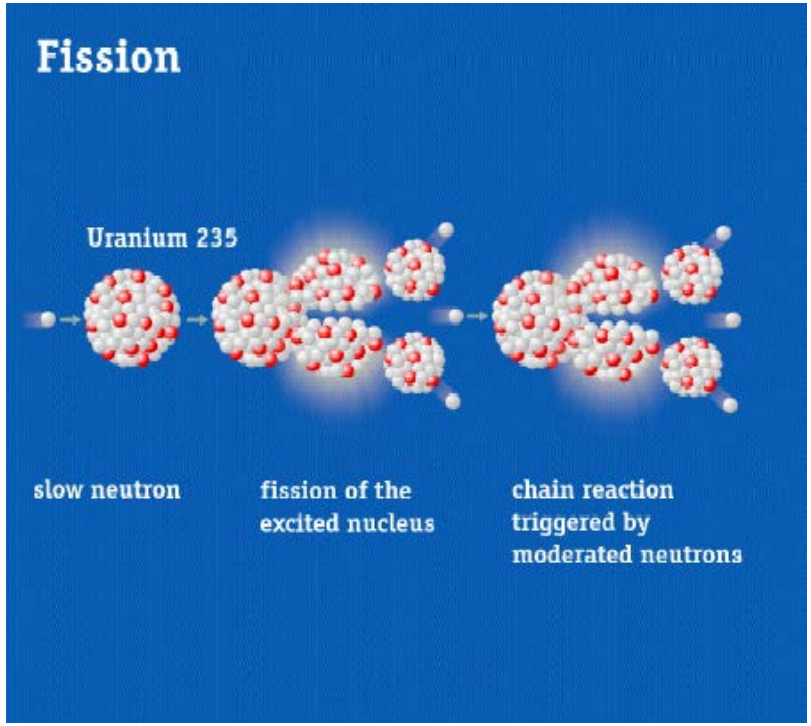
Nobelpris 1935
James Chadwick

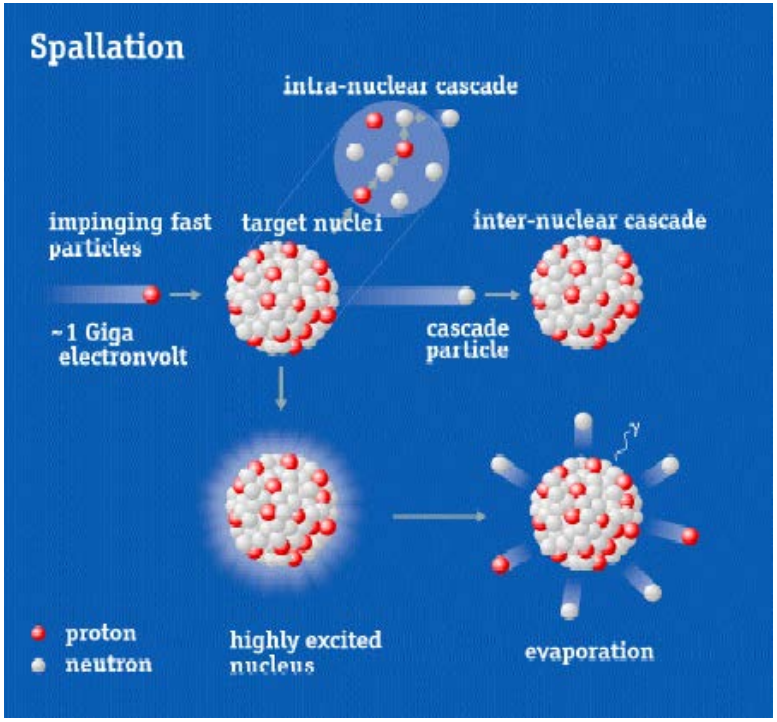


Outline

- Neutronens egenskaber
- Neutronproduktion, neutronoptik og lidt om hvordan ESS ændrer spillets regler
- Vekselvirkninger (neutroner vs røntgen)
- Eksempler på videnskab:
  - Imaging-teknikker
  - Krystalstruktur og spredningskontrast (H/D)
  - Magnetisk struktur
  - (Dynamik)

Produktion af neutroner





Den traditionelle metode:
- Atomreaktor
- Fission
- Kontinuert neutronstråle

Den moderne metode:
- Proton-accelerator
- Spallation
- Pulset neutronstråle

Neutronerne skabes med energier af størrelsesorden Mega-elektronvolt, MeV

Moderation

De neutroner, der anvendes i materialeforsknings-eksperimenter har energier af størrelsesorden milli-elektronvolt, meV

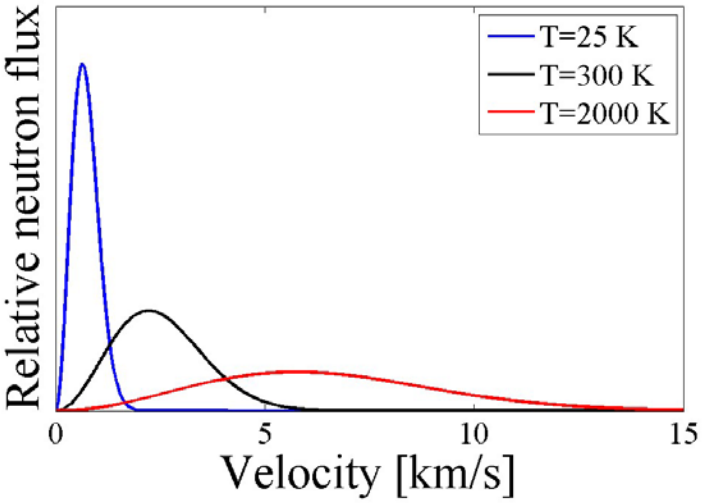
Problem:
Kræver 9 størrelsesordeners energi-reduktion, fra MeV til meV
Løsning:

- Uelastiske kollision med lette atomer
- Moderator-temperatur bestemmer neutron-energifordeling (Maxwell)

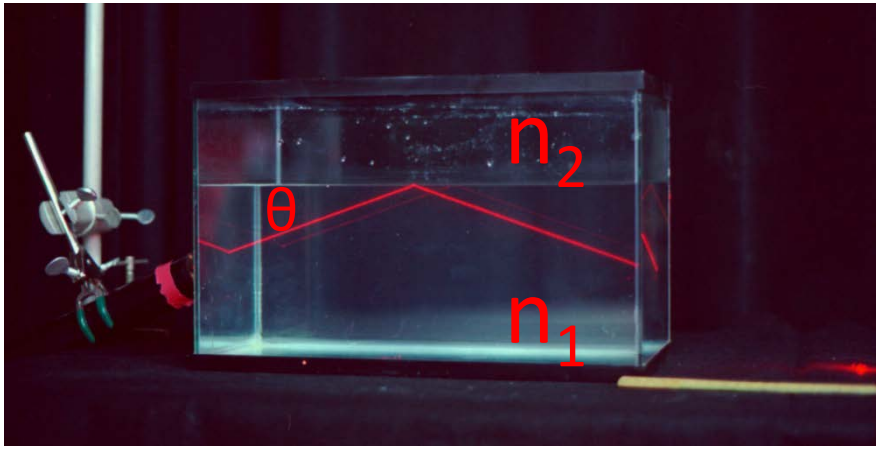
Vigtigt da forskellige eksperimenter, kræver forskellige fordelinger

Moderator materialer:

Flydende H_2/D_2	:T~20 K
Metan	:T~100 K
H_2O/D_2O	:T~300 K
Grafit	:T~2000K



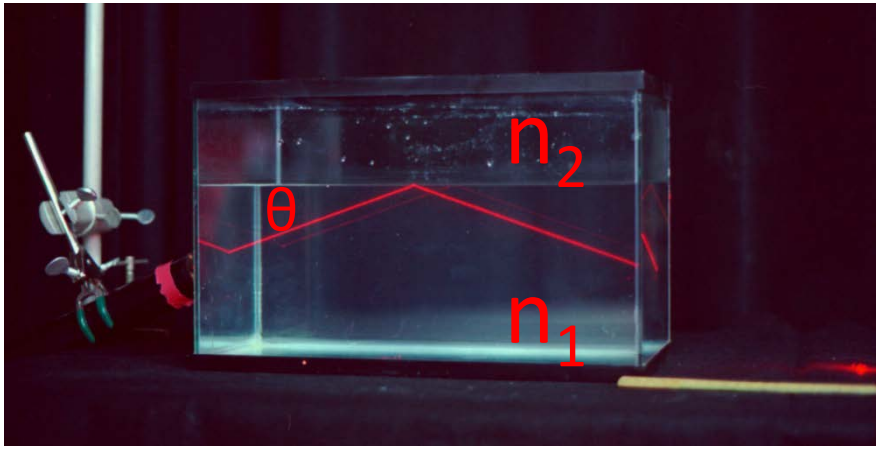
Neutron guides



Fra klassisk optik:

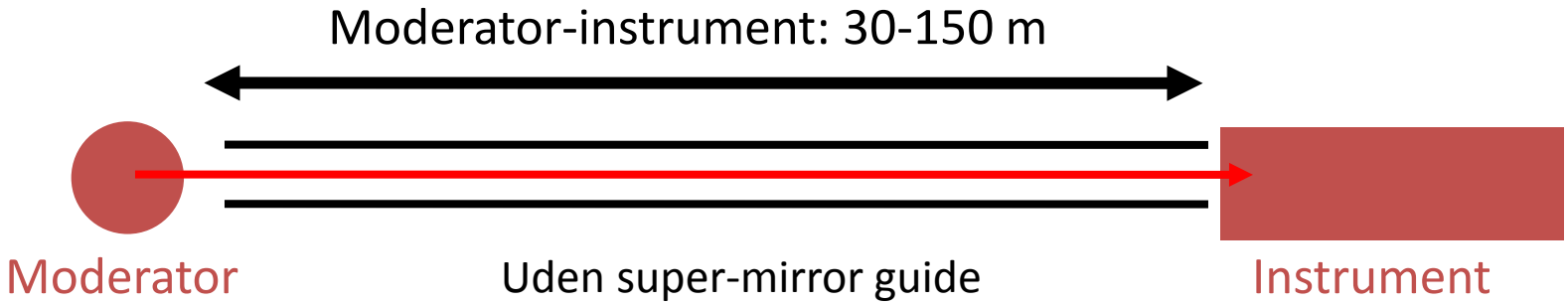
- Total-reflektion hvis de refractive index opfylder $n_1 > n_2$
- Neutroner: Total reflektion fra vacuum (n_1=1) til visse materialer (n_2<1)
- Materiale-afhængig kritisk vinkel θ_c

Neutron guides

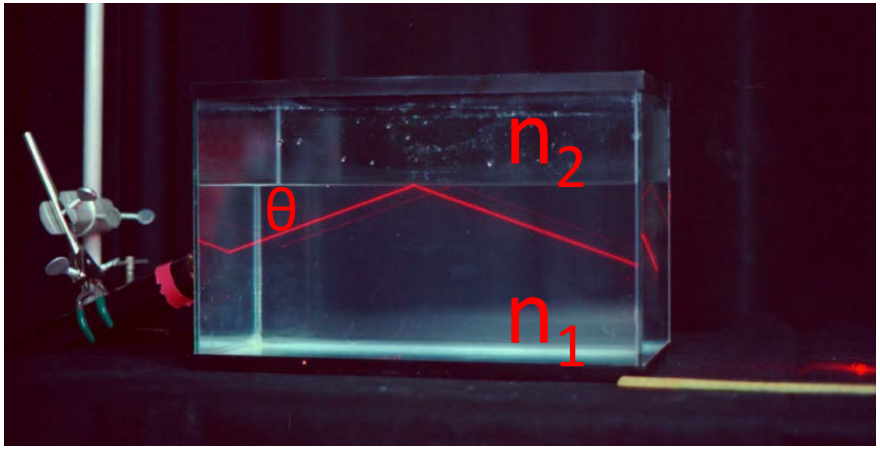


Fra klassisk optik:

- Total-reflektion hvis de refractive index opfylder $n_1 > n_2$
- Neutroner: Total reflektion fra vacuum (n_1=1) til visse materialer (n_2<1)
- Materiale-afhængig kritisk vinkel θ_c

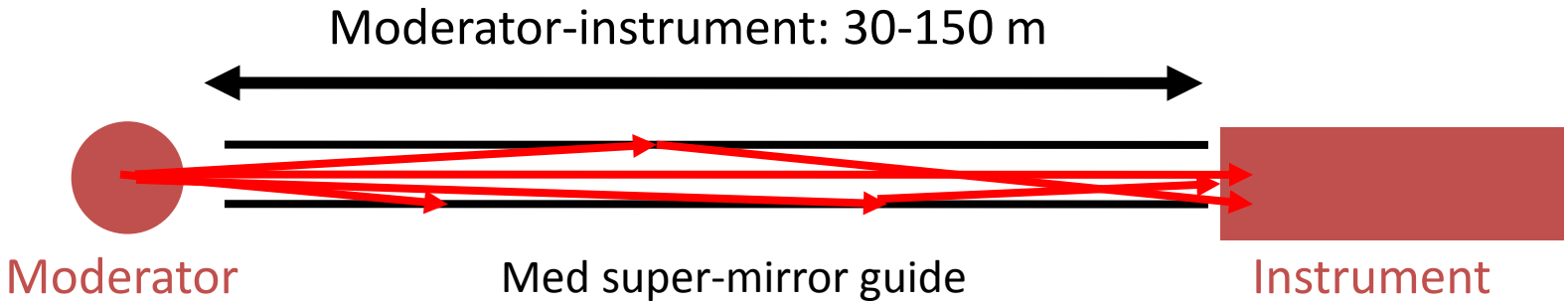


Neutron guides

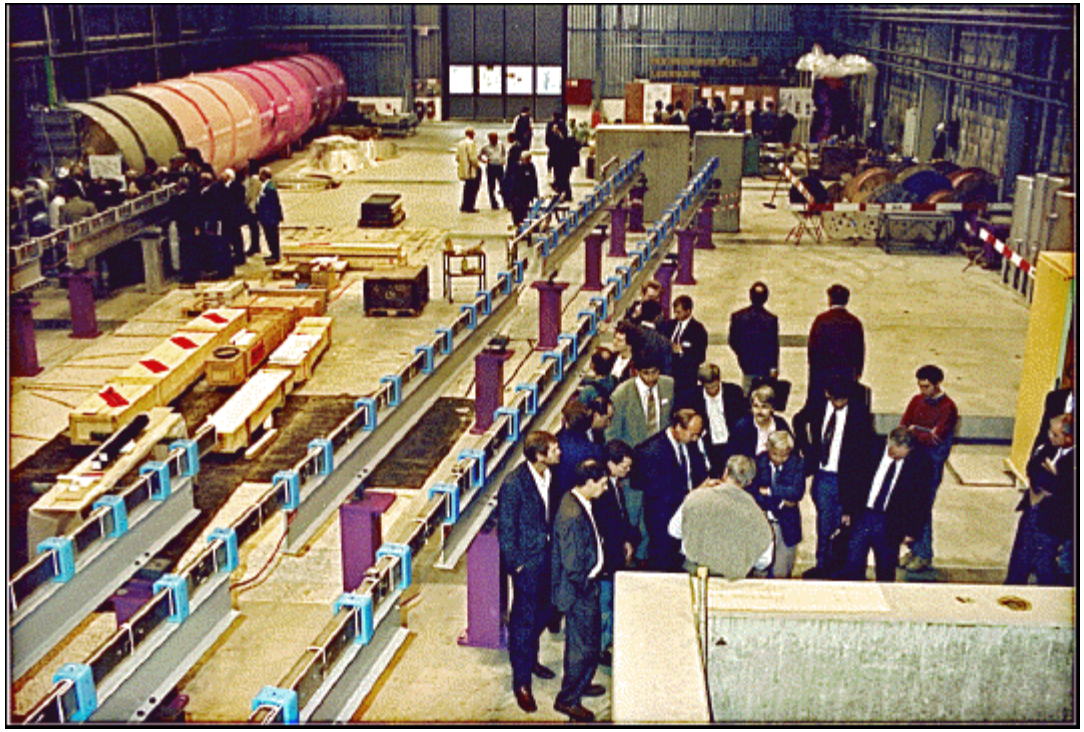


Fra klassisk optik:

- Total-reflektion hvis de refractive index opfylder $n_1 > n_2$
- Neutroner: Total reflektion fra vacuum (n_1=1) til viss materialer (n_2<1)
- Materiale-afhængig kritisk vinkel θ_c

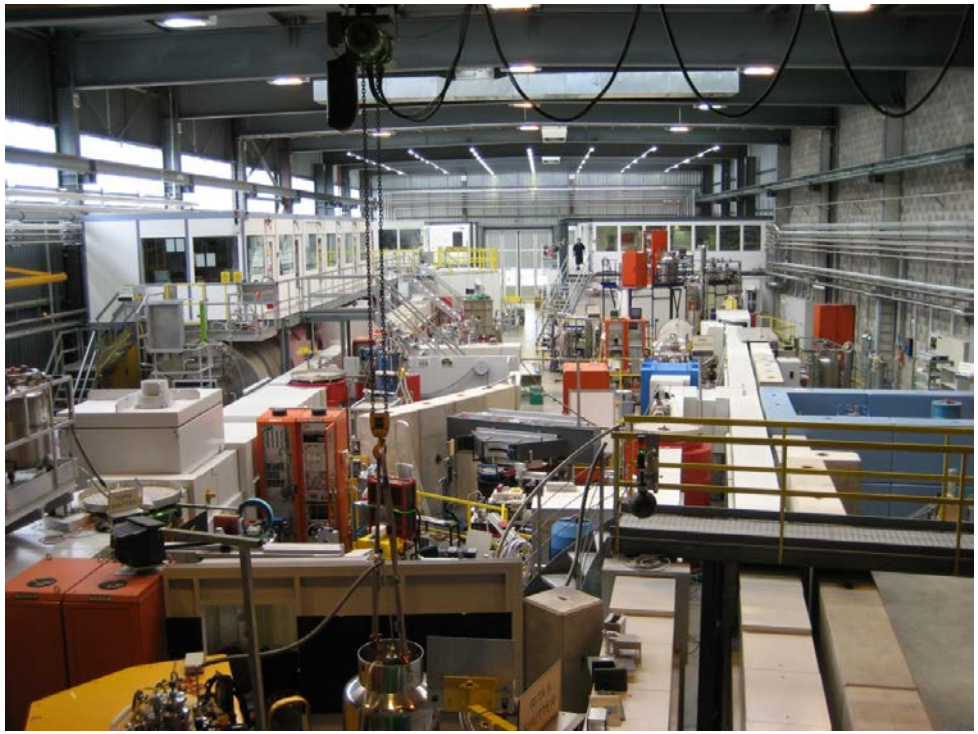


Neutron guides



Supermirror guides uden afskærmning
Paul Scherrer Institutet (CH) ca. 1994

Neutron guides

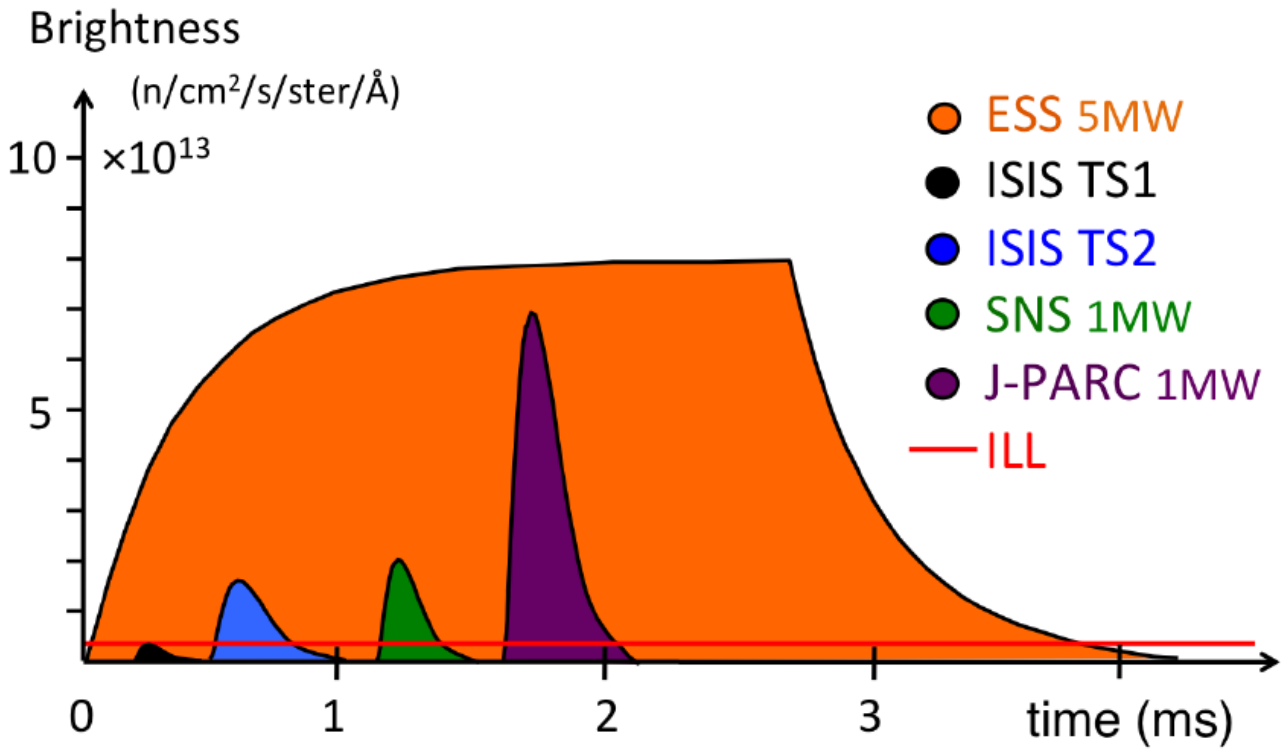


Med afskærmning og instrumenter
Paul Scherrer Institutet (CH) i dag

European Spallation Source

- Sverige er vært; Danmark er medvært
- Anlægsomkostninger: 13.8 GDKK (3.5*MAX-IV)
- Dansk bidrag: 12.5% ~1.7 GDKK
- Driftsomkostninger: ~1.0 GDKK/år
- Data Management of Software Center i København
- 17 europæiske medlemslande
- 5 MW kilde
- 14 Hz
- 2.86 ms pulser (lang-pulset)

European Spallation Source



- Tidsmidling: ESS (pulser) ≈ ILL (reaktor)
- Totale gain faktorer 30-1000 ift state-of-the-art
- Tillader et væld af forsøg der er i dag er umulige
- Ny medicin, Nye materialer, Ny teknologi, …

Ikke kun ét mål – ikke kun grundforskning

Outline

- Neutronens egenskaber
- Neutronproduktion, neutronoptik og lidt om hvordan ESS ændrer spillets regler
- Vekselvirkninger (neutroner vs røntgen)
- Eksempler på videnskab:
  - Imaging-teknikker
  - Krystalstruktur og spredningskontrast (H/D)
  - Magnetisk struktur
  - (Dynamik)

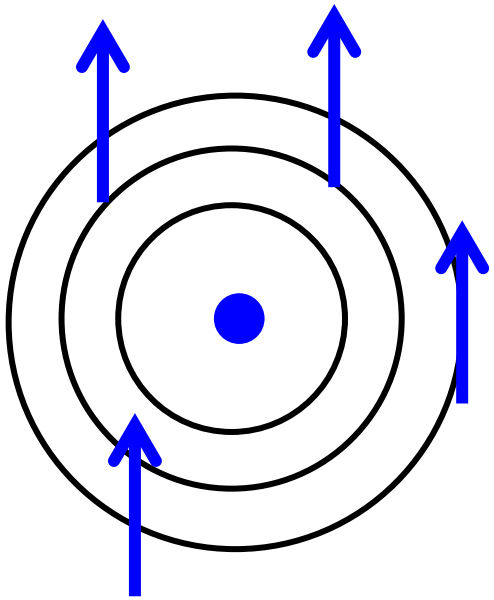
To vekselvirkninger:

1. Struktur: Stærk vekselvirkning med atom-kerner
2. Magnetisme: Electromagnetisk vekselvirkning imellem neutronens spin og det magnetifelt elektroner angulære momenter skaber

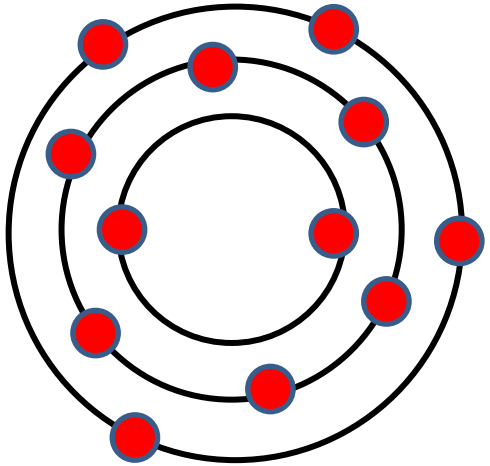
Bemærk:

- De to vekselvirkninger er omtrent lige stærke
- Neutroner ser *ikke* elektroners ladning

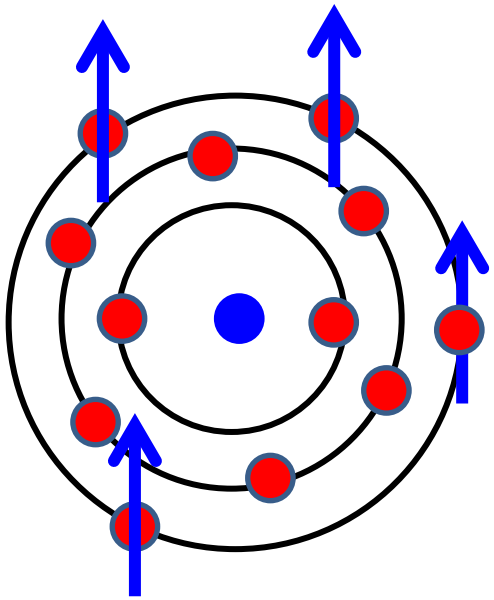
Neutroner



Røntgen

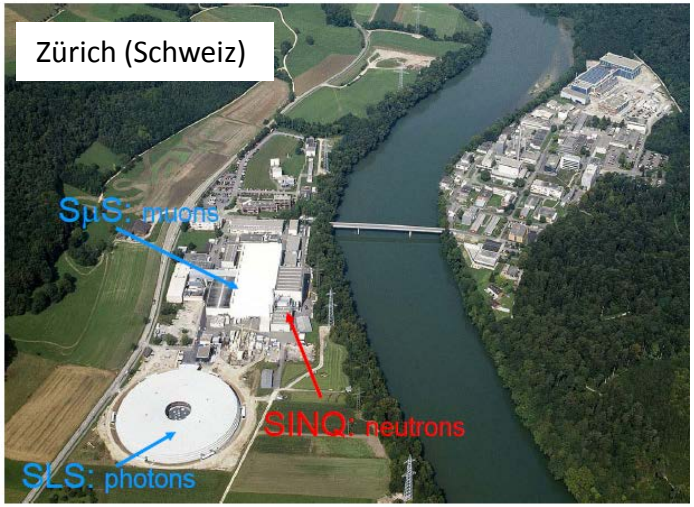


Neutroner og Røntgen



Neutroner og røntgen er komplementære!

Neutroner og Røntgen



Neutroner og Røntgen

Ikke altid helt enige om hvad der er bedst

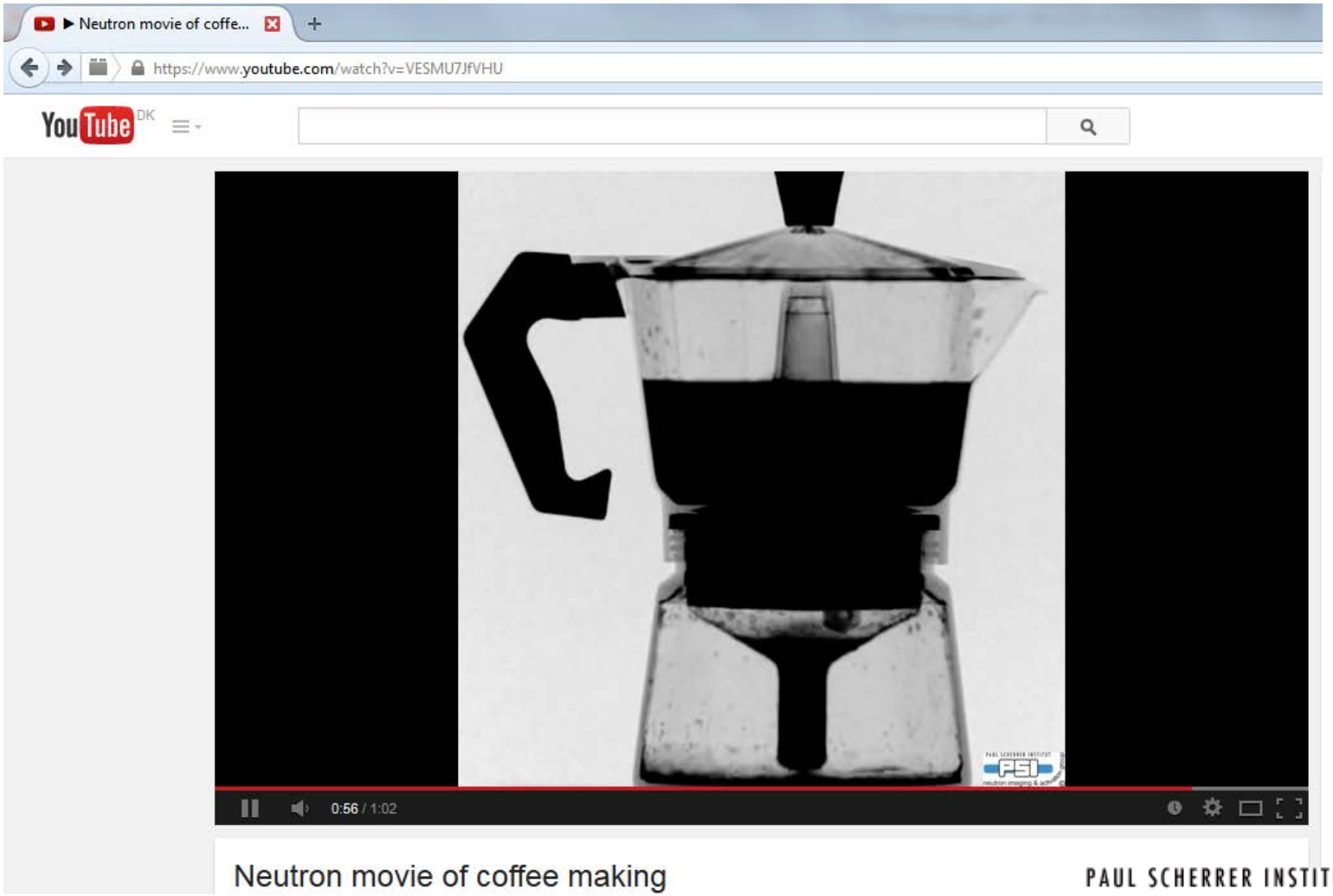
Neutroner og Røntgen

Neutroner	Røntgen
• Bølgelængde ~ atomare afstande • Energier meV ~ typiske svingninger	• Bølgelængde ~ atomare afstande • Energier i keV >> typiske svingninger
• Struktur/Magnetisme ~ 1:1	• Struktur/Magnetisme ~ $1:10^{-6}$
• Absorbtions og spredningstværsnit varierer IKKE systematisk med Z	• Absorbtions og spredningstværsnit varierer systematisk med Z
• Høj gennemtrængningsevne • Nemt at se lette grundstoffer • Stærk spredningskontrast imellem isotoper af samme grundstof	• Lavere gennemtrængningsevne • Svært at se de lette grundstoffer
• Lav flux: ~10^8 neutroner/cm^2/s • Ingen strålingsbeskadigelse	• Høj flux: ~10^{15} fotoner/cm^2/s • Strålingsbeskadigelse en bekymring

Outline

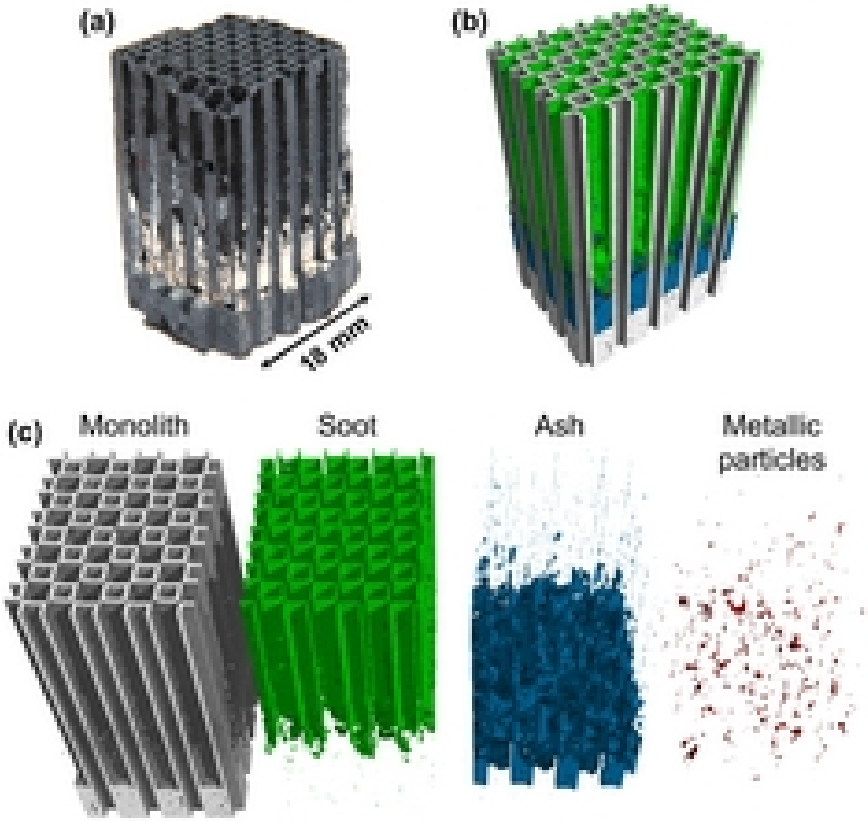
- Neutronens egenskaber
- Neutronproduktion, neutronoptik og lidt om hvordan ESS ændrer spillets regler
- Vekselvirkninger (neutroner vs røntgen)
- Eksempler på videnskab:
  - Imaging-teknikker
  - Krystalstruktur
  - Spredningskontrast (H/D)
  - Magnetisk struktur
  - Gitter- og magnetisk dynamik

Imaging: Kaffe-brygning



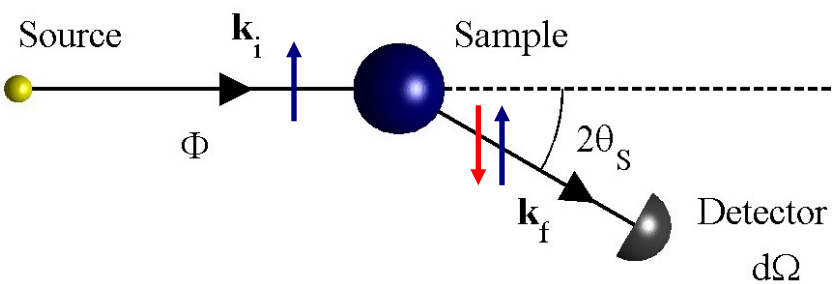
Data taget af forskere fra Paul Scherrer Instituttet i Schweiz

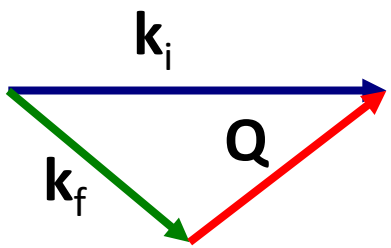
Imaging: Diesel-filter



Data taget af forskere fra Paul Scherrer Instituttet i Schweiz

Spredningsforsøg og bevarelsessætninger





$$\boldsymbol{p} = \hbar \boldsymbol{k}$$

Impulsbevarelse

$$\vec{Q} = \vec{k}_i - \vec{k}_f$$

Energibevarelse

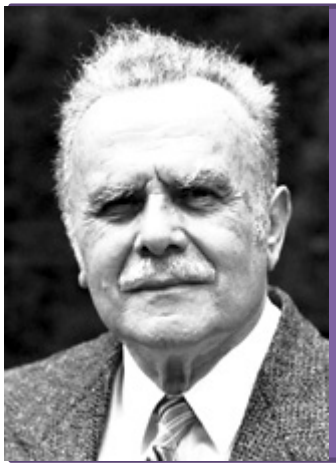
$$\hbar\omega = E_i - E_f$$

1994: Nobelprisvindere

"for pioneering contributions to the development of neutron scattering techniques for studies of condensed matter"

Clifford G. Shull (1915-2001), USA
"for the development of the neutron diffraction technique"

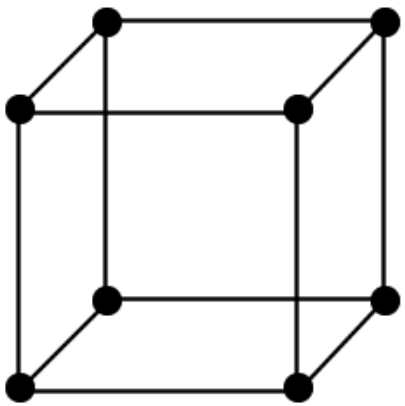
”Hvor atomer er …



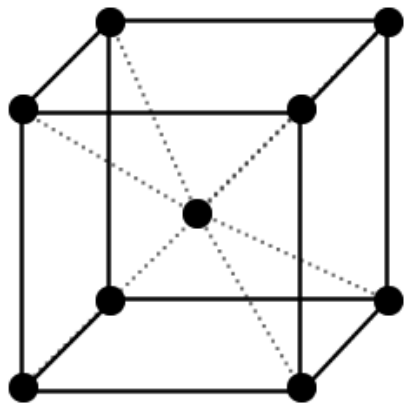
Bertram N. Brockhouse (1918-2003), Canada
"for the development of neutron spectroscopy"

”… og hvad atomer gør”

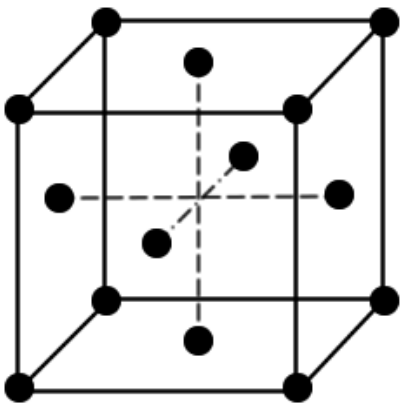
Krystalstruktur



P (Primitive)



I (Body)



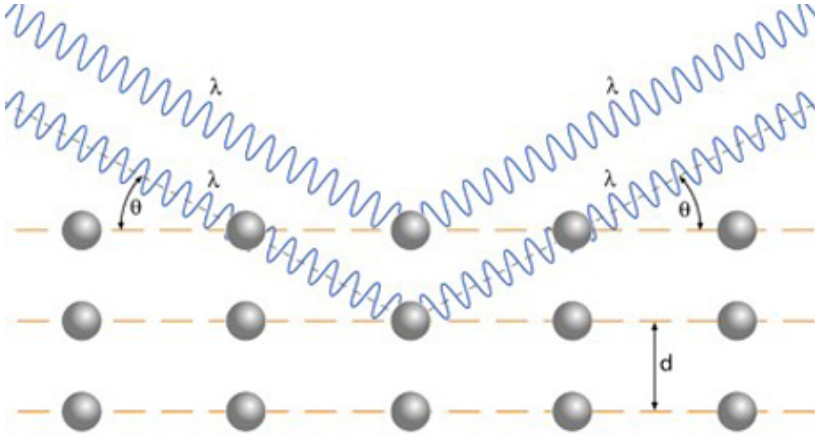
F (Face)

α-Polonium

Lithium
Natrium
Kalium
Vanadium
Chrom
Jern
Rubidium
…

Aluminium
Calcium
Nikkel
Kobber
Strontium
Rhodium
Paladium
…

Krystalstruktur

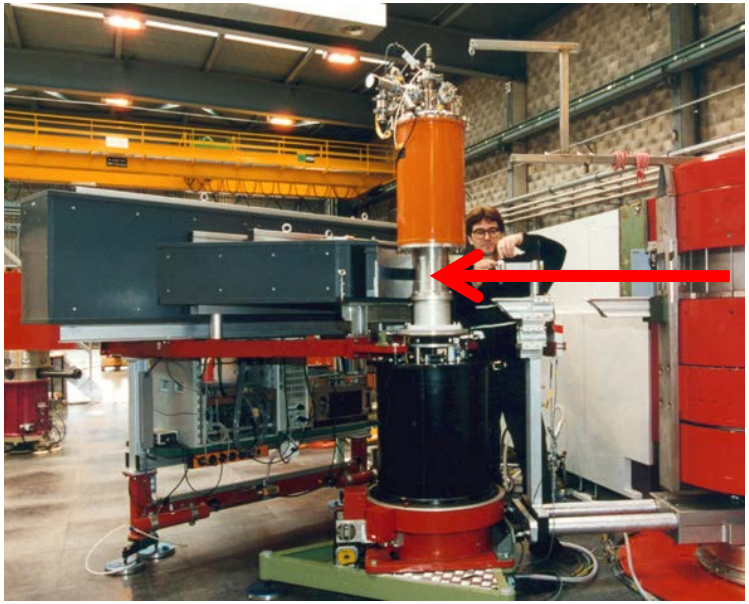


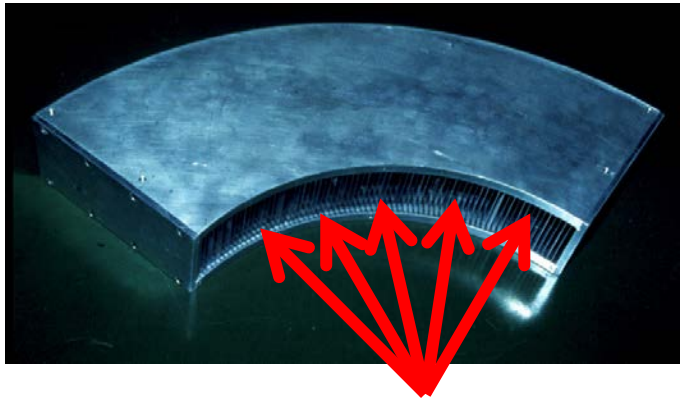
$$n\lambda = 2d\sin\theta$$

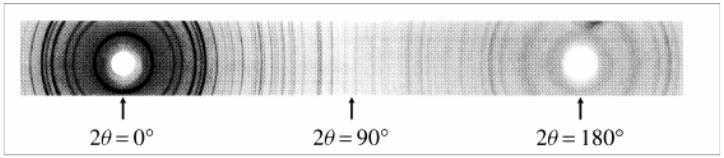
<u>Pointe:</u>

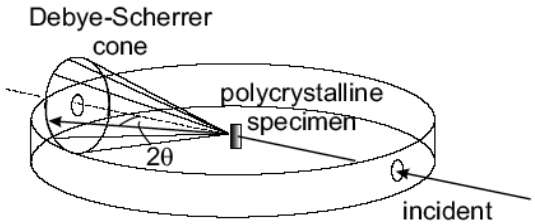
Bestemte familier af gitterplaner (d) giver anledning til spredning af neutroner med bølgelænge (λ) i specifikke retninger (θ)

Krystalstruktur

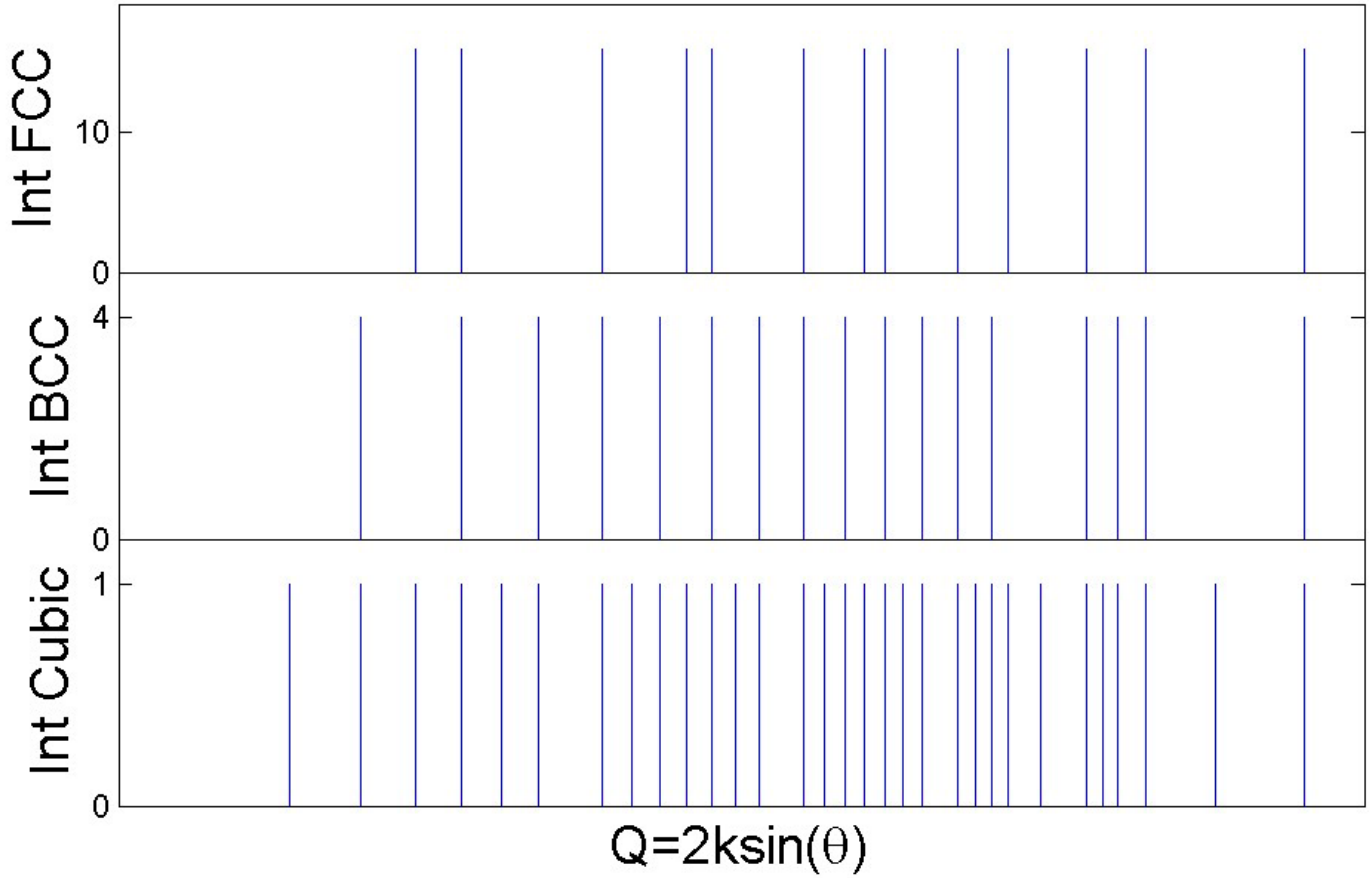


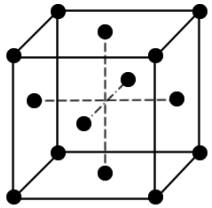




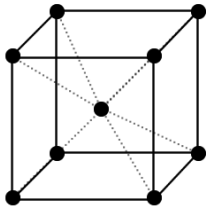


Krystalstruktur

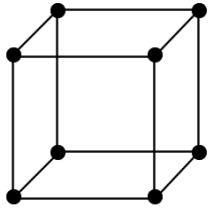




F (Face)

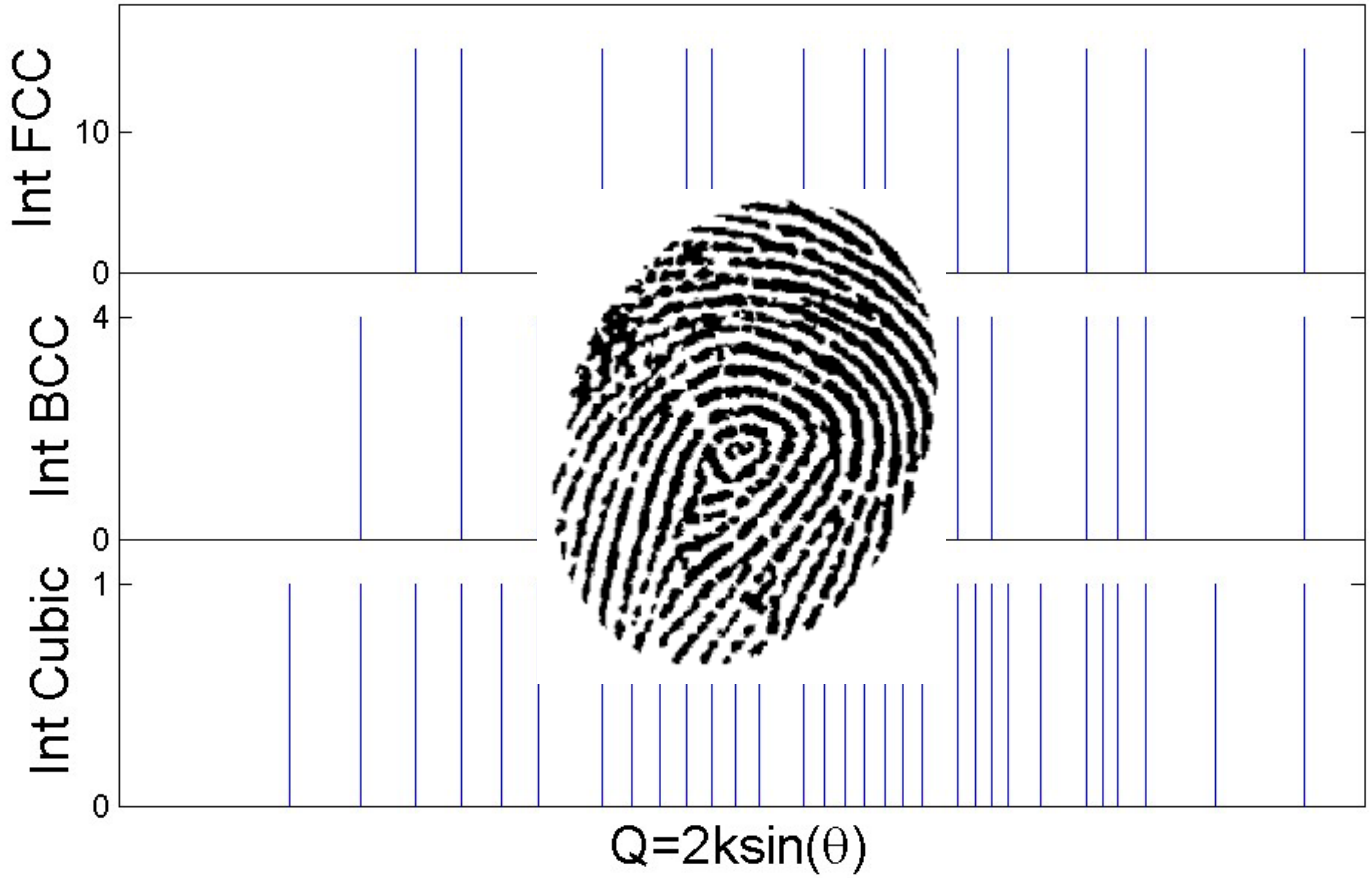


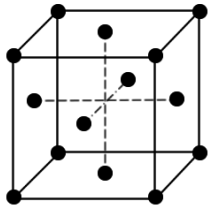
I (Body)



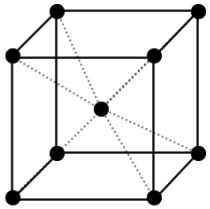
P (Primitive)

Krystalstruktur

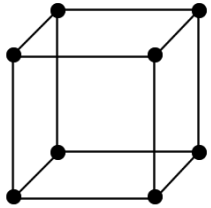




F (Face)

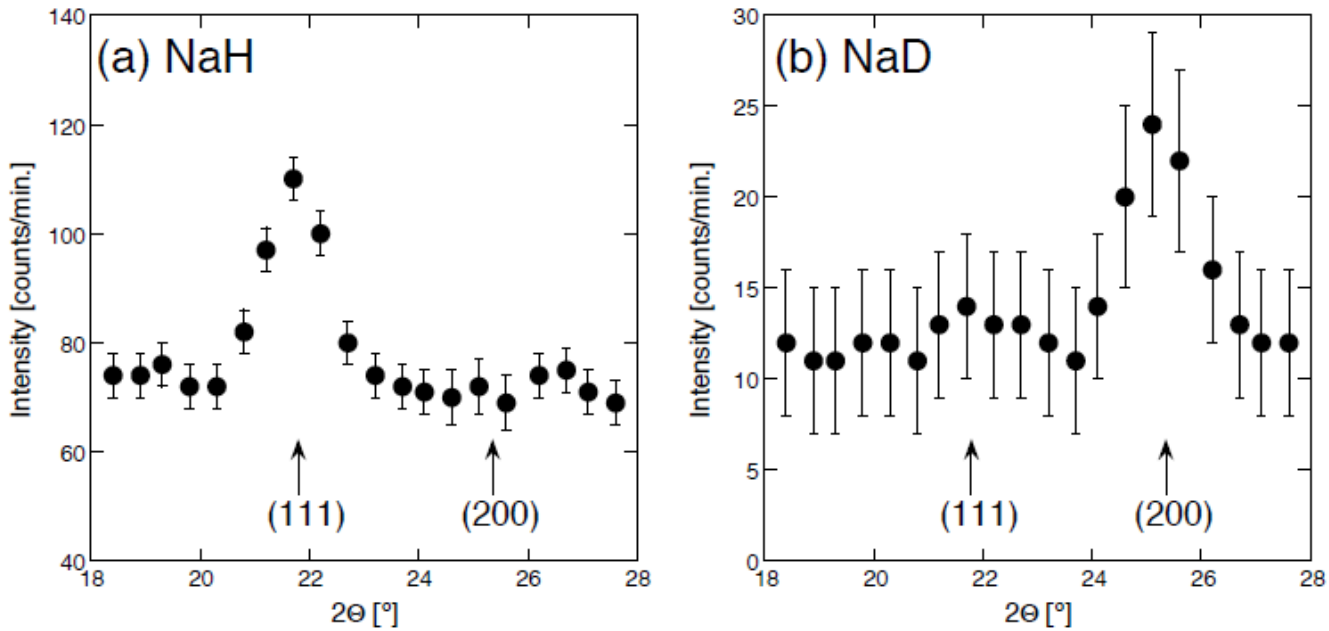


I (Body)



P (Primitive)

Spredningskontrast (H/D)



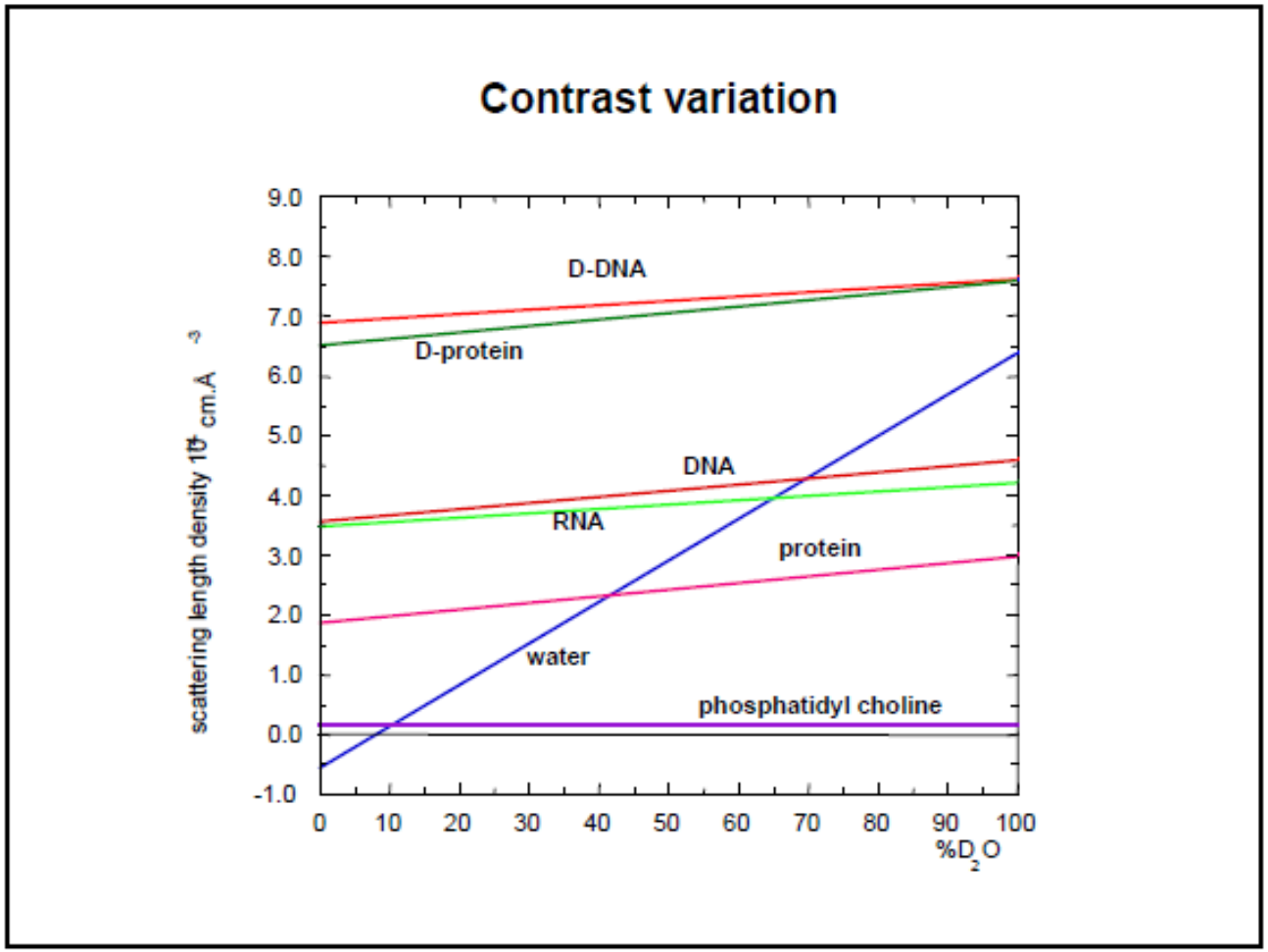
H og D er kemisk identiske, men der skete mange ændringer

- Baggrundsniveauet gik drastisk ned
- (111) forsvandt
- (200) trådte tydeligt frem

H and D er meget forskellige for neutroner

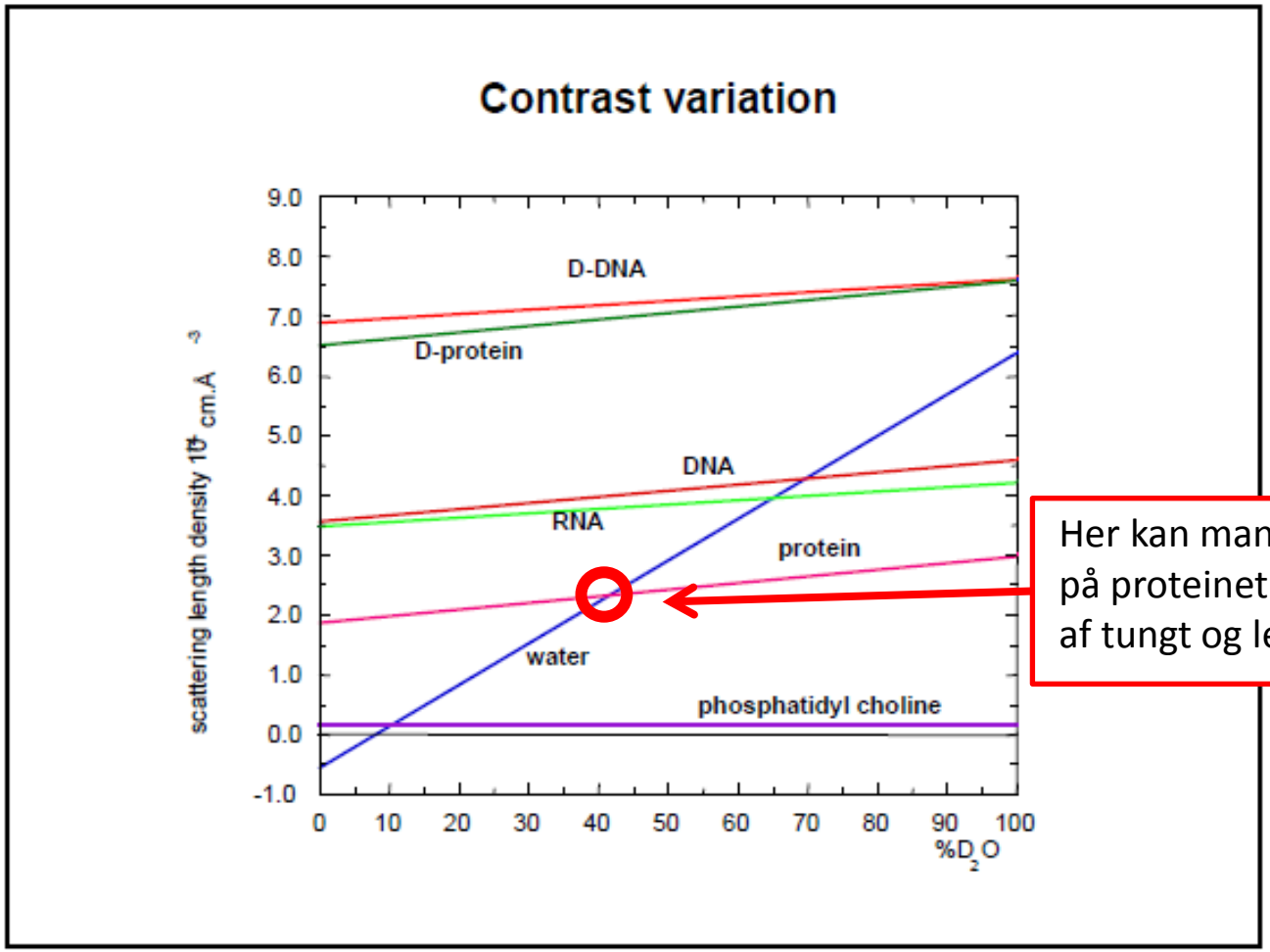
Original artikel: Shull et al, Phys Rev. (1948)

Spredningskontrast (H/D)



From: T. Forsyth, http://www.oxfordneutronschool.org/lectures2007/lectures.htm

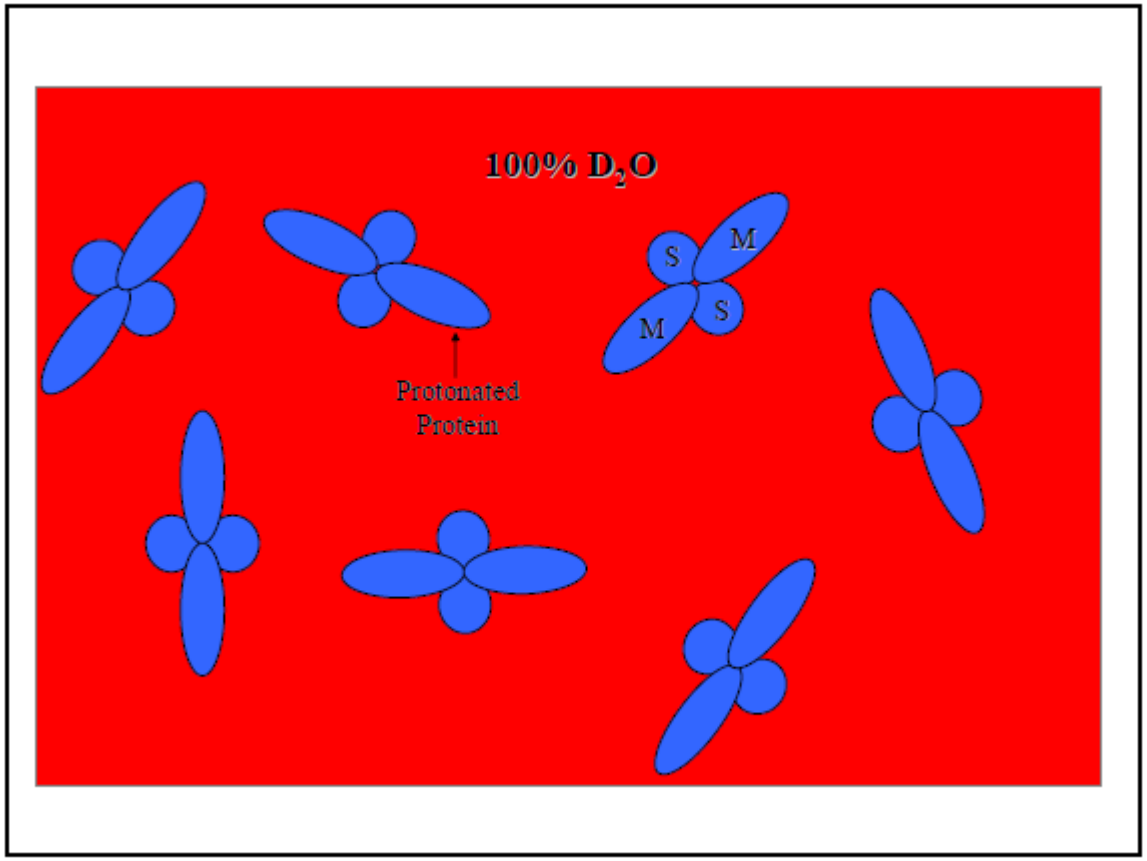
Spredningskontrast (H/D)



Her kan man ikke se forskel på proteinet og blandingen af tungt og let vand

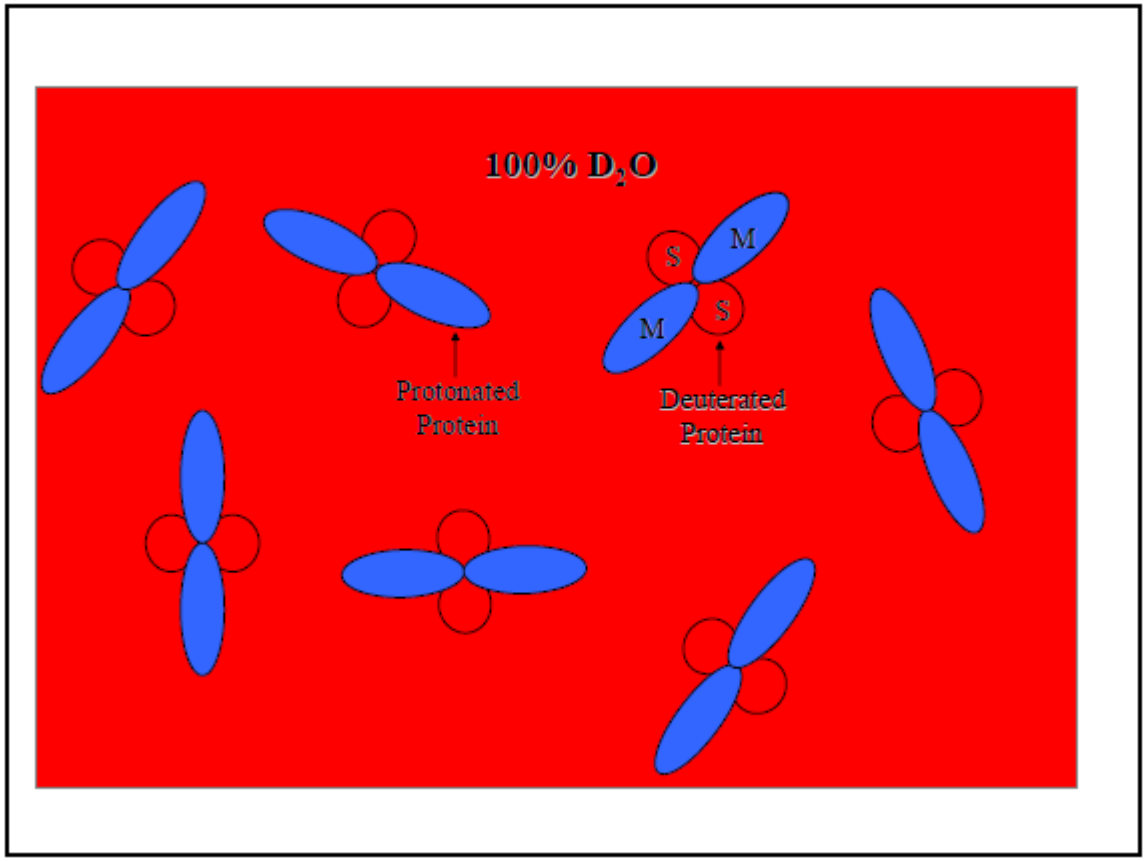
From: T. Forsyth, http://www.oxfordneutronschool.org/lectures2007/lectures.htm

Spredningskontrast (H/D)



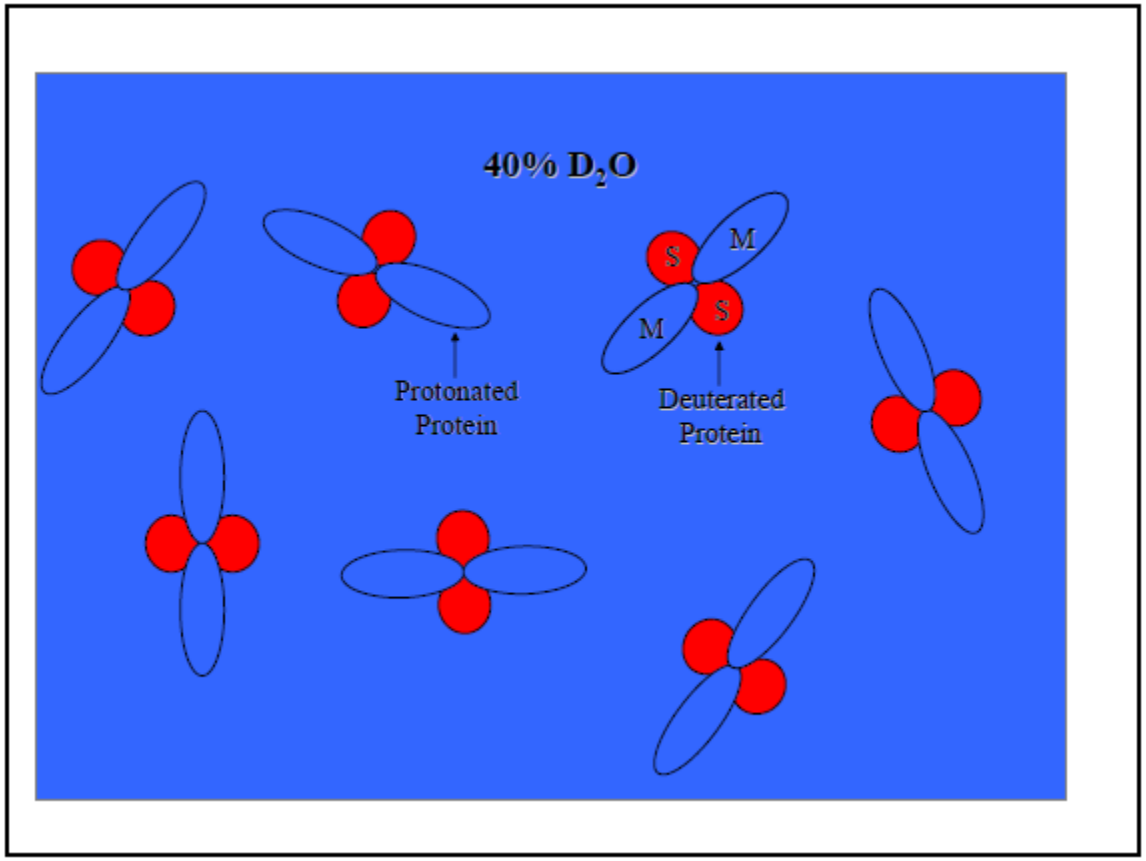
From: T. Forsyth, http://www.oxfordneutronschool.org/lectures2007/lectures.htm

Spredningskontrast (H/D)



From: T. Forsyth, http://www.oxfordneutronschool.org/lectures2007/lectures.htm

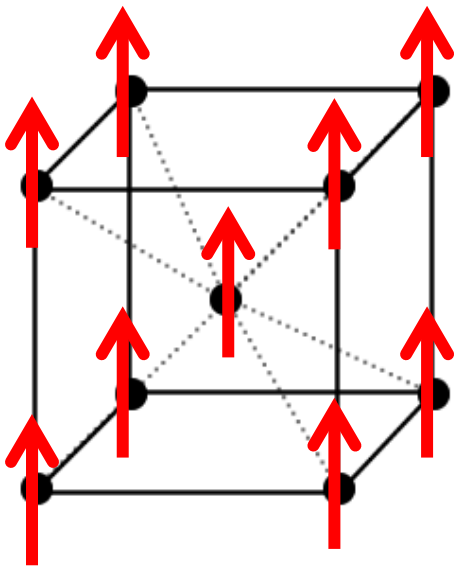
Spredningskontrast (H/D)



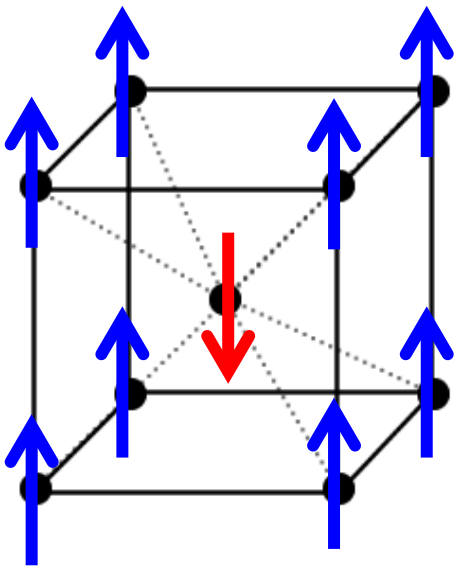
From: T. Forsyth, http://www.oxfordneutronschool.org/lectures2007/lectures.htm

Magnetisk struktur

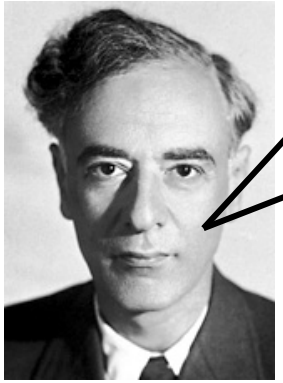
Ferromagnet



Antiferromagnet



Magnetisk struktur



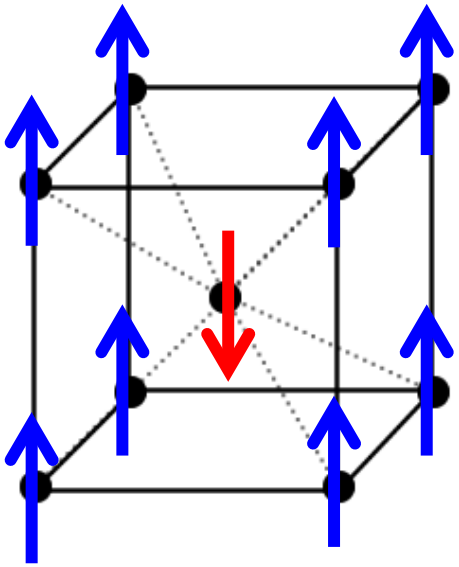
Nyet!

Lev D. Landau

Mais oui!

Louis E. F. Néel

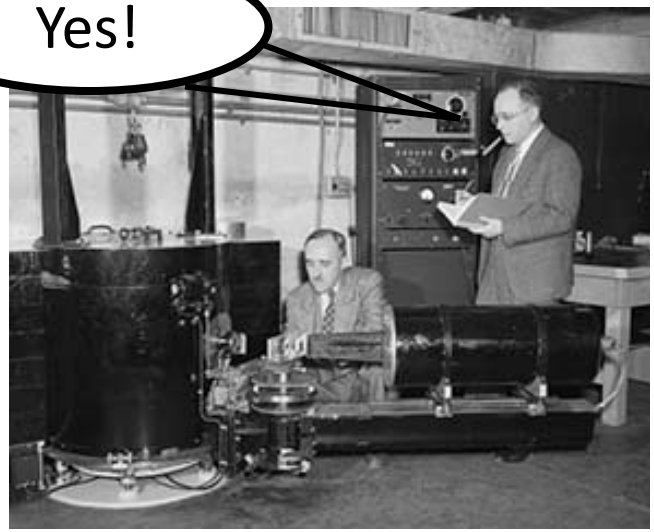
Antiferromagnet



Landau og Néel var uenige om hvorvidt antiferromagnetisme findes. Neutroner hjalp med til at vise at begge havde ret

Magnetisk struktur

Yes!



Wollan & Shull (1949)

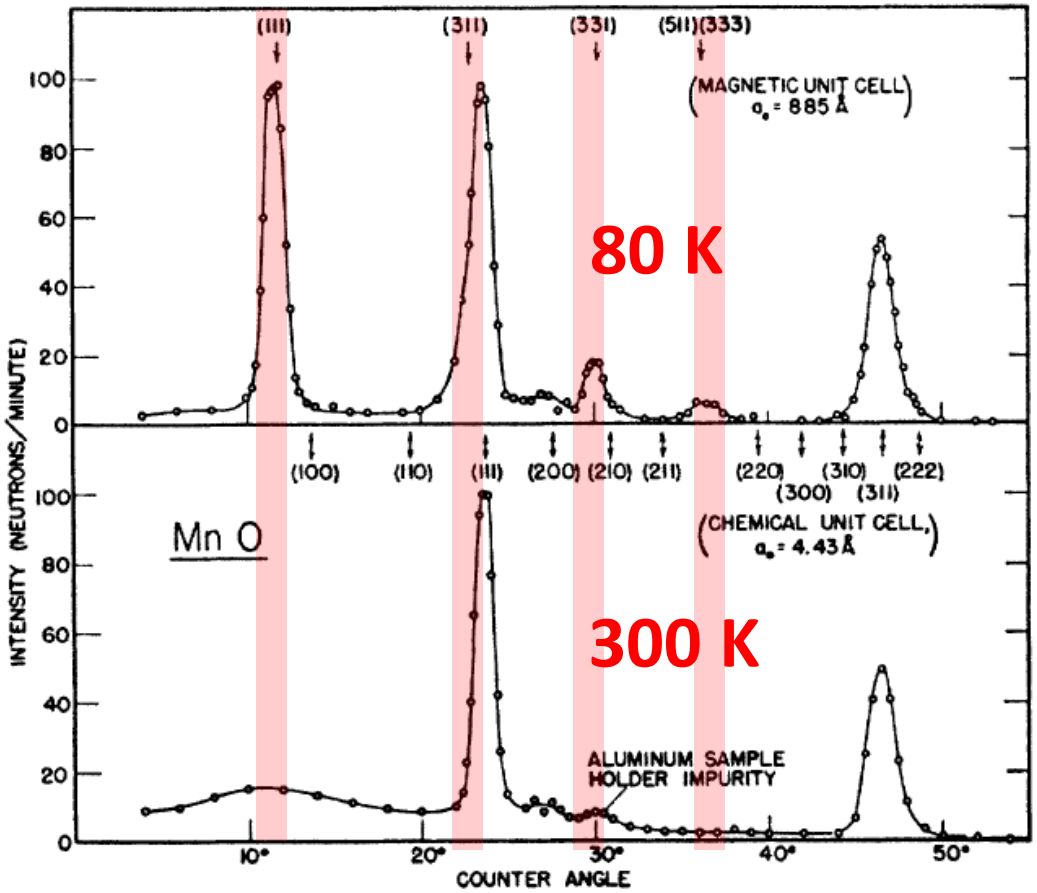
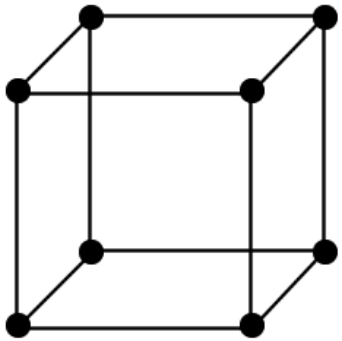


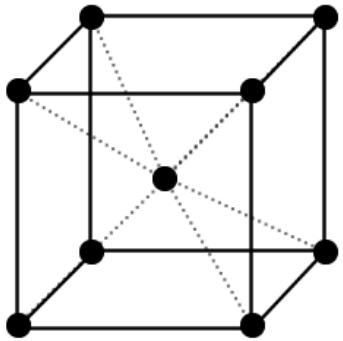
FIG. 1. Neutron diffraction patterns for MnO at room temperature and at 80°K.

Nye Bragg toppe → Nye symmetri (antiferrommagnetisme)

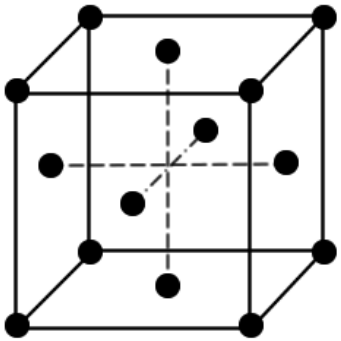
Gitter dynamik



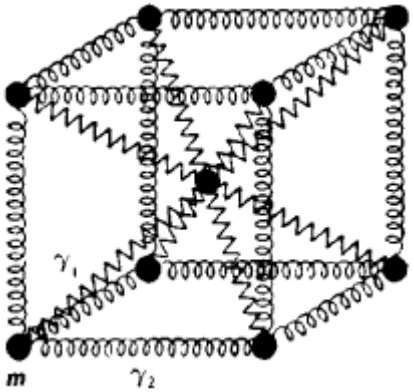
P (Primitive)

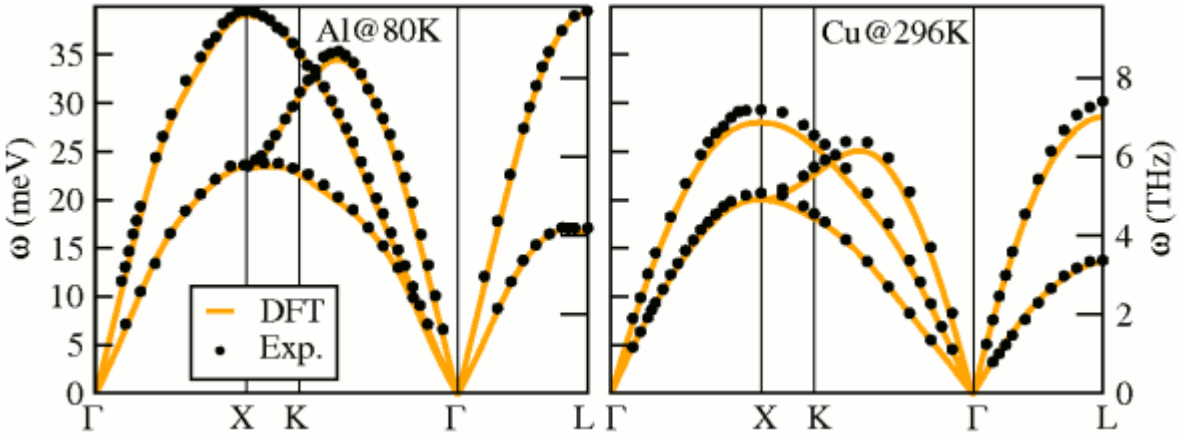


I (Body)



F (Face)



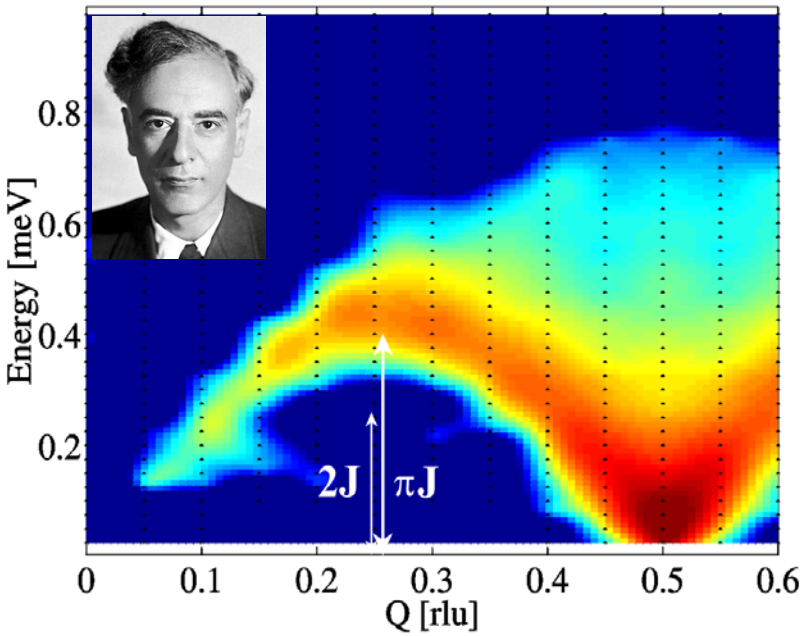


Krystal-impuls Q

Med neutroner kan man se hvordan atomare gitre vibrerer (fononer)

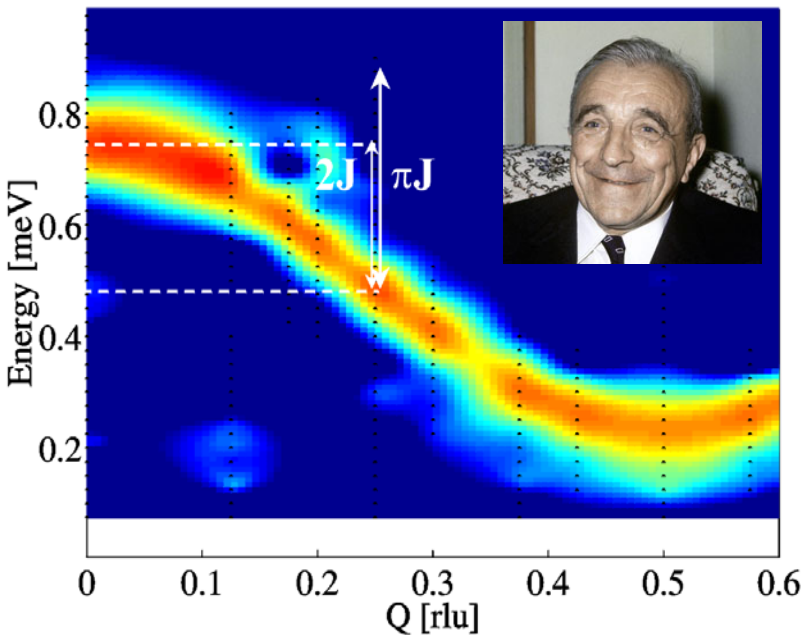
Magnetisk dynamik

B=0 100 mK



$$\hbar\omega = \pi J \, |\sin(qa)]|$$

B=5T 100 mK

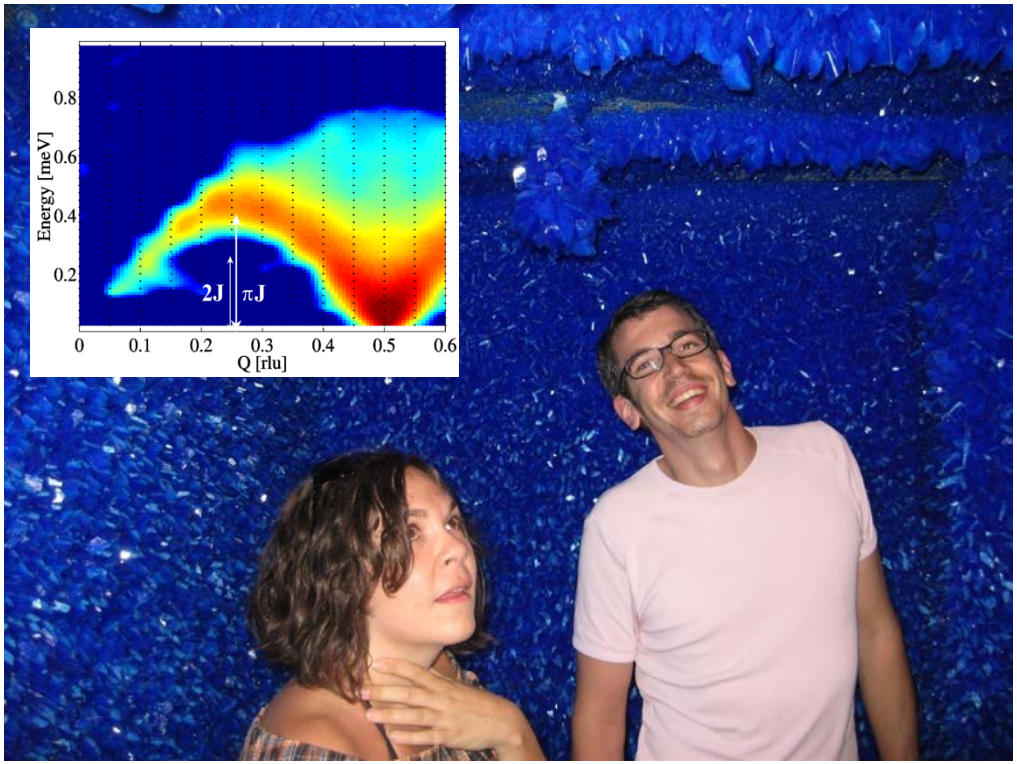


$$\hbar\omega = 2J \, [\cos(qa)+1]$$

$CuSO_4 \cdot 5D_2O$ – fra kvantemekanik til klassisk fysik ved hjælp af magnetfelt. Landau havde også ret!

Mourigal, Nature Physics (2013)

Tak for opmærksomheden



Cobber-sulfat lejlighed (2008)
http://www.ysp.co.uk/exhibitions/roger-hiorns-seizure
European Spallation Source
http://europeanspallationsource.se/