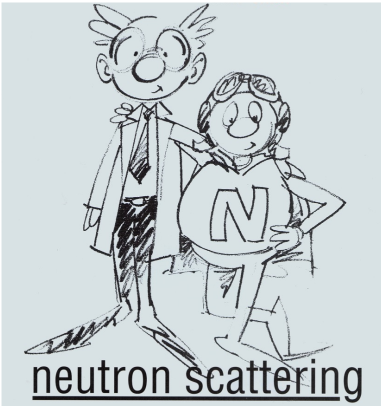

Interaction of Xrays and Neutrons with Materials

by

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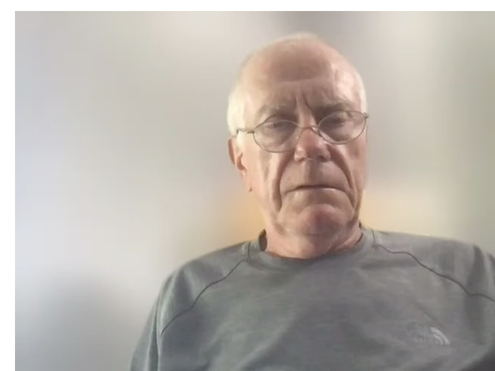
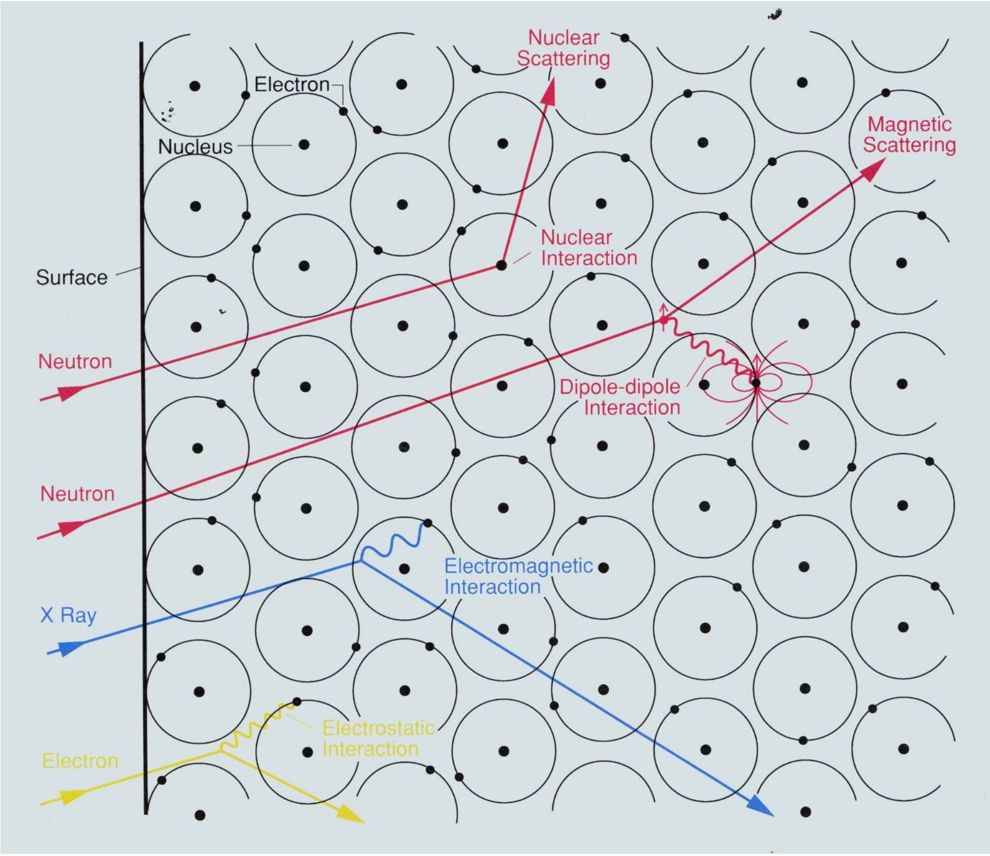
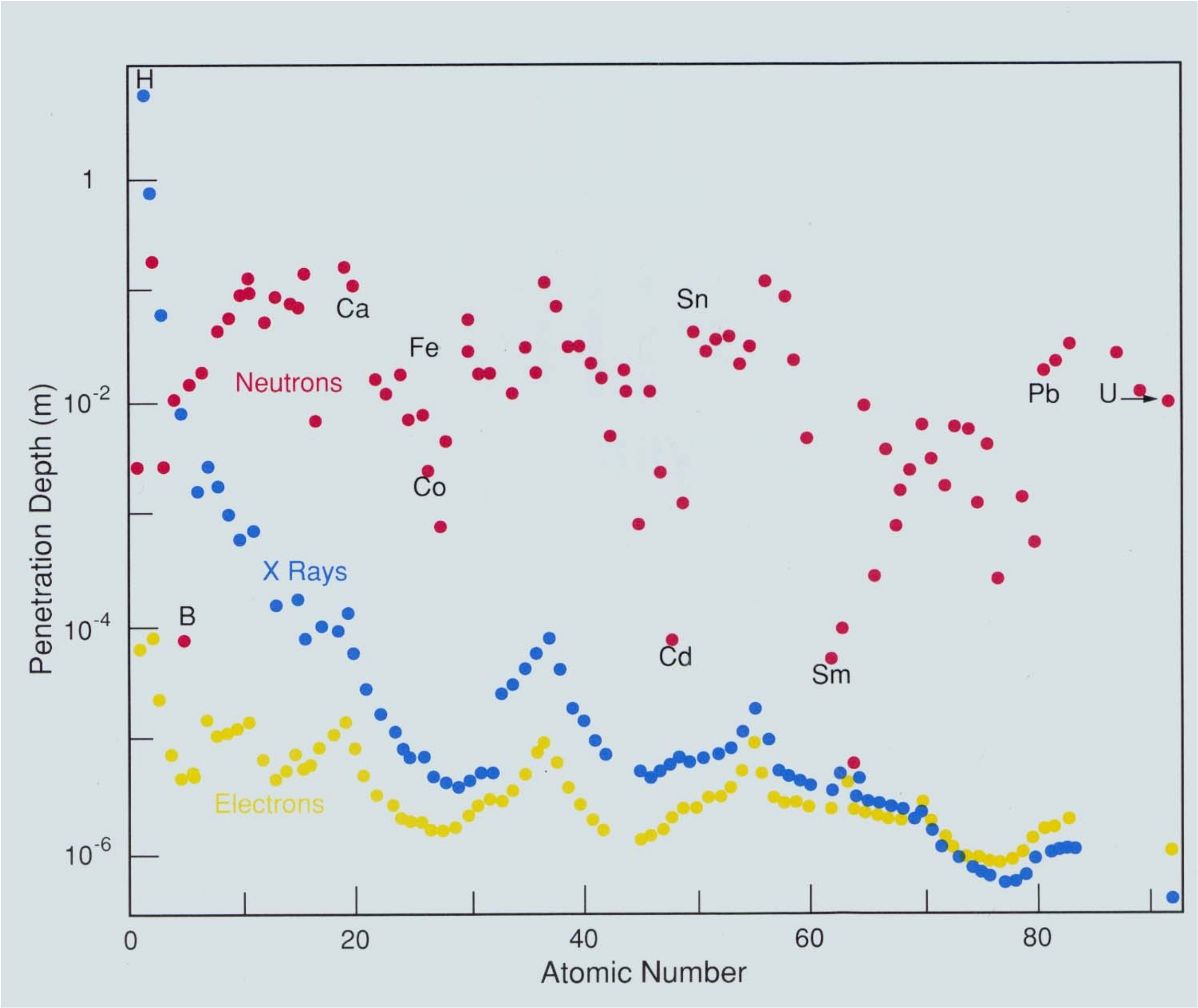


Interaction Mechanisms



- Neutrons interact with atomic nuclei via very short range (~fm) forces.
- Neutrons interact with unpaired electrons via magnetic dipole interaction.
- X-rays interact with electrons via an electromagnetic interaction

Thermal Neutrons, 8 keV X-Rays & Low Energy Electrons:- Penetration in Matter

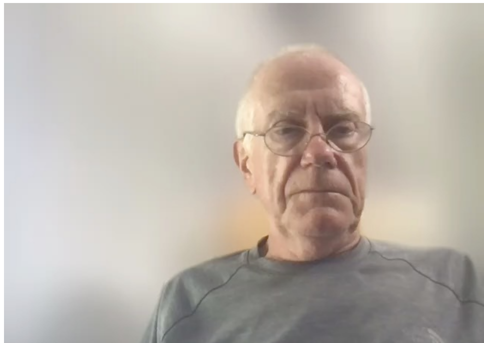


Note for neutrons:

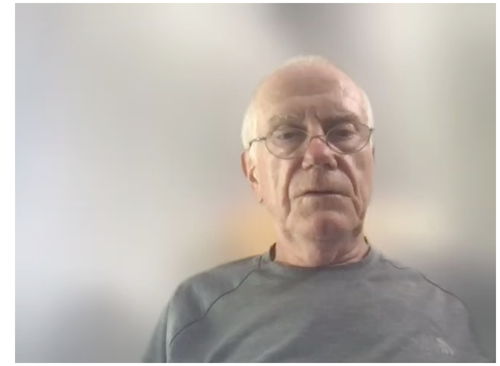
- H/D difference
- Cd, B, Sm
- no systematic Z dependence

For x-rays:

- decreasing penetration as Z increases



Comparison on Neutron & X-Ray Scattering by Various Elements



Element	**Neutrons** (10^{-12} cm)	**X-rays** (10^{-12} cm)	**Electrons** (Z^2)
^{1}H	**-0.374**	**0.28**	1
^{2}H (D)	**0.667**	**0.28**	1
C	0.665	1.67	6
N	0.940	1.97	7
O	0.580	2.25	8
P	0.520	4.23	15

Types of Interaction

- Neutrons interacting with nuclei
  - Absorption by nuclei – cross section (i.e. absorption probability) for thermal neutrons usually $\sim 1/v$, resonances at high energy (> keV)
  - Coherent scattering – scattering from different nuclei add in phase
  - Incoherent scattering – random phases between scattering from different nuclei

- Neutrons interacting with magnetic fields
  - Magnetic dipolar interaction – scattering from magnetic field due to unpaired electrons – coherent

- X-rays interacting with electrons
  - Photoelectric absorption – x-rays kicks electron from shell to continuum
    - Leads to fluorescent X-ray emission when hole in shell is filled from outer shell
    - Goes as $1/E^3$ but with sharp steps at shell energies when new channel opens
  - Thomson scattering – elastic and coherent
  - Compton scattering – inelastic and incoherent

The Neutron has Both Particle-Like and Wave-Like Properties

- Mass: $m_n = 1.675 \times 10^{-27}$ kg
- Charge = 0; Spin = ½
- Magnetic dipole moment: $\mu_n = -1.913\ \mu_N$
- Nuclear magneton: $\mu_N = eh/4\pi m_p = 5.051 \times 10^{-27}\ \mathrm{J\ T^{-1}}$
- Velocity (v), kinetic energy (E), wavevector (k), wavelength (λ), temperature (T).
- $E = m_n v^2/2 = k_B T = (hk/2\pi)^2/2m_n$; $k = 2\pi/\lambda = m_n v/(h/2\pi)$

	Energy (meV)	**Temp (K)**	**Wavelength (nm)**
Cold	**0.1 – 10**	**1 – 120**	**0.4 – 3**
Thermal	**5 – 100**	**60 – 1000**	**0.1 – 0.4**
Hot	**100 – 500**	**1000 – 6000**	**0.04 – 0.1**

λ (nm) = 395.6 / v (m/s)

E (meV) = 0.02072 k^2 (k in $\mathrm{nm^{-1}}$)

X-Rays also have Wave-Like and Particle-Like Properties

$$E = h\upsilon = hc/\lambda = (h/2\pi)c(2\pi/\lambda) = \hbar ck = pc$$

Charge = 0; magnetic moment = 0; spin = 1

E (keV)	λ(Å)
0.8	15.0
8.0	1.5
40.0	0.3
100.0	0.125

Typical interatomic distance in a crystal is 3.5 Å

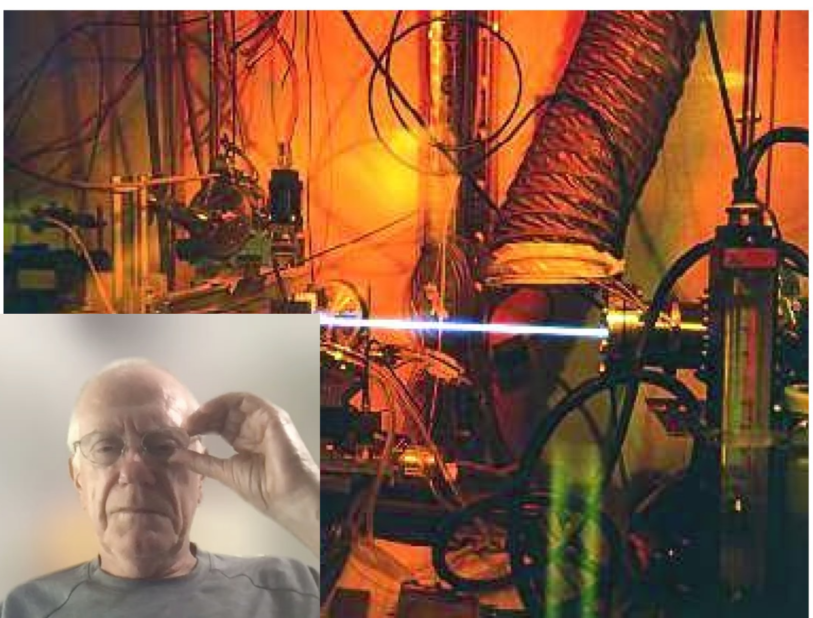
Brightness & Fluxes for Neutron & X-Ray Sources

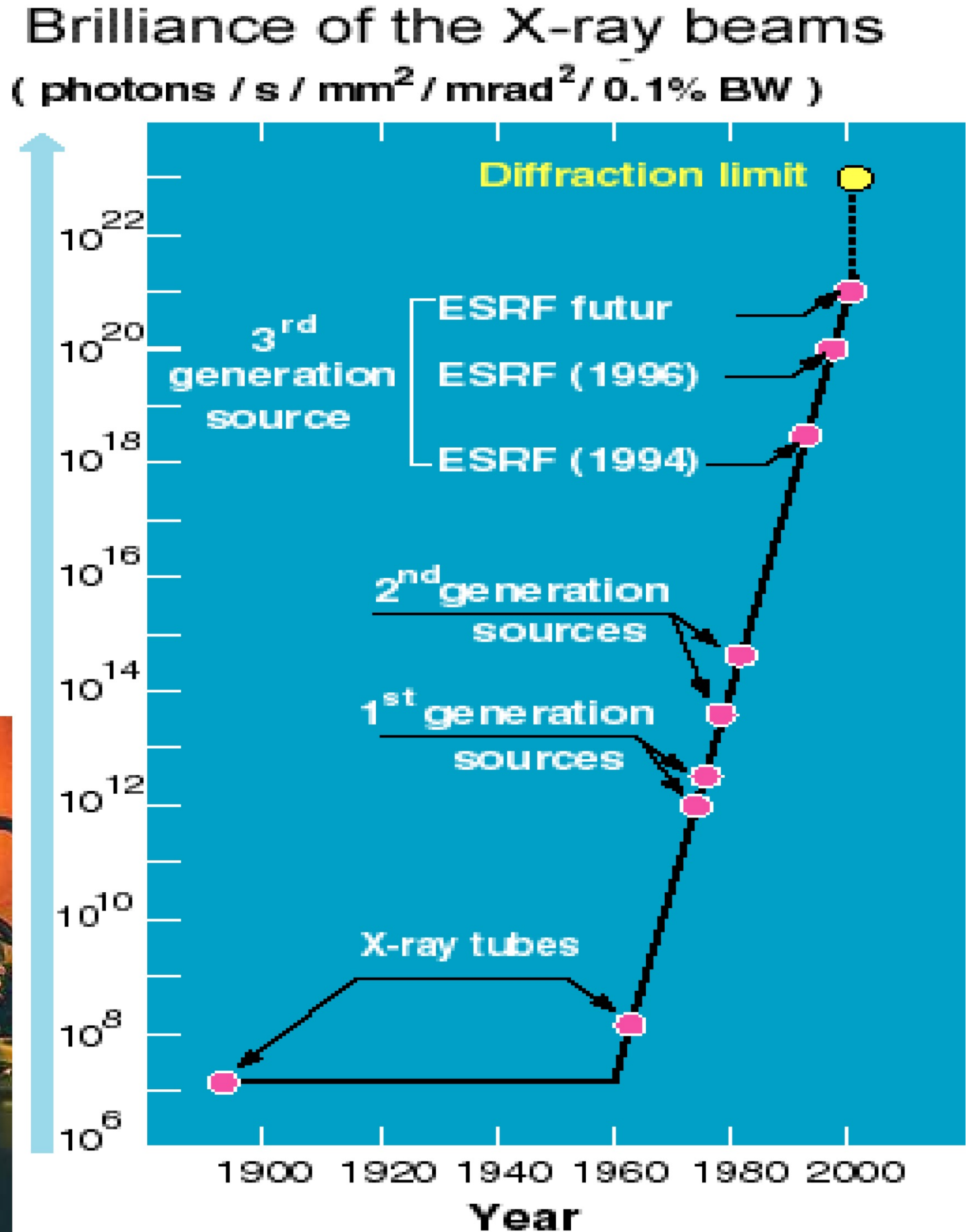
	Brightness *($s^{-1}\ m^{-2}\ ster^{-1}$)*	*dE/E* *(%)*	*Divergence* *($mrad^2$)*	*Flux* *($s^{-1}\ m^{-2}$)*
Neutrons	10^{15}	2	10 x 10	10^{11}
Rotating Anode	10^{16}	3	0.5 x 10	5×10^{10}
Bending Magnet	10^{24}	0.01	0.1 x 5	5×10^{17}
Wiggler	10^{26}	0.01	0.1 x 1	10^{19}
Undulator (APS)	10^{33}	0.01	0.01 x 0.1	10^{24}

Flux = brightness * divergence; brilliance = brightness / energy bandwidth

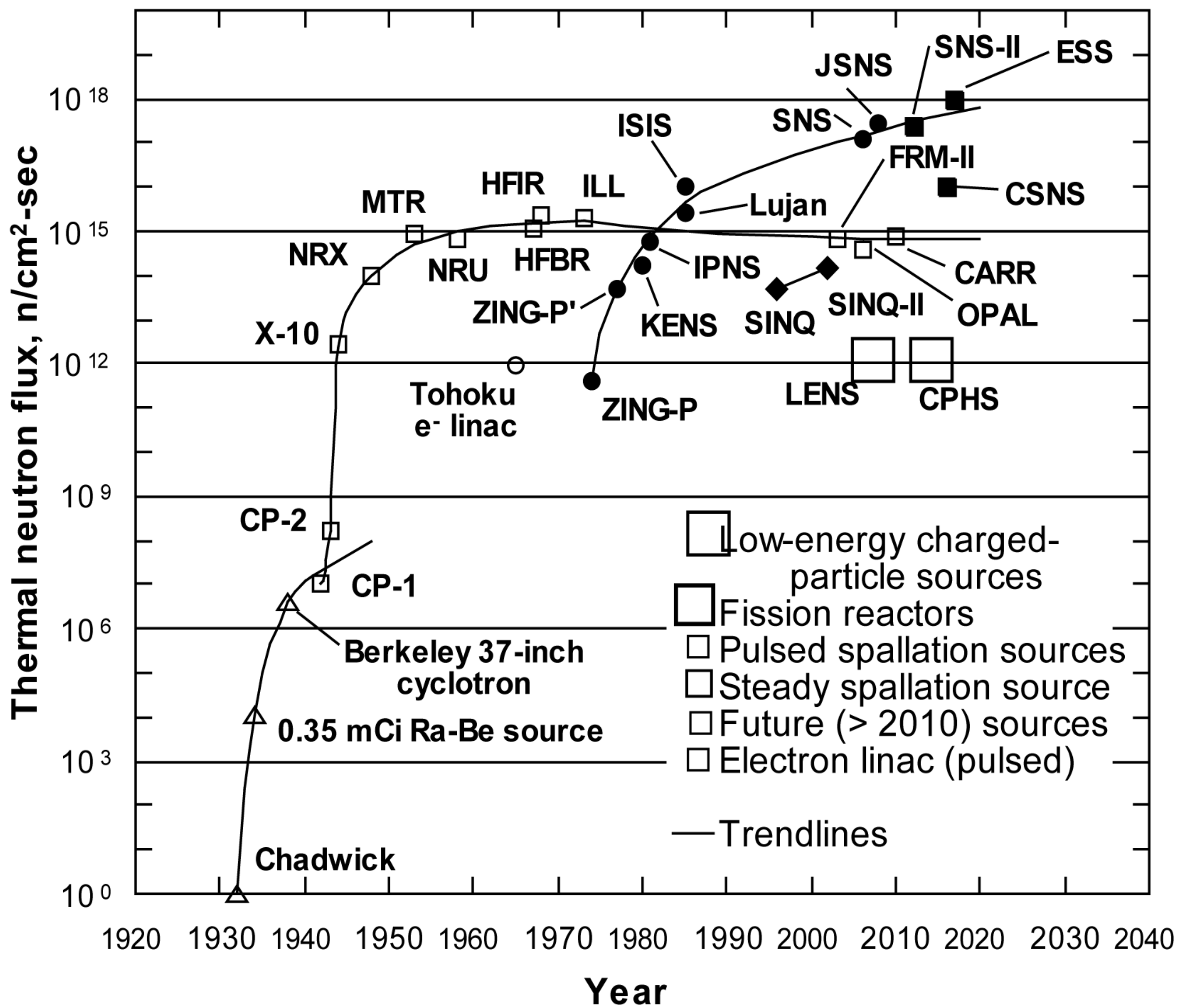
Why Synchrotron-radiation ?

Intensity !!!





Brugger Plot



Redrawn 2009