Introduction to Neutron Scattering

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Advanced Solid State Physics II

Outline

- Background
- Properties of Neutron
- Neutron Scattering Principles
- Neutron Scattering Experiments
- Neutron Production
- Summary

The Nobel Prize in Physics 1994

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

"for the development of neutron spectroscopy"

Bertram N. Brockhouse

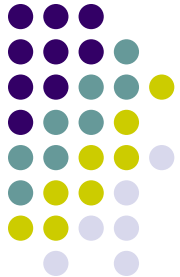
1/2 of the prize

"for the development of the neutron diffraction technique"

Clifford G. Shull

1/2 of the prize

Why Scientist Like Neutrons?



Neutrons have No Charge!

- **Highly penetrating**

Neutro

- **Magn**
- **Fluct**
- **Magnetic materials**

Neutrons have Spin!

- **Polarized beams**
- **Atomic orientation**
- **Coherent and incoherent scattering**

The Energies of neutrons are similar to the energies of elementary excitations!

- **Molecular Vibrations and Lattice modes**

ar to

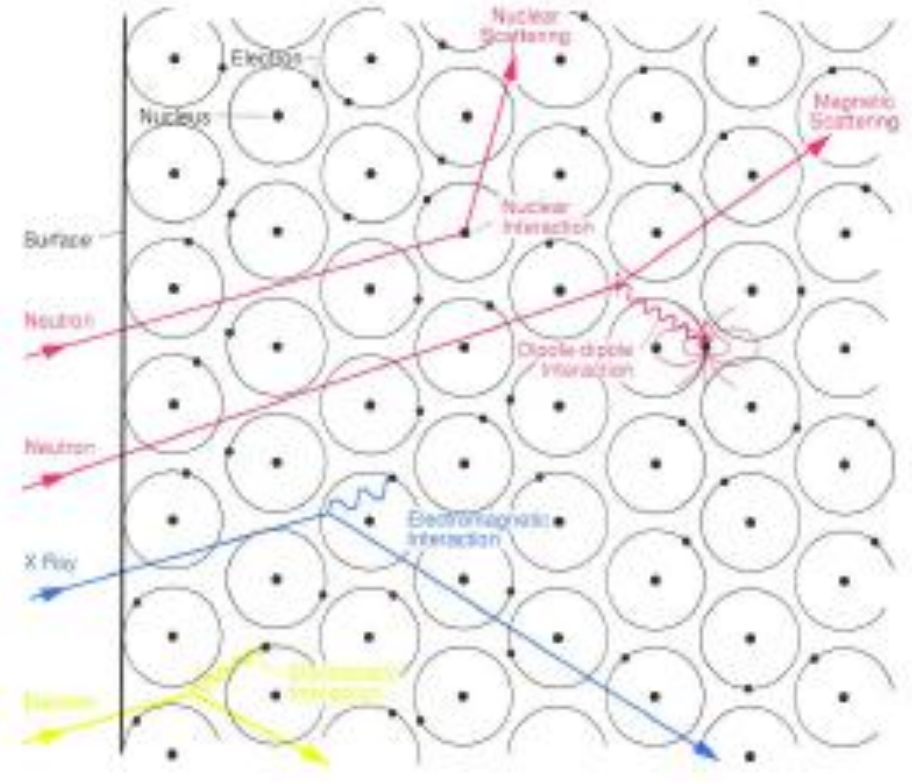
- **Sensitive to structure**
- **Gathers information from 10^{-10} to 10^{-7} m**
- **Crystal structures and atomic spacings**

Neutrons probe Nuclei!

- **Light atom sensitive**

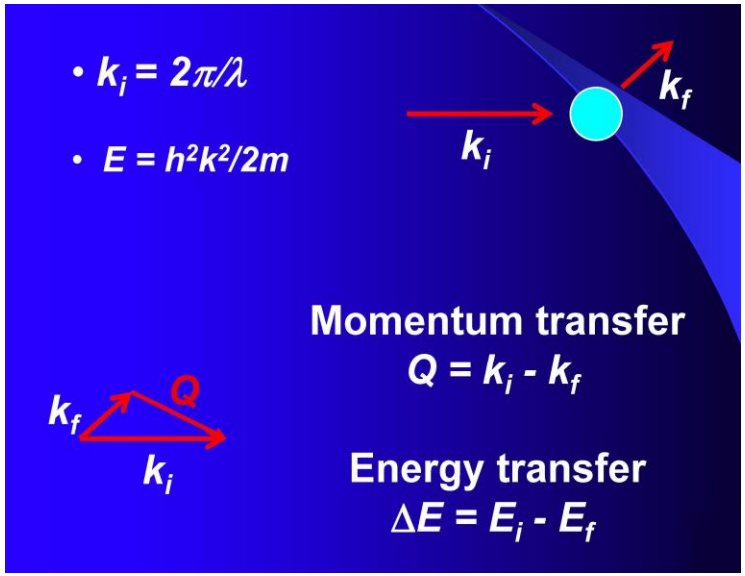
Can Investigate structural and dynamic properties

Scattering Interaction



Neutron interacts with atoms with very short range of nuclear force and also interacts with unpaired electrons in solids

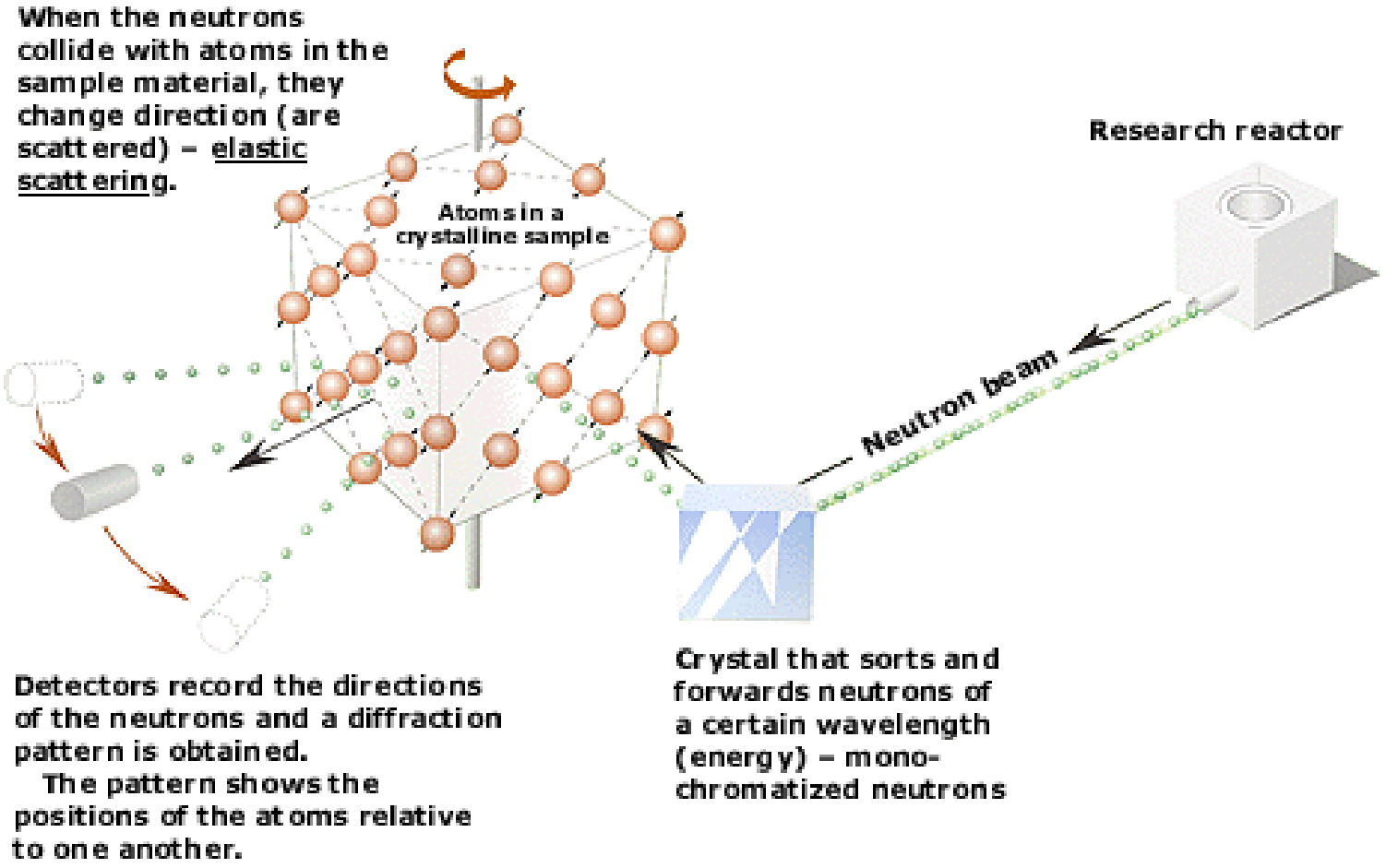
Neutron Scattering Law



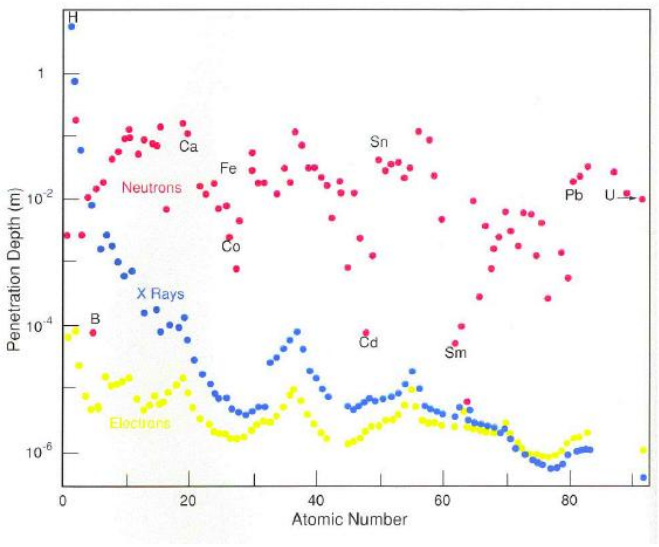
This Law is simply proportional to the Fourier transform of a function that gives the probability of finding two atoms a certain distance apart

$$\mathbf{I}(\mathbf{Q},\epsilon) = \frac{1}{\hbar}\frac{k'}{k}\sum_{j,k} b_j b_k \int_{-\infty}^{\infty} < e^{-iQ\cdot r_k(0)} e^{iQ\cdot r_j(t)} > e^{-i\epsilon t} dt$$

Neutrons Scattering Experiments(1)

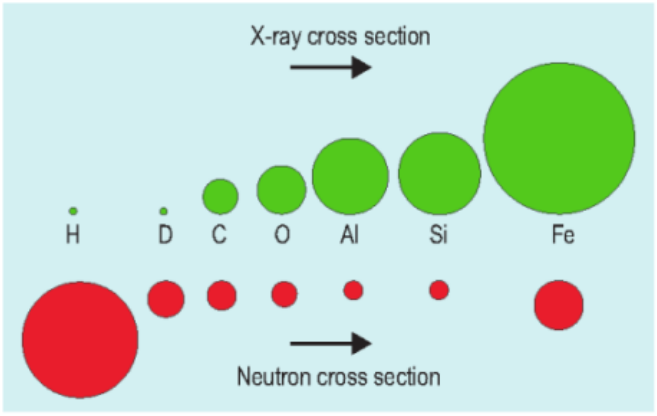


Comparing to X-ray



Neutrons can penetrate matter far better than charges particles.

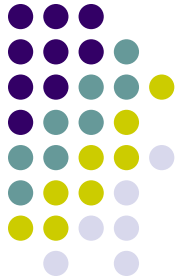
Two-edge sword: sometimes neutrons are only weakly scattered



Heavy atoms with many electrons scatter X-rays more efficiently than light atoms, such as O,H.

However, neutron can be easily scattered by light atoms.

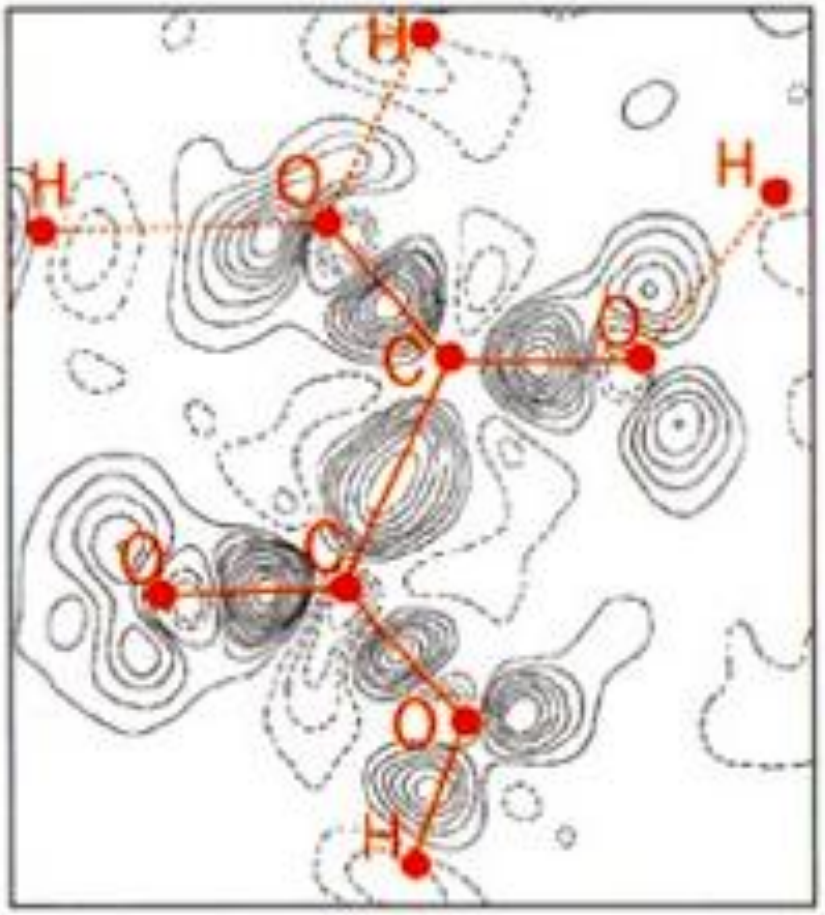
The Role of Neutron Scattering



- Never use neutrons if there is another technique that will give the same information
- – Neutrons are almost always more expensive and only available at large facilities
- – You need large samples and long data collection times

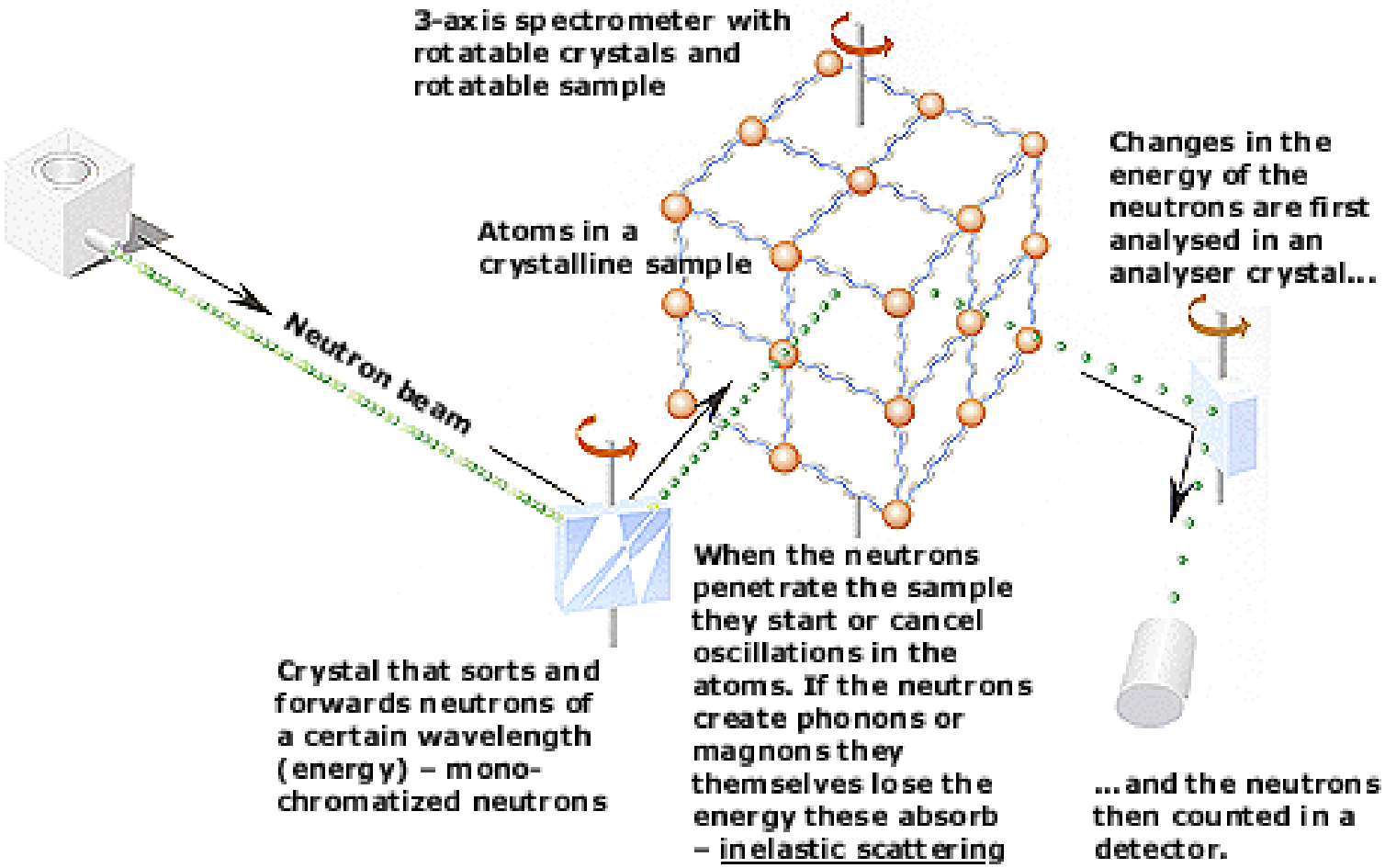
- Neutron scattering provides information that is complementary to other techniques
- – Scattering techniques give statistical information rather than discrete “pictures”
- – Different scattering power of x-rays & neutrons highlight different atoms
  - Particularly useful for locating water molecules using neutrons

An Example

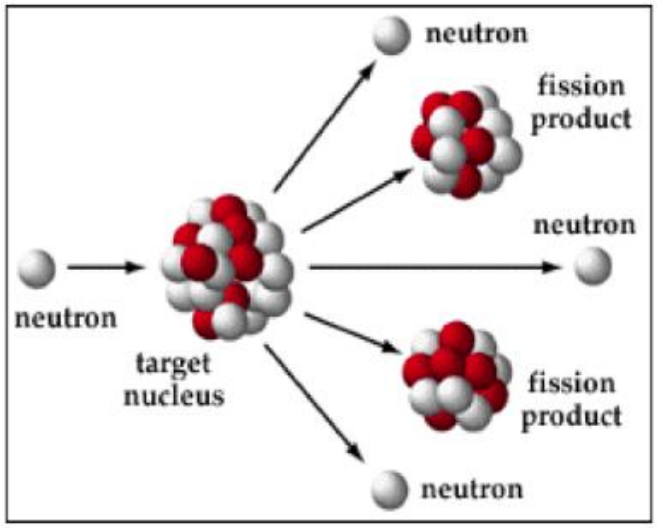


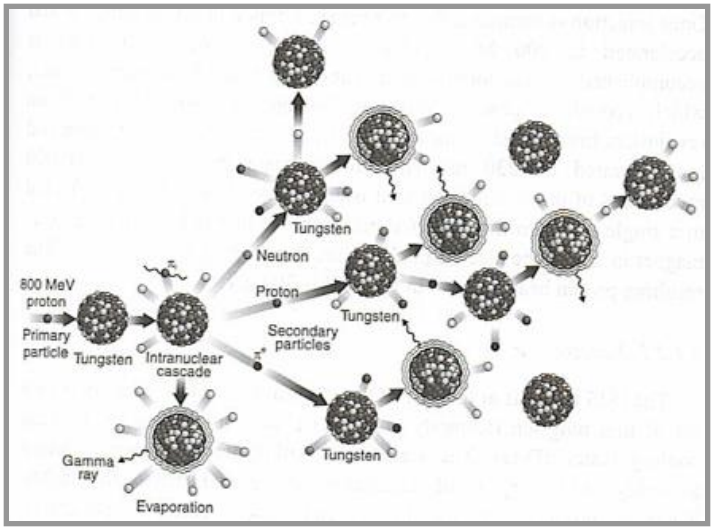
- Neutron and X-ray diffraction mix map

Neutrons Scattering Experiments(2)



Neutron Production



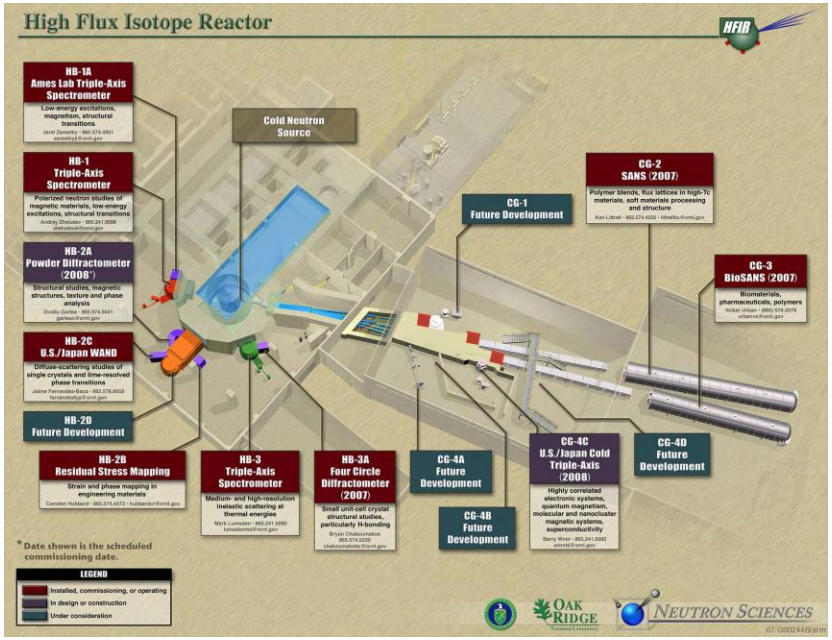


Research Reactor

Spallation Source

Neutron Scattering Facilities

Facilities List in the world



- High Flux Isotope Reactor(HFIR)
- Spallation Neutron Source(SNS)

Summary

- Neutrons are produced in two main ways

1. Research reactor
2. Spallation Source

- Utilizes the properties of the neutrons

- In material science, neutrons are useful in determining not only structural properties of a material, but also the vibrational, magnetic, and lattice excitation.

- Neutrons scattering is also very helpful in other areas such as structural biology, chemistry.