Introduction to Neutron Scattering and Description of ORNL Facilities

Wenbin Wang

Instructor Dagotto

Advanced Solid State Physics II (homework project)

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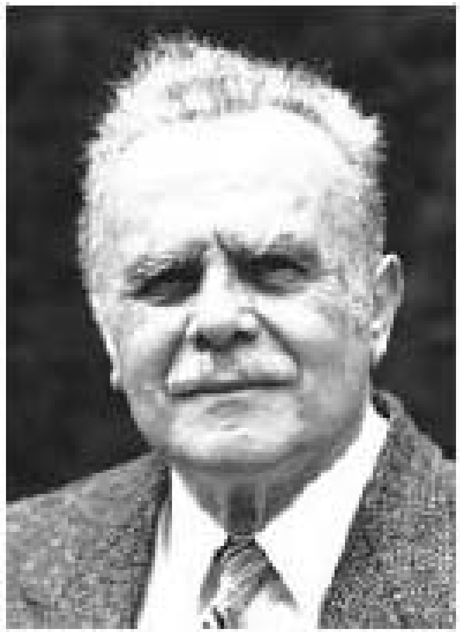
Outline

- Brief Introduce of Neutron Science
- The Advantages of Neutron Scattering

- The Principles of Neutron Scattering
  1. Elastic and Inelastic Neutron Scattering
  2. Basic theory of Neutron Scattering

- Facilities of Neutron Scattering in ORNL
  1. How to Get Neutrons
  2. Facilities
- Conclusion

The Nobel Prize in Physics 1994

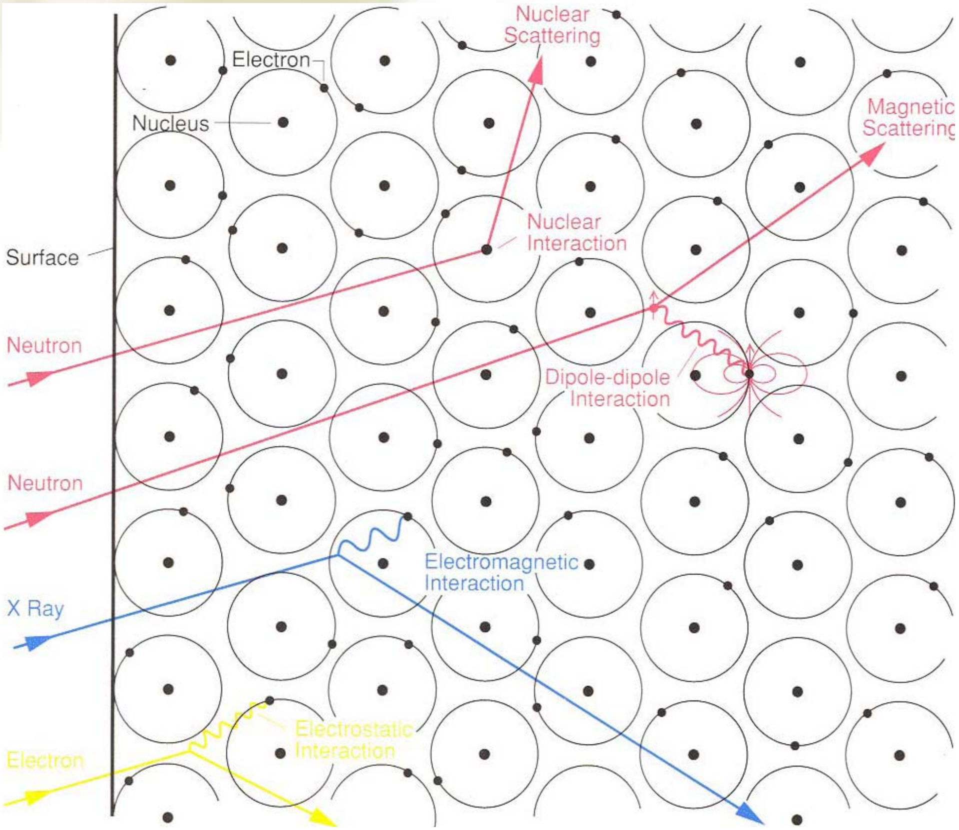


Bertram N. Brockhouse

Clifford G. Shull

neutrons see where atoms are and what they do

Why neutrons??

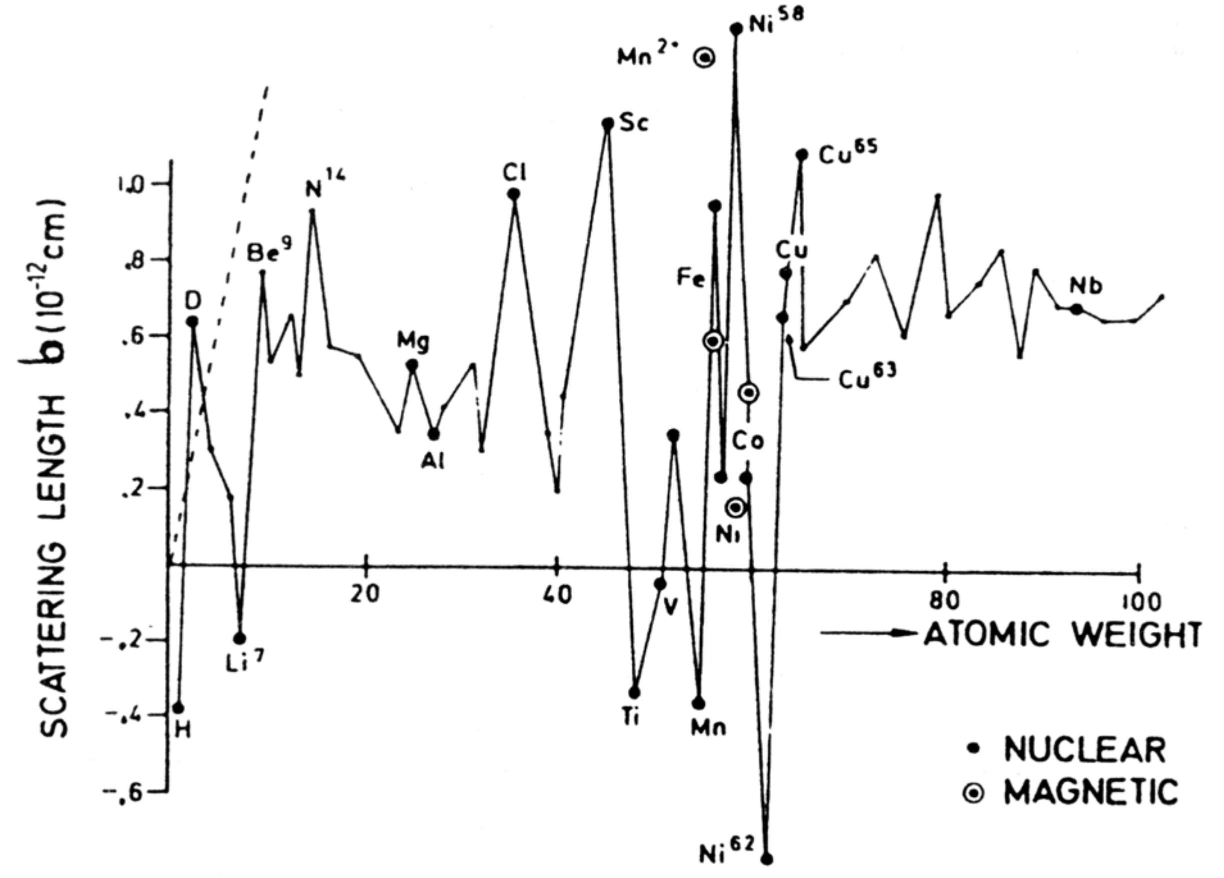


- Neutrons have No Charge!
- Neutrons can probe Nuclei!
- Light atom sensitive
- Sensitive to isotopic substitution

Isotopic Contrast for Neutrons

Hydrogen Isotope	Scattering Length b (fm)
^{1}H	-3.7409 (11)
^{2}D	6.674 (6)
^{3}T	4.792 (27)

Nickel Isotope	Scattering Lengths b (fm)
^{58}Ni	15.0 (5)
^{60}Ni	2.8 (1)
^{61}Ni	7.60 (6)
^{62}Ni	-8.7 (2)
^{64}Ni	-0.38 (7)



- variation of the scattering lengths for the different elements

Other advantages

- Highly penetrating: study bulk samples; Can be used in extremes
- Neutrons have a Magnetic Moment: studying magnetic order , magnetic structure in materials
- Nondestructive: used for a sensitive, nondestructive study

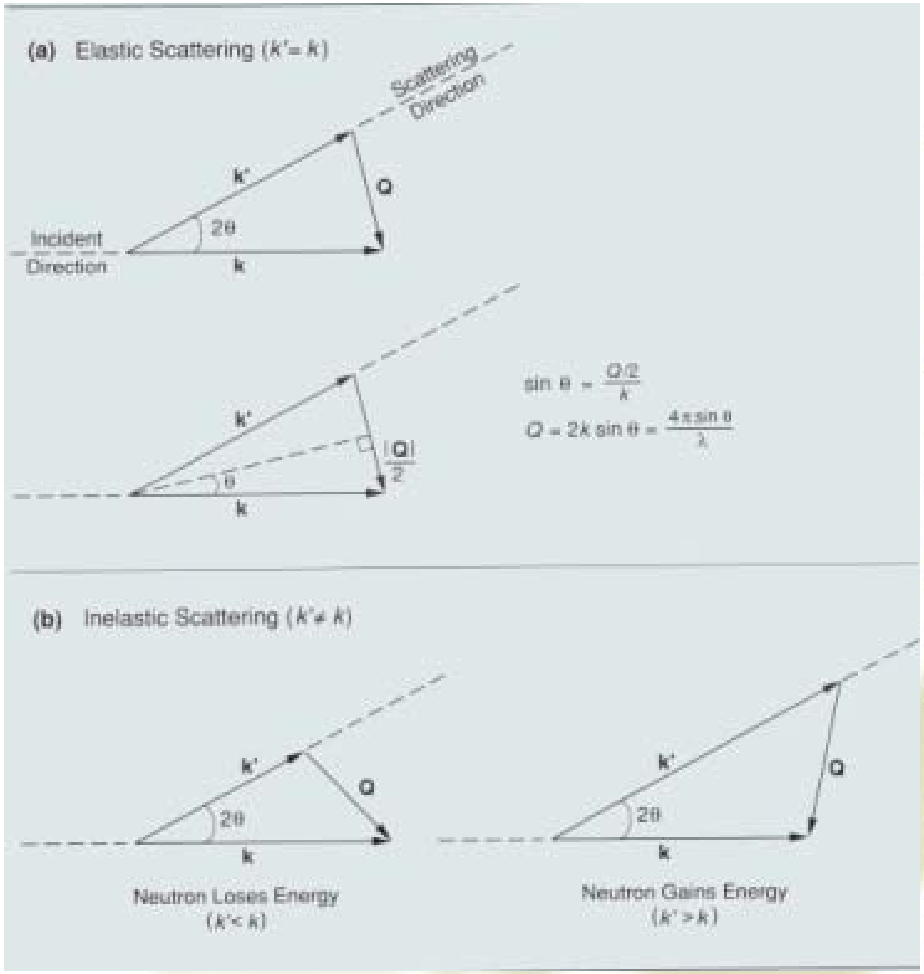
What is neutron scattering?

Elastic Neutron Scattering

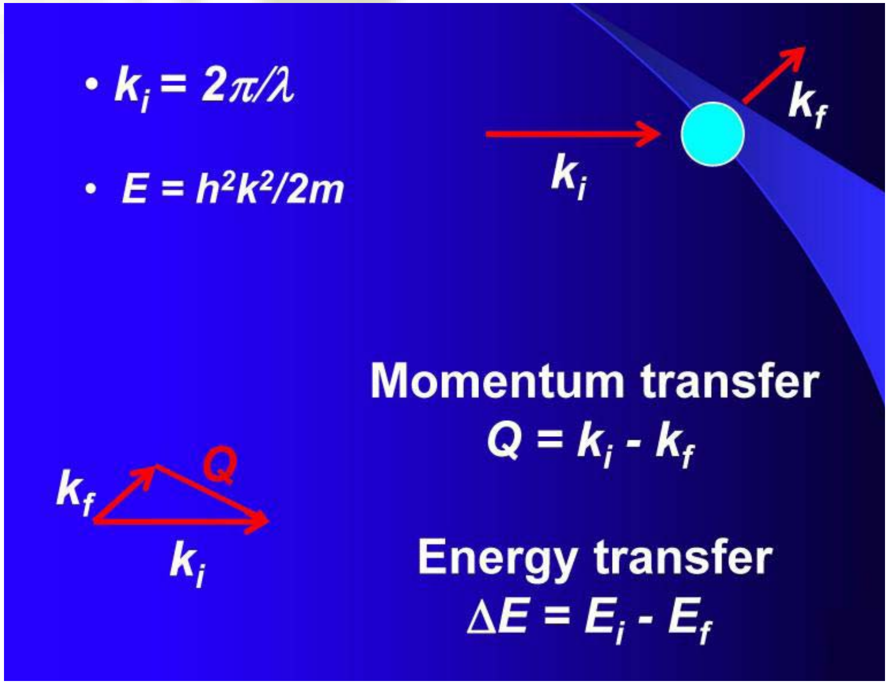
- No loss of energy
- Momentum and angle of the neutrons will change.

Inelastic Neutron Scattering

- Examines both momentum and energy dependencies.



Basic function of Neutron Scattering



- The magnitudes of the Q is determined by the differences between incident wave vector and scared wave vector of the neutrons
- E is the energy of the neutrons changed during the scattering

Scattering Law

- The actual interaction between a neutron and a nucleus replaced by pseudo-potential.
- The probability of an incident plane being scattered by V(r) is proportional to:

$$\left|\int e^{ik\cdot r} V(r) e^{-ik'\cdot r} d^3 r\right|^2 = \left|\int e^{iQ\cdot r} V(r) d^3 r\right|^2$$

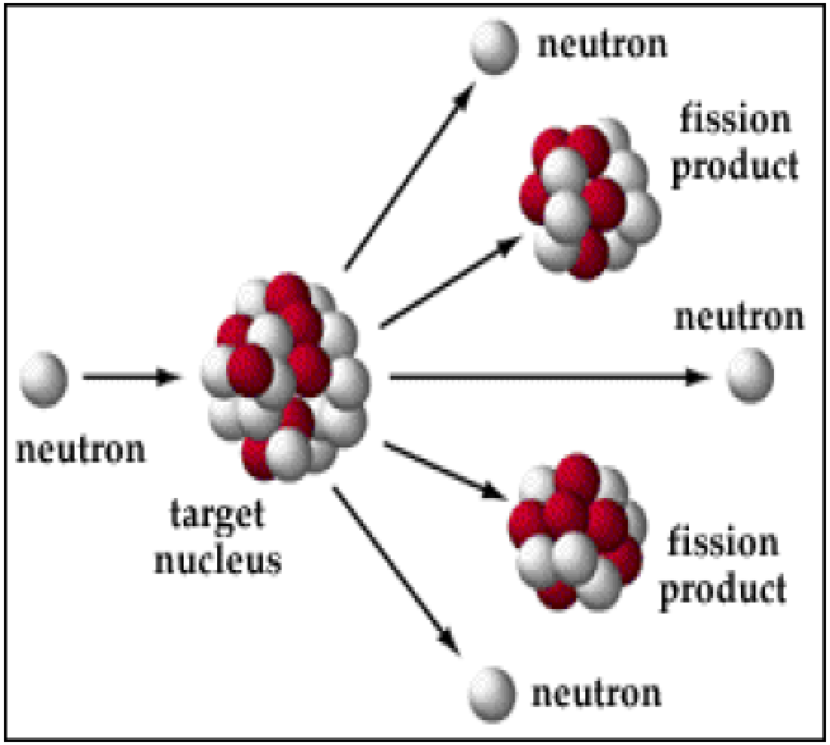
- For assembly of nuclei, the potential is the sum of individual neutron-nuclei interactions:

$$V(r) = \sum_j b_j \delta(r - r_j)$$

- The scattering intensity I:

$$I(Q,\varepsilon) = \frac{1}{h}\frac{k'}{k}\sum_{j,k} b_j b_k \int_{-\infty}^{\infty} \left\langle e^{-iQ\cdot r_k(0)} e^{iQ\cdot r_j(t)} \right\rangle e^{-i\varepsilon t} dt$$

Reactor Sources



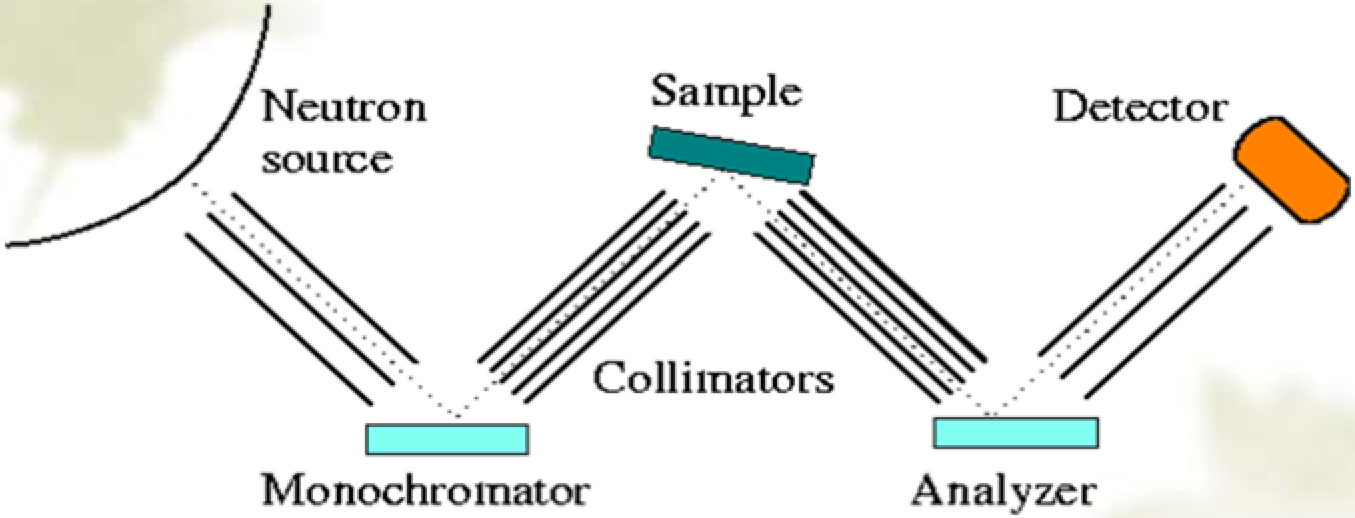
- Uses nucleus fission of U-235 in a chain reaction to create neutrons
- Continuous neutron flux
- Flux is dependent on fission rate
- Create some other isotopes
- Creates radioactive nuclear waste

Cold neutrons

Neutrons must be “cool down” before used for scattering experiment

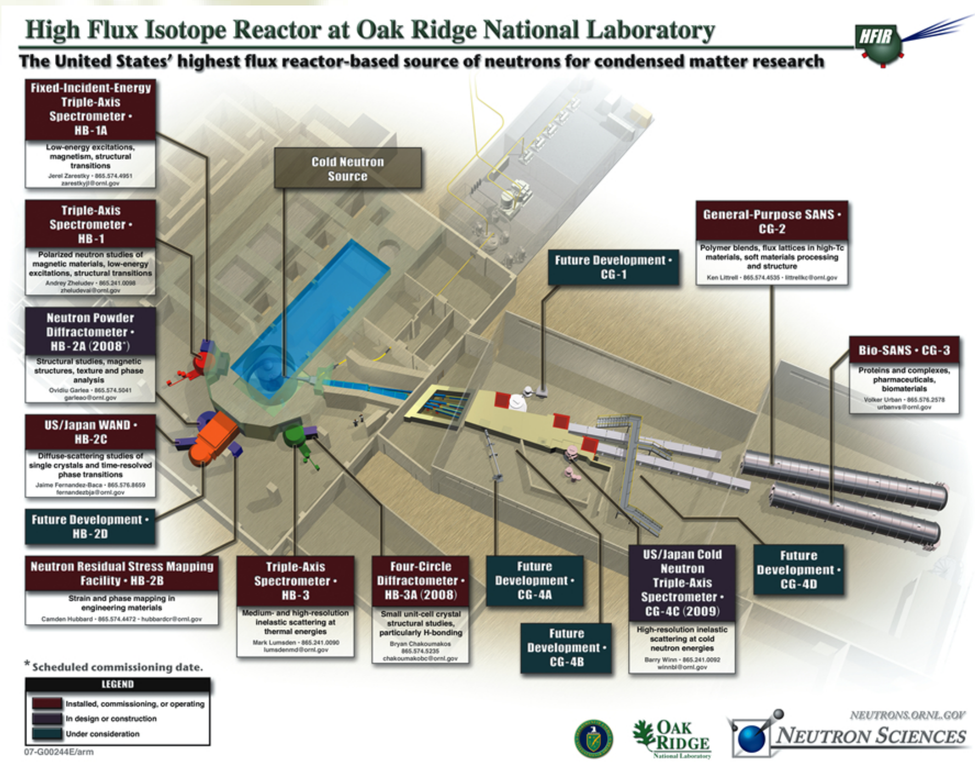
- Neutron wavelength are too short to investigation condensed matter
- High energy tend to damage solids by knocking atoms out of their official position
- Cooling is done by bring neutrons in to thermal equilibrium

triple-axis spectrometer



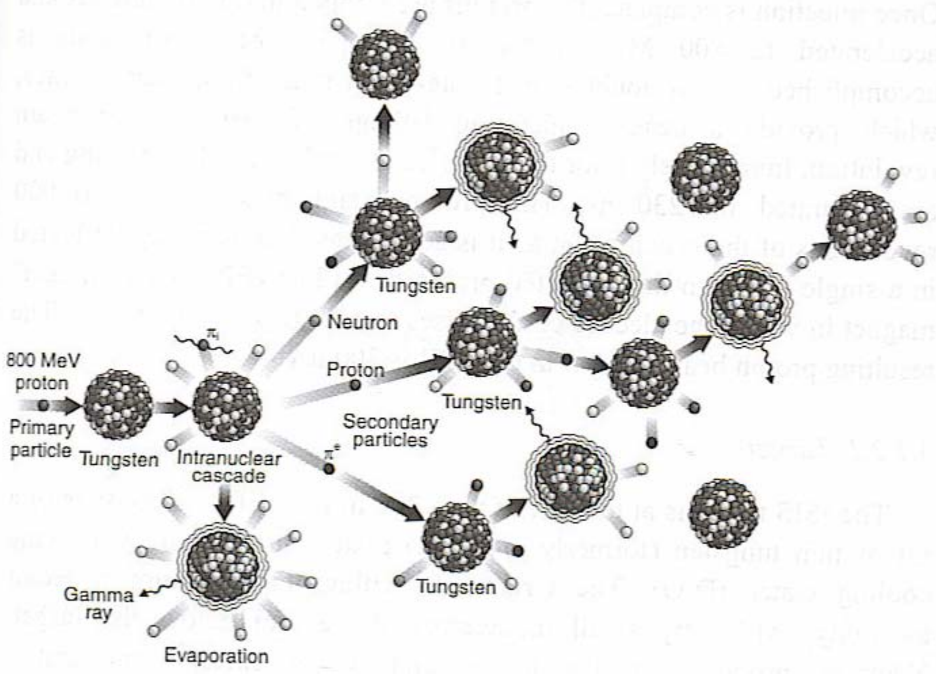
- The monochromator
- The sample
- The analyzer

HFIR (High Flux Isotope Reactor)



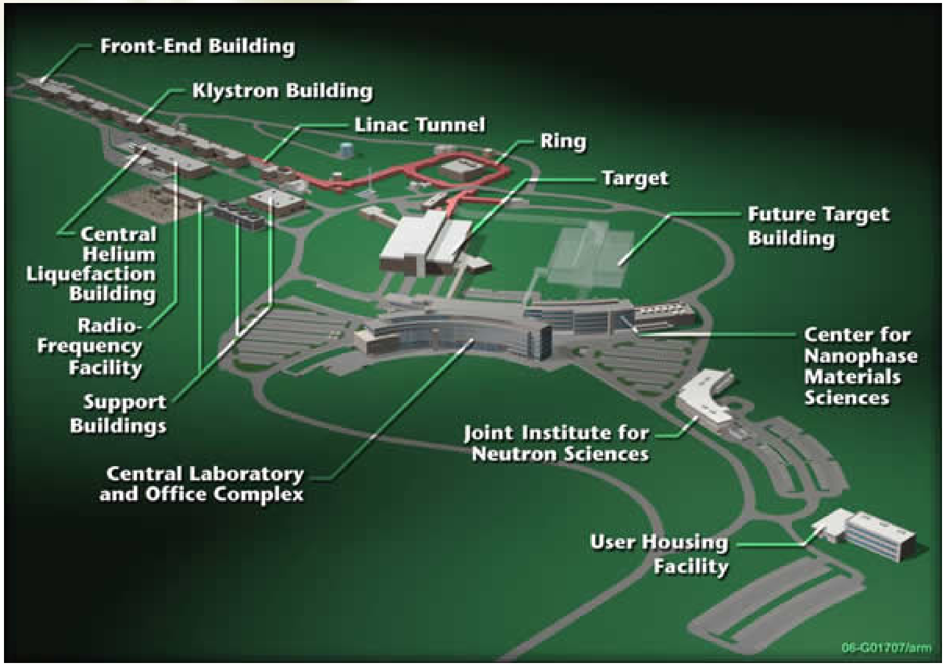
- Use reactor-based source
- provides one of the highest steady-state neutron fluxes of any research reactor in the world

Spallation Sources



- Uses a cascade effect from the collision of a proton on a heavy metal.
- Pulsed Source
- High Intensity
- Heat production is relatively low

SNS (Spallation Neutron Source)



- provide spallation source
- more powerful than the most intense existing pulsed (non-fission) spallation source

Conclusion

- Study structure and dynamics of the high temperature superconductors
- biologist use this advance method to study the interaction between proteins and the genetic material of viruses
- use it to clarification of still unknown phenomena in processes such as recharging of electric batteries

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