A Short History of Neutron & X-ray Scattering

by

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Our culture depends on materials

- Material properties depend on structure at multiple length scales and time scales
- Designing new & better materials depends on mastering complex synthesis & understanding the relationship between structure/dynamics and material properties
- X-rays and neutrons provide two important tools for probing materials structure & its variations with time (dynamics).

Wilhelm Conrad Röntgen 1845-1923

EINE NEUE ART

VON

STRAHLEN.

VON

DR. W. RÖNTGEN,

Ö. O. PROFESSOR AN DER K. UNIVERSITÄT WÜRZBURG.

WÜRZBURG.

VERLAG UND DRUCK DER STAHEL'SCHEN K. HOF- UND UNIVERSITÄTS-
BUCH- UND KUNSTHANDLUNG.

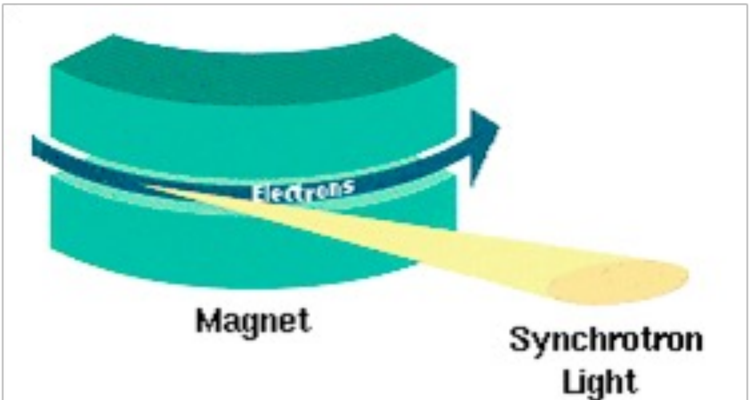
Ende 1895.

60 ₰.

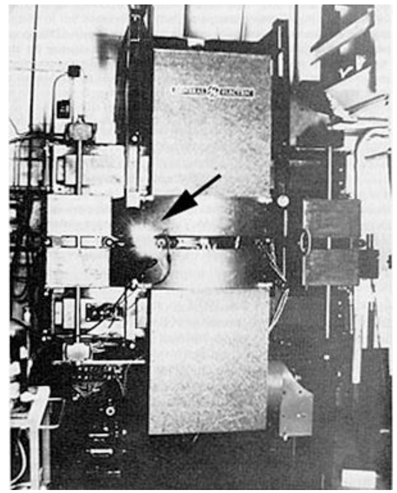
1895: Discovery of X-Rays

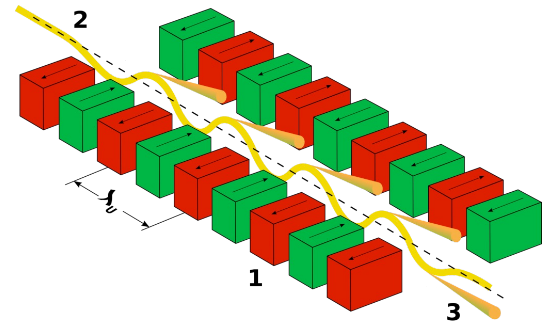
Synchrotron Radiation

- Produced when charged particles (electrons, positrons) accelerate perpendicular to their velocity



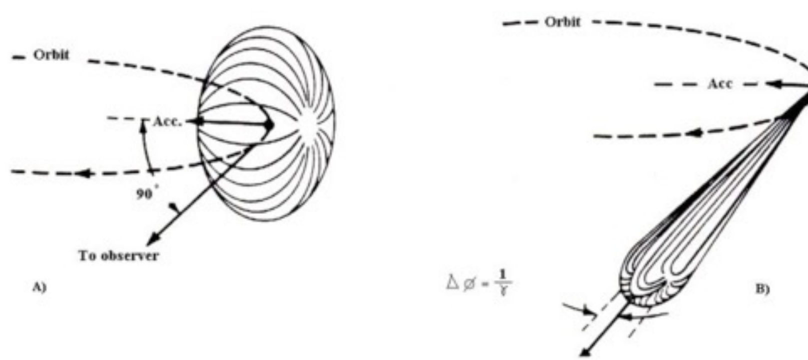
Bending magnet





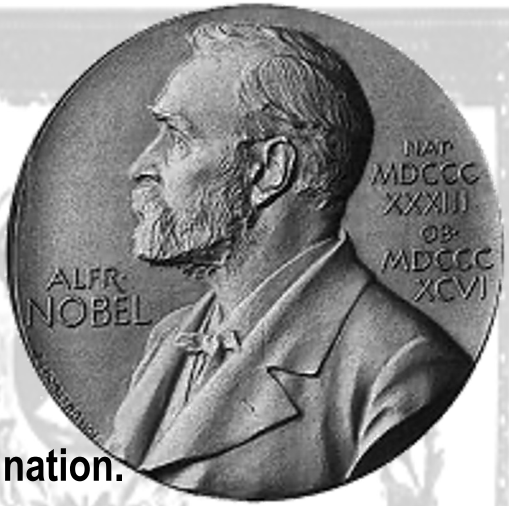
Undulator or Wiggler

- Discovered in 1946 using GE synchrotron. Emitted in forward cone with small divergence. Polarized



- Watson and Perlman;Science 1978 Mar 24;199(4335):1295-302: Seeing with a new light: synchrotron radiation

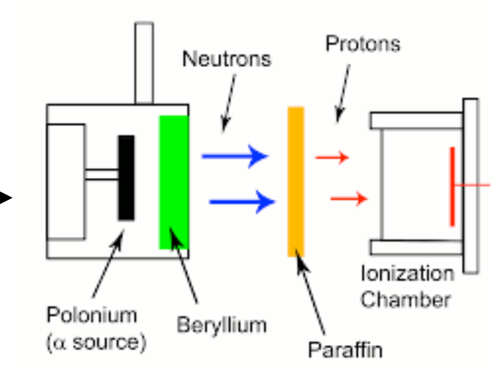
Nobel Prizes for Research with X-Rays



1901 W. C. Röntgen in Physics for the discovery of x-rays.
1914 M. von Laue in Physics for x-ray diffraction from crystals.
1915 W. H. Bragg and W. L. Bragg in Physics for crystal structure determination.
1917 C. G. Barkla in Physics for characteristic radiation of elements.
1924 K. M. G. Siegbahn in Physics for x-ray spectroscopy.
1927 A. H. Compton in Physics for scattering of x-rays by electrons.
1936 P. Debye in Chemistry for diffraction of x-rays and electrons in gases.
1962 M. Perutz and J. Kendrew in Chemistry for the structure of hemoglobin.
1962 J. Watson, M. Wilkins, and F. Crick in Medicine for the structure of DNA.
1979 A. McLeod Cormack and G. Newbold Hounsfield in Medicine for computed axial tomography.
1981 K. M. Siegbahn in Physics for high resolution electron spectroscopy.
1985 H. Hauptman and J. Karle in Chemistry for direct methods to determine x-ray structures.
1988 J. Deisenhofer, R. Huber, and H. Michel in Chemistry for the structures of proteins that are crucial to photosynthesis.
2006 R. Kornberg in Chemistry for studies of the molecular basis of eukaryotic transcription.
2009 V.Ramakrishnan, T.A.Steitz and A.E.Yonath for studies of the structure and function of the ribosome.
2010 A. Geim & K. Novoselov for graphene

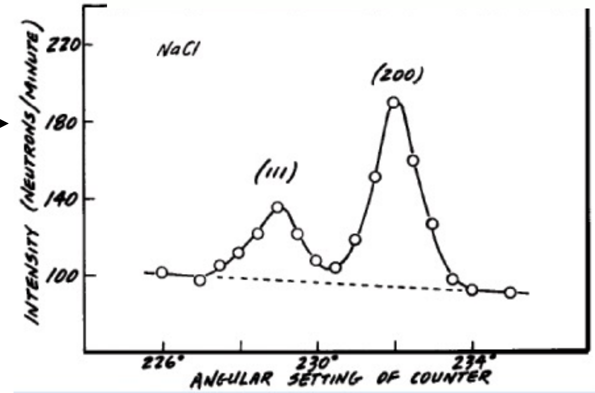
Some Neutron History

- 1932 – Chadwick discovers the neutron



- 1934 – thermalisation (Fermi)
- 1936 – scattering theory (Breit, Wigner)
- 1936 – wave interference (Mitchell, Powers)
- 1939 – fission

- 1945 – diffraction (Shull, Wollan), reflection, refraction



- 1948 – coherent & incoherent scattering (Shull, Wollan)
- 1948 – spallation
- 1949 – structure of AFM (Shull)

- 1951 – polarized neutrons (Shull & Wollan)
- 1955 – three axis spectrometer (Brockhouse)
- 1958 – rotons in helium (Palevsky, Otnes, Larsson)

- 1962 – Kohn anomalies
- 1960 – 79 – soft phonons & structural phase transitions
- 1969 – 79 – scaling and universality

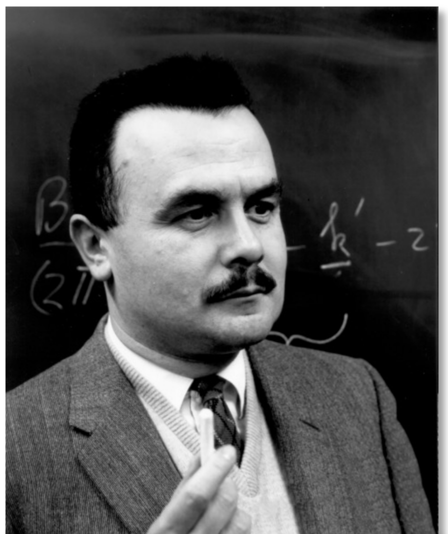
- 1972 – conformation of polymers
-
- 1994 – Nobel Prize for Shull and Brockhouse

Cliff Shull (1915 – 2001)

Nobel Prize in Physics, 1994

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

Bertram N. Brockhouse



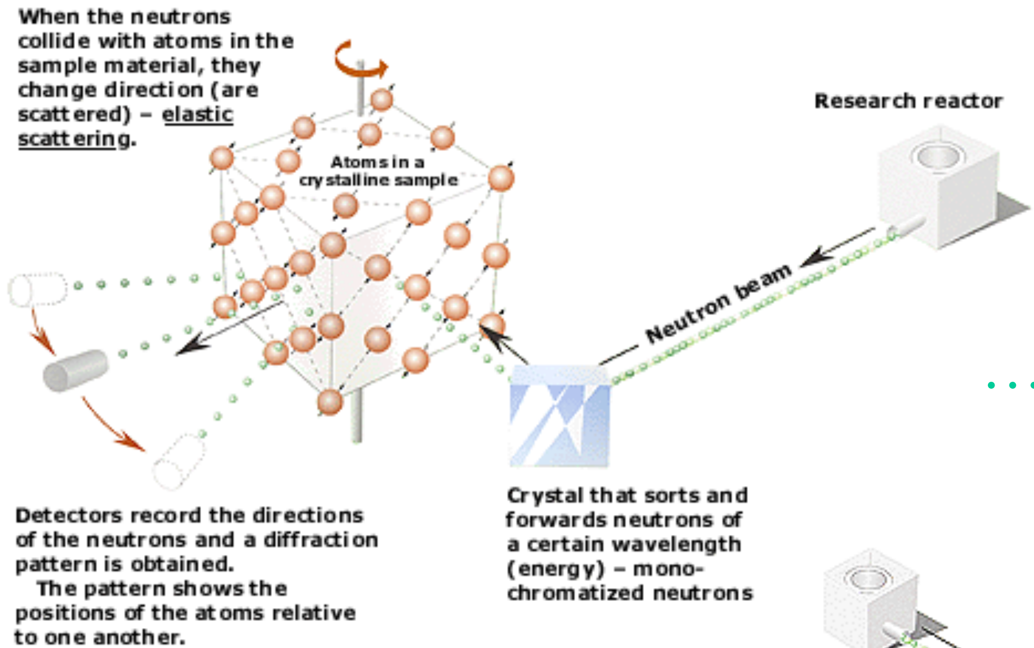
Development of neutron spectroscopy

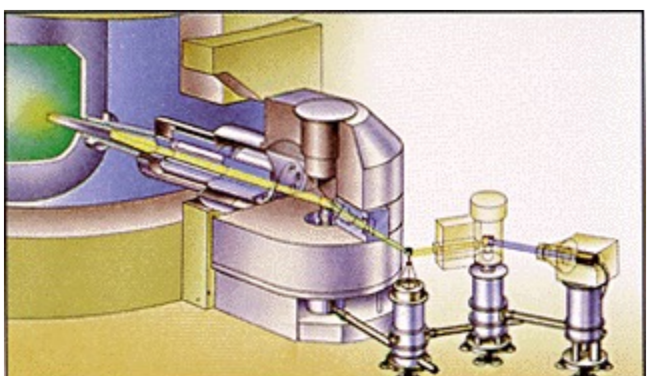
Clifford G. Shull

Development of the neutron diffraction technique

The 1994 Nobel Prize in Physics – Shull & Brockhouse

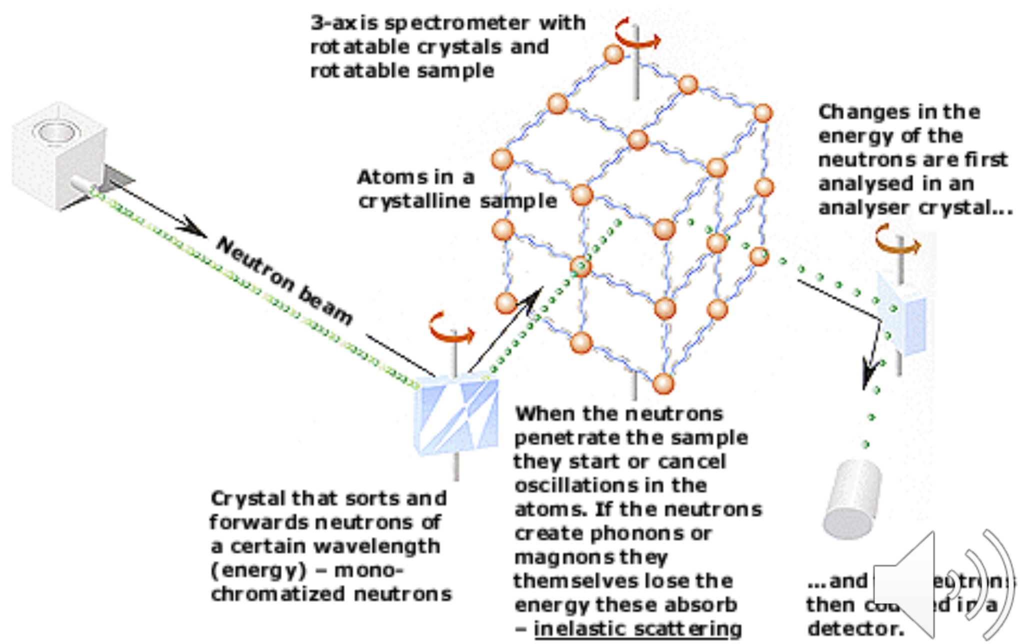
Neutrons show where the atoms are….





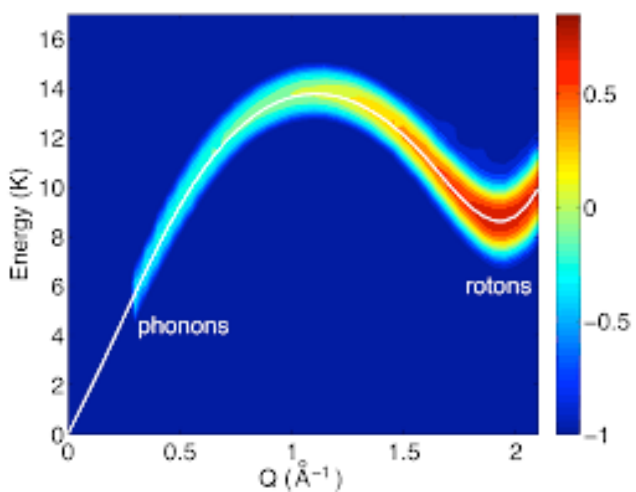
3-axis spectrometer

…and what the atoms do.



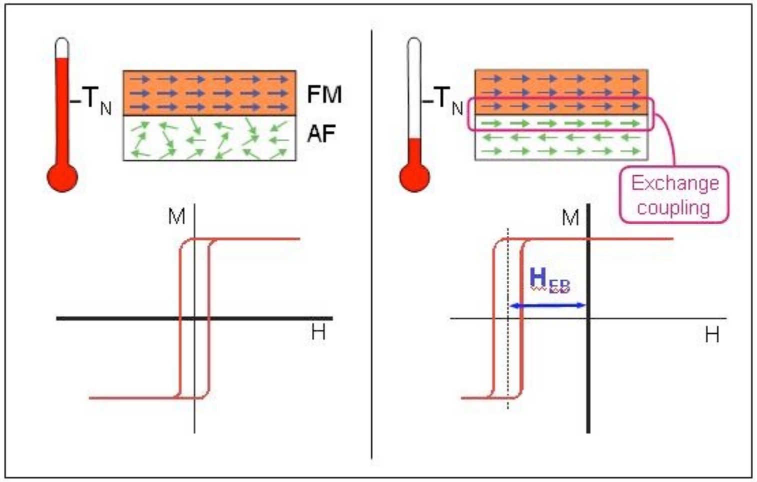
Historic accomplishments (Neutrons)

- *Antiferromagnetic Structures*
- Rare earth spirals and other spin structures
- Spin wave dispersion (FM and AFM)
- Our whole understanding of the details of exchange interactions in solids
- Magnetism and Superconductivity
- Phonon dispersion curves in crystals and anharmonicity
- Crystal fields
- Excitations in normal liquids
- *Rotons in superfluid helium*
- Condensate fraction in helium



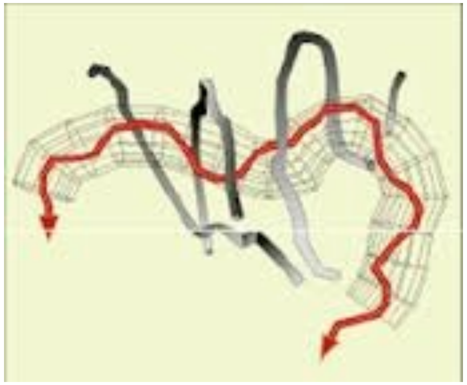
Recent Applications of Neutrons

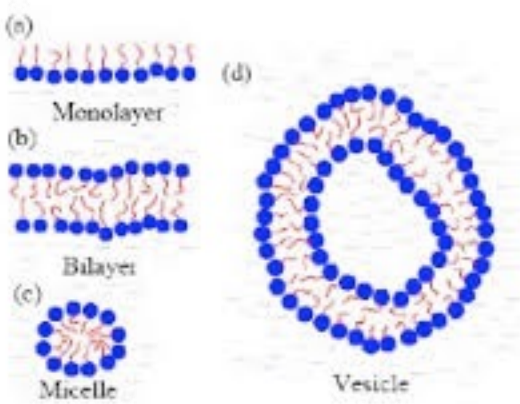
- Quantum Phase Transitions and Critical points
- Magnetic order and magnetic fluctuations in the high-Tc cuprates
- Gaps and low-lying excitations (including phonons) in High-Tc
- Magnetic Order and spin fluctuations in highly-correlated systems
- Manganites
- Magnetic nanodot/antidot arrays
- *Exchange bias*
- Protein dynamics
- Glass transition in polymer films
- Boson peaks in glasses
- Protonation states in biological macromolecules from nuclear density maps

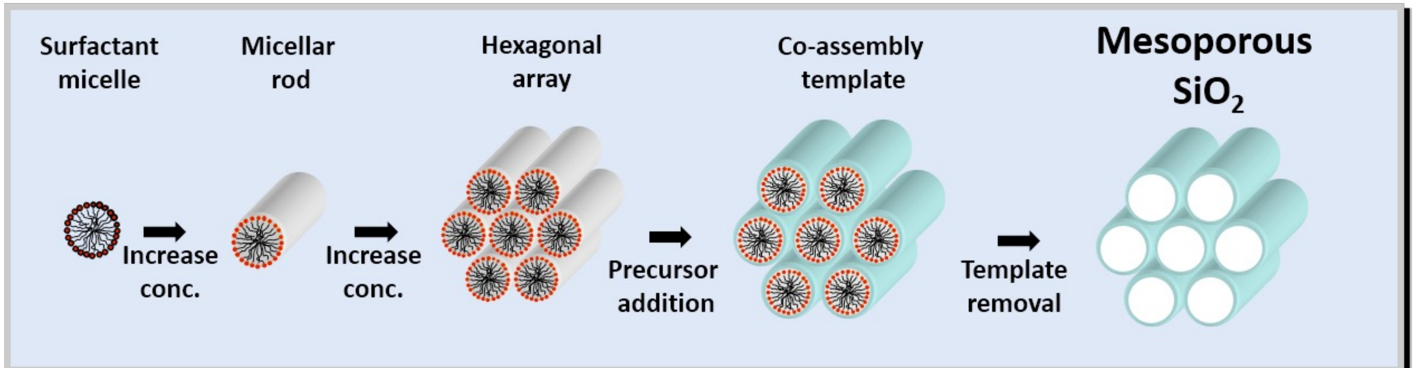


Neutron Applications to "large" structures

- Scaling Theory of polymers
- *Reptation in Polymers*
- Alpha and beta relaxation in glasses
- *Structures of surfactants and membranes*
- Structure of Ribozome
- Momentum Distributions
- Materials—precipitates, steels, cement, etc.
- Excitations and Phase transitions in confined Systems (phase separation in Vycor glass; Ripplons in superfluid He films, etc.)



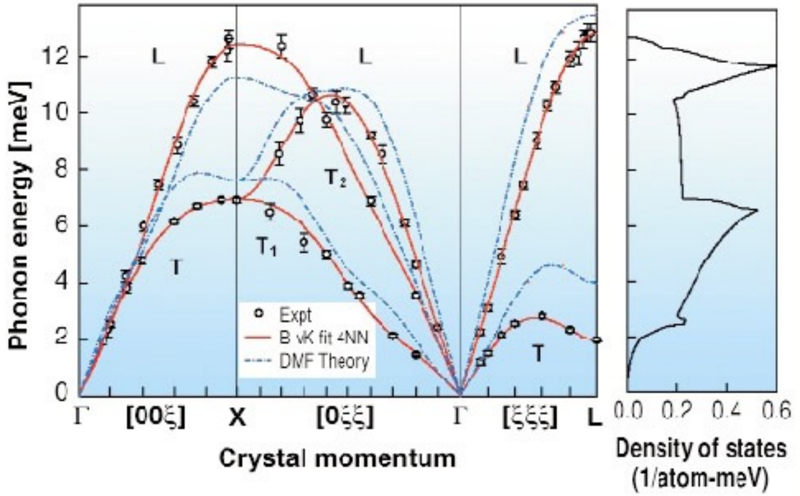




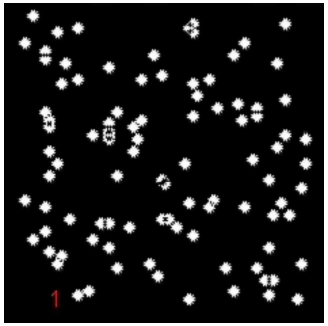
Science with X-Rays

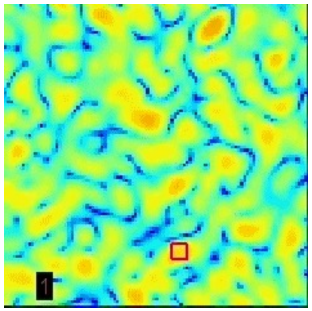
- Diffraction and crystal structures
- Structure Factors of liquids and glasses
- Surface and Interface structures
- Structures of Thin Films
- ARPES
- EXAFS, XANES
- Studies of Magnetism with resonant XM
- *Inelastic X-ray scattering: phonons, electronic excitations*
- Imaging/Tomography with very high spatial resolution
- Microscopy
- *X-ray photon correlation spectroscopy*

Plutonium phonons

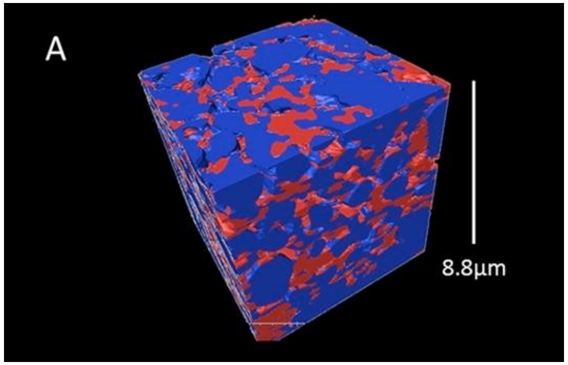


http://sinhagroup.ucsd.edu/Research_XPCS.htm

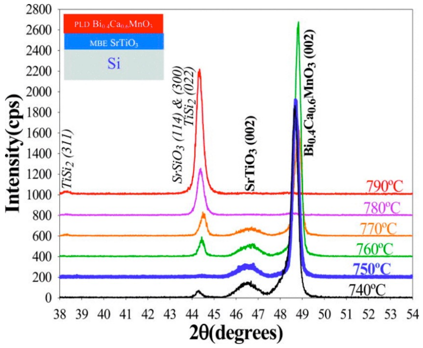




Microstructure of battery electrodes



Applications of X-rays to Surface/Interface Scattering



- study the morphology of surface and interface roughness
- wetting films
- film growth exponents
- capillary waves on liquid surfaces (polymers, microemulsions, liquid metals, etc.)
- islands on block copolymer films
- pitting corrosion
- magnetic roughness
- study the morphology of magnetic domains in magnetic films.
- Nanodot arrays
- Tribology, Adhesion, Electrodeposition