Lecture 2. Neutron Instruments

Basically two kinds of instrument –

Diffractometers

– neutron wave properties used
based on Bragg's law
no change of energy detected

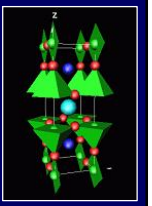
Spectrometers

– neutron particle properties used
based on Newton's laws
change of energy detected

Neutrons are beautiful !

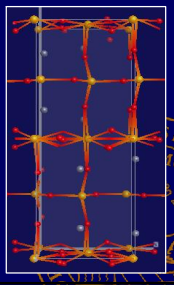
Wave Particle Magnetic moment Neutral



Diffractometers - Measure structures
– neutron wave properties used
1 - 10 Ångstrom based on Bragg's law
no change of energy detected

Spectrometers - Measure dynamics
– neutron particle properties used
1 - 80 meV based on Newton's laws
change of energy detected



Diffractometers - no change of energy detected

1 Powder Diffractometers

Debye & Scherrer (1916)

Powder Diffraction

$$\text{Bragg's Law } \lambda = 2d \sin\theta$$

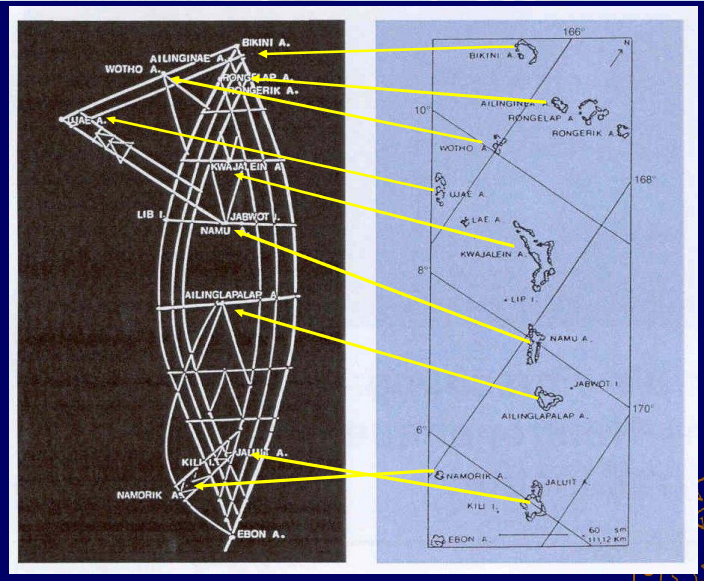
2 Single Crystal Diffractometers

Von Laue (1910)

Single Crystal Diffraction

Max von Laue

Waves tell you where things are - Marshall Islands



Basically, two kinds of diffractometer –

a. Monochromatic incident beam

Measure intensity as a function of scattering angle

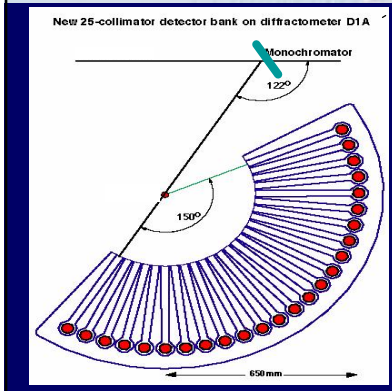
b. White incident beam - time of flight

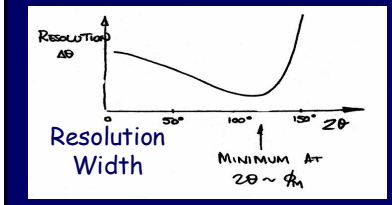
Measure intensity as a function of neutron wavelength

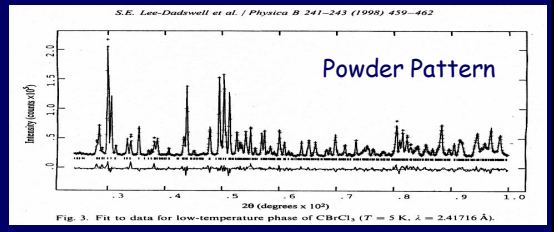
Bragg's Law $\lambda = 2d \sin \theta$

$\lambda = h/mv$ de Broglie's relation

a. The monochromatic beam method

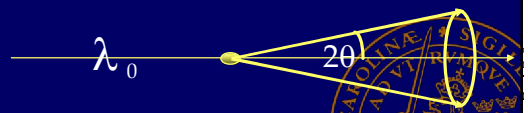




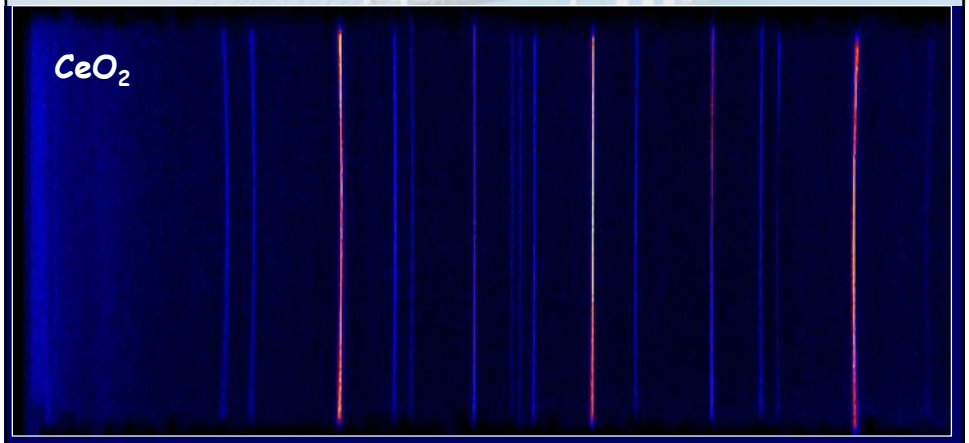


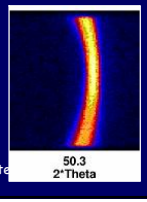
d spacing Å

The Debye-Scherrer cone

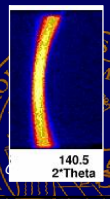


Powder Diffractometer with Position Sensitive Detectors



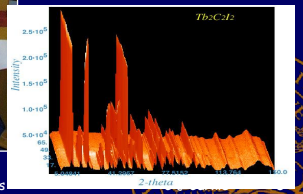


The Debye-Scherrer cones

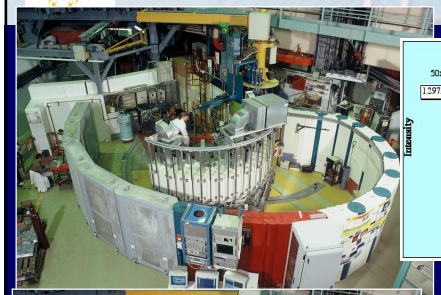


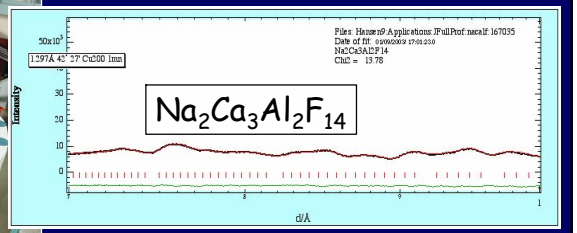
The D20 high intensity powder diffractometer

Kremer & Ouladdiaf
40 temperatures
90 minutes

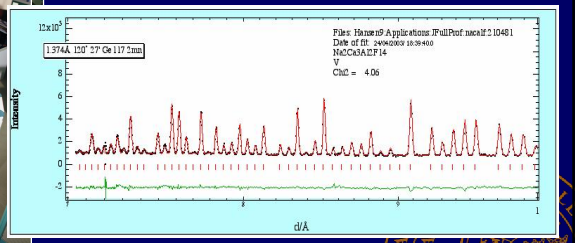


Small changes can have significant effects

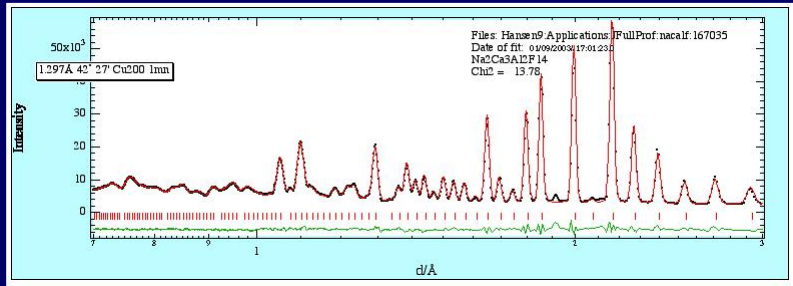


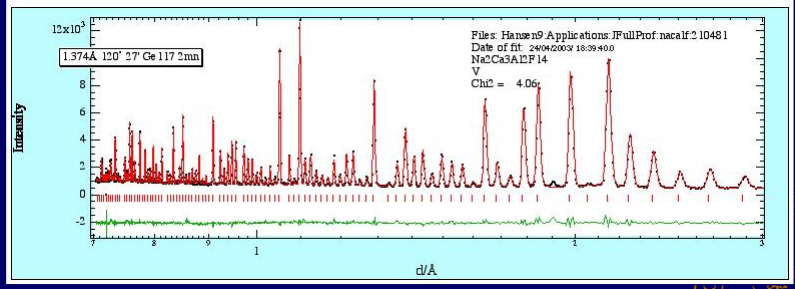


$Na_2Ca_3Al_2F_{14}$

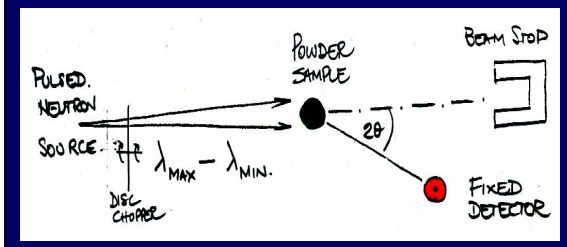


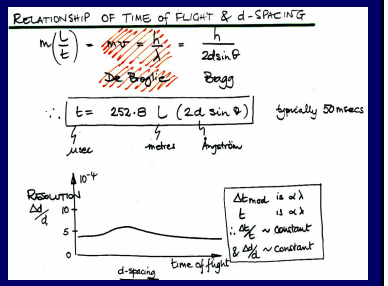
Small changes can have significant effects





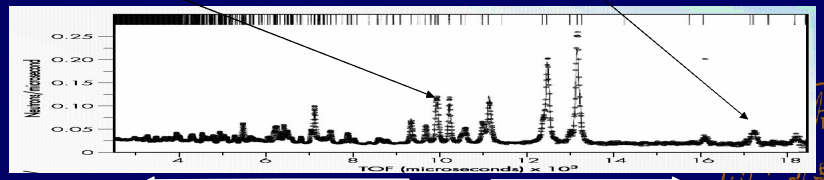
b. The white beam method – time of flight





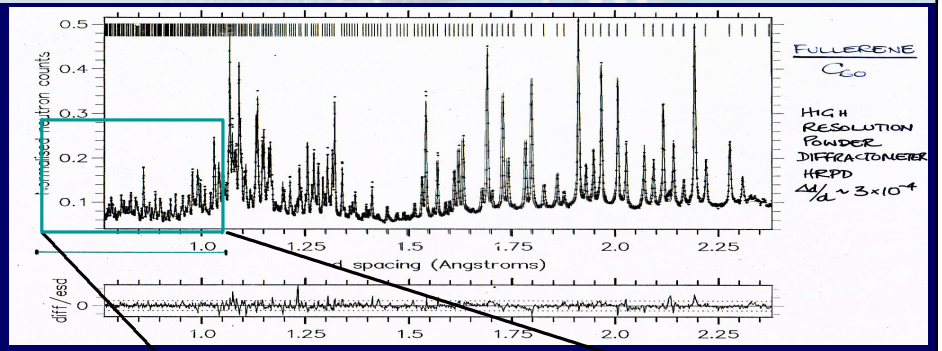
Intensity - content of unit cell

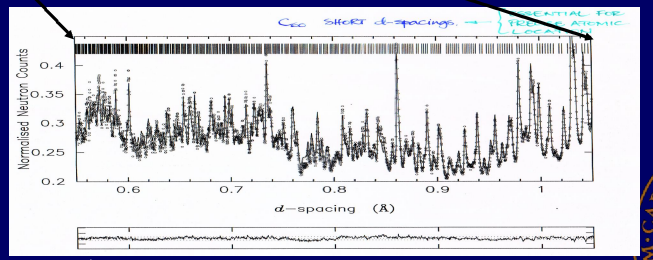
d spacing - shape & size of unit cell



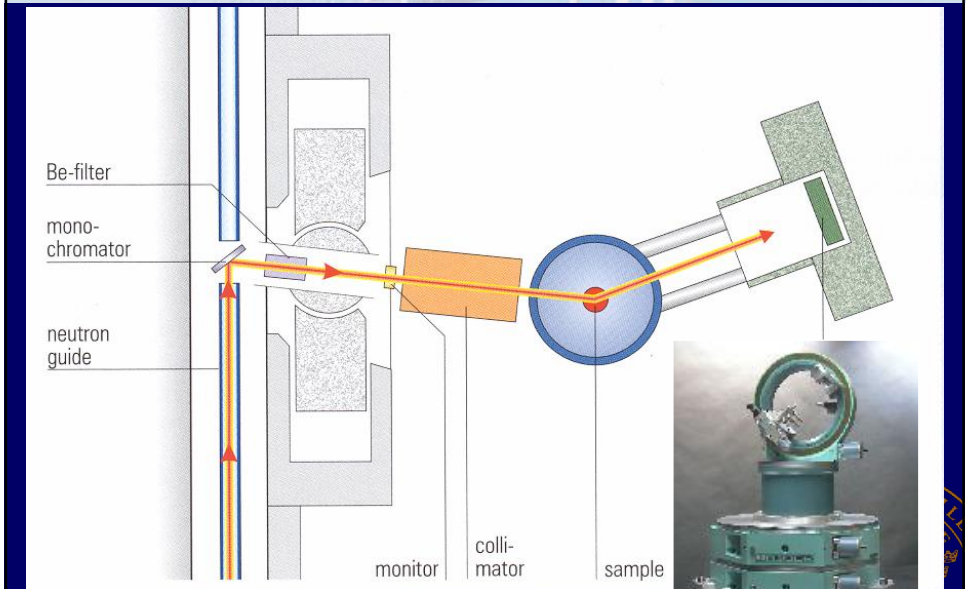
scattering angle 2θ — d spacing Å

Powder Diffraction from Fullerene C_{60}

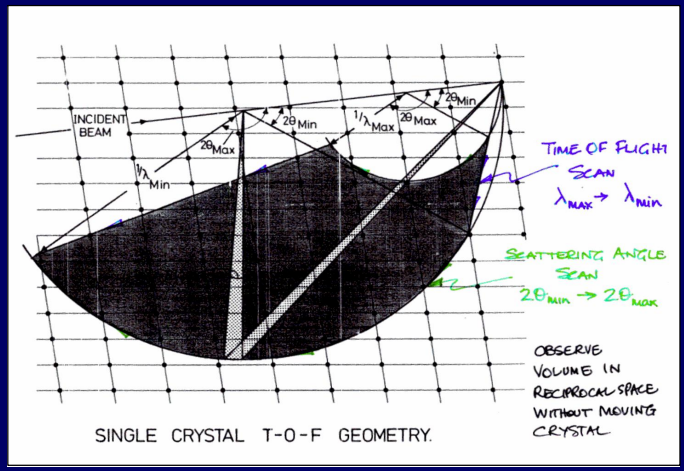




A basic single crystal Diffractometer



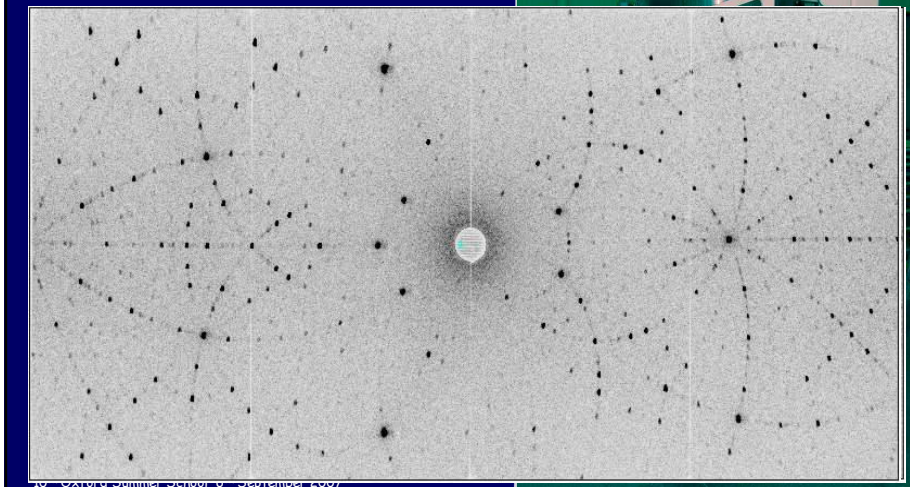
White Beam Single Crystal Diffraction



Scan in Scattering Angle and in incident wavelength gives 2-D data set <u>simultaneously</u>

VIVALDI
5-fold symmetry of ZnMgY quasi-crystal

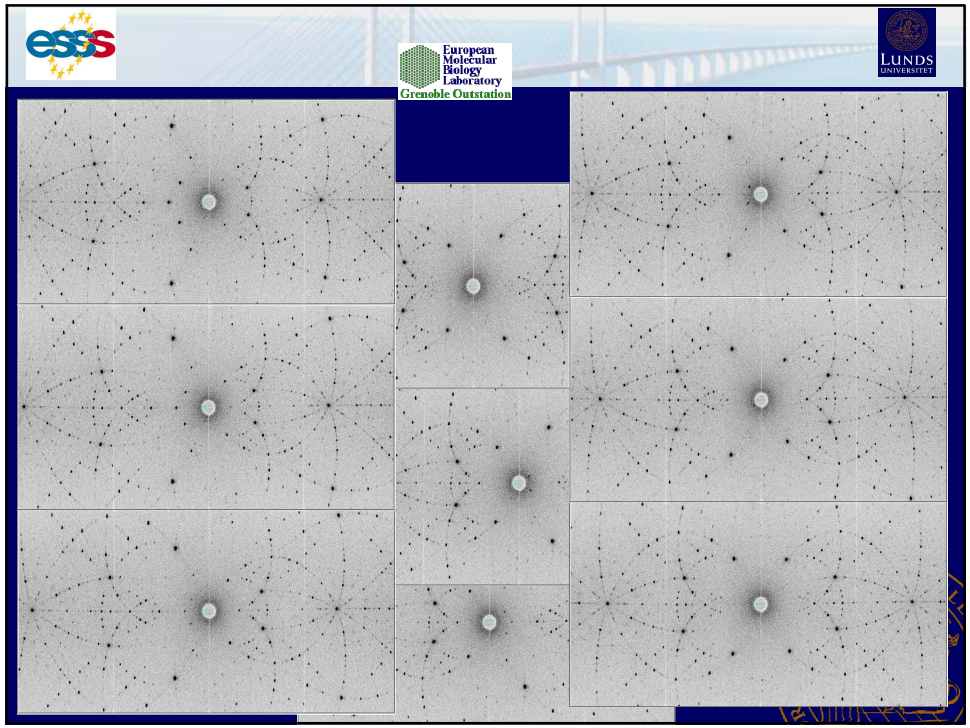
McIntyre, Cowan (1999)



VIVALDI
5-fold symmetry of ZnMgY quasi-crystal

McIntyre, Cowan (1999)

10th Oxford Summer School 6th September 2007



X-rays v. neutron scattering lengths

X-ray

Scattering proportional to Z

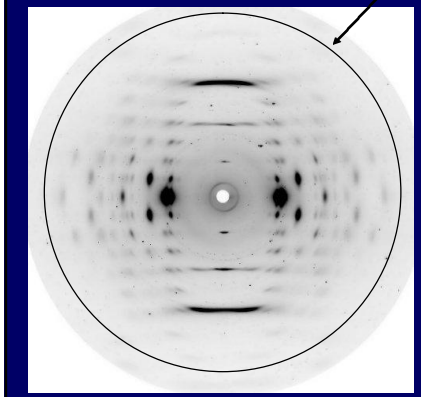
H	B	C	O	Al	Si	P	Ti	Fe
1	3	4	8	13	14	15	22	26

Neutron

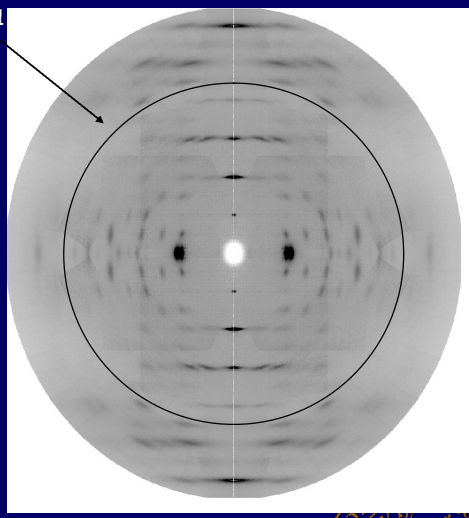
Scattering not proportional to Z

-3.74	5.30	6.65	5.80	3.45	4.15	5.13	-3.44	9.45

X-ray & neutron fibre diffraction data



Kevlar, x-ray data from APS λ = 0.8Å



Kevlar, neutron data from ILL Grenoble λ = 1.31Å

Trevor Forsyth

First Demonstration of Diffraction of Neutrons

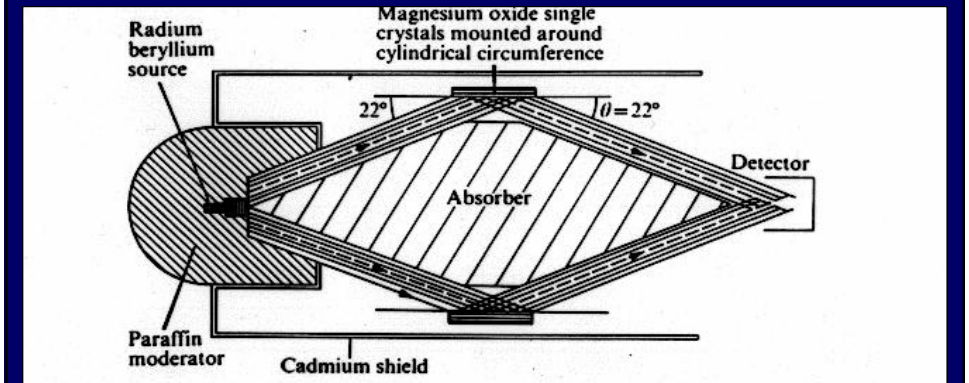


FIG. 1. Mitchell and Powers's apparatus for demonstrating the diffraction of neutrons. (After Mitchell and Powers 1936.)

Mitchell & Powers (1936)

3. Other Elastic Instruments

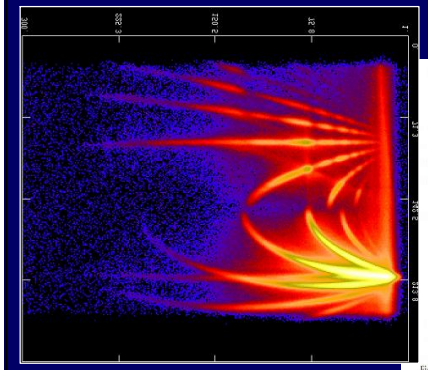
a. Reflectometers

b. Small Angle Scattering Instruments

c. Liquids & Amorphous Diffractometers

d. Interferometers

Time of Flight Reflectometers



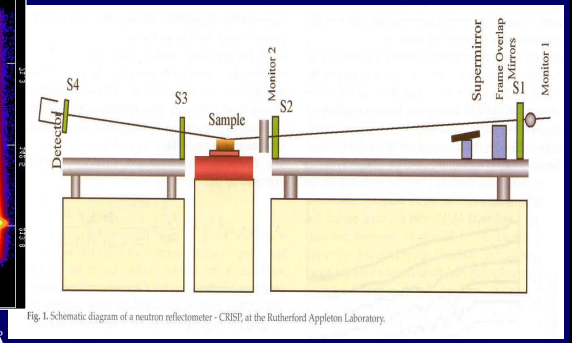


Fig. 1. Schematic diagram of a neutron reflectometer - CRISP, at the Rutherford Appleton Laboratory.

30Å ← 2Å

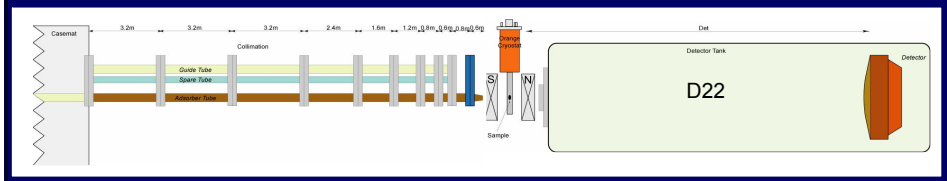
D17 at ILL

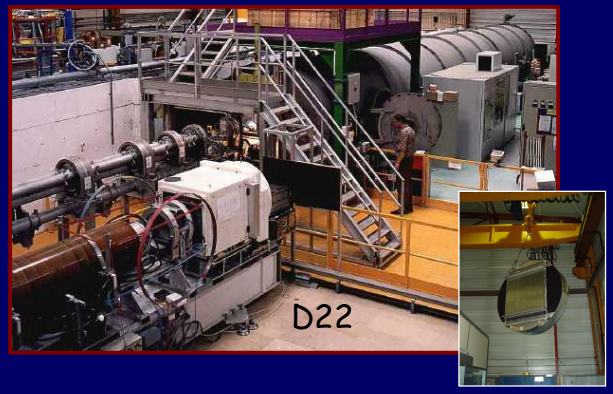
CRISP at ISIS

Supercooling of Co & Fe/Al metallic alloys

Cologne - Paris

Diffraction at Small Angle - SANS





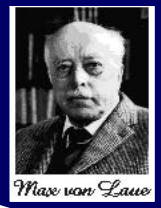
From Diffraction to Spectroscopy

Neutrons are beautiful!

Wave
Particle
Magnetic moment
Neutral

Diffraction

$\lambda = 2d \sin\theta$ Bragg's Law



Spectroscopy

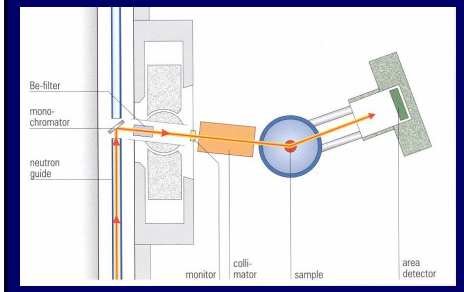
$\lambda = h/mv$
de Broglie's relation
$E = \frac{1}{2} mv^2$
$k = 2\pi/\lambda$

$h\omega = E_1 - E_2$ Energy Transfer

$hQ = hk_1 - hk_2$ Momentum Transfer

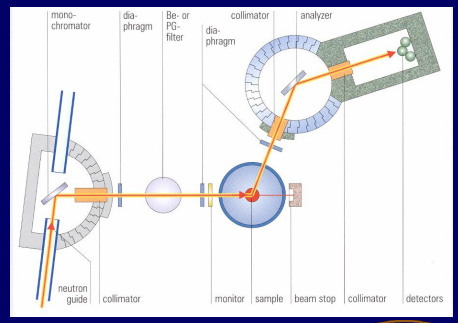
From Diffractometers to Spectrometers

Twin Axis Diffractometer



Diffraction

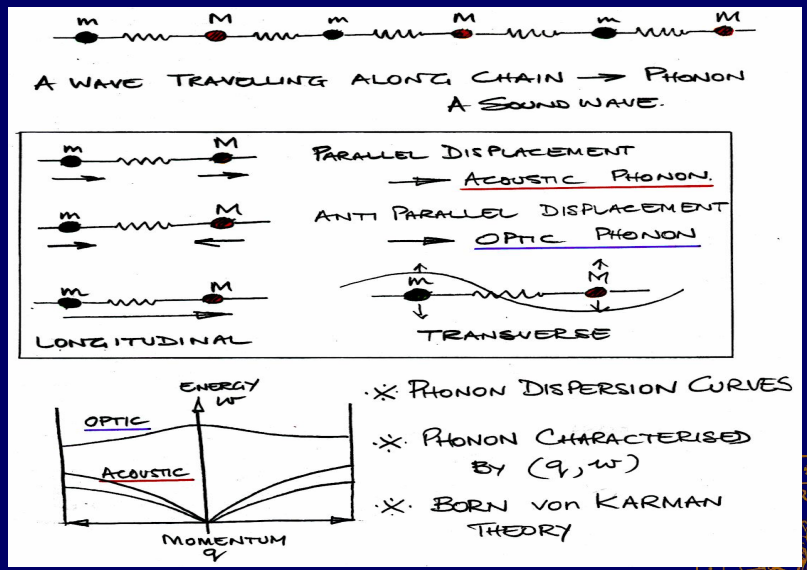
Spectroscopy



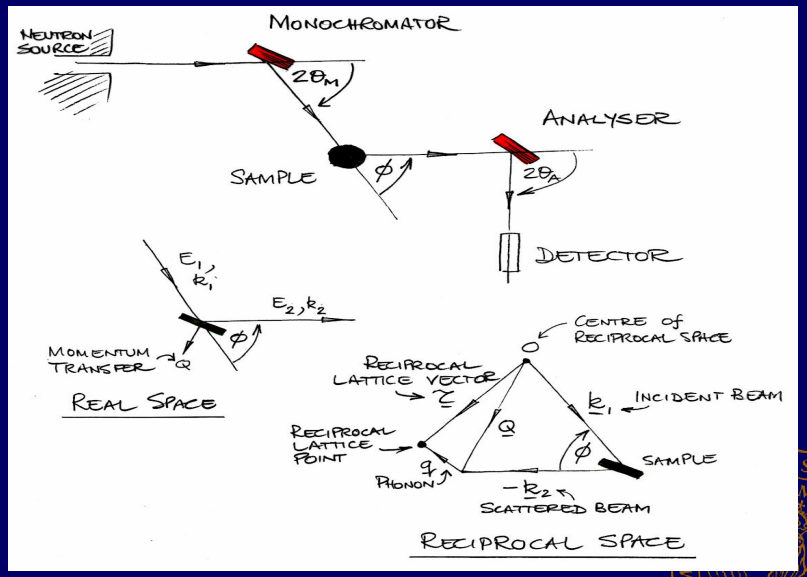
Triple Axis Spectrometer

So, what kinds of spectrometer are there ……?

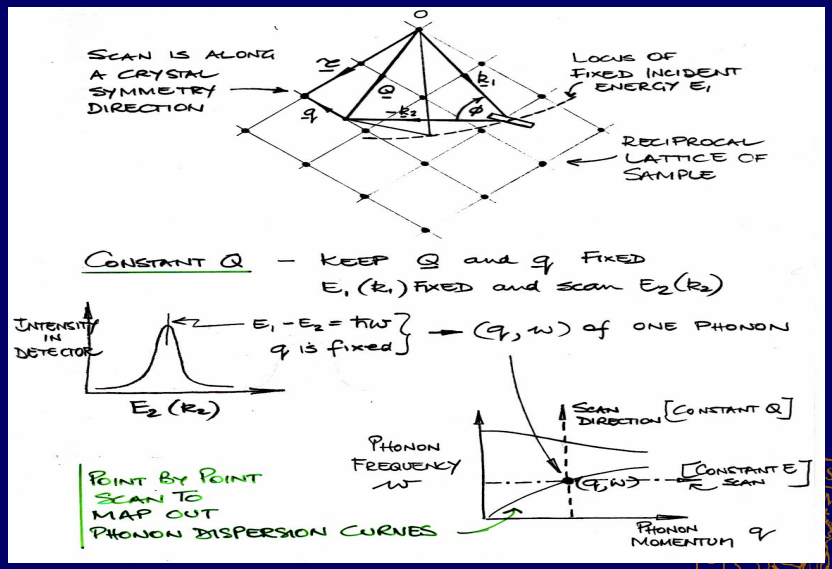
Coherent Excitations in Crystals - Phonons



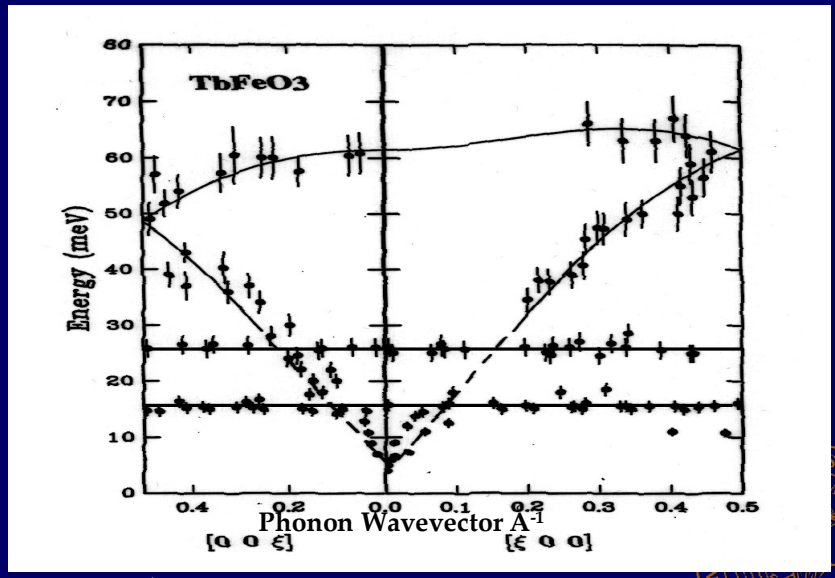
The Triple Axis Spectrometer



Measuring a Phonon Dispersion Curve

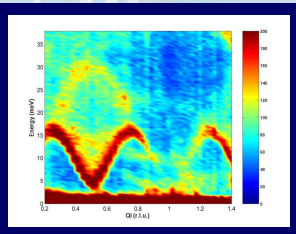


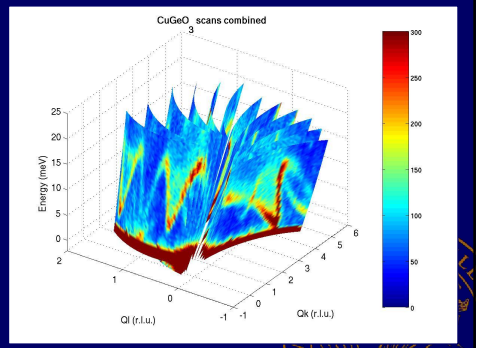
Traditional Dispersion Curves



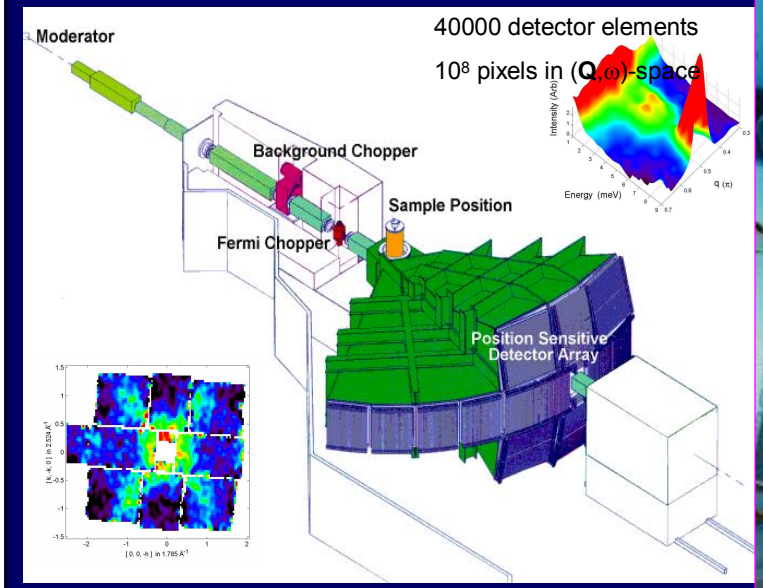
Instrument Development pays dividends

Phonon dispersion curves in $CuGeO_3$
volume ~ 500 mm^3

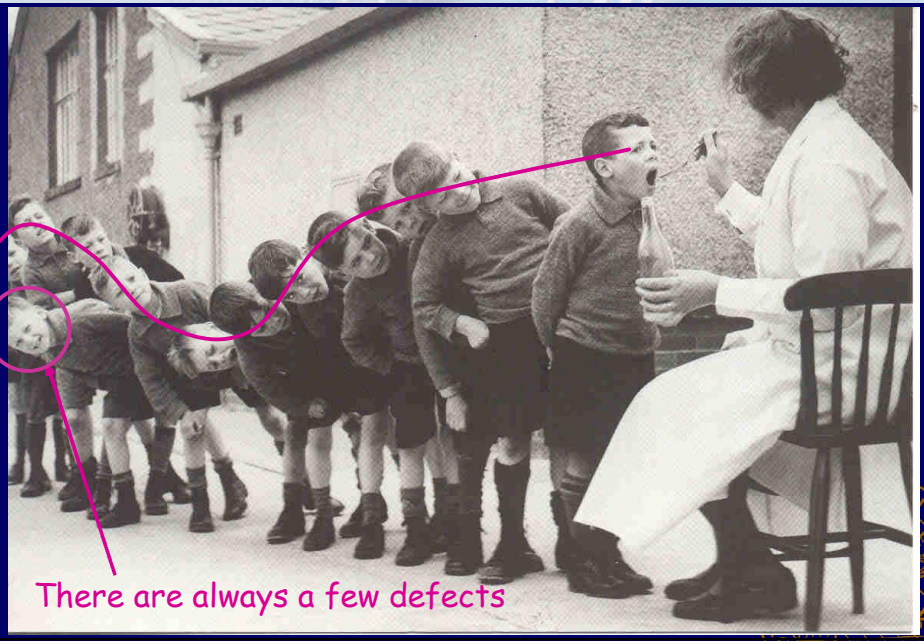




Time of Flight instruments have advantages

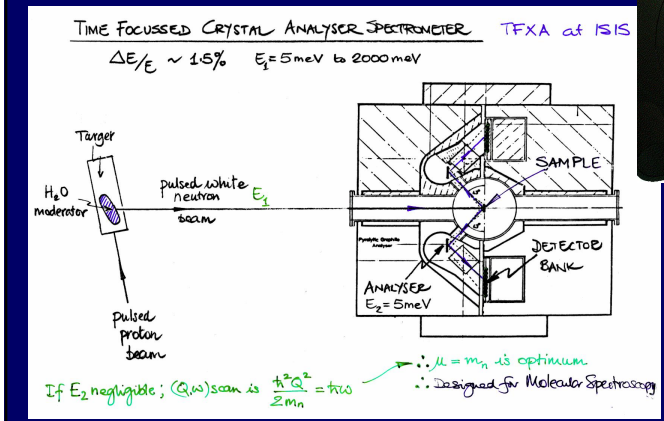


Coherence is all around us…



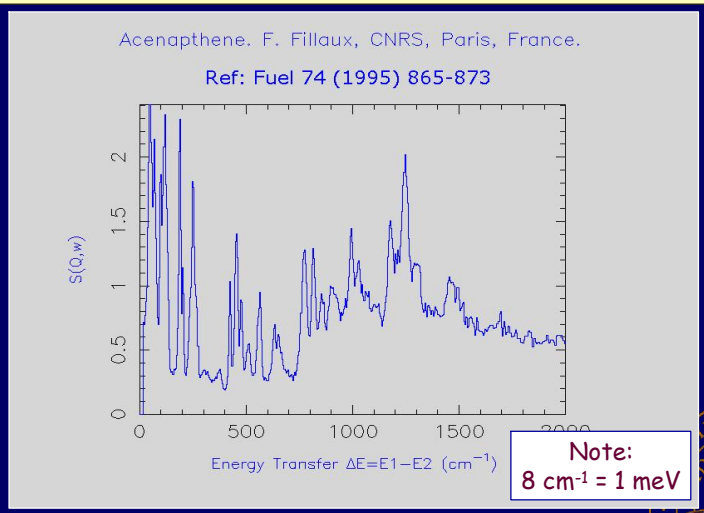
Molecular Spectroscopy

TOSCA at ISIS



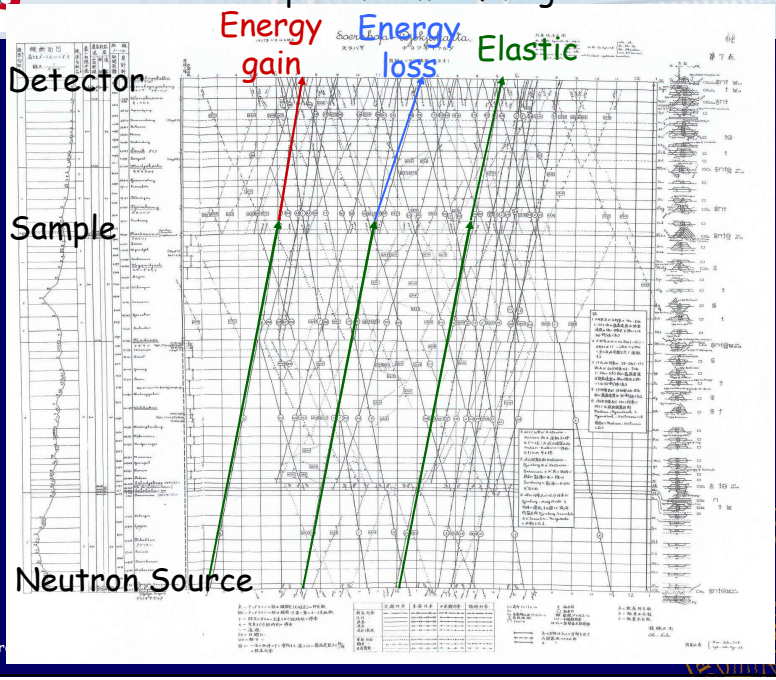
Built in Florence by Marco Zoppi & Milva Celli

Molecular Spectroscopy data from TOSCA - Acenapthene



Note:
8 cm^{-1} = 1 meV

Train Graphs & Time of Flight



3. Other Inelastic Instruments

a. Quasielastic Spectrometers

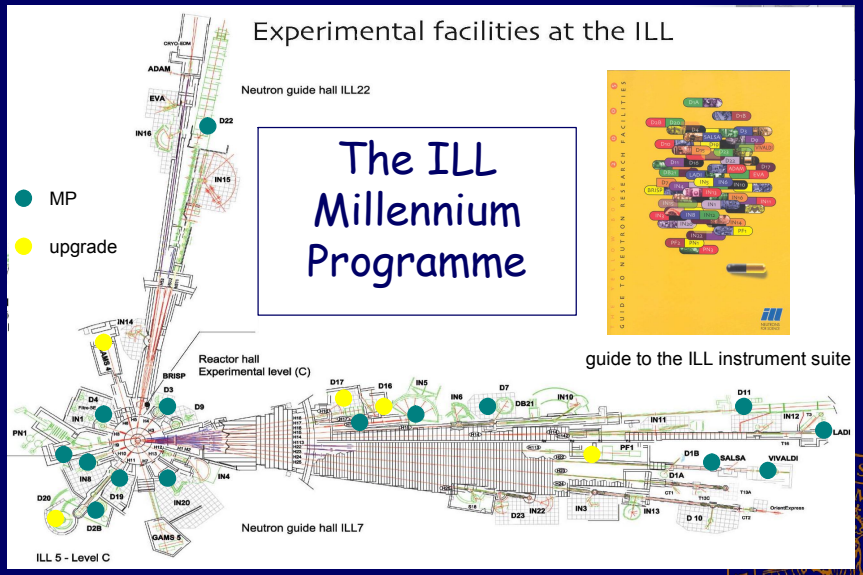
Backscattering

Time of Flight like IN5

b. Spin Echo Instruments

None on pulsed sources – yet…

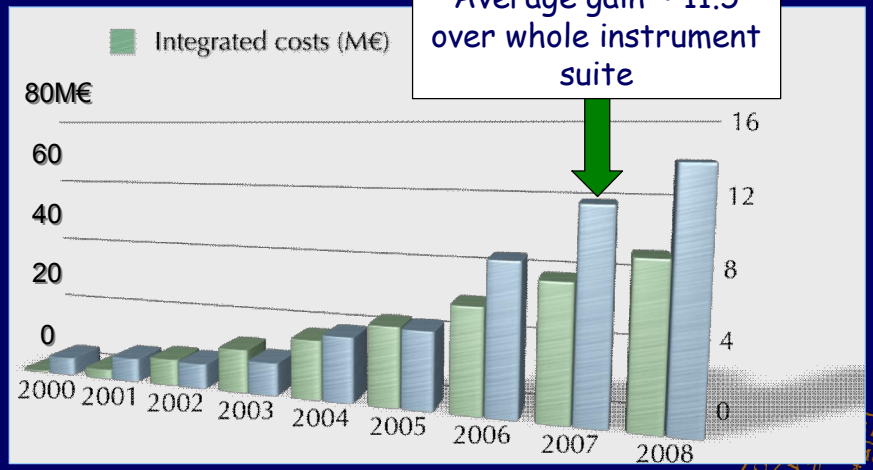
ESS will have 22 instruments at 4M€ each



The ILL's Millennium Programme

Instrument gain factors

Average gain ~ 11.5 over whole instrument suite



160M€ Investment

How to build a Neutron Spectrometer.....

.....quickly!

MAPS at ISIS

Further Reading

1. Neutron Diffraction G Bacon
Oxford Univ Press (1982)

2. Neutron Diffraction H Dachs
Springer Verlag (1983)

3. The Dynamics of Liquids M Zoppi & U Balacani
Oxford Univ Press (1994)

4. Single Crystal Diffraction C C Wilson
Gordon & Breach (2000)

5. Coherent Inelastic Neutron Scattering in Lattice Dynamics B Dorner Springer Verlag (1982)

6. The Phonon Atlas Bilz & Kress Springer Verlag