TRIPLE-AXIS SPECTROMETER DrüchaL

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Abstract

DrüchaL is a triple-axis spectrometer located at a cold guide. The characteristics of guide and instrument allow the use of a broad spectral range of neutrons. The resolution in momentum and energy transfer ($\hbar\vec{Q}$, $\hbar\omega$) can be tuned to match the experimental requirements by using either collimators or focusing systems (monochromator, anti-trumpet, analyser).

1. Introduction

The triple-axis spectrometer DrüchaL ("**Drü**-achsigs am **cha**lte **L**eiter", Swiss dialect for "triple-axis at cold guide") is a sister instrument of TASP [1]. Both spectrometers are identically constructed as far as possible, the main difference being the positions at the guide: DrüchaL is located in an intermediate position close to the source whereas TASP is in an end position.

The triple-axis spectrometer (TAS) was invented 40 years ago by Brockhouse [2], and the basic design has not been changed since then: the reason is that a TAS is the most versatile instrument for inelastic neutron scattering experiments on single crystals. From the experimentalist's viewpoint, it offers the unique possibility of measuring intensities at well-defined points in $(\vec{Q},\omega)$ space, e.g. points of high symmetry in reciprocal space, where theory predicts an unusual behaviour, e.g. as function of temperature (structural transition), etc.. However one has to be aware that such a selective measurement might not make a very efficient use of all the scattered neutrons and that a TAS has a low data acquisition rate.

2. Fundamentals

Scattering process

The central quantity of interest is the scattering function $S(\vec{Q},\omega)$:

$$\frac{d^2\sigma}{d\Omega\, dE'} \approx \frac{k}{k_0} S(\vec{Q},\omega)$$

The basic task of the theorist is to calculate this quantity with the help of an appropriate microscopic model. The task of the experimenter is to extract this function from the experiment and to assess the precision of the data in the sense of statistics and resolution.

> ***The 'instrument' is the 'technical vehicle' that allows the scientist to have experimental access to the cross-section.***

Kinematic range

The vector sum $\vec{Q} = \vec{k} - \vec{k}'$ can be represented as a triangle ('scattering triangle')

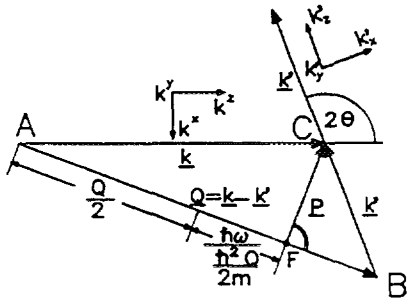

Figure 1:

The scattering triangle $\vec{Q} = \vec{k} - \vec{k}'$ for inelastic scattering with energy transfer $\hbar\omega$

In order to see what region in $(\vec{Q},\omega)$-space is accessible in an experiment at a given $\vec{k}$, we can plot the 3-dim loci of point B (Fig. 1) as a function of the co-ordinates Q_1 (parallel to $\vec{k}$), Q_2 (perpendicular to $\vec{k}$) and $\hbar\omega$. This results in the surface of a paraboloid with apex $(k,0,E)$ whose locus is the dispersion relation for the free neutron $E = (\hbar^2 k^2/2m)$.

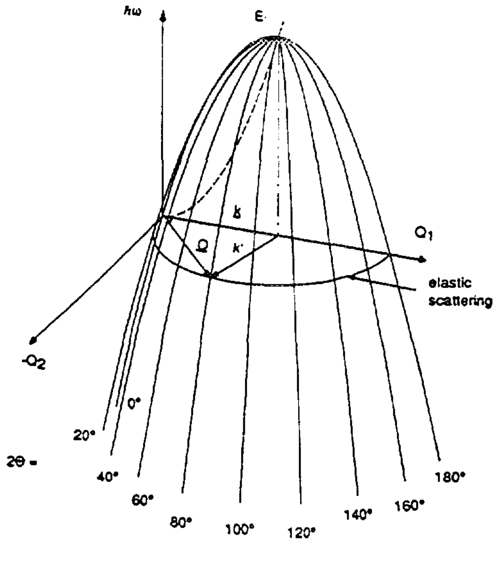

Figure 2:

The locus for all allowed $\vec{Q},\omega$-combinations in a neutron scattering process is a paraboloid with apex $(k,0,E)$; parabolae are shown for different scattering angles 2θ

In order for scattering to be possible, the scattering law must intersect this paraboloid whose size depends on $\vec{k}$ of the incident energy only.

The experimental determination of the scattering function $S(\vec{Q},\omega)$ in the variables $\vec{Q}$ and ω is therefore restricted by these kinematical limits (i.e. small $\vec{Q}$ and large $\hbar\omega$ are not easily accessible).

Further restrictions are given by the mechanical construction of the instrument (monochromator and analyser 2θ-angles, scattering angle, shielding, etc.), by special sample environment (cryostat, furnace, pressure cell, etc.), and by neutron background problems (e.g. scattering at very small angles).

Resolution - Intensity

The goal of the measurement is to determine $S(\vec{Q},\omega)$ with the maximum possible precision, and hence it would be desirable to have $\vec{k}$ or $\vec{k}'$ defined as precisely as possible. Apart from this being impossible due to the way in which available phase space operators work, this would also result in an almost complete loss of intensity and hence poor statistics. It is therefore necessary, to retain a finite, but optimised volume $\delta\vec{k}$ and $\delta\vec{k}'$ around $\vec{k}$ and $\vec{k}'$, resulting in an uncertainty of the value of $\vec{Q}$, $\delta\vec{Q}$ and, of course, also of ω, $\delta\omega$.

Neutron scattering is a 'signal limited' technique, a consequence of both the low phase space density of neutron sources and of the weak interaction between neutrons and matter. Therefore it is generally not possible (although desirable) to measure cross-sections with best resolution in momentum transfer and energy transfer.

There are in principle several possibilities to improve the situation:

i) increase the source flux: *restricted (power density, costs)*
ii) increase the counting time: *limited (number of facilities)*
iii) increase the sample size: *limited (new materials, absorption, etc.)*
iv) decrease the resolution of the spectrometer:

"dedicated" spectrometers.

In other words, it is necessary to make a selection. But in order to do this, the cross-section has to be known ($\vec{Q}$-dependence, ω-dependence): one has to know which quantity can be 'relaxed', or over which quantity can (experimentally) be integrated.

However the physics to be investigated in the future is not known! The problem that arises in constructing a new spectrometer is that it must be ***dedicated and versatile,*** *or in other words, one has to solve the problem of the* ***'squared circle'.***

3. DrüchaL

The dedication of DrüchaL starts with the choice of the incoming energies to be used: **cold neutrons** got the priority. Because the spallation process produces very high energy neutrons, the primary shielding of the source is rather thick and therefore the use of **neutron guides** is mandatory. This has the advantage of a lower neutron background because the spectrometer can be placed away from the source. The drawback of a reduced intensity due to the good angular resolution (critical angle of total reflection) can be overcome by a **supermirror coating** with an m-value of ~ 2 [1].

The SINQ 'day 1' target will produce a moderate neutron flux, and therefore 'day 1' **monochromator** and **analyser** are equipped with **pyrolithic graphite** crystals. Options of **vertical focusing** and **horizontal focusing** on the monochromator and analyser respectively will give an enhanced neutron flux (at the expense of resolution). A further increase for small samples can be obtained by inserting a **converging guide** ('anti-trumpet') between monochromator and sample.

A vertical section through the instrument is shown in Fig. 3, the main components can easily be identified. The 'Tanzboden' is made of **granite**, with an (expected) better durability than marble. Air cushions, rotatory modules and length modules are commercial products. The monochromator shielding with blocks moving on a two-level system ('high' in the direction of the monochromatic beam, 'low' in order to pass below the guide) is completely mechanically controlled with a 2 stage lift-system (i.e. no pneumatic pistons, no electric switches). Goniometers for monochromator, sample and analyser alignments respectively are again standard products. The analyser shielding blocks are pneumatically lifted by a single piston (between analyser and detector). The neutron shielding is 'home-made', a mixture of polyurethane and boron carbide, poured in corresponding moulds. Only non-magnetic material has been used for all mechanical components near the neutron beam path in order to allow polarised neutron experiments.

The electronics (hardware) is PSI standard, the software is an upgraded version of MAD-TAS. Instrument control can be made either by a laptop near by the instrument, or from a cabin.

Planning and realisation of a new neutron source with appropriate instrumentation are tedious processes. Decisions have sometimes to be made at early stages without knowing all the future details. DrüchaL has been constructed with the premise 'not to loose any good neutron, and not to pick-up any bad neutron', and we expect that DrüchaL will satisfy the user's demands of the coming years.

[1] P. Böni and P. Keller, this Summer School
[2] B.N. Brockhouse and A.T. Stewart, Trans. Roy. Soc. Can. III, 50 (1956), and Rev. Mod. Phys. **30**, 236 (1958)

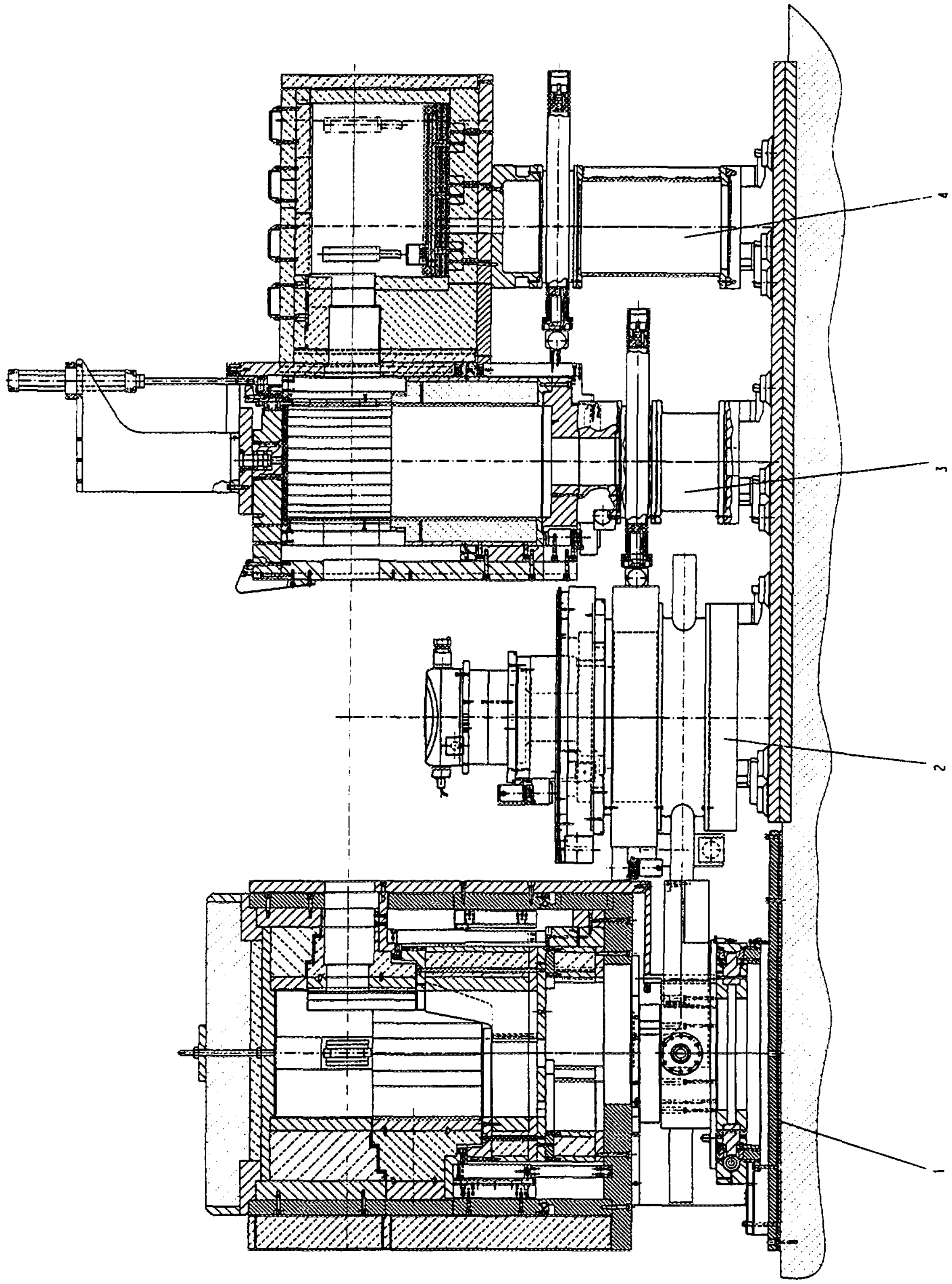

Figure 3: Vertical section through DrüchaL (for a horizontal view, see Fig. 2 in [1].)

Technical Specification of DrüchaL

Guide hall, neutron guide 1RN13 (30 x 120 mm), 37 m from the cold source

monochromator	scattering angle $29° \leq 2\,\theta_M \leq 145°$ PG (002) (d=3.355 Å), vertically focusing 2 meV $\leq E_M \leq$ 30 meV
focusing anti-trumpet	L=1160 mm, supermirror m~4
sample	scattering angle $-155° < 2\,\theta_S < 155°$ table: max. load 500 kg
collimation	α_0 (supermirror guide) = 120 / k_M (min/Å^{-1}) $\alpha_1, \alpha_2, \alpha_3$ = 20', 40', 80', open
analyser	PG (002), option for horizontal focusing scattering angle $-145° \leq 2\,\theta_A \leq 145°$
detectors	2 monitors (incident and monochromatic beam, ^{3}He detector (50 mm Ø, 170 mm L)
typical resolution	$\Delta E \sim 0.01$ meV (E_M = 2 meV) $\Delta E \sim 0.46$ meV (E_M = 14.7 meV)
lengths	variable (monochromator-sample, sample-analyser, and analyser-detector)
filters	graphite (40 x 130 x 50 mm), beryllium (cooled, 40 x 130 x 170 mm)
instrument responsible	Willi Bührer