Experimental report

27/08/2021

Proposal:	**3-15-95**	**Council:**	4/2020
Title:	New forces		
Research area:	Physics		

This proposal is a resubmission of 3-15-94

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Experimental team:	
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Samples: Si

Instrument	Requested days	Allocated days	From	To
D20	1	1	01/09/2020	03/09/2020
D1B	2	0		

Abstract:

The possibility of new short-range forces existence is given by many theories of Standard Model extension. We propose to use neutron powder diffraction for getting constraints on coupling constant of such new force. These constraints can be obtained from scattering amplitude dependence on momentum transferred. Experiment suggested allows to improve best current constraints by about 2 orders in interaction radius range of 10^(-13) - 10^(-10) m.

1. **Introduction.** The experiment was performed at D20 diffractometer of ILL. The sample was a silicon powder NIST SRM 640f. Measurements were made at 2 wavelengths of 1,3Å and 2,41Å at 4 temperatures each. For 1,3Å the temperatures were 4K, 6K, 77K and 300K; for 2,41Å they were 4K, 8K, 77K and 300K. For both wavelengths measuring time was 2 hours and 2 minutes. The sample was contained in a vanadium cylinder with a diameter of 6mm. Silicon powder mass was 1,27g. Empty cylinders were also measured for both wavelengths at 300K during 20 minutes and then normalized to counting time of silicon.
2. **Empty cylinders subtraction.** In order to tell a vanadium background from a silicon one empty cylinders diffractograms were subtracted from the silicon diffractograms for respective wavelengths (Fig.1, Fig.2).

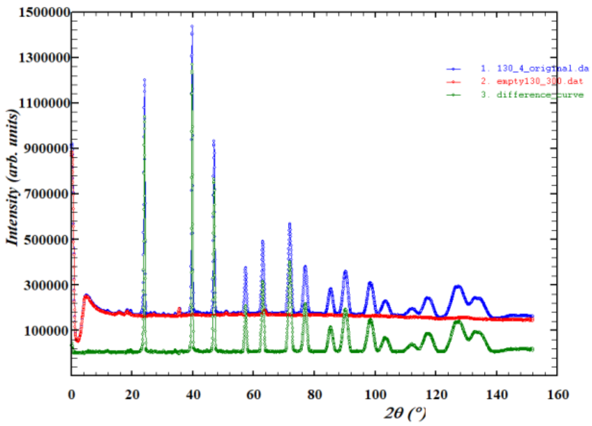

Fig.1. Diffractograms difference for 1,3Å.

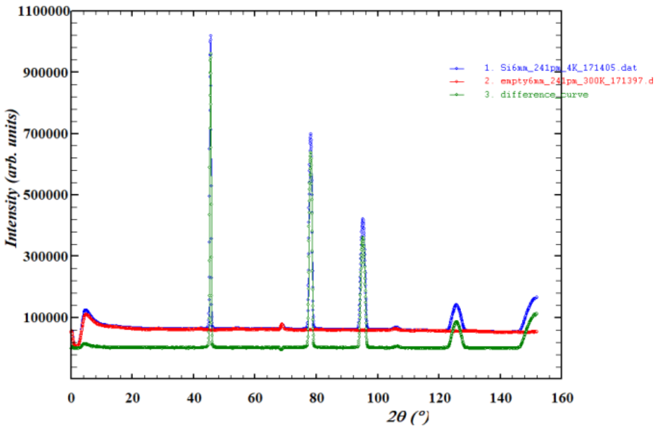

Fig.2. Diffractograms difference for 2,41Å.

3. **Background processing**. Background turned out to be very sloppy even after subtraction of the sample holder diffractogram. Moreover, its behavior was similar for different wavelengths. This is probably due to the efficiency of the detector registration. An option that the reason is the diffraction at vanadium sample holder or aluminum cryostat (including high order harmonics) was checked and denied. Assuming that the vanadium background should be a constant the efficiency was calculated as the ratio of the sample holder diffractogram (excluding peaks) and the arithmetical mean of the background. The difference of the diffractograms of the sample and the empty cylinder was then divided by the efficiency. The remaining background was fitted by a 2nd order polynomial using only regions with knowingly no peaks (Fig.3) and subtracted from the respective diffractograms.
4. **Rietveld refinement.** Rietveld refinement was performed using FullProf to obtain "theoretical" diffractograms of silicon (Fig.4). Atom coordinates, cell parameters, occupancy and thermal parameter (Debye-Waller factor) were taken from the literature (for respective temperatures) and were not refined so that they didn't include the searching effect. For the same purposes the FWHM, shape and asymmetry parameters were refined for one temperature (4K) and then used for other temperatures as fixed parameters. Background parameters were not used because background was considered to be taken into account before. The only parameters that were refined for all the temperatures were the scale factor and the zero shift.

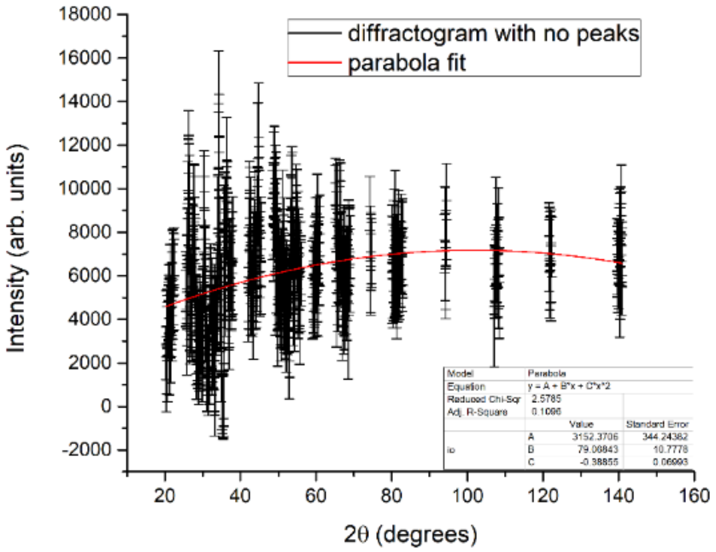

Fig.3. Background fit for 1,3Å, 4K.

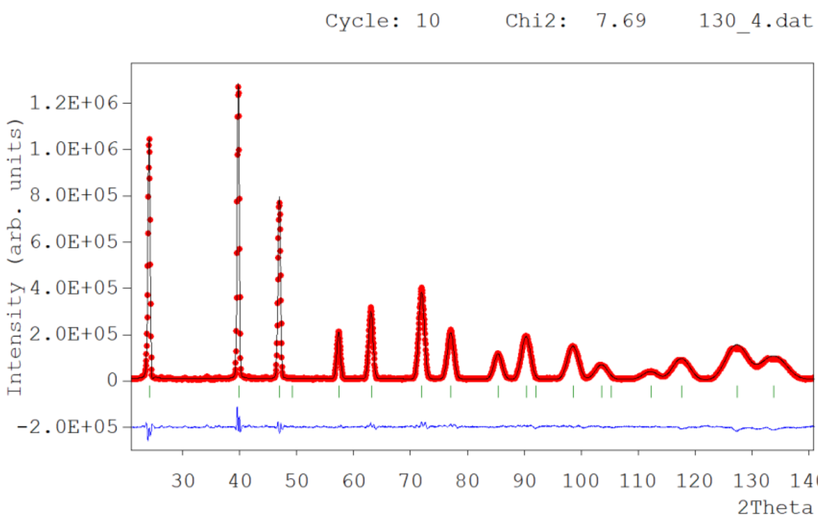

Fig.4. Rietveld refinement of silicon diffractogram for 1,3Å, 4K.

5. **Addition to the scattering amplitude.** The intensity of Bragg's reflection I (integrated intensity) equals squared structure factor F_g, which is expressed in terms of atomic scattering amplitudes a_j:

$$I \sim |F_g|^2 = \left|\sum_j a_j e^{iqr_j}\right|^2 = |a_{Si}K_g|^2,$$

where $K_g = \sum_j a_j e^{iqr_j}$. If the new force exist scattering amplitude may be expressed as

$$a_{Si} = a_{nucl} + a_{new},$$

where a_{nucl} is a nuclear scattering amplitude and a_{new}, is an addition to the scattering amplitude due to the new force. So, the "experimental" integrated intensity:

$$I_{exp} \sim a_{Si}^2 = (a_{nucl} + a_{new})^2 \approx a_{nucl}^2 + 2a_{nucl}a_{new}.$$

On the other hand, "theoretical" integrated intensity obtained from Rietveld refinement has no contribution of the new force:

$$I_{th} \sim a_{Si}^2 = a_{nucl}^2.$$

Hence, the addition to the scattering amplitude may be obtained:

$$a_{new} \sim \frac{a_{nucl}}{2}\frac{I_{exp} - I_{th}}{I_{th}} \equiv \frac{a_{nucl}}{2}\frac{\Delta I}{I}.$$

Integrated intensities I_{exp}, I_{th} were calculated as a sum of the counts of a peak.

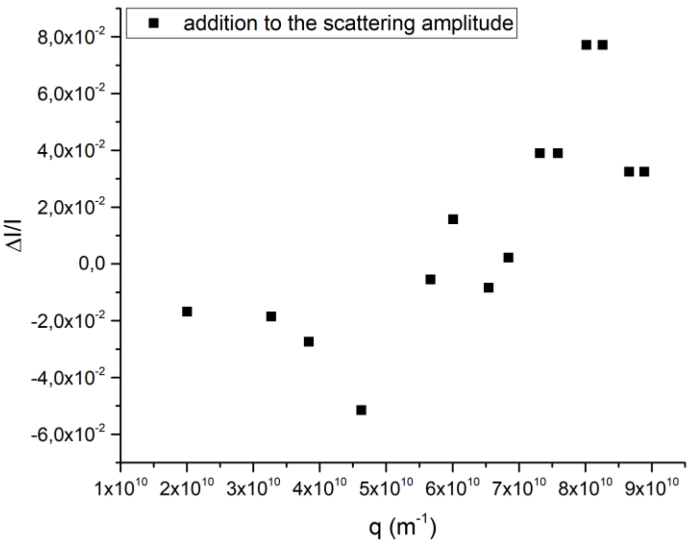

Fig.5. Addition to the scattering amplitude a_{new} versus momentum transferred q for 1,3Å, 4K

If the new interaction is mediated by massive bosons the scattering amplitude due to this interaction may be written as

$$a_{new} = -A\frac{g^2}{4\pi}\hbar c\frac{2m\lambda^2/\hbar^2}{1 + \lambda^2 q^2},$$

where A – silicon atom mass, g – coupling constant, λ – interaction radius, q – momentum transferred. Hence, one can obtain constraints of the coupling constant g as a function of interaction radius λ. This is the ultimate aim of the analysis.

6. **300K anomaly.** It was noticed that at 1,3Å the first 3 peaks of the diffractogram of 300K are higher than those of 4K, 6K and 77K while all the other peaks are lower (as one would expect). This anomaly is not observed at 2,41Å. The reason of this is still unknown.

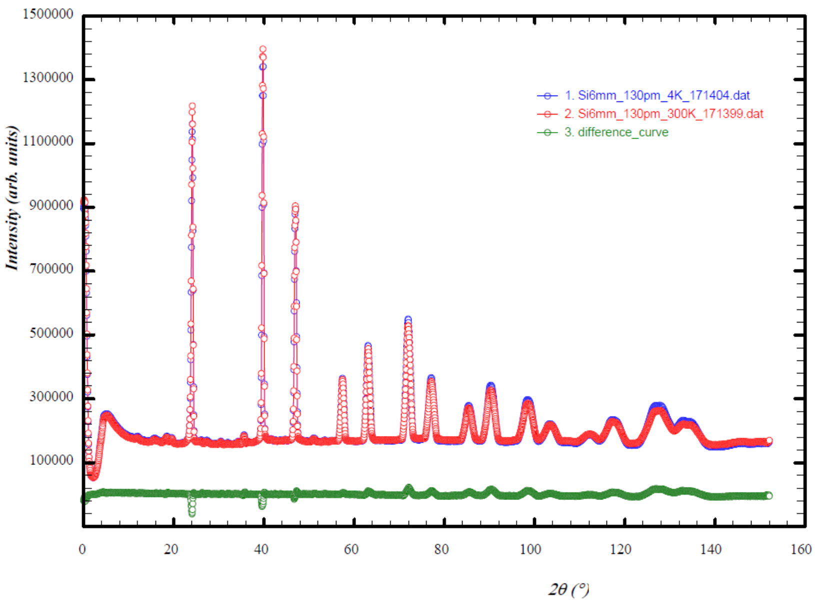

Fig.6 300K (red), 4K (blue) diffractograms and their difference (green)