R&D for Neutron Physics

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Introduction
T-violation search using compound nuclear resonance

Candidates of Sample targets

$^{139}\text{La}$  ($E_n = 0.73\text{eV}$)

$^{131}\text{Xe}$  ($E_n = 3.2 \text{ eV}$)

$^{81}\text{Br}$, $^{115}\text{In}$, $^{117}\text{Sn}$

Measurements

neutron attenuation

$(n,\gamma)$ measurements

Attenuation Method

$\sigma$

$polarized\ neutron$

$polarized\ target$

$neutron\ detector$
Requirements for Neutron Detector

For La case, (at L= 21.5 m)
0.7- 0.8 eV neutrons are coming 120 usec
→ 160 Mcps / cm²

For Xe case,
3.0 -3.5 eV neutrons are coming in 67usec
→ 420Mcps /cm²

ref) Kino et.al., NIM A626 (2011) 58
High count rate detector

- fast DAQ system
- fast decay time scintillator
- n/γ separation, simple algorithm → install to DAQ system

Candidate of scintillator

<table>
<thead>
<tr>
<th>Candidate</th>
<th>Light output % Anthracene</th>
<th>Wavelength (nm)</th>
<th>Decay time(ns)</th>
<th>neutron converter</th>
<th>neutron absorption at 0.75eV, 1cm thickness</th>
<th>neutron absorption at 3eV, 1cm thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>NE213 BC501A, EJ301</td>
<td>Liquid</td>
<td>78</td>
<td>425</td>
<td>3.2</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>BC523A</td>
<td>Liquid</td>
<td>65</td>
<td>425</td>
<td>3.7</td>
<td>Boron 4.41 %</td>
<td>82%</td>
</tr>
<tr>
<td>GS20 (Li Glass)</td>
<td>Solid</td>
<td>20 - 30</td>
<td>395</td>
<td>16, 49 &amp; 78</td>
<td>Lithium 6.6 %</td>
<td>93%</td>
</tr>
<tr>
<td>LBO:Cu (Li2B4O7)</td>
<td>Solid</td>
<td>0.5</td>
<td>360</td>
<td>&lt; 1</td>
<td>Li 8% B 26%</td>
<td>99%</td>
</tr>
</tbody>
</table>
Neutron Mirror Development

DC magnetron sputtering system with Ux Lab.

First example of multilayer neutron mirror by DC Sputter.

\[ m = 2, \ 14\ \text{layer} \]
Nichrome -Ti multilayer: 7 nm thickness, 14 layers

Neutron Reflectivity measurement at J-PARC MLF BL16 SOFIA

Roughness : 10Å

Reflectivity vs. q [nm⁻¹]

Preliminary
Polarized Neutron beam - SEOP

3He Polarization : (61.4 ±0.2) %  
( at J-PARC MLF BL05)

Neutron Polarization : 19 % (E_n=0.75 eV)
Device development

We need neutron devices for our experiments

Mainly for $\text{nnbar}$ oscillation search
  • neutron mirror (multilayer material mirror)
    : $m=6 \sim 10$ ($\sim 10,000$ layer)

Mainly for T-Violation search
  • Neutron Polarizer (or Analyzer)
    : epithermal neutron beam ($\sim \text{eV}$)
  • High counting rate neutron detector : $\sim \text{GHz/detector}$

We also need neutron beam for developing these devices.
→ We decide to construct new compact neutron source
  In Nagoya University Campus.
Compact Neutron Source

Nagoya University Accelerator-driven Neutron Source

NUANS

Nagoya University Science-Engineering Quantum Beam
Intra-university Collaboration

NUANS

Two beamlines are designing at NUANS

1st beamline (42kW)
  • Device and system development for BNCT (Li-Target, moderator, etc⋅⋅⋅)

2nd beamline (4kW)
  • Neutron Imaging
  • Neutron Detector Development
  • Neutron optics Development (mirror, lens, etc⋅⋅⋅)
  • Education
Location of NUANS

ES Hall

NUANS

Campus Map of Nagoya University

NUANS Hall
Electrostatic proton accelerator

Dynamitron Accelerator (DC beam) by IBA Indust.
Proton Energy: 1.9MeV-2.8MeV
Proton beam current: Maximum 15mA, 1.5mA(2nd BL)
Size: 7.5m x 2.8m 6.5ton

HV Power       ECR       Acc. tube       Quad. Mag.       Beam exit
SF₆ tank
NUANS is constructing now!

Proton Accelerator

Control room

1st Beamline (20°)

2nd Beamline (70°)

5m
NUANS is constructing now!
NUANS is constructing now!

1st Beamline (20°)
2nd beamline

- multi-purpose beamline: easy handle, low cost
- Neutron Imaging
- Neutron detector and devices development
  - Proton beam current $1.5\text{mA} \sim 4\text{kW}$
  - Be target $\phi 100\text{mm}$ → target simulation
  - Polyethylene moderator (thermal neutron)
  - radiation level: $< 0.1 \mu\text{Sv/h}$ (desired value)
    - shield weight: $< 2 \text{ton}$: request by floor capacity
  - thermal neutron flux $10^6\text{n/cm}^2/\text{s} @50\text{cm}$
    - Neutron Flight path: Short (50cm) or Long (2m)
Proton beamline

Ion source and Acc. tube

Dynamitron

Dipole Magnet (Bending)

Q1 Q2 Q3

2nd Beamline

Control room

5m

File = gshow2/gshow_building_xz.out

Geometry in xz (Building)

Date = 18:18 16-Sep-20

plotted by

A

G

E

L

4.35

calculated by

P

H

T

S

2.

−2000

−1500

−1000

−500 0 500

z [cm]

x [cm]

Air

Wall

PE-B

Pb

C

PE

V

Void

Concrete

PE-LiF

Bi

MgF2

$POUSPMSPPN

OE#FBNMJOF

%ZOBNJUSPO

1SPUPOCFBNMJOF

%JQPMF.BHOFU

#FOEJOH

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222

Ion source and Acc. tube

N
Proton beam simulation

We want to set the proton beam size around $\phi 80 \text{ mm}$ at target position.

Sim. Code: TRACE3D

$\rightarrow$ Available to control the beam size: $\phi 60\text{mm} - \phi 100\text{mm}$
Neutron target

1st BL: $^7$Li target
   high neutron intensity
   Chemically unstable

2nd BL: $^9$Be target
   Chemically stable
   Succeeded to use at RANS, KUANS

Li Neutron yield $\sim 10^{13}$ n/sec for 15mA

Be Neutron yield $\sim 10^{12}$ n/sec for 15mA

Hydrogen blistering

Be Target was broken by hydrogen blistering. Be target is also difficult to use for low energy neutron source.
Neutron Target: Proton Injection simulation

Energy vs Thickness at Incident beam of 2.8MeV

$^9$Be(p,n) threshold is 2.06 MeV

Proton $E_p=2.8\text{MeV}$
Neutron Shielding

Polyethylene
Slowdown the neutron velocity by elastic scattering with the hydrogen. Neutron absorption is decrease with velocity.

Boron ($\text{B}_2\text{O}_3$)
absorb thermal neutron and emitt gamma-ray
$^{10}\text{B}(n, \alpha)^7\text{Li} \quad ^7\text{Li} \rightarrow ^7\text{Li} + \gamma$

Lead
Shielding the gamma-ray and transparence neutron

Neutron beam

Polyethylene ($\text{B}_2\text{O}_310\%$)
moderate and absorb

$r$-ray

Lead
$r$-ray shielding
Optimize the target shielding by PHITS

around the 2nd target shielding

- Shielding: BPE (Polyethylene with B_2O_3), Lead
- Weight (inside the red line): about 1.7ton
- Radiation level at border door: about 0.05 \mu Sv/h
Neutron beam flux

We can select two neutron paths.

\[ O(10^6) \text{ /cm}^2\text{/s} \]
@50cm (short flight path)

\[ O(10^4) \text{ /cm}^2\text{/s}^1 \]
@250cm (long flight path)

[Diagram showing neutron and proton paths]
Imaging port of 2nd BL (Short)

Neutron flux distribution on the scintillator surface

Scintillator size: 10cm x 10cm
Beam flux: Max = 9.5 \times 10^5 \text{ n/cm}^2/\text{s},
Min.=7.3 \times 10^5 \text{ n/cm}^2/\text{s}
25\% peak to peak

File = gshow2/gshow_2ndaround_xz.out
Geometry in xz (around 2nd target)

Date = 16:47 28-Sep-20

plotted by ANGELE

4.35 calculated by PHITS

2.7

400 450 500 550
z [cm]

50

0

−50

400 450 500 550
x [cm]

100

50

0

−50

Scintillator
Camera box

Neutron flux distribution on the scintillator surface
Imaging Camera box for Engineering application

CCD and Scintillator system

Spatial resolution: \(~200\ \mu\text{m}\)

Irradiation time: \(~\text{min.}\)

Movie is available: (DC beam)
Summary

We are developing Neutron devices

- Multilayer Neutron Mirror by using DC sputter system.
  NiCr-Ti  m=2, 14 layers mirror
- $^3$He Spin filter for polarized neutron beam
- High counting rate (1GHz) Neutron detector

- NUANS for neutron device development.
  NUANS with electrostatic accelerator
  \[ E_p = 2.8 \text{MeV} \quad I_p = 15 \text{mA} \quad (42 \text{kW}) \]
  Designing and constructing beamlines
  - Li and Be target (Be for physics experiment)
  - Proton beamline simulation
  - Shielding < 0.1 $\mu$V/h,  weight < 2 ton
  - Neutron flux estimation :
    \[ 10^4 n/cm^2/s \text{ at } 2 \text{m from moderator} \]
Thank you for your attention