Accelerator/Decelerator of Slow Neutrons

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for nuclear & particle physics using neutrons.
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Search for Neutron EDM at J-PARC (Electric Dipole Moment)

Neutron Accelerator

Principle of Acceleration and Rebunching

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Motivation  Neutron EDM

Neutron Electric Dipole Moment (nEDM) signals the violation of time-reversal (T) invariance.

Present upper limit  \[ |d_n| < 2.9 \times 10^{-26} \text{ e cm} \]

is approaching to the predictions of some physics beyond the standard model of particle physics.

Standard Model : \[ |d_n| \sim 10^{-32} \text{ e cm} \]

New Physics (SUSY ...) : \[ |d_n| \sim 10^{-27} \sim -28 \text{ e cm} \]

More precisely !
Motivation  UCN

Very slow neutrons (Ultra Cold Neutrons: UCNs) can be stored in bottle by reflections off the material wall.

UCNs: energy < 200 neV
velocity < 7 m/s

Change of precession frequency according to the direction of electric field is measured.

\[
\frac{\omega_{\pm}}{2\pi} = 3 \times 10^1 \frac{B}{1 \mu T} \pm 5 \times 10^{-8} \frac{d_n}{10^{-26} e \cdot cm} \frac{E}{10kV/cm}
\]

1 μT  1 fT equiv.

Small storage area is better.

Neutron density is important to reduce the systematic errors.

More Dense UCNs!
Motivation: nEDM at J-PARC (P33)

- Pulsed UCN converter (sD$_2$)
- UCN Transport with Rebuncher (neutron space-time focusing)
- EDM cell with high precision magnetometer
- Ultra-cold neutrons
- UV laser for magnetometer
- Proton beam from LINAC

Large production by J-PARC LINAC
(instantaneous high power: 20 MW)
- Transport optics (focusing with pulsed neutron decelerator)
- High precision measurement (magnetometer using UV laser)

- $10^{-27}$ e cm (phase1, 5 years)
- $10^{-28}$ e cm (phase2)
Motivation: nEDM at J-PARC (P33)

Pulsed UCNs spread spatially,
Density decreases quickly
without any treatment.

Transport without loss of density!
Motivation  nEDM at J-PARC (P33)

UCN Rebuncher = Neutron Accelerator

If the pulse shape is recovered at storage area, the high density can be achieved.
Neutron Accelerator

Adiabatic Fast Passage (AFP) spin flipper is used for control of the neutron energy.

RF magnetic field in gradient field gives/removes the energy with spin flip.

\[ 2\mu B = \hbar \omega \]

30 MHz = 1T = 120 neV

Opposite-spin neutrons are accelerated.
Neutron Accelerator

Adiabatic Fast Passage (AFP) spin flipper is used for control of the neutron energy.

RF magnetic field in gradient field gives/removes the energy with spin flip.

\[ 2\mu B = \hbar \omega \]

30 MHz = 1T = 120 neV

Faster neutrons arrive early.

Large deceleration = High Freq. RF

Slower neutrons arrive late.

Small deceleration = Low Freq. RF

Energy exchange is proportional to the RF frequency.

Sweeping frequency according to time
Anisotropic inter-poles make homogeneous gradient field.

Prototype RF

RF coil (one-turn)

RF Amp 1kW

Resonance circuit (Variable capacitor)

RF matching 15 - 30 MHz

Reflection [dB]

Q value

Frequency [MHz]

Reflection Q value

Demonstration of Rebunching

UCN beam line PF2
High Flux Reactor
ILL, France

Continuous UCN beam was chopped by shutter to simulate **pulsed source**.

Sweeping RF frequency is synchronized with the shutter.
Demonstration of Rebunching

Results

Too fast for EDM exp.  

RF OFF

RF ON

Decelerated!

Blue : Exp. Data  
Red : Simulation

Y. Arimoto, et., al.,  
Demonstration of Rebunching

Results

Focusing of UCNs was observed!

Summary

Now we can control neutron velocity precisely.

This type of neutron accelerator can be connected one after another.

Controllable energy  = 120 neV / T / unit
Summary

Neutron EDM (nEDM) signals new physics beyond standard model. nEDM experiment requires dense Ultra Cold Neutrons (UCNs).

By controlling the energy distribution of UCNs, the pulse shape of the UCNs can be reconstructed at experimental area.

UCN Rebuncher = Neutron Accelerator

Spin flipper with frequency-sweeping RF can be Neutron Accelerator.

We have developed prototype of Neutron Accelerator and demonstrated the space-time focusing.

We are now planning the new nEDM experiment using this focusing technique at J-PARC.