Radiation Damage and Recovery in Polarized Ammonia Targets

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Outline

- Spin Physics at TJNAF (Jefferson Lab)
- Dynamic Nuclear Polarization
  - Radiation Recovery: Anneals
- Hall C: SANE
  - Polarization Decay with Dose
  - Optimal Microwave Frequency with Dose
  - Anneal History
  - Unexpected Results
- Hall B: EG1-DVCS

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Spin Physics at Jefferson Lab

- Continuous Electron Beam Accelerator Facility: 6.0 GeV Polarized Electrons
- Spring 2009: Polarized Target Experiments in all 3 Halls
- Hall A: Polarized $^3$He Gas
- Hall B & Hall C:
  - Polarized $^{14}$NH$_3$ provided by Univ. of Virginia
Dynamic Nuclear Polarization

- Leverages paramagnetic radicals which provide electron-proton hyperfine splitting in a high magnetic field, at 1K
- Microwaves drive “forbidden transitions” to populate levels
  - Electron relaxation time \(\sim\) milliseconds
  - Proton relaxation time \(\sim\) 10s of minutes

- In Ammonia \((^{14}\text{NH}_3)\), paramagnetic centers, primarily \(\text{NH}_2\) are produced by irradiating material at a small electron accelerator
  - Irradiation dose \(\sim 10^{17}\) e\(^-\)/cm\(^2\) at 19 MeV, under 87K Ar
- Polarizations after this “warm” dose routinely break 90% under DNP at 5T, cooled in a He\(^4\) evaporation fridge to 1K
Dynamic Nuclear Polarization

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Radiation Recovery: Anneals

- Beam on target has both prompt and cumulative effects
  - Heating from beam reduces efficiency of DNP, lose ~5-7%
- Over time, dose damages material; additional paramagnetic centers allow spins to relax, reducing polarization beyond practical usability
- Anneals restore this cumulative polarization loss
  - Removing material from beam and microwaves, it is heated to between 70-100K for 10-60 minutes to allow excess, unwanted radicals to recombine
- Allows polarizations to reach previous maximum values
- As material accumulates dose, after several anneals, rate of polarization decay in beam increases
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Polarized Ammonia Target Experiments in 2009

Hall C: SANE
- Inclusive, double polarization
- Spin asymmetry $A_1$
- Spin structure function $g_2$
- Higher twist, quark-gluon correlations
- $2.5 \leq Q^2 \leq 6.5$ GeV$^2$, $0.3 \leq x_BJ \leq 0.8$
- "U.Va." $^{14}$NH$_3$ DNP Target:
  - 5T at 90°-180° to beam
  - Polarization >70% at beam current ~100nA, 1K

Hall B: EG1-DVCS
- GPD study via Deeply Virtual Compton Scattering
- CEBAF Large Acceptance Spectrometer: CLAS
- Single and double spin asymmetry simultaneously
- $Q^2 \leq 1$ GeV$^2$
- "Hall B" $^{14}$NH$_3$ DNP Target:
  - 5T at 180° to beam
  - Polarization >70% at beam current ~7nA, 1.2K
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U.Va. Polarized Target

Diagram of the polarized target setup, showing the microwave input, NMR signal output, refrigerator, pumps, LN₂ tanks, liquid helium, magnet, NMR coil, target (inside coil), beam direction, and magnetic field strength (5T).
SANE: Polarization Decay with Dose

Polarization vs Dose on Material Start Run 72986

- Current Loss
- Building Radicals
- Current Change

Dose Deposited ($10^{15}$ e$^-$/cm$^2$)
SANE: Polarization Decay with Dose

Polarization vs Dose on Material Start Run 72417

Dose Deposited ($10^{15}$ e$^{-}$/cm$^2$)

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SANE: Polarization Decay with Dose

Polarization vs Dose on Material Start Run 72428

- Positive Polarization
- Negative Polarization

Fast Decay

Polarization vs Dose Deposited (10^{15} \text{e}^-/\text{cm}^2)
SANE: “Optimal” Microwave Frequency vs. Dose

SANE $\mu$Wave Frequency vs Dose since last Anneal

Microwave Frequency (GHz)

Dose Deposited ($10^{15} \text{ e}^-/\text{cm}^2$)

Negative Polarization

Positive Polarization

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SANE: Anneal History

SANE $^{14}$NH$_3$ Anneal History

Temperature (K) or Polarization (%)

Time (mins) of Anneal

Anneal Temperature (K)

Peak Top Polarization After Anneal (%)

Peak Bottom Polarization After Anneal (%)

Ammonia Material Replacement

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Radiation Damage in SANE Ammonia

- Previously unseen features in SANE $^{14}$NH$_3$ after removal
- Persistent activity: above average activity on 2 samples
  - Gamma Spectrum Analysis peak at 477.7 KeV: Be-7
  - $^{14}$N(γ,X)$^7$Be cross section 0.12 mb
- Unexpected color
  - Newly frozen ammonia appears white, but after a “warm” irradiation, solid ammonia beads have a distinctive purple hue, which fades slowly to white over months
  - This purple hue is typically deepened with further dose
  - During SANE, several samples exhibited a brown color
  - Samples with persistent activity exhibited this coloration
Radiation Damage in SANE Ammonia

- Previously unseen features in SANE $^{14}$NH$_3$ after removal
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Radiation Damage in SANE Ammonia
EG1-DVCS: Polarization Decay with Dose, Top
EG1-DVCS: Polarization Decay with Dose, Bottom
EG1-DVCS: “Optimal” Microwave Freq vs. Dose Accumulation
Conclusions

- Rates effects in polarization decay over dose:
  - Current disparity results in “faster” decay in Hall C
- Optimal µWave Frequency vs. Dose on Target:
  - Similar features in both Halls B & C despite current disparity
    - Gap between +,- polarization frequencies same:
      - Starting gap ~0.2 GHz
      - Ending gap ~0.4 GHz
      - Curving neg. pol. frequency curve, flattens by 1e15 e^-/cm^2
      - Linear pos. pol. frequency curve
- Radiation Damage in ^14NH_3 creates Be-7, discoloration
Radiation Damage in SANE Ammonia
Hall C: Spin Asymmetries on the Nucleon

- January to March, 2009
- 450 beam hours on ammonia at ~100nA
- 10 ammonia samples, 26 anneals
  - Subpar material (~80% polarization after warm irradiation) due to failing Klystron in irradiation accelerator
- Run delays due to magnet, fridge & accelerator failure
  - Magnet instability caused interruptions
  - Fridge replacement in situ
    - He level probe removed: further interruptions
    - Nose fill tube removed: anneal temperature gradient