

Overview of processes involved in Spin Transfer

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Summary

- Bodega Bay Workshop 18–21 April 1985 in California
- Spin frontier for the partonic structure of the nucleon
- Channelling in a bent crystal inducing polarisation
- Spin observables for fermion fermion elastic collisions
- Conclusions and outlook

Twelve Ideas at the Bodega Bay Workshop

- Decay in flight of produced antihyperons
- Spin filtering: polarised hydrogen target in storage ring
- Stochastic techniques à la stochastic cooling
- Dynamic polarisation: polarised electrons and microwaves
- Spontaneous spin-flip synchrotron radiation
- Spin-flip synchrotron radiation induced by X-ray laser

More Ideas from the Bodega Bay Workshop

- Directly produced polarised antiprotons by scattering
- Repeated Stern-Gerlach deflection through quadrupoles
- Formation of antihydrogen: use of atomic beam methods
- Polarisation during storage in a Penning trap
- Polarising by Channelling through a thin metallic foil
- Interaction with polarised photons from diamond crystal

Channelling

Bent crystals have readily channelled many types of particle.

- CERN, Scandale et al., PRL 98 (2007) 154801
- RHIC, Fliller et al., PRSTAB 9 (2006) 013501
- IHEP, Afonin et al., Frascati Workshop (2004)
- FERMILAB-CONF-06-309-AD, Carrigan et al.

Ukhanov has suggested that bent crystals may polarise fermions through repeated interaction with nuclei (Kyoto Spin06 p 940).

The critical angle for axial channelling in a crystal derived by Lindhard in the first reference of NIM B 207 (2003) 402 (Uggerhøj et al.) corresponds to squared momentum transfer

$$t_a = -4Z\alpha p / \beta d$$

in the case of a particle of unit charge with momentum p and velocity β moving in the potential well around strings of nuclei of charge Ze spaced a distance d apart. From BK, LL (1974)

$$t_c = -8\pi Z\alpha / \beta \sigma_{\text{tot}}$$

is where electromagnetic and hadronic effects are comparable.

Scattering in the Coulomb interference region on $Z = 14$ silicon nuclei in a crystal appears to occur for laboratory momenta

$$p < 8\pi d / \sigma_{\text{tot}} \approx 10 \text{ TeV}/c .$$

Such collision of fermions may polarise them (Ukhanov Spin06). Consider the interference of helicity flip and nonflip amplitudes

$$M_+(s, t) \propto \sigma_{\text{tot}} \left(i + \rho - \frac{t_c}{t} \right)$$

$$M_-(s, t) \propto \sigma_{\text{tot}} \left(iI + R - \frac{\kappa_p t_c}{2t} \right) \frac{\sqrt{-t}}{m_p}$$

ρ and R being relative real parts and I an imaginary flip part.

An extremum of the single spin asymmetry A_N normal to the scattering plane occurs near $t_m = \sqrt{3} t_c$ (PR D59 114010)

$$A_N^{\max} = \frac{\kappa_p - 2I}{4m_p} \sqrt{-3t_m}$$

where κ_p is the anomalous magnetic moment of the hadron. For particle channelling close to $t = 0$ the normal single spin asymmetry behaves as a cubic in the momentum transfer $\sqrt{-t}$

$$A_N \approx \frac{\kappa_p - 2I}{m_p} \frac{t}{t_c} \sqrt{-t} .$$

Some double spin asymmetries A_{ij} , K_{ij} , and D_{ij} also have singular terms in t arising from photon exchange (PR D18 694) that may alter the dynamics of the build-up of polarisation.

Channelling Summary

- Successive collisions in a crystal may amplify polarisation
- A significant hadronic analyzing power may be sufficient
- An analyzing power has an extremum in interference region
- The helicity flip hadronic amplitude may be important
- Spin transfer and depolarisation observables need study

Polarisation Transfer

- Selective attenuation of particles circulating in a storage ring due to their spin dependent interaction with a polarised target was suggested by Csonka in 1968 as a way of polarising a beam.
- Such a method has polarised protons via their passage through a polarised hydrogen storage cell (PRL 71 13799).
- Hadronic and electromagnetic interactions induce differing losses for distinct orientations of the spin of a proton.

Antiproton Polarisation

- Proton proton spin observables are known at low energy
- Antiproton proton spin cross sections are not well known
- Models of the antiproton proton interaction have appeared
- Haidenbauer, Klempt, Contalbrigo have reviews of models
- Antiproton polarisation may be transferred from leptons

Polarisation Evolution

For particles circulating at frequency ν through a polarised target of areal density n and polarisation P , a coupled system

$$\frac{d}{d\tau} \begin{bmatrix} N \\ J \end{bmatrix} = -n\nu \begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} N \\ J \end{bmatrix}$$

describes the rate of change of the number of beam particles $N(\tau)$ and their total spin $J(\tau)$, (WM, CM, PRE 2006). Loss of particles involves integration beyond an acceptance angle, θ_a

$$a = 2\pi \int_{\theta_a}^{\pi} \frac{d\sigma}{d\Omega} \sin\theta d\theta$$

Beam loss is induced by scattering over all angles beyond θ_a the acceptance angle of the storage ring (NN, FP, Spin06).

The spin averaged differential cross section in a above, for antiproton electron elastic scattering to leading order in $1/t$, is

$$s \frac{d\sigma}{d\Omega} = \frac{(2 \alpha m_e E_l)^2}{t^2}.$$

Changes in the total spin J due to matrix element c involve spin transfer, K_{ii} and asymmetry A_{ii} parameters integrated over particular angular ranges and multiplied by the target polarisation P . Depolarisation involves the matrix element d .

Spin transfer and asymmetry parameters for polarisations normal to the scattering plane have $1/t$ terms

$$s \frac{d\sigma}{d\Omega} K_{NN} = s \frac{d\sigma}{d\Omega} A_{NN} \approx \frac{2\alpha^2}{t} \mu_p m_e m_p$$

as do those with longitudinal directions of the spin if E_l and μ_p are the laboratory energy and magnetic moment of the hadron

$$s \frac{d\sigma}{d\Omega} K_{LL} = s \frac{d\sigma}{d\Omega} A_{LL} \approx \frac{2\alpha^2}{t} \mu_p m_e E_l$$

Electromagnetic spin transfer observables $K_{SS} = A_{SS}$ and the

depolarisation parameter $1 - D_{NN}$ are not singular in t . Some baryon depolarisation does occur due to the singular terms

$$(1 - D_{LL}) s \frac{d\sigma}{d\Omega} = (1 - D_{SS}) s \frac{d\sigma}{d\Omega} \approx \frac{2\alpha^2}{t} \left(\frac{m_p m_e E_l}{k} \right)^2$$

A change in the total spin J results from the matrix element c which has a contribution involving a product of P with the spin transfer observable integrated over angles θ above a minimum angle θ_0 linked to the average distance between charges, an impact parameter beyond which scattering is inhibited.

$$P \pi \int_{\theta_0}^{\theta_a} (2 K_{LL} \text{ or } K_{NN} + K_{SS}) \frac{d\sigma}{d\Omega} \sin \theta d\theta$$

In the transverse case, an azimuthal average leads to the appearance of both asymmetries K_{NN} and K_{SS} . A contribution to the matrix element d results from a similar integral over the azimuthally averaged depolarisation observable, below acceptance. In the short term, the rate of increase of hadron polarisation J/N is given approximately by

$$dJ/d\tau \approx -n\nu cN$$

where c relates to integrals over double spin asymmetries that have singular behaviour in t and are enhanced by such factors as

$$\ln(t_a/t_0) = \ln(t_a/n).$$

Transfer at Low Energy

In a distorted wave approximation involving Coulomb effects, the Mainz group find that the angle integrated polarisation transfer cross section for proton electron elastic scattering is some nine orders of magnitude greater than that expected

$$| \langle A_{LL} d\sigma/d\Omega \rangle | \quad \text{is } 10^9 \text{ times larger}$$

from a plane wave one photon exchange calculation at an incident proton laboratory kinetic energy of 1.2 keV. The same would apply for antiproton positron collisions. It would be interesting to know if the double spin asymmetry and depolarization observables show a similar dramatic change.

Studies incorporating cooling mechanisms may be concerned with the value at low energies of

- the integrated depolarization cross section over angle
- the elastic spin averaged differential cross section

The large increase with energies decreasing to about 1 keV, a lower limit to the distorted wave approximation, compensates for the low lepton areal density when comparison is made with a method using storage cells.

Conclusions

- Spin dependent antiproton collisions test QCD transversity
- Maximum analyzing power at interference probes spin effects
- Significant double spin asymmetries near forward direction
- Important for stored antiproton polarisation build-up