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4.4.2.6.4. *Zeeman polarizer*

The reflection width of perfect silicon crystals for thermal neutrons and the Zeeman splitting ($\Delta E = 2\mu B$) of a field of about 10 kGs are comparable and therefore can be used to polarize a neutron beam. For a monochromatic beam (energy E_0) in a strong magnetic field region, the result of the Zeeman splitting will be a separation into two polarized subbeams, one polarized along **B** with energy $E_0 + \mu B$, and the other polarized antiparallel to **B** with energy $E_0 - \mu B$. The two polarized beams can be selected by rocking a perfect crystal in the field region B (Forte & Zeyen, 1989).

4.4.2.7. *Spin-orientation devices*

Polarization is the state of spin orientation of an assembly of particles in a target or beam. The beam polarization vector **P** is defined as the vector average of this spin state and is often described by the density matrix $\rho = \frac{1}{2}(1 + \sigma \mathbf{P})$. The polarization is then defined as $\mathbf{P} = \mathrm{Tr}(\rho\sigma)$. If the polarization vector is inclined to the field direction in a homogenous magnetic field, **B**, the polarization vector will precess with the classical Larmor frequency $\omega_L = |\gamma| B$. This results in a precessing spin polarization. For most experiments, it is sufficient to consider the linear polarization vector in the direction of an applied magnetic field. If, however, the magnetic field direction changes along the path of the neutron, it is also possible that the direction of **P** will change. If the frequency, Ω, with which the magnetic field changes is such that

$$\Omega = \mathrm{d}(\mathbf{B}/|\mathbf{B}|)/\,\mathrm{d}t \ll \omega_L, \qquad (4.4.2.19)$$

then the polarization vector follows the field rotation adiabatically. Alternatively, when $\Omega \gg \omega_L$, the magnetic field changes so rapidly that **P** cannot follow, and the condition is known as non-adiabatic fast passage. All spin-orientation devices are based on these concepts.

4.4.2.7.1. *Maintaining the direction of polarization*

A polarized beam will tend to become depolarized during passage through a region of zero field, since the field direction is ill defined over the beam cross section. Thus, in order to keep the polarization direction aligned along a defined quantization axis, special precautions must be taken.

The simplest way of maintaining the polarization of neutrons is to use a guide field to produce a well defined field **B** over the whole flight path of the beam. If the field changes direction, it has to fulfil the adiabatic condition $\Omega \ll \omega_L$, *i.e.* the field changes must take place over a time interval that is long compared with the Larmor period. In this case, the polarization follows the field direction adiabatically with an angle of deviation $\Delta\theta \leq 2\arctan(\Omega/\omega_L)$ (Schärpf, 1980).

Alternatively, some instruments (*e.g.* zero-field spin-echo spectrometers and polarimeters) use polarized neutron beams in regions of zero field. The spin orientation remains constant in a zero-field region, but the passage of the neutron beam into and out of the zero-field region must be well controlled. In order to provide a well defined region of transition from a guide-field region to a zero-field region, a non-adiabatic fast passage through the windings of a rectangular input solenoid can be used, either with a toroidal closure of the outside field or with a μ-metal closure frame. The latter serves as a mirror for the coil ends, with the effect of producing the field homogeneity of a long coil but avoiding the field divergence at the end of the coil.

4.4.2.7.2. *Rotation of the polarization direction*

The polarization direction can be changed by the adiabatic change of the guide-field direction so that the direction of the polarization follows it. Such a rotation is performed by a spin turner or spin rotator (Schärpf & Capellmann, 1993; Williams, 1988).

Alternatively, the direction of polarization can be rotated relative to the guide field by using the property of precession described above. If a polarized beam enters a region where the field is inclined to the polarization axis, then the polarization vector **P** will precess about the new field direction. The precession angle will depend on the magnitude of the field and the time spent in the field region. By adjustment of these two parameters together with the field direction, a defined, though wavelength-dependent, rotation of **P** can be achieved. A simple device uses the non-adiabatic fast passage through the windings of two rectangular solenoids, wound orthogonally one on top of the other. In this way, the direction of the precession field axis is determined by the ratio of the currents in the two coils, and the sizes of the fields determine the angle φ of the precession. The orientation of the polarization vector can therefore be defined in any direction.

In order to produce a continuous rotation of the polarization, *i.e.* a well defined precession, as required in neutron spin-echo (NSE) applications, precession coils are used. In the simplest case, these are long solenoids where the change of the field integral over the cross section can be corrected by Fresnel coils (Mezei, 1972). More recently, Zeyen & Rem (1996) have developed and implemented optimal field-shape (OFS) coils. The field in these coils follows a cosine squared shape that results from the optimization of the line integral homogeneity. The OFS coils can be wound over a very small diameter, thereby reducing stray fields drastically.

4.4.2.7.3. *Flipping of the polarization direction*

The term 'flipping' was originally applied to the situation where the beam polarization direction is reversed with respect to a guide field, *i.e.* it describes a transition of the polarization direction from parallel to antiparallel to the guide field and *vice versa*. A device that produces this 180° rotation is called a π flipper. A $\pi/2$ flipper, as the name suggests, produces a 90° rotation and is normally used to initiate precession by turning the polarization at 90° to the guide field.

The most direct wavelength-independent way of producing such a transition is again a non-adiabatic fast passage from the region of one field direction to the region of the other field direction. This can be realized by a current sheet like the Dabbs foil (Dabbs, Roberts & Bernstein, 1955), a Kjeller eight (Abrahams, Steinsvoll, Bongaarts & De Lange, 1962) or a cryoflipper (Forsyth, 1979).

Alternatively, a spin flip can be produced using a precession coil, as described above, in which the polarization direction makes a precession of just π about a direction orthogonal to the guide field direction (Mezei, 1972). Normally, two orthogonally wound coils are used, where the second, correction, coil serves to compensate the guide field in the interior of the precession coil. Such a flipper is wavelength dependent and can be easily tuned by varying the currents in the coils.

Another group of flippers uses the non-adiabatic transition through a well defined region of zero field. Examples of this type of flipper are the two-coil flipper of Drabkin, Zabidarov, Kasman & Okorokov (1969) and the line-shape flipper of Korneev & Kudriashov (1981).

references