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Determination of the Circular Polarized Fraction of Light using a Voltage Driven Nematic Liquid Crystal Wave-Plate

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We present a two measurement method to extract the circularly polarized fraction of light at a particular wavelength. It involves a voltage driven nematic liquid crystal wave-plate and a polarizing filter oriented with their axes 45° to each other. The circular polarized component is calculated from intensities transmitted when the liquid crystal wave-plate acts as a 1/4 wave-plate at one voltage and 3/4-wave plate at another.

Keywords: circular polarized light; nematic liquid crystal wave-plates

Evidence for the usefulness of Helium-3 gas as an enhancer for lung MRI continues to grow [1]. The goal of our research is to help promote the use of Helium-3 (^{3}He) in enhanced lung MRIs by constructing a portable, fully automated machine to polarize Helium-3 gas. Here we present an example where the remarkable electro-optic properties of nematic liquid crystals help miniaturize and automate a process that currently requires several square meters of lab space and the attention of several highly skilled personnel.

We use a density matrix [2] description of the polarized states of light. This is a more general description than needed for liquid crystal device optics. We like it because it accesses analytic tools, techniques and measurement theory developed for Quantum Mechanics [2] (that can be related to parameters used in older phenomenological descriptions of polarized light) and can be extended to quantify (for example) the director orientation (optic axis) of the beautiful micrographs used to analyze liquid crystalline order.

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To polarize (magnetize) ^{3}He, we use the classical MEOP (metastability exchange and optical pumping) method. In MEOP, a weak electrodeless discharge at a pressure of 1 torr creates a ^{3}He plasma that is irradiated with circular polarized light (1083 nm) directed along a weak magnetic guide field [3], **H** in Figure 1.

The polarization, **P**, of ^{3}He in this gas can be determined by measuring the circular polarized fraction of 668 nm light emitted by the plasma in the direction of the magnetic field [4]. A device to determine the fraction of polarized light during the MEOP process cannot have moving parts (to avoid magnetic fields that will disturb the guide field, **H**) and must be insensitive to the pumping radiation (1083 nm) which is also along **H** (Fig. 1).

The method we propose is the following. Measure the intensity of the 668 nm light emitted by the plasma e.g. with a photodetector, after is has passed first through a liquid crystal wave-plate then a polarizing filter (e.g. a Polaroid) (Fig. 2).

Set the fast axis (F) of the wave-plate at an angle θ to the reference direction x. The direction of the **E** vector passed by the polarizing filter is set at an angle ψ to x. Voltages are applied so that the retardance of the wave-plate can be either $\lambda/4$ or $3\lambda/4$.

In the analysis, we represent the state of polarization in photon spin space by a 2×2 density matrix, ρ, with elements: $\rho_{11} = \mathrm{a} + \mathrm{b}$ and $\rho_{22} = \mathrm{a} - \mathrm{b}$ while $\rho_{12} = \mathrm{c} - \mathrm{id}$ is the complex conjugate of $\rho_{21} = \mathrm{c} + \mathrm{id}$: $\mathrm{i}^2 = -1$ and the axis of quantization is the direction of propagation.

Elements of the density matrix, ρ, are related to the phenomenological Stokes parameters as:

$$\mathrm{a} = \mathrm{I}/2, \ \mathrm{b} = \mathrm{V}/2, \ \mathrm{c} = -\mathrm{Q}/2, \ \mathrm{d} = \mathrm{U}/2.$$

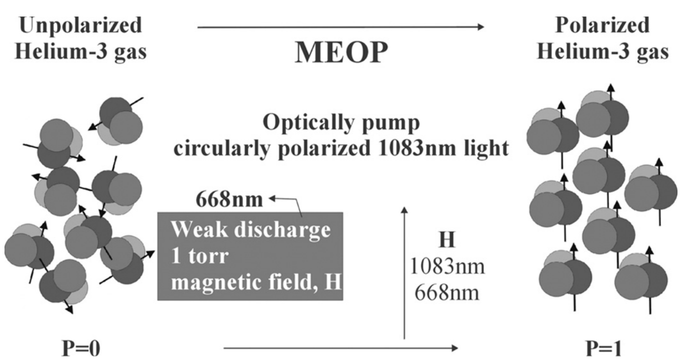

FIGURE 1 Schematic for the MEOP method to polarize Helium-3 gas.

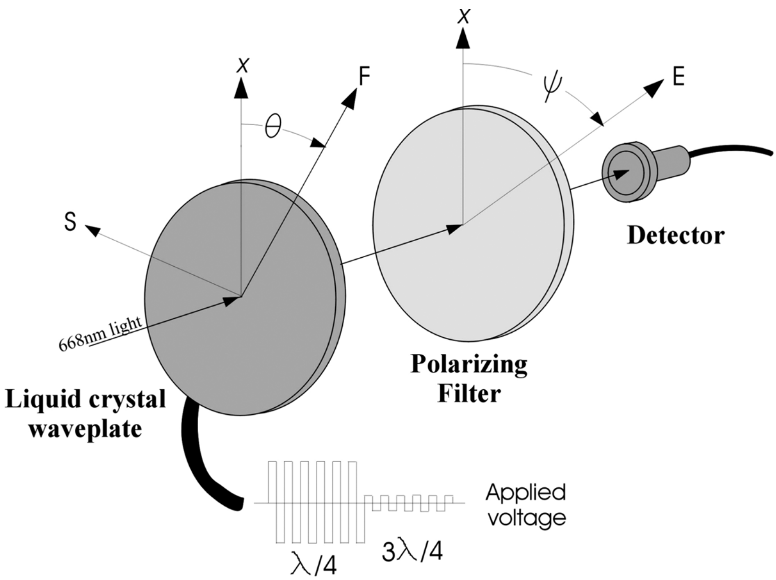

FIGURE 2 Set-up to measure the circularly polarized fraction of 668 nm light emitted by the Helium-3 plasma.

When the wave-plate is set to be a $\lambda/4$ plate, the transmitted intensity is I_1:

$$I_1 = a - b\ sin(2\psi - 2\theta) - (c\ cos2\theta + d\ sin2\theta)\ cos(2\psi - 2\theta).$$

When the wave-plate is set to be a $3\lambda/4$ plate, the transmitted intensity is I_2:

$$I_2 = a + b\ sin(2\psi - 2\theta) - (c\ cos2\theta + d\ sin2\theta)\ cos(2\psi - 2\theta).$$

Choose θ to have any value, and $\psi = \theta + 45^\circ$. Then:

$$\mathbf{I}_1 = \mathbf{a} - \mathbf{b} \text{ and } \mathbf{I}_2 = \mathbf{a} + \mathbf{b}.$$

Thus, the fraction of circularly polarized light is $(I_2 - I_1)/(I_2 + I_1)$.

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