Hanle electromagnetically induced transparency and absorption resonances with a Laguerre-Gaussian laser beam

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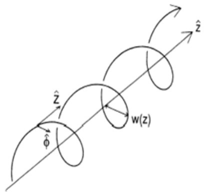
Laguerre-Gaussian beam

- **A helical wave front with doughnut shape intensity distribution with zero intensity at the center.**
- **Carries an orbital angular momentum and has a non-vanishing azimuthal phase dependence**



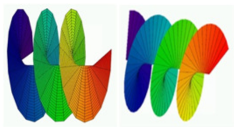
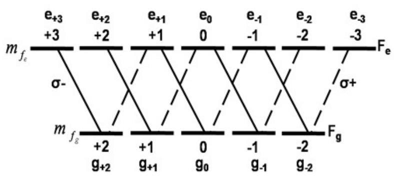


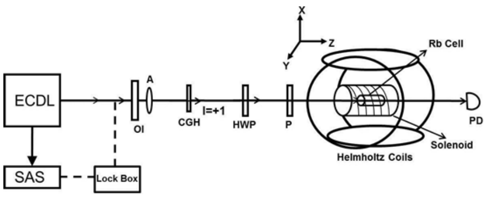
Fig. 1: Propagation of LG beam **Fig. 2: LG_0^{+1} and LG_0^{-1}**

Fig. 3: Picture of the generated LG beam; LG_0^{+1} LG_0^{0} LG_0^{-1}

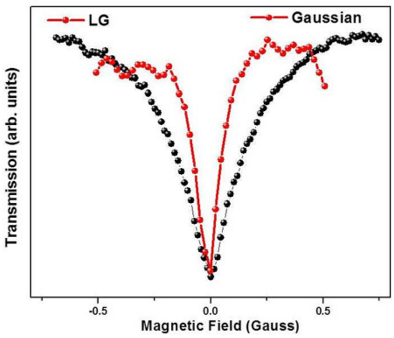
Atomic level configuration for $F_g=2 \rightarrow F_e=3$



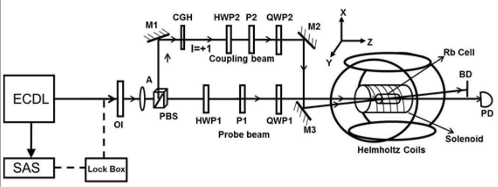
Experimental set-up for one-beam system



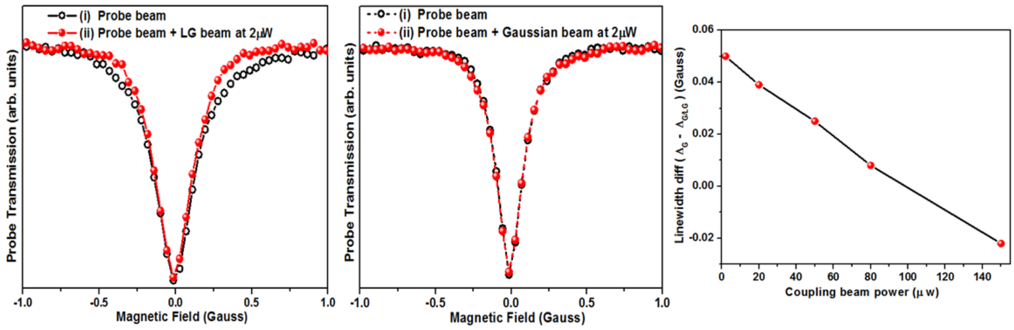
Measured Hanle EIA profiles for Gaussian and LG beams



Experimental set-up for two-beam system



Experimental Results



Theory of Electromagnetically Induced Transparency and Absorption Resonances with a LG beam

The field amplitude satisfying the wave equation in the paraxial approximation is given by

$$E_{LG} = \varepsilon_{klp}(\mathbf{R})e^{i\Theta_{klp}(\mathbf{R})} - c.c$$

$k \rightarrow$ wave vector,
$l \rightarrow$ Azimuthal mode index,
$p \rightarrow$ Radial mode index.

$\varepsilon_{klp}(\mathbf{R}) \rightarrow$ mode amplitude and
$\Theta_{klp}(\mathbf{R}) \rightarrow$ phase factor of the electric field respectively

For z << Rayleigh length 'z_R' and making the dipole approximation, E_{LG} reduces to

$$E_{LG} \approx E^{o}_{LG}\left(\frac{r}{w(z)}\right)^{|l|} e^{-\frac{r^2}{w(z)^2}} e^{-il\phi} + c.c$$

The time evolution of the density matrix ρ is given by the Liouville equation

$$\frac{d\rho}{dt} = \frac{i}{\hbar}[\rho,\tilde{H}] - \frac{1}{2}\{R,\rho\} + \Lambda_{\Gamma} + \Lambda_{\Upsilon}$$

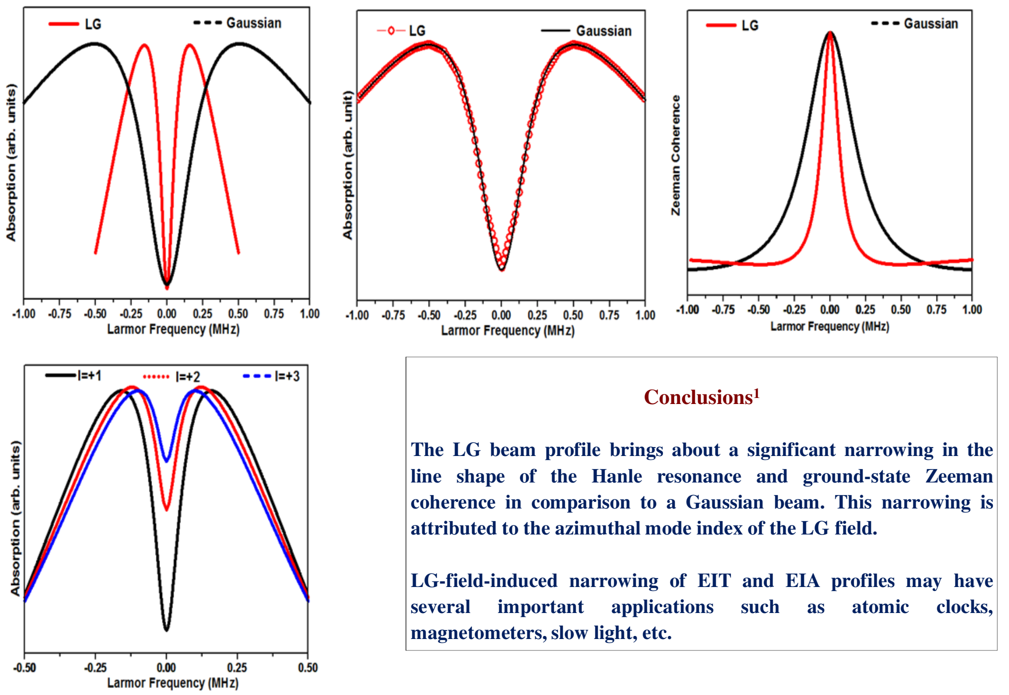
The steady state probe absorption α is given by

$$\alpha = \sum_{\substack{i,j\\ i\neq j}} \frac{2\sqrt{2}\pi\omega_o N}{\hbar c\Omega}|d_{ij}|^2 \begin{pmatrix} J_e & 1 & J_g \\ -m_e & q & m_g \end{pmatrix} \mathrm{Im}[\rho_{e_i}\rho_{g_j}]$$

Computed probe absorption for the LG beam

$$\alpha_{LG} = \int_{r=0}^{w_o}\int_{\phi=0}^{2\pi}\sum_{\substack{i,j\\ i\neq j}} \frac{2\sqrt{2}\pi\omega_o N}{\hbar c\Omega^{o}_{LG}\left(\frac{r}{w(z)}\right)^{|l|} e^{-\frac{r^2}{w(z)^2}} e^{-il\phi}}|d_{ij}|^2 \begin{pmatrix} J_e & 1 & J_g \\ -m_e & q & m_g \end{pmatrix} \mathrm{Im}[\rho_{e_i}\rho_{g_j}]\,dr\,d\phi$$

Computational Results



Conclusions[1]

The LG beam profile brings about a significant narrowing in the line shape of the Hanle resonance and ground-state Zeeman coherence in comparison to a Gaussian beam. This narrowing is attributed to the azimuthal mode index of the LG field.

LG-field-induced narrowing of EIT and EIA profiles may have several important applications such as atomic clocks, magnetometers, slow light, etc.

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1) *Phys. Rev. A* 81, 043804 (2010)