Research Networking Programmes

Short Visit Grant ☒ or Exchange Visit Grant ☐

(please tick the relevant box)

Scientific Report

The scientific report (WORD or PDF file – maximum of eight A4 pages) should be submitted online within one month of the event. It will be published on the ESF website.

Proposal Title: Atom Optics: From C light field traps to structured atomic vortex beam prisms

Application Reference N°: 7241

1) Purpose of the visit

To continue and extend the scientific collaboration with Prof. Babiker and his collaborators at the Depart. of Physics of University of York UK

2) Description of the work carried out during the visit

- Seminar at the Department of Physics and Electronics Univerity of York
  On vortices: a compendium of physical concepts and mathematical techniques
  University of York Department of Physics, April 27 2015.
  Abstract
  Vortices are presented, starting from multivalued complex functions exhibiting singularities and proceeding to consider the Hilbert space formed by orbital angular momentum (OAM) states that provides representation to ISO(2) Euclidean algebra generators identified as the relevant physical observables. Next, the three classes of physical vortices, i.e. light, electron and atom vortices, are considered and basic construction techniques such as computer generated fork holograms, spiral phase plates, beam splitters, and the paraxial wave equation Laguerre-Gauss solutions are discussed. The mechanical effects of vorticity are investigated next by studying interaction models coupling matter to light carrying OAM of fractional or irrational angular momentum or with so-called C shaped beams. The resulting dynamical equations of motion appeared to be generalizations of the well known Raman-Nath equations of light-matter interaction.

-- Collaboration with Prof. M. Babiker and Prof. Jun Yuan and team of their PhD students.

Topics

- Creation of electron beams having a C shape transverce intensity profile : construction of diffraction gradings, analytic calulation of the intensity profiles, physical properties of C beams e.g. methods of imprinding OAM on Gaussian electron beams, possible applications in e.g. imaging, mechanical effects in interaction with matter. Study of unitary transformation creating irrational OAM electron beams. Investigations of the resulting electron OAM wavefunction: normalization, orthogonality uncertainties.
- Irrational vortex index : general constaction with emphasis in electron beams. Theoretical analysis of the possible type of irrational OAM index. Fractional, non-fractional, algebraic integers, real number OAM index values. Study of the experimental project carried out by prof. Yuan lab, for the construction of electon beams with OAM of and real value. Comparison with analytic calculation carried out for the mechanical effects e.g. particle trapping, of particles inside C shape potential traps generatd by beams with C shape transverse intensity profile. Optical and mechanical possibilities of distinguising rational form irrational OAM values.

Collaboration with Prof. M. Babiker (joint project Dr. V. Lembessis, King Saud University)

Topics

- Atomic vortex beams II

Atomic diffraction in potentials with radial singularities constructed by interference patterns of light beams carrying orbital angular momentum have been investigated. The approximate seperability condition between radial and azimuthal variables, valid in areas radially remoted from singularities of optical potential has been introduced. The resulting diffracted radial and angular wavefunctions are have been studied in relation to solutions of Bessel and Mathieu equations respectively. This work is a continuation of the article Babiker: V. E. Lembessis, D. Ellinas, M. Babiker, and O. Al-Dossary, "Atomic vortex beams ", Phys. Rev. A 89, 053616 (2014)

- Gouy phase of Laguerre-Gauss beams and its mechanical effects

This is a new collatoration project in its exploratory phase. What is the physical significance of the so called Gouy angular phase in OAM carrying beams. What is its mechanical manifestation in the fields of atom optics, especially in optical traps and optical lattices, and could be the possible applications. Can we quantify these effects of Gouy phase especially in the case of well known circular optical lattice called optical Ferris? Investigation of the literature about the physica of Gouy phase. Preliminary calculations for the case of optical phase.

3) Description of the main results obtained

Collaboration with Prof. M. Babiker and Prof. Jun Yuan (Univ. of York) and team of their research associates and PhD students.

Topics

- Creation of electron beams having a C shape transverce intensity profile:

C electron beams have been investigated following the original construction of York's group. The parametric depended imprinting of vorticity to a wavefunction via an appropriately constructed diffraction mask is shown to be a unitary transformation generated by a parametric Hamiltonian. Special cases of zero OAM imprinting and of vortex states with minimum uncertainty are discussed. The relation of C electron beams to the so called elegant Hermite-Gaussian beams is under investigation.

- C shaped optical potentials: mechanical effects

C shaped optical potentials constructed by light beams carrying orbital angular momentum e.g. Laguerre-Gauss light beams, have been considered within the context of atom-light interaction. The equations of quantum motion for atoms have been derived for a class of such C shaped potentials, such as potentials made by a well in the form of circular arc or from a union of such circular wells. The resulting dynamical equations of motion are driven by Hamiltonians which are infinite Toeplitz matrices. The equations appeared to be generalizations of the well known Raman-Nath equations of light-matter interaction. Approximate schemes of potential that could result into Hamitonian generators being band Toeplitz matrices have been investigated. The trapping and/or propagetion of atomic wavepackes within such C shape light potentials is under investigation.

Collaboration with Prof. M. Babiker (joint project Dr. V. Lembessis, King Saud University)

Topics

- Atomic vortex beams II:

Application of holographic reconstruction method original conceived for making optical and electron vortices to first construct the intensity pattern or mask function of the fork type.

A 2D Fourier transform issued by Fraunhofer integral is carried out in the form of Hankel transform obtain diffracted atom vortex beam. The intensity pattern function provides an atomic trapping potential. The radial and azimuthal dependence of this potential is studied at the beam waist level numerical and analytical. It posses ineteresting novel features: radial singularities (i.e. at some radii it becomes infinite, the values of those radii are determined by the parameter of the mask making light beams e.g. the tilting parameter between them); there is azimuthal rotational symmetry only for zero OAM light beams, for non zero OAM the potentail is axial symmetrix but not azimuthially symmetric. For regions in the z=0 plane far away from the radial singularities, the approximate seperability of radial and azimuthal parts for the eigenvalue problem equation is introduced. In this seperability regime radial and angular wavefunctions are determined and classified via the known solutions of the modified and ordinary Bessel equations of zero, positive and negative order. Given that Bessel function described vibrating drums as surfuces which vibrate like flat drum-heads in the shape of the circle or the square, we conclude that radially our atomic vortex intensity behavies like an atomic drum-head.

Next the angular eigenvalue problem is cast in the form of Mathieu equation and studied in terms of its two classes of orthogonal solutions, i.e. the cosine-elliptic and sine-elliptic. As usually the Mathieu equation depends on a crucial parameter which when it tends to zero reduces Mathieu equation to the equation of harmonic motion, otherwise Mathieu equation is identified with equation of motion for pendulum. In our case the

parameter is found to be proportional to the detuning, and since with work in the far off resonace regime, the azimuthal Mathieu equation describes a pendulum.
This work is still in progress.

- Gouy phase and curvate term of Laguerre-Gauss beams and its mechanical effects:
  Preliminary results with the collaborators of the project show that e.g. the optical Ferris get modified by taking into account the Gauy phase, in the sense that the potentail dips becomes more dense around the circle. This effect should be double checked and interpreted further.

4) Future collaboration with host institution (if applicable)

Continuation and extension of the research collaboration with Professor M. Babiker exists and is planned in some new fields and topics along the lines reported above. Also a new collaboration with Professor J. Yuan has been initiated and some joint work with both of them is planned and expected.

5) **Projected publications / articles resulting or to result from the grant** ***(ESF must be acknowledged in publications resulting from the grantee's work in relation with the grant)***

Projected publication (tentative titles and list of authors)
- Atomic vortex beams II (D. Ellinas, V. Lembessis, M. Babiker)
-Gouy phase of Laguerre-Gauss beams and its mechanical effects (V. Lembessis, M. Babiker, D. Ellinas)
- Creation of electron beams having a C shape transverce intensity profile (D. Ellinas, M. Babiker, M. Mousley, J. Yuan)
-C shaped optical potentials: mechanical effects (D. Ellinas, M. Babiker, V. Lembessiss, M. Mousley, J. Yuan)

6) Other comments (if any)