Report on a short visit grant No. 4089 15 June - 28 June 2011, at the Institute of Physics, University of Augsburg, Germany

Jerzy Łuczka
Institute of Physics, University of Silesia, 40-007 Katowice, Poland

Research project: "Quantumness of nonsuperconducting nanorings"

Quantum mechanical character of relatively large objects operating at meso– or nanoscales has recently attracted considerable attention of theorists, experimentalists and technologists. As such systems exhibit various quantum phenomena, they can serve not only as a natural range for testing our understanding of quantum mechanics but also as a promising resource for quantum computation, quantum information storage and generally nanotechnology. To ensure that the considered system is essentially quantum one needs to perform a suitable *quantumness test* [1], i.e. a measurement of a certain, carefully prepared observable. Such an observable is often highly non–trivial and, to prove quantumness, one attempts to perform a more modest task: one tries to recognize specific quantum features of the system.

We have studied nonsuperconducting nanorings and seek nonclassical features of magnetic flux passing through nanorings. We have also considered superconducting rings because of two reasons: (i) to compare quantumness of both systems; (ii) supercondicting rings are much better elaborated and more frequently expoited in experiments. Classical and semi–classical properties of magnetic fluxes in such rings have already been analyzed. One of the most remarkable nonclassical features is "quadrature" squeezing [2]. In the considered case, it corresponds to the variance of the magnetic flux. The quantumness is identify in regimes where the normalized variance is less than 1/4 (the regimes of the quadrature squeezing[2]). We focused on purely quantum (i.e. nonclassical) characteristics of the magnetic flux and showed that in specific states, the so-called Gazeau-Klauder (GK) states [3], the magnetic flux can be squeezed. In other words, in such states quantum noise is reduced and, in consequence, fluctuations of the magnetic flux are also reduced. Moreover, we have pointed out the Gazeau-Klauder states for which the quantum noise is maximally reduced and then fluctuations of the magnetic flux are minimal. We have numerically constructed the set of GK states truncating the infinite dimensional Hilbert space of the system. We have tested this procedure and ascertained that for the chosen model parameters the dimension $D = 40$ is sufficient to obtain converged results. We have found that in dependence upon a state in which the magnetic flux is, it can behave more classically or more quantumly. We have tried to find the later and identified a part of a set of the Gazeau–Klauder states in which quadrature squeezing is exhibited. For superconducting ring, the quadrature squeezing occurs for values of the parametr $J \in (J_1, J_2)$, where J is related to the mean value of energy in a given GK state. For non-superconducting rings, the quadrature squeezing occurs for small values of the parametr $J \in (0, J_1)$ and for large values of the parameter $J > J_2$. We expected some similarities between these two systems and we can not explain why these two systems behave in a different way. More deeper studies should be continued to explain it.

Preparation of the GK states would in general require highly sophisticated quantum engineering. Nevertheless, properly chosen the GK states can provide an experimental test which could detects nonclassical behavior of the magnetic flux. Recent progress in entirely novel experimental techniques makes the verification of our findings quite realistic. One of the scanning device could be a SQUID microscope that can detect extremely small magnetic fields like those produced by the circulating currents in the rings. The next could be nanoscale cantilevers [4]. The new experimental setup allowed to make measurements a full order of magnitude more precise than any previous attempts.

We intend to publish a paper on the above mentioned problems but now we have to work out a program which allow to extend the range of validity of numerical construction of the Gazeau-Klauder states and more detailed analysis is needed.

References

[1] Alicki R and Van Ryn N 2008 *J. Phys. A: Math. Theor.* **41** 062001
Alicki R, Piani M and Van Ryn N 2008 *J. Phys. A: Math. Theor.* **41** 495303

[2] Gerry C C and Knight P L 2005 *Introductory quantum optics* (Cambridge: Cambridge Univ. Press)

[3] Gazeau J P and Klauder J R 1999 *J. Phys. A: Math. Gen.* **32** 123

[4] Bleszynski-Jayich A C, Shanks W E, Peaudecerf B, Ginossar E, von Oppen F, Glazman L and Harris J G E 2009 *Science* **326** 272