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Introduction to the 12th Central European Workshop on Quantum Optics

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Abstract. A brief comment concerning the history of Central European Workshops on Quantum Optics and the development of quantum optics is presented.

1. Brief description of CEWQO

More than a decade ago, a small group of scientists from Budapest (Hungary), led by Prof. Joszef Janszky, and from Bratislava (Slovak Republic), led by Prof. Vladimir Bužek, joined their efforts to organise a Central European Workshop on Quantum Optics (CEWQO). In a very few years, this small, local meeting has grown into an important annual European conference. The two characteristic features of the CEWQO series, namely the high level of invited talks delivered by the leaders in the field and the low participation price, make these conferences quite attractive, especially for young scientists.

Another important trait of CEWQO consists in the inclusion of the most important directions and implementations of quantum optics into the scientific program. For example, the topics discussed in the 12th CEWQO were divided into the following four groups:
- Modern trends in quantum optics and photonics,
- Quantum optics of atoms and molecules,
- Quantum optics of condensed matter,
- Quantum information technologies based on quantum optics.

The varying geographical locations of meetings are also important. For example, the last 12th CEWQO was hosted by Bilkent University (Ankara, Turkey) in June 2005. The three previous workshops were organised in Szeged (Hungary, 2002), Rostock (Germany, 2003), and Trieste (Italy, 2004). The Atominstitute (Vienna, Austria) will play host to the next CEWQO in May 2006 (see: www.ati.ac.at/~neutropt/cewqo2006).

2. Survey of quantum optics

Right after the announcement of the 2005 Nobel Prize in physics, October 4, 2005, science writer Joanna Rose asked Professor Roy Glauber (Nobel Winner in Physics):

"People used to call you Father of Quantum Optics".

He replied:

"Oh, yes. Well, they seem to use that term, which ... I hope it's not just a reference to my considerable age. The subject, in a sense, did not exist before the early 1960s; and yet, in another sense, it had already existed for sixty-odd years."

For reference, see: http://nobelprize.org/physics/laureats/2005/glauber-interview.html.

As a matter of fact, development of quantum optics was a part and parcel of formation of modern physics since beginning of the 20th century. Namely, the works by Max Planck on black-body radiation and the quantum of action (Planck 1900, Plank 1901) and by Albert Einstein on the photo-effect (Einstein 2005) have given rise to quantum mechanics.

Note that according to Wikipedia (http://en.wikipedia.org/wiki/Photon), the term "photon" was introduced in 1926 by famous physical chemist Gilbert N. Lewis from the University of California at Berkley.

The theoretical basis of quantum optics (of quantum electrodynamics, in general) was built by Paul Dirac in the late twenties (Dirac 1927(a,b)). In a sense, it was the first step towards a unification of quantum mechanics with special relativity. In these works, he pioneered the use of the operator theory, describing photons in terms of creation and annihilation operators that form a representation of the Weyl-Heisenberg algebra. He also developed the fundamental notion of the electromagnetic vacuum state. Further investigation has shown that the properties of electromagnetic vacuum are responsible for a number of important physical effects such as the natural linewidth (Weisskopf an Wigner 1930(a,b)), the Lamb shift (Lamb and Retherford 1947), the Casimir force between conductors (Casimir 1949, Casimir and Polder 1948), and the quantum beats (Chow *et al.* 1975, Herman *et al.* 1975).

In spite of a great success in the development of quantum field theory and the understanding of properties of charged elementary particles interacting with each other by means of photon exchange (e.g., see: Feynman 1985), the theoretical investigation of optical phenomena was remaining a semiclassical one for a long time, even during the early days of laser physics (Yariv 1967). This means that the sources of photons (atoms, molecules, etc) were considered within quantum mechanics, while the radiation field was treated classically.

The birth of quantum optics as a novel branch of physics was heralded by the implementation of the Hanbury Brown and Twiss interferometer (Hanbury Brown and Twiss 1956, 1958), that allowed to reveal information about statistical properties of photon beams through the measurement of correlations in the fluctuations of photocurrents from two photodetectors illuminated by light from the same source, by the derivation of Mandels formula for photoelectric counting (Mandel 1959), and by the work on a completely quantum description of optical coherence (Klauder 1960, Glauber 1963(a,b), Sudarshan 1963). The verification of the Poisson distribution of photons for laser sources (Arecchi *et al.* 1966) and of photon bunching for Gaussian sources (Arecchi 1965, Morgan and Mandel 1966) were the first experimental results in the field.

The potential of quantum optical experiments was strongly increased through the use of ion traps (Dehmelt 1976, Neuhauser *et al.* 1978), optical molasses (Letokhov and Minogin 1976, Chu *et al.* 1985), the creation of a single-atom laser (Meschede *et al.* 1985, Haroche and Raimond 1985), and the development of other advanced techniques (for references see monographs: Perina 1991, Mandel and Wolf 1995, Scully and Zubairy 1997, Vogel *et al* 2001).

The unprecedented precision of measurements and the possibility to work with pure quantum objects like single atoms and single photons have turned quantum optics into the main tool of testing the fundamentals of quantum physics. In particular, it has led to the discovery of new quantum effects without classical analogue such as antibunching of photons (Kimble *et al.* 1977), sub-Poisson statistics of photon distributions (Short and Mandel 1983), and squeezing of quantum fluctuations (Slusher *et al.* 1985, Wu *et al.* 1986; for review, see Loudon and Knight 1987 and Dodonov 2002). Thus, the fundamental difference between the classical and quantum levels of the description of Nature and the nonexistence of a quasi-classical limit in general

has been demonstrated. In addition, the absence of "hidden classical variables" within the framework of quantum mechanics has been experimentally proved through the use of methods of quantum optics (Aspect *et al.* 1982(a,b)).

Further development of ideas and methods of quantum optics has led to the observation of Bose-Einstein condensation of atoms and molecules and to creation of atom lasers (Anderson *et al.* 1995, Mewes *et al.* 1997, Bloch *et al.* 1999). Even genuinely quantum-optical experiments, such as the Hanbury Brown-Twiss setup are nowadays transferred to ultracold atomic gases, for measuring the quantum correlations between atoms (Yasuda and Shimizu 1996, Fölling *et al.* 2005, Schellekens *et al.* 2005).

Besides the role in testing of fundamentals of physics, quantum optics provides some other brunches of physics with powerful and precise methods of investigation. The correlation spectroscopy of solids (Hakioğlu and Shumovsky 1997), quantum optical effects in mesoscopic electron systems (Oliver *et al.* 1999) and quantum optics of nano-structures like quantum wells and quantum dots (Jacobson *et al.* 1995, Michler *et al.* 2000) should be mentioned here.

3. Quantum optics and quantum information

Among the numerous modern applications of quantum optics, quantum information technologies play a very important role. The point is that we are living in the so-called "information age" when the scientific, technological, and economic progress of humanity depends increasingly on the capability to develop and implement new information technologies. Computing's exponential increase in power and a similar increase in the capacity of information nets require nowadays qualitatively new information technologies.

It has been realized recently that quantum physics gives rise to novel algorithms, providing computations with unprecedented speed (Shor 1994, Grover 1997), to new methods of coding and cryptography that are completely secured from eavesdropping (Bennet and Brassard 1984, Ekert 1991), and to many other advantages over classical information processing and computing algorithms.

It is interesting that nowadays the trapped ion is considered as a system useful for quantum computing (Schrade *et al* 1995).

The key physical resource of quantum information processing and quantum computing is provided by quantum entanglement, a special state of two- or multi-partite system, carrying information in terms of specific quantum correlations between the parties. The quantum entanglement can be easily modelled by photons and two- and multi-level atoms (e.g., see Myatt *et al.* 2000, Rempe 2000, Raymond *et al.* 2001, Gisin *et al.* 2002, Shumovsky and Rupasov 2003, Polzik 2004), which are the typical objects of quantum optics. For example, the practical realization of quantum key distribution is based on the properties of polarised photon twins (Lorünser *et al.* 2004).

Thus, despite the long history, quantum optics nowadays remains an extremely important branch of physics. It represents a natural base for development of advanced technologies. Its methods provide the best tool for experimental investigation of fundamentals of modern physics.

At the same time, there is a number of principle questions inside quantum electrodynamics that still remain unclear (e.g., see: Lamb 1995, Scully and Zubairy 1997).

4. Concluding remarks

This issue of Journal of Physics (Conference Series) represents the proceedings of the 12th Central European Workshop on Quantum Optics, both invited and contributed works. The topics range from the development of new experimental techniques in quantum optics to its various applications. The papers are published in alphabetic order with respect to the surname of the first authors.

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