Les Houches summer school

Quantum Entanglement and information processing

Final report

The les Houches School on "Quantum Entanglement and Information Processing" has been held in the Les Houches venue, belonging to Université Joseph Fourier, from July 1st, 2003 to July 25. There was a real need for a comprehensive school on quantum entanglement and information processing because this field has emerged recently and is the focus of an intense activity. Besides some graduate courses, there was no available training program presenting all theoretical and experimental aspects of the field. The school has presented for the first time a comprehensive program, addressed to all communities involved, and taking care of establishing a common language. This school has already triggered scientific exchanges between many groups who had no direct contacts before and in particular between European ones.

The school project has been very attractive. We received almost 200 application files, for about 50 available positions. Most of them originated from bright students with a good research background in quantum information, quantum optics or solid state physics. The selection process, based on the application file and recommendation letters by renowned scientists allowed us to select the students able to take the best benefit from the school teaching.

The school finally gathered 54 students from all countries. 36 of them were nationals or active inside an EC member state, 1 national of EC but active outside of EC. 23 nations were represented among the students, giving a strong international character to this event. The generous support of the European Community, through the "High Level scientific conference" program and through the Quiprocone Network of Excellence, made it possible to offer attractive financial conditions to most students, the maximum fee charged, both for the teaching and the accommodation, being 200 Euros. This contributed to making the school accessible to all best students without financial considerations.

The students have met some of the most outstanding scientists in the field (see the detailed program below), in an informal atmosphere, allowing for deep discussions after the lectures. They have greatly benefited of all the scientific debates raised by the lectures. The contacts established between the students will favour the development of a unified quantum information community, which is essential for the growth of the field.

Three main highlights can be singled out.

-First, the series of eight lectures by I. Chuang on ***the principles of quantum computing*** (QC) has risen a tremendous interest among the students. A work group has been created to reach a deeper understanding of these lectures, and I. Chuang has provided problems to solve. These problems have triggered intense discussions involving the students and the lecturers, and this brain-storming will likely contribute clarify the main issues in this field. In particular, new

quantum computing algorithms have been debated, and some pending issues have even be solved. The series of lectures by J. Jones on ***NMR quantum computing*** has provided an excellent playground for the application of all the theoretical concepts developed in the QC lectures, while giving a clear overview of the NMR-based Quantum Computing schemes.

-Second, one major goal of this summer school was to establish connections between the communities of quantum optics and of quantum electronic devices working in the area of quantum computing. When two communities share the same goals, the universality of physics unavoidably leads to similar developments. However, the communication barrier is often high, and few physicists are able to overcome it. This school has contributed to bridge the existing gap between communities, for the benefit of the future actors in the field of quantum computing. The lectures by S. Haroche on ***quantum optics and decoherence*** have given a theoretical framework sufficiently wide for that purpose. The lectures by C. Glattli et M. Devoret on quantum devices have provided the complementary framework for circuits, so that the students have benefited of the more specialised lectures on ***Cavity quantum electrodynamics*** (M. Brune), on ***ion traps*** (R. Blatt, P. Zoller, D. Wineland), on ***entangled photons*** (A. Zeilinger), on ***Josephson qubit circuits*** (D. Vion, J. Martinis, H. Mooij), and on ***quantum nanomagnets*** (W. Wernsdorfer). The invited seminar by R. Schoelkopf on the direct application of Cavity QED concepts to Josephson systems has clearly proven the scientific interest of the cross fertilisation between the communities of quantum optics and of quantum electronic devices. Fruitful contacts have already been established between European groups, and some problems have even be solved during the school (i.e.: application of the knowledge of single electron devices (quantronics group at CEA Saclay, France) to ion trap physics (Innsbruck U., Austria)).

-Third, the school has provided a unique opportunity to discuss the various schemes proposed for secure communications thanks to quantum mechanics, an area called ***quantum cryptography***. For the first time, all the existing proposals have been taught in a comprehensive way by N. Gisin and P. Grangier. In view of the practical importance of quantum cryptography (which may well lead to the first applications of quantum information), the school has significantly contributed to the clarification of this domain by providing a true scientific discussion of the advantages and drawbacks of the various existing quantum cryptography schemes. In particular, the comparison between schemes based on entangled single photons and on continuous variable states has been the object of intense and fruitful discussions, and the issue of the security of these schemes has been clarified.

The lectures have been made available in real time on the school web site
www-houches.ujf-grenoble.fr/ete-79/jmr/houches79.html

All the lecturers will provide a written version of their lectures, which will be published in a book of the prestigious *Les Houches* series. The editors are Daniel Esteve, Jean-Michel Raimond and Jean Dalibard. The publisher is Springer-EDP-Sciences, and publication is scheduled on June 2004. This book, entitled **QUANTUM ENTANGLEMENT AND INFORMATION PROCESSING,** with about 700 pages, will not only provide a comprehensive and pedagogical introduction to the concepts of quantum information, but will expose all the implementations performed up to now of quantum bit devices. We think that this book will have a large impact, and will provide an essential source of information for students and researchers in the field.

Detailed program:

- R. Blatt (U. Innsbruck) and D. Wineland (NIST, Boulder): Quantu information processing in ion traps.
- I. Chuang (MIT, Cambridge): Principles of quantum computing.
- M. Devoret (Yale U.) and C. Glattli (CEA and ENS, Paris): Introduction to quantum electronic circuits.
- S. Haroche (Collège de France and ENS, Paris): Introduction to quantum optics and decoherence.
- J. Jones (Oxford U.): Quantum information and Nuclear Magnetic Resonance.
- M. Brune (ENS, Paris): Cavity quantum electrodynamics.
- N. Gisin (U. Genève): Quantum cryptography.
- P. Grangier (IOTA, Orsay): Quantum cryptography: from single photons to many photons.
- J. Martinis (NIST, Boulder): Phase superconducting quantum bit circuits.
- H. Mooij (T.U. Delft): Flux superconducting quantum bit circuits.
- D. Vion (SPEC, CEA-Saclay): Charge superconducting quantum bit circuits.
- W. Wernsdorfer (LLN, Grenoble): Quantum nanomagnets.
- Zeilinger (U. Vienna): Entangled photons and quantum communication.
- P. Zoller (U. Innsbruck): Quantum communication and quantum computing with cold atoms and photons.
- R. Schoelkopf (Yale U.): The prospects for strong cavity QED with superconducting qubits

In addition, 14 short seminars have been contributed by selected students to present specialized topics complementing the main lectures.

Jean-Michel Raimond

Laboratoire Kastler Brossel

Ecole Normale Supérieure

24 rue Lhomond 75005 Paris,

jmr@lkb.ens.fr