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The Frontiers of Science and Measurement : Report on a seminar jointly organised by the National Physical Laboratory and the Institute of Physics on 26th May 1993

Clifford C Hodge and David W Robinson
Division of Quantum Metrology
National Physical Laboratory
Teddington
Middlesex
United Kingdom
TW11 0LW

ABSTRACT

A Seminar entitled "Frontiers of Science and Measurement" was held at the National Physical Laboratory (NPL) on 26th May 1993. It was aimed at facilitating the exchange of ideas and research interests in the expectation of encouraging future collaborative activities. The response from delegates was positive. For some this was their first visit to the NPL. Many expressed the wish for closer links with NPL and the need for follow-on meetings to explore the more promising areas identified at the Seminar.

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1 INTRODUCTION

A remarkable feature of recent developments at the frontiers of physics has been the speed with which novel precision measurement applications have followed from many of the most exciting developments. It is as if precision metrology often provides the first application of much new physics. As evidence, consider macroscopic quantum effects in superconductivity leading to voltage standards and novel detectors from d.c. to teraHertz frequencies, all pioneered in National Standards Laboratories. Likewise, the Quantised Hall Effect led with great speed to the realisation of an atomic unit of resistance. The ability to cool or trap small numbers of ions or atoms has already led to more precise determinations of fundamental constants and is likely to lead to new frequency standards. Among the many applications of scanning tunnelling microscopy and its derivatives, dimensional measurement innovations are of key importance.

Therefore, the main objectives of this meeting were to facilitate further cross-fertilisation of ideas between those who were leaders in their fields of "frontier physics" and those who possessed an interest in all forms of high-precision measurement. A broad-ranging and inter-disciplinary approach was implemented to stimulate the flow of ideas and applications, from academia through to industry. The day's programme was planned to embrace the theme of the Seminar with keynote presentations by leading experts in optical spectroscopy, quantum electronics, nanotechnology and gravity wave detection. This was completed with afternoon tours of NPL's fundamental metrology laboratories and an open poster session covering an even wider range of advanced science. Despite the disparate nature of the subjects covered, it was particularly encouraging that more than 70 people participated in the day's activities.

The distribution of delegates was evenly balanced. Of the 70 people who registered for the meeting, 28 were from Universities (for example, Imperial College, Nottingham, Southampton and Glasgow), 18 from industry (for example, Hitachi Cambridge Laboratories, Oxford Instruments, Sharp Laboratories of Europe, and GEC Marconi) and 24 representatives from NPL. The Seminar was aimed at attracting a broad range of physicists and engineers involved in high precision measurement and instrumentation and this was well reflected in the delegates' wide range of disciplines. Furthermore, this testimony to the intimate links between frontier science and measurement technology was highlighted throughout the morning presentations.

2 MEETING REPORT

Dr. Brian Petley introduced the Seminar, pointing out how the continuing requirement for advances in the accuracy of measurement has historically required an order of magnitude improvement every ten to fifteen years. The push for this was ultimately generated by industrial end users, but researchers in metrology must now be developing the techniques which will be required for the next generation of instruments. For the United Kingdom to remain a major player in world markets it is important that industry is able to exploit metrological developments as rapidly as possible. A key message of this introduction was that Science still offered plenty of scope for improving measurement accuracy by some orders of magnitude and that time and frequency measurement held the key to modern technology.

Professor Allister Ferguson, Strathclyde University, echoed this message by highlighting some of the most recent developments in quantum optics and spectroscopy, pointing out that those working in the visible region of the electromagnetic spectrum are rapidly catching up with microwave engineers with respect to the range of devices and techniques available to them. For example, frequency doubling, mixing and parametric amplification are readily achieved. However, frequency intercomparison chains remain complicated and expensive and one clear requirement is for improved optical frequency interpolation. A second major input to improvements in spectroscopy has come from control of the atomic environment through developments such as ion and atom cooling and, more recently, cavity quantum

electrodynamics. Atomic interferometry is also an exciting recent development. Professor Ferguson described an atomic Fabry-Perot étalon in which a single, cooled atom could be dropped onto a surface and would bounce many times by means of evanescent wave recoil, forming an atom in a cavity. Atomic interferometers have shown how measurement of the recoil energy of a caesium atom can provide precise measurements of the local acceleration due to gravity, g. It was clear that some of these latest developments may offer the key to improving real standards by orders of magnitude.

Professor Lawrence Eaves, Nottingham University, reviewed the rapidly-developing field of quantum transport, both in 1-D and 2-D structures. He considered explanations for the, perhaps, unexpected extraordinary accuracy of the Quantised Hall Effect (demonstrated by Dr. Anthony Hartland's team at NPL to be material-independent at the parts per billion level.) The decoupling of edge- and bulk-states in the transport properties of a two-dimensional electron gas implies that fluctuations in the local potential arising from local doping fluctuations do not contribute measurably to departures from strict quantisation. Another fascinating insight into quantum transport has recently come from observation of Single Electron Tunnelling effects and quantum capacitors. Capacitance values below 1 femtoFarad have only become available with the application of sub-micron lithography to superconducting or semiconducting structures. This area promises many novel electronic devices as well as a third quantum electrical standard, in the form of a current in which the passage of single electrons is synchronised to an applied radio-frequency signal. This may hold the prospect of closing the measurement triangle.

Professor Jim Hough's group at Glasgow University has continued to make great strides towards developing the displacement transducers required for, perhaps, the most challenging measurement problem actively being pursued - the observation of gravity waves. For reliable and relatively frequent detections of these minute ripples in space-time, strain sensitivities of the order 10^{-22} are required. Ultra-high precision optical interferometry using kilometre-length baselines currently provides the best basis for such a measurement and Professor Hough described the technological problems which are being (and need to be) solved to provide the necessary capability. Ultra-high reflectivity mirror coatings, extreme vibration isolation and low-noise detector technology are just some of the spin-off application areas promised from this ultimate metrology problem. There appears to be significant potential benefits for continuing collaboration between NPL and Glasgow in the future.

The poster session consisted of more than 20 exhibits covering much of NPL's leading-edge measurement science, ranging from fundamental atomic constant determinations to X-ray interferometry and high-temperature superconductivity applications. This was followed by laboratory tours and demonstrations which focused upon a selection of NPL's "Frontier Measurement" laboratories, emphasising NPL's commitment to engage in novel research and to seek spin-off applications. For some this was their first visit to NPL and a opportunity to see a wide range of activity. Others took the opportunity of discussing overlapping research interests with specific NPL groups, with the aim of developing new collaborative programmes.

3 DISCUSSION

In the closing session, Dr. David Robinson summarised the main points of the Seminar and went on to describe existing mechanisms for collaboration at NPL (with Universities through EMRA's and CASE studentships, for example, and with industry through LINK and EC-Framework Programmes). In discussion it was emphasised that the only response to the problem of shrinking resources was to stimulate more effective collaboration and technology transfer. It was NPL's responsibility, particularly in view of the revised emphasis from the Government White Paper on Science and Technology on improving the competitiveness of UK industry, to seek new ways of fostering collaboration between leading-edge academic science and the metrology that both underpinned science, and provided one of the keys to

the successful exploitation of that science. It was agreed that the way forward should be via collaboration on specific projects (with follow-up by those concerned) and with follow-up seminars, concentrating on specific problems. Opportunities exist, for example in the opto-electronics sector, with the increased reliability of quantum-well lasers and ultra-low-loss fibre optics development, thereby taking advantage of the increased demand for enhanced band-width (teraHertz) telecommunications.

4 THE NEXT STEPS

It was not anticipated that this meeting would necessarily identify particular areas for collaboration during the day, with such a wide ranging meeting. Therefore, questionnaires were distributed to delegates to obtain their thoughts on potential areas for collaboration or suggestions for future meetings. Responses included a number of suggestions, for example :

1 Future activities should include mechanisms for achieving a wide dissemination of specific opportunities in some detail;

2) Future meetings might include a general call for papers across a wide range of disciplines (rather than just invited papers);

3) Future meetings might use the keynote subjects from this meeting as a basis for future workshops.

In summarising the Meeting, there was a very positive response from delegates attending the "Frontiers of Science and Measurement" Seminar. For some, this was their first visit to NPL and an opportunity to observe, first-hand, the novel research in progress at NPL. Many expressed the wish for closer links with NPL, and possible collaboration, and there was a demand for future meetings in the most promising areas identified by this Seminar.

To this end, a "Frontiers of Science and Measurement" (FSM) Programme Committee will be formed to plan future meetings in this series. Preliminary suggestions for follow-up meetings in the form of a series of one-day seminars have been proposed. These would consist of a series of topics having cross-divisional interest from a metrological viewpoint, but which could find a technical focus sufficient to create the environment for spin-off in the form of collaborative activities. Ideas suggested included Cryogenic Metrology, Frequency Measurement, Quantum Optics and a focused subset of the Nanotechnology area. In order to avoid proliferation of meetings the support from other Groups, who are already planning meetings of this nature, will be sought. A summarised version of this Report, concentrating on the FSM Meeting, will appear in Measurement Science and Technology.