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Proceedings of the 1983 International School and Symposium on PRECISION MEASUREMENT AND GRAVITY EXPERIMENT

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FOREWORD

As science develops, the needs of higher precisions increase. This is especially true in physics. As physics advances we look for new frontiers. These new frontiers can be found in higher energy accelerators, extreme astrophysical situations and precision measurements of minute effects. As the building of higher energy accelerators become more and more difficult, high energy physicists are looking more for cosmological clues of the early universe, astrophysics of compact objects, and precision measurements of minute effects (such as proton decay, double beta decay, neutron electric dipole moment, (g-2) factor, etc.). We need some confidence in a correct relativistic gravity theory to infer from astrophysical observations about nongravitational phenomena. This confidence, in turn, relies on the precise measurements of some minute gravitational effects. The weight of precision measurement in physics is growing steadily.

Due to its weakness in laboratory dimensions, gravity experiments are very good testing ground of precision measurement. On the other hand, gravity experiments need many techniques and development from precision measurement. In the course of performing gravity experiments, precision techniques are frequently developed too. This happened many times in the history.

In the early development of science, gravity experiments——both laboratory and astronomical——have played crucial roles. Galileo's observation that free-fall motion is one of constant acceleration and is independent of composition laid the foundation of gravity and gave impetus to Newton's formulation of mechanics. Tycho Brahe's observation of the motions of the planets together with Kepler's three laws about these motions led to Newton's law of gravitation and gave further impetus to Newton's formulation of mechanics. Despite of these early development, gravity experiments did not form a field until quite recently. For centuries, they consisted mainly of the measurements of G, variant tests of the equivalence of gravitational and inertial mass, and the observation of the motions of the planets.

The advent of general relativity provides great challenges to the experimentalists. There have been great efforts of verifying or find the correct relativistic theory of gravity empirically. Moreover, although the classical laws of gravitation have formed the first fundamental laws of physics, at present the gravitational interaction is still the least understood microscopically. This microscopic challege is even greater. Nevertheless, with all the efforts of testing relativistic gravity, doing gravitational astrophysics and exploring the microscopic origin of gravity, gravitational experiments have slowly but steadily formed a coherent discipline. To stress the coherence, we shall call this discipline the field of gravity experiment in analogy to the field of precision measurement.

In the field of precision measurement, metrology and precision spectroscopy are two major subfields. Metrology is the basis of precision measurement and advanced industrial development. Precision spectroscopy is an important subject in its own right. It challenges experimental and theoretical physicists both to make more precise measurements and to find adequate theoretical models——and new physics. Metrology,

precision spectroscopy and gravity experiment are subjects of major concerns of this conference.

To foster international cooperation and to provide an international forum among scientists and engineers actively engaged in the above fields we organized the International Symposium on Precision Measurement and Gravity Experiment (PMGE Symposium). To provide opportunities for graduate students, upper-class undergraduates, and junior workers to get aquainted with these fields, to be better prepared for the symposium and to study basic developments in their related fields, we organized the International School on Precision Measurement and Gravity Experiment (PMGE School). In this conference (PMGE School + Symposium), over two hundred persons have participated. During each session, the average number of participants is about fifty. Many leading experts were invited to give lectures and symposium talks. To have a larger number of people accessible to these lectures and talks and to foster further discussions in the fields of precision measurement and gravity experiment, we asked every speaker to write up his article. Their efforts in preparing lectures and talks, and in writing up coherent and comprehensive articles show up in the present proceedings. We hope this volume would be valuable for many people interested in these fields.

The proceedings are divided into six parts. They consist of both introductory lectures and detailed accounts of more specific reseaches. We hope that this interweaving together of two approaches would be more accessible and beneficial to junior workers and researchers in related disciplines.

Part one consists of three articles. In Faller's lecture on the physics of basketball, he gives an introduction to scientific thinking. From the analysis of how to play a basketball, one learns some general stategies of how to perform an experiment. In his second lecture, Faller describes a brief history of telescopes and analyzes the forces that mold them. This serves as an introduction to optics and mechanical design which are indispensible in many precise measurements. In the third article, Teller tells the story of gravitation from Greeks to Einstein's general relativity in a vivid style with his special insights. These three articles serve as an introduction to the whole book.

Feedback controls are necessities for precision measurement and gravity experiment. In the first article of part two, W.S. Cheung gives a very readable introduction to the principles and applications of feedback controls. This is followed by Leyh's example of a precision viscometer. In the latter half of part two, Ritter and his group at the University of Virginia analyze active magnetic suspensions in detail. These subjects give further examples of feedback controls, and would be of many practical applications.

Part three treats metrology and related subjects. After I have given an introduction to metrology, Morimura describes various methods and accuracies involved in advanced geometric metrology. In the Workshops on Remote Sensing and Precision Measurement, April 11 - 16, 1983, National Central University, Chung-Li, T. Gast and Y.-C. Chen gave a comprehensive treatment of sensitive measurements of displacements and masses using feedback controls. We invited them to rewrite their lecture notes for the present publication. They did so and we are very grateful to their

kindness and efforts. In many cases in precise measurements, Brownian motion is a limiting factor. In his article on this subject, Morimura reports on an experimental study of the Brownian motion. C.S. Su gives a nice introduction to the mass spectrometric measurements of isotopic masses and abundances and reports on the present status of the precision measurement laboratories for vacuum and optics in the Precision Instrument Development Center. J.-F. Chen and H.-Y. Lin report, respectively, on the four cesium beam frequency and time standards, and on the environmental stress testing for reliability improvement in the Telecommunication Laboratories. A comprehensive report on the progress in metrology and precision measurement in Japan is written by Morimura. We can learn a lot from this progress. A history of the precision measurement group at the University of Virginia is reported by C.H. Leyh. This gives an example of how a precision measurement group is established.

Part four treats the subjects of precision spectroscopy and picosecond/subpicosecond measurements. After giving an introduction to precision laser spectroscopy, J.-T. Shy with DeSerio, Farley and Wing reports on their recent results in the laser spectroscopy of deuterated triatomic hydrogen molecular ions. Combining his three lectures in the School and two talks in the Symposium, W.H. Wing writes a single comprehensive and monumental article on the limits to precision in spectroscopy. C.Y. Leung surveys the recent rapid developments in the picosecond and subpicosecond measurement techniques using ultrashort optical pulses from modelocked laser systems. These articles will surely be valuable to their respective fields. As an application of the picosecond/subpicosecond measurements, H. Yilmaz reports the setup of the one-way velocity of light measurement at Hamamatsu TV Co. and analyzes its theoretical significance.

Precision rotors and gravimeters are good examples of precision measurement. Their implementations are demanding while applications wide. In the first article of part five, Ritter and Cheung treat many aspects of macroscopic rotors in detail. This article will be useful for many implementations of precision rotors. In his article on little "g", Faller gives a lucid historical account of the development of absolute gravimeters together with their merits and problems. With his colleagues, Faller reports on the promise and plans for the JILA gravimeter employing many illustrations.

Part six treats equivalence principles and gravity experiments. It mainly concerns with the behavior of matter in an external gravitational fields. In three articles on equivalence principles, Hughes-Drever experiments and polarized test-body experiments, I review equivalence principles and analyze in depth the theoretical significance of various related experiments. Faller and Koldewyn report on the preliminary results of their measurement of the Newtonian gravitational constant using an active magnetic suspension torsion fiber. Their experiences would be valuable to researchers on this topic. Faller, Keiser and Keyser report on their fluid-fiber based torsion pendulum which has a high potential in improving the accuracies of the Eötvös-Dicke experiments. Various gravitation experiments at the University of Virginia are reported by Ritter and Jones; the rotational inertial clock experiment for gravitational redshift comparisons is reported in detail by Leyh with Cheung, Bernard and Ritter. W.S. Cheung reports on the development of the relativity gyroscope experi-

ment at Stanford University. With this development, the attendant technologies —— gyro technology, ultra-low magnetic field, Dewar development, drag-free control and so on —— have been driven to new levels of sensitivity and precision. Going low-temperature is a trend in doing gravitational experiments. C.W.F. Everitt in his paper review how low temperature techniques are helpful in three experiments being developed at Stanford University (gyro experiment, new test of weak equivalence principle, gravitational wave detectors) and might be helpful in other gravitational experiments.

As to the organization of this conference, we are very grateful to sponsors, Academia Sinica, Ministry of Education, National Science Council, National Bureau of Standards, Industrial Technology Research Institute, Telecommunication Laboratories, National Central University, and National Tsing Hua University, for their financial and manpower supports. Every member of the organizing committee should be thanked for their efforts in putting such a conference together; special thanks are due to W.S. Cheung, C.C. Chiang, Y.B. Tsai and W.S. Tse. We are much obliged to the staff members of the Institute of Physics at National Tsing Hua University and the staff members, especially L. Chang, of the Institute of Physics at Academia Sinica for their helps and assistances. For the editing of these proceedings, we are obliged to L.L. Lee, Y.M. Chang and T.L. Fung for their secretarial works.

The proceeds of these proceedings will be used to help organizing the next meeting or meetings of related purposes.

Hsinchu WEI-TOU NI

June 1983

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