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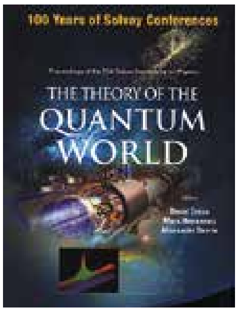

D. Gross, M. Henneaux and A. Sevrin (Editors)
The Theory of the Quantum World
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In 1911, Belgian industrialist Ernest Solvay convened a *Conseil* of 23 distinguished physicists to advise him on energetics, his pet theory. He was well versed in physics and chemistry, accepted the atom as real, and even proposed, in a vague way, the equivalence of mass and energy before Einstein. He was, in modern words, an extreme reductionist, believing that all science, including sociology, derived from basic laws of physics. He also had the good sense to realize in a hurry that he was out of his depth, and to let the scientists set the agenda in the series of Solvay Conferences he started, and his heirs continued to this day. The most famous of them is the 5th, of 1927, where the full-fledged Quantum Theory was debated by its founders.

One hundred years later, the scope and format of the 25th Solvay Conference are, intentionally, closely parallel to those of the first *Conseil*: a highly selected group of physicists, famous or very promising, were invited to assess recent advances and open problems. One obvious difference from 1911 is that Session 1, History and Reflections, is a retrospective on earlier Conferences, with talks from historian J. L. Heilbrun and grand old man Murray Gell-Mann. This is the only Session that's largely accessible to a general reader; the others consist of one or more Rapporteur Talks, which are mostly critical surveys of work in progress, with minimal mention of the great 20th century discoveries; of several Prepared Comments, which can be true comments and additions to the Talks, but mostly are the analog of Contributed Papers at standard meetings; and of extensive Discussions, which are at the level of expert talking to expert, often using concepts and jargon not previously defined. All of this would be largely incomprehensible to an interested amateur like Ernest Solvay, or even to a professional physicist outside his or her own specialty, were it not that one can read the book with the web on the side, to look up strange new concepts, words and acronyms in Wikipedia, and promptly access online some of the references. The web is also needed to compensate for the lack of any Index, and of the running headers usually found in journals. There is only a minimal table of contents, hidden away on page xxiii, that lists the titles of the Sessions, and their Chairmen. Luckily, one can Look Inside the book on Amazon to find out what each participant contributed on which page, as well as other occurrences of a topic that pops up in a Discussion. This makes it possible to pick and choose what to read in this highly informative, but very dense book, which hardly anybody will read sequentially, cover to cover.

In his opening address, conference Chairman David Gross sets the agenda. He recalls that "the first Solvay conference […] addressed the central problem of physics at that time: *Was the quantum structure of matter truly unavoidable?*" and quotes from Lorentz's opening address: "*the old theories have been shown to be powerless to pierce the darkness surrounding us on all sides*". Gross claims that "We face no such crisis today", because "Quantum mechanics works" and further "is hard to modify". He concedes that we must go beyond current quantum theories for reasons of theoretical consistency and completeness, and even that "we may be forced to modify our most fundamental of physical concepts, that of space and time". But he glosses over the fact that, according to astronomers, 95% of the observable universe consists of unexplained dark matter and dark energy, so we still have darkness on all sides. The focus of the conference will be on theory *per se*.

Most of the 74 participants agree with him. One can question whether different schools of thought are equitably represented: the two places with the highest number of participants (7) are Santa Barbara and Princeton, including the Institute, which happen to be where Gross is now, and was previously. However, scientists were invited from a broad geographical range of institutions. In 1911, all the 24 participants came from Europe, and all but Rutherford were born there. Europeans and their descendants are still the majority in 2011, but most participants (43) came from the US, and many of those were born and bred in Asia or South America. What has not changed for the better is the percentage of women: there was 1, Marie Curie, in 1911 (and also in 1927), there are 2 in 2011.

Dissenting opinions are most in evidence on the Foundations of Quantum Mechanics, in the first half of Session 1. Rapporteur Tony Leggett gives a detailed analysis of the Einstein-Rosen-Podolski thought experiment and its implementations, and concludes that one must either accept "spooky action at a distance", or wait for new experiments to close a still-possible "loophole". However, most participants think that one should just accept entanglement , spooky as it can be, since it works in all cases so far and one can profit from it. There is also a consensus that decoherence explains the emergence of classical behavior, including "Schrodinger's cat"; but the "collapse of the wave function" remains a bone of contention.

The second half of Session 1, on Quantum Computing, and Session 2, on Control of Quantum System, set out to explore and expand the entanglement frontier with the enthusiasm of highly successful pioneers. John Preskill sets the tone with "Introduction: Toward Quantum Supremacy" over classical computing, even though he acknowledges that a universal quantum computer remains a distant goal. In the Summary of his Talk, Steve Girvin does not mince words: "We are at the beginning of a Golden Age for coherent quantum control of mesoscopic systems". He is referring in particular to superconducting circuits, but this is generally an age of great promise for quantum information theory and practice. It is certainly a Golden Age in full swing for Quantum Computing and Simulation with Atoms and Photons. Ignatio Cirac gives what he calls a "superficial overview" of this exploding field, in language that's unusually accessible for this volume. Much more is added in the Prepared Comments, including those by Alain Aspect and 3 Nobel laureates in this field: Ketterle, Phillips and Wineland. The fact that these 4 are experimentalists adds considerably to the interest and relevance of Session 2, and of their exchanges with theorists in Discussions throughout the volume. Simulations of condensed matter and field theory systems, including even gravitation, appear particularly rich of promising possibilities.

Session 4, on Quantum Condensed Matter, also has much recent progress to report, although in my opinion is tilting too much towards theory. Rapporteur Samir Sachdev concentrates on the quantum phases of spin systems in a well documented and illustrated review. He also discusses bosons on an optical lattice, an example of connection with the experiments described in Session 2. However, he leaves out high-T_c superconductors, referring to a separate article of his, accessible in arXiv. Cuprates were discussed in his oral presentation, and in a follow-up question by Leggett. There is also a Prepared Comment on "Quantum Magnetism and High Temperature Superconductivity" by experimentalist J. C. S. Davis, but it seems that theorists skirt this thorny problem. They prefer systems of lesser practical interest, but more amenable to analysis, especially by methods communing with string theory. Sachdev even writes "some of the most stringiest tests […] of quantum theory appear in […] electrons in crystals."

In Session 5, we come to Particle and Fields, the frontier of the reductionist approach so favored by Ernest Solvay, and finally completed after a century for ordinary matter. Rapporteur Frank Wilczek promises "A Long View of Particle Physics", but leaves most of it to a longer article of his, available on arXiv. In short, the Standard Model works magnificently and all attempts to go beyond it have made predictions not confirmed by experiment. Nevertheless, it is believed that supersymmetry must be at work, badly broken as it is. It is hoped that LHC will provide guidance by unveiling some effects that clearly go beyond SM, but so far that has not happened.

Finally, we come to Session 6, Quantum Gravity and String Theory, where the ultimate questions are asked, and remain unanswered. It opens with a Talk by Juan Maldacena, "The Quantum Spacetime", that is short, clear and surprisingly readable. It even attempts to explain simply anti–De-Sitter space, AdS. It lists two "surprising predictions" of quantum gravity: (1) Black holes emit Hawking radiation and have entropy, (2) Inflation produces the primordial fluctuations. Prediction (1) seems safely beyond any chance of experimental falsification for a long time, but is receiving a lot of attention, even more so in the last year, because black hole entropy may be key to the presumed fundamental role of information, even quantum information. Information Theory may allow us to go beyond Quantum Field Theory and Gravity, which fail to work together at the Big Bang and in black holes. Spacetime itself should emerge as a smoothed average of a highly bumpy and stringy high-energy reality that is information-based.

Primordial inflation is discussed at length by Alan Guth in his Talk on "Quantum Fluctuations in Cosmology and How they Lead to a Multiverse". The treatment is advertised as pedagogical, but it includes a fairly technical account of the simplest theory of inflation: only one inflaton field (whatever that is), varying slowly compared to the expansion rate of the universe. The great success of this theory is that it accurately predicts the observed fluctuations in the Cosmic Background Radiation. A skeptic could note that the spectrum of fluctuations is not very distinctive and is compatible with different versions of inflation. It would be nice to have the input of observational astronomers on this point, but none was at this conference. Anyhow, the main questions about inflation are: why and how it began, and how and why it ended, at least around us, leaving behind a very small dark energy density that still makes our universe expand. For the Big Bang at the beginning of inflation, and what happened before (if time and space make sense at that stage) we have many wild speculations. Surprisingly, theory shows that inflation cannot end, except locally, and thus has no beginning either, spawning an infinite multiplicity of universes, forever beyond our reach. If we accept this idea of "eternal inflation", we must abandon the cherished notion of science based on observation and analysis supporting each other. Galileo would turn in his grave. We also face conceptual difficulties in dealing with the actual infinity of the multiverse. However, string theory also points, independently, to the existence of a huge number of possible realities, only one of which is what we see around us.

The General Discussion of Session 7 comes back repeatedly to questions about the ultimate limits of Quantum Theory in frank exchanges that often start at a basic level and even border on philosophy. Of course, the level quickly becomes highly technical, even though formulas are not allowed. Some discussions are a direct continuation of lively debates in a previous Session, for instance the one started on page 222, following the talk by Wilczek, on extensions of the Standard Model to include gravity. It seems that Quantum Theory is the key to everything, from lab experiments to the Big Bang, and even Einstein's General Relativity will have to be modified to fit with Quantum Field Theory, rather than the other way around. Much progress is reported in the mathematics of string theory and its extensions, but the connection with observed reality is still vague and has not led to verified predictions. Thus, in a way, the 2011 Conference resembles the first *Conseil* of 1911, which ended in puzzlement, with Einstein saying "the h-disease looks increasingly hopeless" and "nobody really knows anything". The "h-disease" has spread triumphantly and we have learned to live with it, but even Gross, in his Conclusion, admits "I feel something is missing". Perhaps a major breakthrough is around the corner, as it was in 1913 with Bohr's atom.

V. Celli
University of Virginia