AT THE START OF A NEW GOLDEN AGE OF PHYSICS

BRIAN G WYBOURNE
Instytut Fizyki, UMK, Toruń, POLAND
E-mail: bgw@phys.uni.torun.pl

Contrary to the prevailing *End of Physics* and *The End of Science* syndromes we assert that physics has hardly begun and that we are at the beginning of an exciting new "Golden Age of Physics". This assertion we illustrate with examples taken from the last year of the last century and the first year of the new century.

1 Introduction

Prophesying the end of physics[1,2] [a], or indeed of science[3] is not new and has a tendency to be especially prevalent during the transition from one century to another and even more so from one millenium to the next.The development of physics (and I include cosmology in the domain of physics) has occured continuosly though marked by discernible periods of major development that characterise a Golden Age of Physics. This was seen, for example in the development of mechanics under Galileo (1564-1642) and Newton (1642-1727) and then in the 19th century with the unification of electricity, magnetism and optics through Faraday (1791-1867), Maxwell(1831-1879) and others.To many the start of the 20th century is seen as a Golden Age of Physics with the development of quantum and relativity theories. Each such Age has been associated with introduction of major theoretical and experimental methods. Thus the introduction of the telescope led to major developments in celestial mechanics and the growing realisation of the universality of gravitation. The development of devices for measuring time and distance were crucial to establishing the experimental basis of mechanics.

The experiments of Faraday established much of the basic concepts of electromagnetism and yet the three volumes[5] of his collected works are not graced by a single mathematical equation. This was to give the foundations of Maxwell's electromagnetic theory. It is hard to find a single page in the two volumes[6] of Maxwell's collected works that does not contain a mathematical equation. There is a tendency for physicists, towards the end of a Golden Age to be so dazzled by progress as to become reluctant to consider the

[a] *In some of the references I have given the html address from where the reader may download the quoted article. Likewise for some of the images. I have tried to give references to the original technical articles and where possible also references of a less technical nature For reasons of space the Figures are not reproduced herein*

new paradigm[7]. Thus even with the success of Maxwell's electromagnetic theory Kelvin (1824-1907) could remark "*I am never content until I have constructed a mechanical model of what I am studying. If I succeed in making one, I understand; otherwise I do not*". The mechanistic world of Kelvin was replaced by, or perhaps more accurately added to, electromagnetism. So stunning were the successes of electromagnetic theory and optics that Oliver Lodge (1851-1940) could remark, just a few years before the end of the 19th century (1888), "*The whole subject of electrical radiation seems working itself out most splendidly*".

Twenty years ago Stephen Hawking confidently predicted the end of theoretical physics within twenty years[1]. Twenty years on he is sticking to his prediction but the twenty years starts now[4]! Stephen Weinberg[8] has suggested *A Unified Physics by 2050?* while Hans Bethe[9], perhaps more wisely, noted near the conclusion of the last century that *"A hundred years ago, some of the great physicists in England and Continental Europe predicted that physics was at an end. We know what actually happened ... Looking at the predictions of 100 years ago, it would be foolish to make predictions for the next 100 years"*. Likewise, Sir John Maddox[10] has suggested *"The most important discoveries of the next 50 years are likely to be ones of which we cannot now even conceive*

In this lecture I want to primarily highlight discoveries in physics (I make no distinction between physics and astronomy or cosmology - they are one) that have occurred in the past year and within the current year. I believe that these discoveries herald a new Golden Age in physics analogous to those of the past - far from the end of physics, as in the past, physics has only just begun. You young physicists have much to look forward to and much to do! Let me first remark on the interplay between science and technology.

2 The interplay between Science and Technology

Science and technology, while inherently different both in terms of their practitioners and in their methodology are nevertheless dependent upon each other. The one cannot prosper without the other. The interplay between science and technology is all too often overlooked by historians and those considering the development of science. Thus the discovery of the electron could not take place prior to the technical development of the means of producing a vacuum. Otto von Guericke's (1602-1686) construction of a vacuum pump, along with his spectacular public demonstration in 1650 was an essential step in the road to the electronic age. And indeed to a host of modern technology.

Fig.1 **Otto von Guericke's demonstration before the German emperor Ferdinand III with two teams of horses attempting to separate**

the two hemispheres of the Madeburg spheres
http://www.princeton.edu/∼his291/Magdeburg_Spheres.html

Technological progress is essential to the development of science. Some discoveries cannot take place until the technological tools become available. Sometimes this is just as well. Just imagine what would have happened to Copernicus if the Michelson-Morley experiment could have been performed in the sixteenth century[11]. (The curious will note that both Copernicus and Michelson were born in Poland)[b]

Fig. 2. **The interferometer used by Michelson and Morley (1887)**
http://carnap.umd.edu/phil250/picture_archive.html

To many the start of the nineteenth century seemed to usher in a golden age of physics with the rapid development of the twin theories of the quantum and relativity. That period was preceded by a period of extraordinary technological advancement resulting in the creation of new instruments for measuring. The Industrial Revolution led to development of machines for making machines as vividly noted by Disraeli (1804-1881)[12] in his novel *Coningsby* "*And yet the mystery of mysteries is to view machines making machines; a spectacle that fills the mind with curious, and even awful, speculation*". The growth of industry required new technology. Devices for measuring temperature, electric currents, air pressure were all to contribute to making it possible to make experimental studies of electromagnetic radiation, the photoelectric effect, black body radiation etc and ultimately to expose the shortcomings of classical physics. The interferometer was to be associated with relativity and the photoelectric effect with the quantum[13]. It was to take an entire century to become familiar with the full implications of relativity and quantum theory and even yet their full unification is incomplete.

[b]Copernicus (1473-1543) in Toruń and Michelson (1852-1931) in Strzelno. Visitors to Strzelno will find in the village square a plaque marking his birthplace and noting some of his achievements. The family migrated to the USA when Michelson was two years old. In 1894 he said at the dedication of the Ryerson Physical Laboratory, University of Chicago "*The more important fundamental laws and facts of physical science have all been discovered, and these are now so firmly established that the possibility of their ever being supplanted in consequence of new discoveries is exceedingly remote ... Our future discoveries must be looked for in the sixth place of decimals*".
htpp://hum.amu.edu.pl/∼zbzw/ph/sci/aam.htm

3 The New Physics of 1999

3.1 The "impossible" Magnetic Superconductor

Some 40 years ago the Russian theoretician, V. L. Ginsburg "proved" that ferromagnetism and superconductivity are incompatible[14]. In 1999 it was demonstrated experimentally[15] that superconductivity and ferromagnetism co-exist in $RuSr_2GdCu_2O_8$. As one of the principal discovers, Jeff Tallon, noted *"This was not just unexpected; it was highly unlikely ... Nature's treasures can be slowly and systematically mined, but from time to time one simply stumbles on a rare nugget of great value".*

3.2 Slowing down the speed of Light

There is nothing surprising that light travels in a medium slower than in vacuum what was surprising in 1999 was the experimental demonstration[16] that the group velocity can be reduced to as low as 17m/s. This work has led Leonhardt and Piwnicki[17] to use media with extremely low group velocities to create a vortex flow that imprints a long-ranging topological effect on incident light and can behave like an optical black hole.

3.3 Quantum Interference observed for Fullerenes (Bucky Balls)

Matter wave interferometry surpassed all previous studies with the demonstration[18] of the wave-particle duality of fullerene (C_{60}) molecules.The possibility of studying quantum interference of even larger macromolecules or clusters up to small virusesis is being considered..

3.4 Accelerating Expansion of the Universe?

Results from the ambitious Supernova Cosmology Project and the High-Z Supernovae Project started to produce compelling evidence for an accelerating expansion of the universe[19,20]

3.5 Bose-Einstein Condensation Continues

At 10.54 a.m.5th June 1995 physicists at Boulder, Colorada created a new state of matter which could never have existed in Nature anywhere in the universe, this was, of course, the Bose-Einstein condensate[21,22]. While predicted in the early part of the 20th century (1924) its experimental verification was not possible until the concluding decade of that century. The subject con-

tinued to mature throughout 1999[16,23,24] - but could there be other states of matter that have eluded physicists?

3.6 Randall-Sundrum Extra Dimensions

Finding a quantum theory that unites gravity with the three other fundamental forces of nature largely dominated fundamental physics in the closing two decades of the last century. Central to much of these endeavours was superstring theory. Superstring theory has itself gone through periods of tremendous optimism followed by hard work and seemingly almost insoluble mathematical problems. Extra dimensions, beyond the usual four spacetime dimensions, arise. Enormous effort has been put into the "compactification" of these extra dimensions as it has been generally believed that there can only be four non-compact dimensions - the extra dimensions are folded up after the manner of the Kaluza-Klein tradition. 1999 saw a dramatic challenge to this, by now traditional approach, by Randall and Sundrum[25] who showed that we can live in $4 + n$ *non-compact* dimensions in perfect compatibility with experimental gravity. Our four-dimensional universe can be viewed as a membrane (a three-brane) embedded inside a higher dimensional universe. In the closing months of the past century the Randall-Sundrum theory was the subject of many articles in the press with the Los Angeles Times proclaiming **OF SPACE, TIME AND STRINGS: Rocking the foundations of physics**[26]. Prior to the Randall-Sundrum paper it was thought that superstring theory could be forever beyond experimentation[2] but now it is conceivable that experimental observations to underpin the Randall-Sundrum scenario should be within the realms of future colliders[27].

4 Into the 21st Century

The 21st Century commenced with two spectacular achievements in the first two months which I believe is just the beginning and symptomatic of the onset of the new Golden Age of Physics.

4.1 26th January 2000 European Southern Observatory, Chile

For the first time, 26th January 2000, three 8.2-m VLT telescopes were observing in parallel, with a combined mirror surface area of nearly $160m^2$. Since that time a fourth 8.2m VLT has been installed.

Fig.3. The Paranal Observatory in Chile.
http://www.eso.org/outreach/press-rel/pr-2000/phot-15d-00-normal.jpg

These telescopes can be used in an interferometric mode which allows the coherent combination of stellar light beams collected by the four 8-m Telescopes (UTs) and by several smaller Auxiliary Telescopes. This achievement heralds a new age in astronomical observation but this is just the beginning - already active plans are being developed to make an OverWhelming Large (OWL) telescope of 100m diameter[28].

Fig.4. The OWL telescope in perspective.
http://www.eso.org/projects/owl/images/Figure_9.jpg

4.2 10th February 2000 CERN, Switzerland

At a special seminar on 10th February 2000 compelling evidence was presented for the existence of a new state of matter in which quarks, instead of being bound into more complex particles such as protons and neutrons are liberated to roam freely[29]. Unlike the Bose-Einstein condensation mentioned earlier, this new state of matter has existed in the universe though only for about 10 microseconds after the Big Bang. In a very real sense an accelerator can see further back in time than any telescope! CERN modified its Super Proton Synchrotron (SPS) so as to be able to accelerate lead nuclei to relativistic speed and have them impinge on a lead foil target. At the moment of producing the quark-gluon plasma a critical temperature of some 100,000 times that at the centre of the sun and an energy density seven times that of normal nuclear matter is reached.

4.3 13th June 2000 Brookhaven, USA

In June the Relativistic Heavy Ion Collider (RHIC) constructed at Brookhaven National Laboratory started accelerating gold nuclei in opposite directions around a 3.8km ring[30,31] surpassing the CERN experiment. It in turn will be surpassed when, in 2005, CERN's A Large Ion Collider Experiment (ALICE) becomes operational. The study of the quark-gluon plasma as a new state of matter is just beginning.[c]

Fig.5. End view of a collision of two gold nuclei at Brookhaven's RHIC collider. http://www.pubaf.bnl.gov/pr/bnlpr060800.html

[c]Reference to the RHIC facility as the "Hubble Telescope" of Nuclear Physics seems most appropriate though RHIC "sees" further! http://www.aip.org/releases/2000/rhic.html

4.4 June 2000 Christchurch, New Zealand and Wettzell, Germany

The period 1988-1991 saw the successful construction at the University of Canterbury of a square metre ring laser that could operate in single mode as a gyroscope that could be unlocked by the earth's rotation[32] and measure frequency splittings down to microhertz level.

Fig.6.The first UC ring laser - table top physics.
http://www.phys.canterbury.ac.nz/research/ring_laser/thering2.gif

In 1997 collaboration between NZ and Germany led to the construction of a far more precise and stable ring laser also of a square metre which routinely measures parts per million variations in the earth's rotation.

June 2000 saw the development of two very large ring lasers and represented a transition from the original NZ table-top ring laser to ring lasers of considerable size. In Wettzell, Bavaria a 4.2m diameter slab of Zerodur, engineered by Zeiss was installed in a purpose-built laboratory 5 metres underground.

Fig.7. Construction of the Grossring. The Zerodur blank
(4.2 metres diameter) has been prepared by Schott Mainz:
http://www.phys.canterbury.ac.nz/research/ring_laser/GNews.html

The Wettzell Grossring is expected to sense fluctuations in the earth's rotation at the level of 10^{-8} to 10^{-9} of the base value.

At the same time in Christchurch, NZ a NZ-German-US collaboration has commenced construction of a simple ring laser, dubbed Ultra-G, with an area of 370 square meters which though less stable than the GrossRing is expected to be more sensitive and an excellent detector of seismic rotations. Indeed one of the unexpected developments coming out of the ring laser project has been the ability of ring lasers to measure the rotation accompanying the waves from earthquakes, even when their epicentre is on the other side of the world.

The ring laser project demonstrates the construction of a new measuring tool in physics that is producing undreamed of levels of precision. Their application has barely begun.

5 Back to the Future

In the foregoing I have only quoted a few examples of what I see as harbingers of a new Golden Age of Physics. I have said nothing of equally striking and dramatic developments in diverse frontier subjects such quantum optics, quantum computing, neutrino astronomy, gravitational wave detection etc. To many the first three decades of the previous century are seen as a Golden Age of Physics but I am confident that the first three decades of this century

will surpass all that has gone before. Whether for better or worse will depend on the youth of today. I am optimistic that it will be for the better. I hope I leave you with a feeling that physics is only just beginning and the future of physics, while unpredictable, looks more promising of new and exciting discoveries than at any prior time in history. This future is for the young to encompass and develop.

6 Acknowledgements

My work has been supported, in part, by a Polish KBN grant. Once again it is a real pleasure to thank the organisers, especially, Barbara and Tadeusz Lulek, for delightful hospitality and for keeping alive SSPCM!

Appendix Euler's Disk demonstration

As an aside we noted H K Moffatt's[33] very recent analysis of Euler's (1707 - 1783) spinning disk. This problem can be nicely demonstrated by taking a large flat dinner plate having a smooth rim. Hold the plate vertically and give it a sharp twist on a smooth table. Observe the disk starting to precess about its point of contact. Note also the loud sounds and the abrupt ceasing of motion.

References

1. Stephen Hawking, *Is the End in Sight for Theoretical Physics?*, Inaugural Lecture, Cambridge University Press (1980).
2. David Lindley, *The End of Physics, The myth of a unified theory* Basic Books, New York (1993).
3. John Horgan, *The End of Science* Helix Books (1996)
4. Stephen Hawking, *A Unified Theory of Everything* University of Toronto (2000) http://www.math.toronto.edu/∼joel/hawking/transcript.html
5. Micheal Faraday, *Experimental researches in electricity* Dover, New York (1965)
6. James Clerk Maxwell, *The scientific papers of James Clerk Maxwell* Ed. by W.D. Niven Cambridge, University Press (1890)
7. I use the word *paradigm* hesitatingly not wishing to imply coherence with the Kuhnian interpretation of physics which I personally consider as a gross oversimplification of the development of physics.
8. Stephen Weinberg, *A Unified Physics by 2050?* http://www.sciam.com/1999/1299issue/1299weinberg.html
9. Hans Bethe, *Introduction* Rev. Mod. Phys. **71**, Sc0 (1999)

10. Sir John Maddox, *The Unexpected Science to Come...* http://www.sciam.com/1999/1299issue/1299maddox.html
11. B. G. Wybourne, *The Parable of Copernicus and Ptolemy* (1970) http://w.phys.uni.torun.pl/∼bgw/elc.html
12. Benjamin Disraeli, *Coningsby* (1844).
13. The importance of technological developments is brilliantly displayed in Robert A. Millikan's paper, Phys. Rev. **7**, 355-388 (1916) which should be read by every young physicist, though with caution. (See Gerald Holton, *Millikan's struggle with theory*, Europhysics News **31**,12-14 (2000).
14. V. L.. Ginsburg, Sov. Phys. JETP **4**, 153 (1957).
15. C. Bernhard *et al*,*Coexistence of ferromagnetism and superconductivity in the hybrid ruthenate-cuprate compound* $RuSr_2GdCu_2O_8$ *studied by muon spin rotation* (μ *SR) and DC-magnetization* (cond-mat/9901084)
16. L. V. Hau *et al*, *Light speed reduction to 17 metres per second in an ultracold atomic gas*, Nature **397**, 594-8 (1999). For an elementary discussion see Kirk T. McDonald, *Slow light* Am. J. Phys. **68**, 293-4 (2000).
17. U. Leonhardt and P. Piwnicki, *Relativistic Effects of Light in Moving Media with Extremely Low Group Velocity*, Phys. Rev. Let. **84**, 822-5 (2000). (See also: http://www.st-and.ac.uk/∼www_pa/group/ quantumoptics/media.html) For still more see:- Matt Visser, *Optical black holes?* (gr-qc/0002027).
18. Markus Arndt *et al*, *Wave-particle duality of* C_{60} *molecules*, Nature **401**, 680-2 (1999). http://www.quantum.univie.ac.at/
19. S. Perlmutter *et al Measurement of* Ω *and* Λ *from 42 High-Redshift Supernovae* Astrophys. J. **517**, 565-586 (1999) (Astro-ph/9812133).
20. Pedro G Ferreira, *The quintessence of cosmology* CERN Courier http://cerncourier.com/main/article/39/5/11/1
21. M.H. Anderson, J.R. Ensher, M.R. Matthews, C.E. Wieman, and E.A. Cornell,*Observation of Bose-Einstein Condensation in a Dilute Atomic Vapor*, Science **269**, 198 (1995).
22. For an excellent account of Bose-Einstein condensation, by the discoverers see http://jilawww.colorado.edu/bec/
23. Tom Hijmans, *Hydrogen: a quantum gas at last*, Physics World (Feb 1999) 17; D. G. Fried *et al* Phys. Rev. Lett.**81**, 3811-3814 (1998). (physics/9809017)
24. B. DeMarco and D. S. Jin, *Onset of Fermi Degeneracy in a Trapped Atomic Gas*, Science **285**, 1703-1706 (1999).
25. Lisa Randall and Raman Sundrum, *An Alternative to Compactification*, Phys. Rev. Lett. **83**, 4690-4693 (1999). (hep-th/9906064)

26. K. C. Cole, Times Science Writer, Los Angeles Times Thursday November 18, (1999) Page B-2.
27. Joseph Lykken and Lisa Randall, *The Shape of Gravity*, JHEP0006, (2000) 014 (hep-th/9908076).
28. R. Gilmozzi and P. Dierickx, *OWL Concept Study* ESO Messenger No. **100**, 1-55, June (2000) http://www.eso.org/gen-fac/pubs/messenger/
29. CERN Press Release *A New State of Matter created at CERN* http://cern.web.cern.ch/CERN/Announcements/2000/NewStateMatter/
30. BNL News Release http://www.pubaf.bnl.gov/pr/bnlpr060800.html
31. *Brookhaven collider opens its quest for Big Bang conditions*, Nature, **405**,874 (2000).
32. For a general overview of the entire project see:-
Introduction and Summary (August 2000),
http://www.phys.canterbury.ac.nz/research/ring_laser/ring_2000.html
33. H. K. Moffatt, *Euler's disk and its finite-time singularity*, Nature **404**, 833-834 (2000)