WORLD YEAR OF PHYSICS 2005: EINSTEIN IN THE 21ST CENTURY

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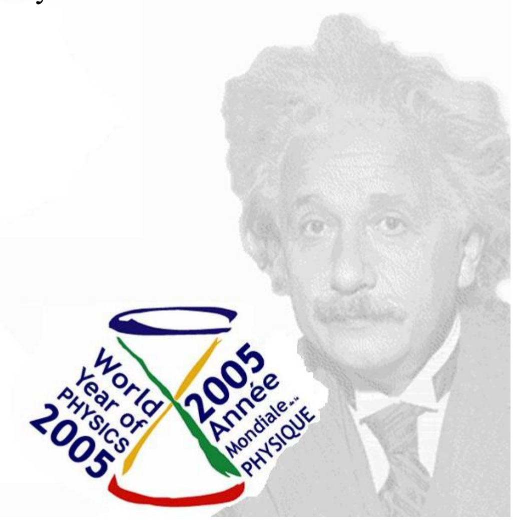
ABSTRACT

The World Year of Physics 2005 is an international celebration endorsed by the United Nations as the 100th anniversary of the "miracle year," in which Einstein reshaped the foundations of physics. The paper commemorates the pioneering contributions of Albert Einstein in 1905, and highlights major developments of the century since then, from black holes and quantum gravity to quarks and semiconductors.



In 2005, we celebrate the World Year of Physics. It was declared by the General Assembly of the United Nations as the "International Year of Physics" on June 10th, 2004, mostly thanks to the efforts of the Canadian Association of Physicists member, Lebohang Moleko (Ref. [1]).

As a physicist, I am no less exited about that than the millennium. The publication of three of Albert Einstein's theoretical papers in 1905 and one in 1906 had very significant consequences for humanity. Einstein's revolutionary ideas on the nature of light, the concepts of time and space, and the unity of energy and matter opened a way to most of the 20th century's developments in physics and profoundly influenced our understanding of the universe we live in.

In the first of these papers, on Brownian motion, Einstein made correct predictions about the motion of particles that are randomly distributed in a fluid. This article helped to establish the modern view that all material objects are composed of individual atoms and molecules attracted to one another by the fundamental forces of nature. The second paper, for which Einstein was awarded the 1921 Nobel Prize, extended Max Planck's revolutionary hypothesis concerning the quantum nature of light to explain the photoelectric effect. Very few physicists understood or were sympathetic to Planck's idea. Although Einstein was not the first to suggest to that the energy contained in a light beam is transferred in individual units, or quanta, he was brave enough to accept and apply this concept, and his work was an important step in the development of quantum mechanics. Einstein's third and most famous paper, "On the Electrodynamics of Moving

Bodies," extended Lorentz's transformation to all moving bodies, thus introducing the special theory of relativity. This work led to Einstein formulating the universally known equation, $E = mc^2$, which was derived in a fourth paper in published in 1906.

Transistors, computers, superconductors, lasers, nuclear power plants, magnetic resonance imaging, Internet, and the Global Positioning System are products of the last century of physics fundamental research. The path from a fundamental concept in quantum physics to a modern computer may not always be obvious. Basic research is a risky activity that seeks scientific knowledge for its own sake, and neither its outcome nor its applications can be predicted in advance. Lord Rutherford, after the first experimental splitting of the atom in 1933, said "The energy produced by the breaking down of the atom is a very poor kind of thing. Anyone who expects a source of power from the transformation of the atom is talking moonshine." Nine years later, Enrico Fermi (Nobel Prize in 1938) discovered neutron-induced radioactivity, and directed the first controlled chain reaction involving nuclear fission.

The transistor may be easily called the most important invention of the last century. Let us consider the transistor's development as an example of the fundamental theory leading to the technological revolution (Ref. [2]).

Late 19th century: Experimentalists studied the atomic spectra of various elements.

1885: Johann Balmer described the discrete spectral lines of the hydrogen atom by one empirical expression.

1900: Max Planck proposed the concept of the quantum in the emission of energy. His discovery of the elemental quanta earned a Nobel Prize in 1918.

1905: Albert Einstein developed the idea of the quantum of energy in the radiation field, the photon.

1911: Ernest Rutherford discovered the atomic nucleus in alpha-particle scattering experiments and confirmed the "planetary model" of the atom.

1913: Niels Bohr developed a semiclassical model of the hydrogen atom based on a quantization of the electron orbit.

1925 and 1926: Werner Heisenberg (Nobel Prize in 1932) and Erwin Schrödinger (Nobel Prize in 1933) developed quantum mechanics. Quantum mechanics is founded on the apparent randomness in nature described by Heisenberg's Uncertainty principle. Einstein could not accept it, claiming "God does not play dice". This time, he was wrong.

1928: Felix Bloch applied the full machinery of quantum mechanics to the problem of conduction in solids, spearheading the development of the modern theory of solids.

His discovery of nuclear magnetic resonance in solids earned his a Nobel Prize in 1952.

1929: Walter Schottky and others found electron “holes” in the valence band structure of semiconductors, uncovering the mechanism of semiconductor behavior.

1933: Solid-state diodes were used as receiving rectifiers.

Late 1930s and early 1940s: Investigators began doping silicon and germanium to create new semiconductors.

1947: John Bardeen and Walter Brattain took out a patent for the transistor, and William Schockley applied for a patent for the transistor effect and a transistor amplifier. Their work on investigations on semiconductors and invention of the transistor, earned Nobel Prize in 1956.

1951: Semiconductors entered the world market.

1955: Transistors had replaced nearly all tubes.

1959: Robert Noyce and Jack Kilby invented the integrated circuit.

Not all modern physics discoveries have such glorious applications. There is no foreseeable use for a black hole or a neutron star, for example. It does not mean they are not worth our attention. For the infinitely small of particles, for the infinitely large of the cosmos, the fundamental laws of physics are the same. Stellar evolution is defined by the properties of the elementary particles. All elements in your body except for hydrogen are created inside of the stars. William Fowler’s theory of element generation suggests that in stellar evolution elements are synthesized progressively from light elements to heavy ones, from primordial hydrogen to iron, in thermonuclear reactions that also produce energy according to the famous $E=mc^2$. With the collapse of more massive stars, the explosive rebound known as supernova occurs, and makes possible the synthesis of the heaviest elements like uranium. The smaller stars, like our Sun, are unable to fuse nuclei beyond helium. After accumulating helium “ash” in the core and lacking the temperature to fuse any further, these stars no longer have enough thermonuclear heat energy to counteract the influence of their own gravity, and collapse forming so called white dwarf stars. Subrahmanyan Chandrasekhar determined that a star having a mass more than 1.44 times that of our Sun does not settle for a white dwarf but instead continues to contract, blows off its gaseous envelope in a supernova explosion, and becomes a neutron star. An even more massive star continues to collapse and becomes a black hole. In 1983, Chandrasekhar shared a Noble Prize with Fowler.

While teaching astrophysics and cosmology, I get to talk not just about stars and galaxies, but also about elementary subatomic particles, the solar neutrino problem, four fundamental interactions (nuclear, electromagnetic, weak, and gravitational), dark matter, and quantum gravity. Just recently, tests of Einstein’s special and general theories of relativity have reached new levels of precision. General relativity is now the "standard model" of gravity, and gravitational physics has become a truly experimental science (Ref. [3]).

Einstein spent most of his later years trying to come up with a way of unifying gravitational and electromagnetic interactions. He didn't quite do it, but we have made some progress since then. If our theory of the Big Bang is correct, the Universe consisting of a single point began to expand about 14 billion years ago. We can only guess about so called Planck epoch, from zero seconds to about 10^{-43} seconds, when temperature and energy were infinite and the Universe was governed by quantum gravity. However, we are ready to make some reasonable assumptions about the epoch governed GUT, Grand Unified Theory, from 10^{-43} s to 10^{-35} s, when strong, weak, and electromagnetic forces were united at energy of 10^{19} GeV. At this time, gravity "decouples". By 10^{-4} s, as the Universe expands and cools off, the strong force separates from the electroweak force somewhere around 10^{14} GeV. At last, electromagnetic and weak interactions break apart at 100 GeV, and we arrive to the Universe as we see it today, with the four separate fundamental forces.

Now, if you want to unify all fundamental interactions, you have to start from the lower end. First, get the electric and the magnetic forces together. James Clerk Maxwell did that in the end of the 19th century. His theory was not hard to prove experimentally: our entire electric grid is the result of his discovery. Next, get electromagnetic theory quantized. The basic principles of quantum electrodynamics were developed by another genius of modern physics, Richard Feynman (the joint Nobel Prize with Schwinger and Tomonaga, 1965). Now, we are ready to add the weak interaction to the mix. Unification of the electromagnetism and the weak interaction has been achieved by Glashow, Salam, and Weinberg, winners of the Nobel Prize from 1979. In 1983, experiments at a high-energy particle accelerator gave proof that the W and Z particles, predicted by the electroweak theory, can indeed be produced at 100 GeV.

The next step would be adding the strong interaction, in glorious Grand Unified Theory, GUT. If the simple realization that the electrical current can create magnetic field, and vice versa, (the theory of electromagnetism), has given us electric motors, imagine how much more we could do combining electromagnetic, weak and strong interactions! The energy crisis would certainly be over. However, the experimental proof of GUT would require energy of 10^{19} GeV. With the largest accelerator, we can go up to 1 TeV (10^{12} eV). And, of course, the experiment with quantum gravity is well beyond our reach.

There are always great enigmas in the fundamental laws of the Universe of matter, and there is the great need for scientific research in the twenty-first century.

My own area of research lies in subatomic theory. This theory deals with the most elementary constituents of matter and their interactions. By the 1930s, atoms were understood to be made of a nucleus composed of protons and neutrons (James Chadwick, the Nobel Prize for the discovery of neutron, 1935) and an outer cloud of electrons (Joseph John Thomson, the Nobel Prize in 1906). These three particles were thought to be the only constituents of all matter. But then the nucleus was split, more than two hundred other particles were discovered, most of which were mesons and baryons. The subatomic physics was in a mess, and Murray Gell-Mann came to the rescue. In 1953, he introduced the concept of "strangeness," a quantum property that accounted for previously puzzling decay patterns of certain mesons. In 1961, Gell-Mann and Ne'eman independently proposed a scheme for classifying previously discovered strongly interacting particles into a beautiful, orderly arrangement of families. Called the Eightfold Way (after Buddha's Eightfold Path to Enlightenment and bliss), this mathematical classification scheme suggested that it should be possible to explain certain properties of known particles in terms of even more fundamental particles, or building blocks. Gell-Mann named these sub-subatomic particles "quarks", a word rhyming with "walk". When one of the composite particles appeared to be absent from the pattern, Gell-Mann decided that nature would not spoil the perfect order by leaving out a particle. He calculated properties of the missing particle, and it soon was found experimentally. For his contributions and discoveries concerning the classification of elementary particles and their interactions, Gell-Mann was awarded the Nobel Prize in 1969.

I was seventeen when I first learned about quarks. I distinctly remember my fascination with the mathematical beauty of their arrangement. I am fascinated still. This moment in high school defined my career choice, the choice I have never regretted. I hope that the current high school students can find the same kind of inspiration during their modern physics classes. Einstein was a genius of his time, but he was not “the last great thing” to happen in physics. Multiple exiting discoveries were made since his time. Discovery of quarks was one of the majors.

Science and technology developed extremely rapidly during the 20th century. However, it is not obvious if we have conditions for such exponential growth at the current moment. To sustain the conditions necessary for fundamental discoveries in the future, we should stimulate the interest of young people to pursue scientific careers and to revive in them a taste for the scientific approach.

Most of the young people I have encountered can be divided in two categories. One category is looking for good jobs and fast money. The other group sincerely wants to help people. These students have to realize that not all of them have to be nurses or social workers. Physical sciences produce a direct impact on the creation of new technologies, and new technologies are urgently needed by the developing countries. The ethical responsibilities for physicists are no less enormous and challenging as responsibilities of medical workers, for example.

According to Ref [1], “It is indeed essential to understand that the twenty-first century will have an increasing need for the concepts and tools provided by the physical sciences in finding solutions to major problems which confront us, such as energy production, environmental protection, and even public health.”

Michael Morrow, the president of the Canadian Association of Physicists, has stressed the importance of early physics education. He says that: "When you share your enthusiasm for physics with a high school or grade school class, you are speaking to future leaders, educators, entrepreneurs, scientists and artists. You may or may not spark the imagination of a future physicist, but you will rarely have such a great opportunity to bring an appreciation of physics to a broader, more receptive or more potentially influential segment of society."

He is right, of course. High school physics teachers play a much more critical role in defining the future of our society than many of them may realize. I am keen to support their efforts in any way I can. Everybody interested is welcome to contact me for school presentations anywhere in Nova Scotia. Please write to svetlana.barkanova@acadiau.ca.

The Canadian Association of Physicists (CAP, http://www.cap.ca/) is eager to provide educational support, and is very capable to do so. In this period of inadequate funding for scientific research and education, it is especially important to have a strong national organization to represent and support physics in Canada. Since 1945, CAP has been highlighting achievements in Canadian physics, pursuing significant educational and public outreach, and organizing special events and public lectures all throughout Canada. As well as being the World Year of Physics, 2005 is also celebrated as the 60th Anniversary of the CAP. High School and Junior College Teachers are welcome to join.

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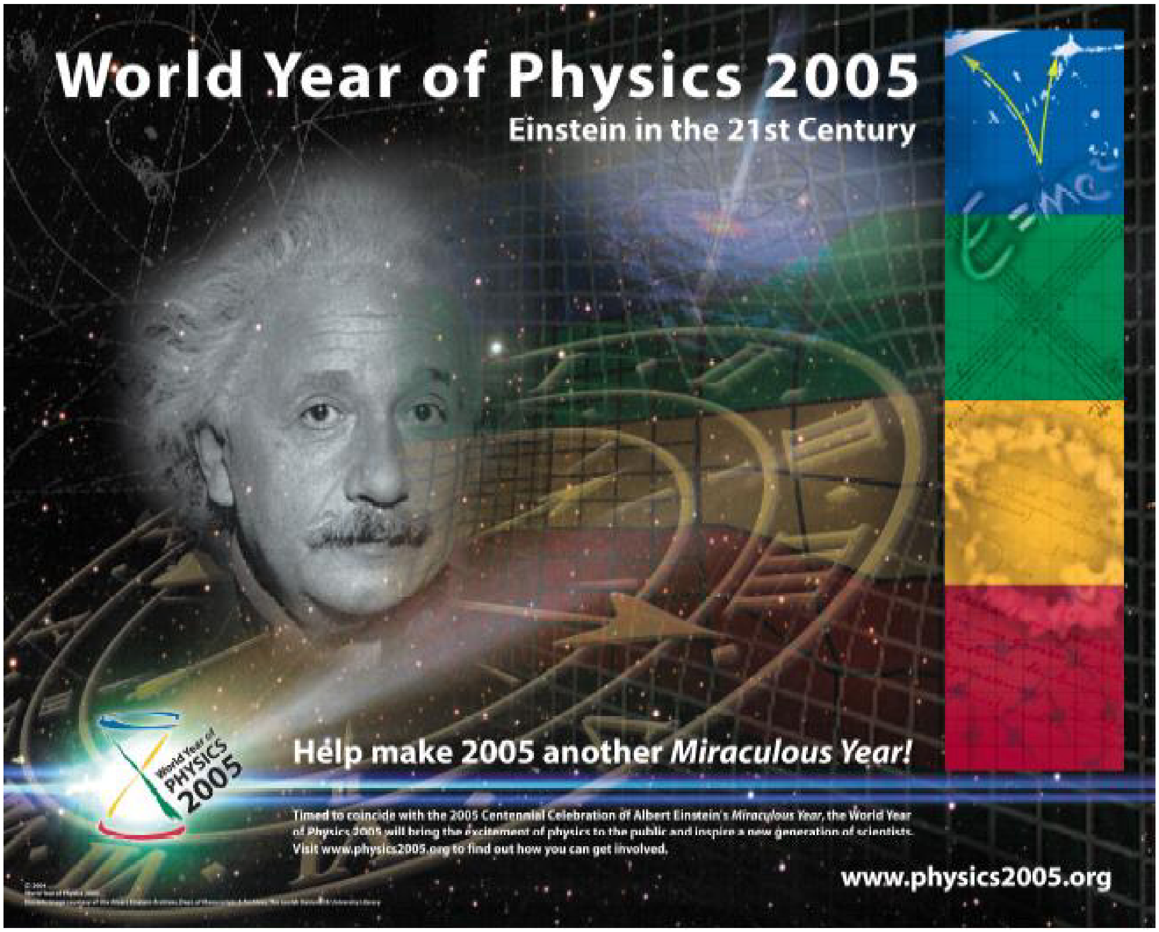
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