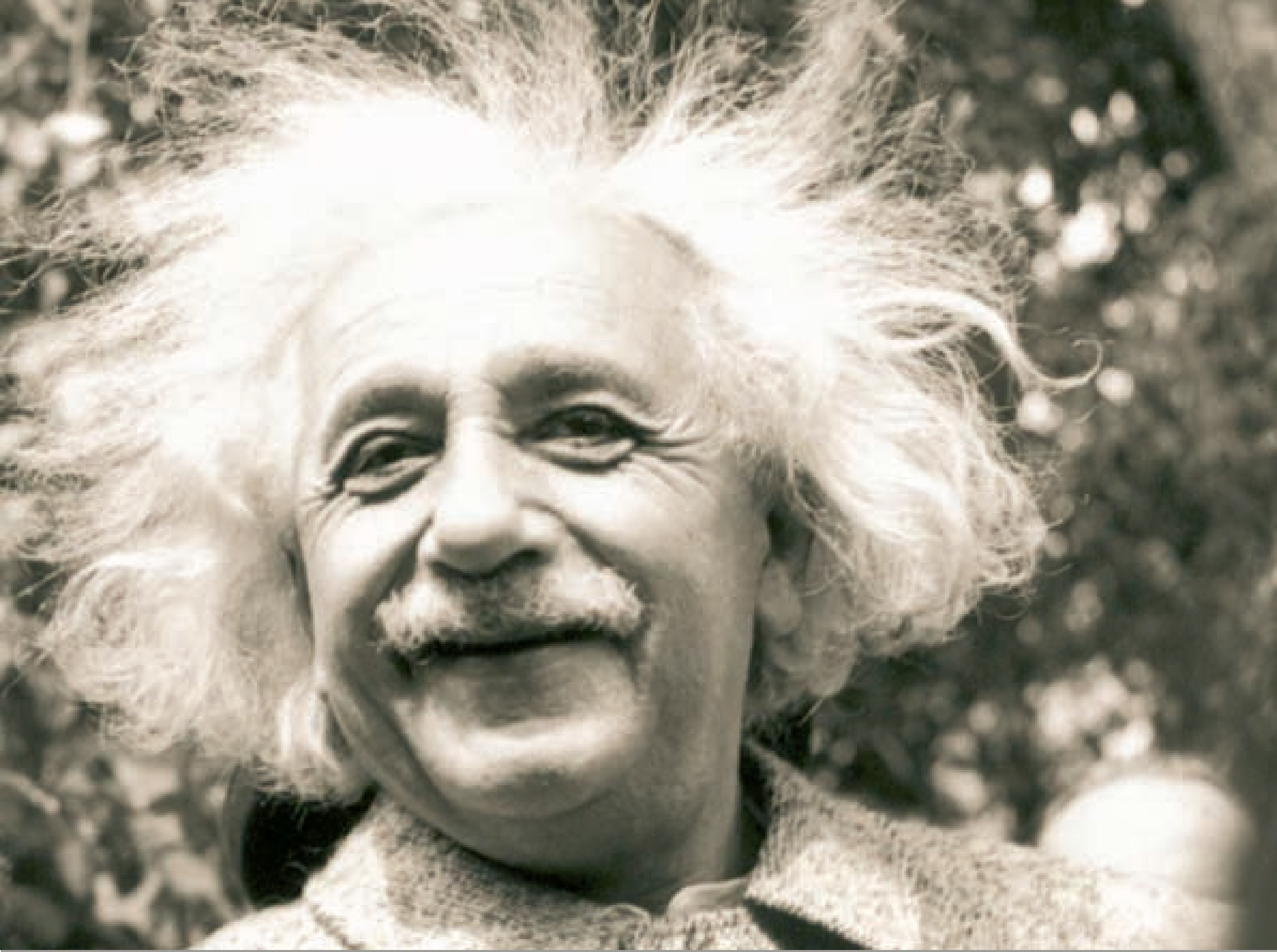


Einstein's Legacy

An Interview with Herwig Schopper

Last June, the United Nations declared 2005 the International Year of Physics and invited UNESCO to take the lead in celebrating the hundredth anniversary of Albert Einstein's legendary articles on relativity, quantum theory and Brownian motion.

Herwig Schopper is former Director-General of the European Organization for Nuclear Research (CERN, 1981—1988) and a recipient of UNESCO's Gold Albert Einstein Medal, in 2004, for services rendered to physics and international cooperation. He is also current President of the Council governing the new SESAME research centre for the Middle East, founded under the auspices of UNESCO. Here, he describes how Einstein's theory revolutionized ideas on fundamental questions and how this breakthrough has itself revolutionized society as we know it. As he explains, the adventure is far from over.

Why is 1905 remembered as the annus mirabilis, or Miraculous Year?

Einstein formulated two theories of relativity: the first of these, the *special* theory, extends Newtonian mechanics to situations that come close to reaching the highest possible speed, the speed of light. This theory has some consequences which appear completely contradictory to common sense.

They have, however, been confirmed by innumerable experiments. For example, experiments have proven that clocks tick differently in systems moving relative to each other or that the mass of a body depends on its velocity. Another consequence is the possible transmutation of energy into matter and vice versa. This recognition originating from pure basic research was to become the basis for the peaceful and military application of nuclear physics for energy production.

Special relativity like quantum mechanics provides a new framework for describing nature which, however, has to be complemented by additional and independent investigations concerning the behaviour of matter and the forces acting in nature. The term 'relativity' has been the source of many misconceptions.

The special theory does not throw scientific results into doubt; on the contrary, it is based on 'invariants' which do not depend on the position of the observer. The *general* theory of relativity tries to explain the gravitational force in terms of the structure of space-time.

The effect of relativity on daily life is negligible; however, relativity does have to be taken into account for the global positioning system of navigation — another example of how certain effects of basic research can offer the unanticipated bonus of becoming important for applications.

Einstein's theories and subsequent research in nuclear physics paved the way for the hydrogen bomb, which would give the human race the means to annihilate itself. This and the nuclear power plant disasters of Three Mile Island in 1979 and Chernobyl in 1986, not to mention the persistent problems with disposing of radioactive waste, have caused nuclear physics to be viewed with suspicion. Is this reputation justified today?

This view is completely unfounded for a number of reasons. Apart from the use of nuclear power, nuclear physics has found many other applications. Diagnostics in modern medicine is unthinkable without the exploitation of nuclear effects. The most important application is probably imaging with nuclear magnetic resonance, which is at the origin of scanners used in medicine. Ironically, the term 'nuclear' has been suppressed to avoid scaring patients, an indication of a public attitude towards nuclear issues that is somewhat biased and irrational!

X-rays have become an indispensable tool in medicine since their discovery by German physicist Wilhelm Roentgen in 1895. They are now used particularly in tomography, a method of producing cross-sectional images of the body. Particle accelerators, such as betatrons and linear accelerators, are used in almost every hospital to treat cancer with X-rays and synchrotron radiation sources are becoming a precious tool for many other applications in research and industry. Radioactive isotopes are widely used for therapeutic purposes in medicine but also for material testing. The PET diagnostic annihilates matter with antimatter to obtain information on the metabolism inside the brain. Protons and other heavy particles are explored as a tool to treat particular forms of cancer like brain cancer.

These are only a few examples of how humankind benefits from applications of nuclear physics. Unfortunately, the public associates nuclear physics with the atomic bomb to a large extent. The latter has become discredited owing to the fact that the physical processes for making an atomic bomb and producing energy for peaceful purposes are very similar; both entail converting mass into energy according to the famous Einstein formula: $E = mc^2$, or, put into words, energy is equal to mass times the square of the speed of light.

Of course, nuclear power, like any other source of energy, involves risks which have to be taken into consideration. Future developments like the use of fusion rather than of fission will reduce the risks. The difference between the two is that nuclear fusion joins two light elements, forming a more massive element, whereas nuclear fission splits a massive element into fragments. Both release energy in the process but, in fission, the fragments are very radioactive with long lifetimes, whereas, in fusion, the 'ashes' are not radioactive.

It seems unlikely that we will be able to avoid the environmental problem of excess CO_2 without recourse to nuclear power. Of course, alternative energy sources should be developed and exploited as much as possible but it will be impossible to satisfy the justified energy demands of the Third World without taking advantage of all energy sources, including nuclear power. Indeed, countries like China are considering that nuclear power is necessary for their economy.

The decades immediately following the Second World War were a golden age for Europe, the USA and Japan, as inventions like refrigerators, washing machines and transistor radios made life more comfortable for the masses and nurtured economic growth. Are we living in another golden age?

For many centuries, a high standard of living was reserved for the nobility, an extremely small, privileged layer of human society. This situation began to change drastically around the mid-nineteenth century when modern technologies like steam engines, railways and electricity evolved, progress which we are still building on today. Only with modern technologies has it been possible to increase production to the point where the majority of the population benefits from it[1], albeit in industrialized countries for the most part. Without this technical revolution, open or hidden slavery could not have been abolished, no new social idea could have solved the problem of providing sufficient food, shelter and time for cultural activities. Indeed, even democracy could not have been developed under conditions that forced people to spend practically all their time struggling for survival.

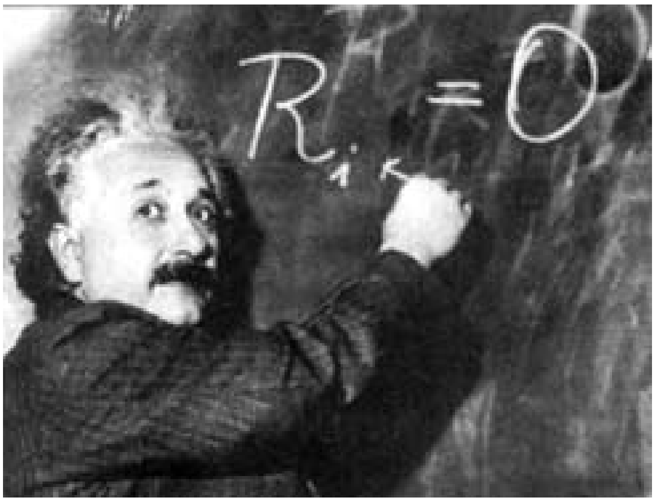
The technological applications which have completely changed our daily lives were all based on the results of basic research but, in many cases, these results were considered completely useless at the time. It was only much later that their relevance for certain applications was discovered. A famous example is that of Michael Faraday[2], who worked on various phenomena to do with electricity. When a representative of the Treasury complained that this kind of research held little promise of benefiting society, Faraday retorted that he might not be able to tell the future but was nevertheless sure the Treasury would one day levy high taxes on his research. And he was right! His work became the basis for modern electrical applications. As for the personal computer, who could imagine it would have such a deep influence on our daily lives? Who would have dreamed that the Web invented at CERN in 1990 for the needs of particle physics, that most abstract of sciences, would revolutionize communication?

Of course, the high standard of living in industrialized countries is not without its negative side-effects, in particular the endangering of the environment. Such problems will only be mastered by more advanced technologies. The main challenge will be to introduce these modern technologies into developing countries, in order to limit environmental damage there too. If this can be achieved, we shall see another golden age — one that is not limited to a few privileged nations — appear on the horizon.

What cutting-edge research is being undertaken today by physicists the world over and how will this research benefit society?

Physics research is progressing on various fronts. In basic research, particle physics and nuclear physics are penetrating deeper into the microcosm to solve the riddles of the building blocks of matter and the forces which act between them. Do we know all forces in nature? The strong and weak nuclear forces were discovered only in the last century. The unification of the magnetic and electric forces has led to the modern electrical industry, to radio, telephone, television and computers. The study of atoms[3], molecules, condensed matter and research in optics have revealed new phenomena, such as high-temperature superconductors or the so-called Bose-Einstein condensate phenomena lasting less than a billionth of a second; it has also forged a deeper understanding of quantum mechanics. As in the past, new knowledge will result in unexpected applications.

In addition, basic research is now aiming directly at applications, as the boundary between basic and applied research becomes more blurred. Nanotechnology, which deals with objects far smaller than a human hair, has components belonging to both basic and applied research.



Perhaps the most important service basic research has provided to society in the past 200 years is a completely new picture of nature, the cosmos and the position of humankind in all of this, a cultural benefit which is equally valuable as the material progress. If thunder is no longer considered an angry expression of the gods, if superstition has been abolished, if we agree that the Earth is not the centre of the cosmos and that the kind of matter we are made of is not the most prevailing in the Universe (as shown recently), it is thanks to modern science. This has great implications for the self-comprehension of humankind.

If the Minister of Science and Technology of a least developed country were to ask you to give reasons why that country should invest in physics research and education, what would you tell the Minister?

I have been asked this question several times by politicians. Developing countries are facing urgent issues, such as the provision of food and water, infrastructure-building and education reform. Huge sums provided by governmental development programmes or humanitarian bodies are being spent on remedying these short-term deficiencies. Despite this, the gap between industrialized and developing countries is in danger of widening in many instances.

In order to catch up, developing countries will have to find a short-cut in the transition from a mainly agricultural or trading society to an industrialized economy. This process took today's industrialized nations about 150 years. To close the gap, developing countries will need to devote a few percent of their available funds to promoting science, research and higher education.

Without some investment in such long-term issues, developing countries will come up against other problems, such as unemployment, as they industrialize. In industrialized countries, employment in agriculture has fallen from 60-70% of the adult population 150 years ago to a meagre few percent today. Third

Focus on Physics Helping the World

This year's IAEA Scientific Forum catches physics fever as the *Year of Physics* moves into it's final months.

The Forum (September 27-28), held in the margins of the 49th IAEA General Conference, is themed *Physics Helping the World* and sessions cover challenges and possible solutions in respect of nuclear science meeting energy needs. Forum participants will also examine the development of advanced materials and technologies for nuclear energy. The third session focuses on the use of ionising radiant for the diagnosis and treatment of diseases such as cancer and discusses the increasing need for well-trained medical physicist in developing countries. The final session examines the global safety regime.

More information can be found at the IAEA General Conference pages at: www.iaea.org

For more information on The International Year of Physics, visit: www.wyp2005.org

World countries will have to establish some industrial activities based on new technologies. That this can be achieved over a relatively short span of time has been demonstrated by the likes of the Republic of Korea and Taiwan (China), among others.

In many respects, technologies are based on science and particularly on physics. Physics also provides the fundamentals for other sciences, such as chemistry and biology. The key to many problems, be they environmental issues, energy-saving and production, or better diagnostics in medicine, to mention but a few, will require intensified physics research. Indeed, interdisciplinary co-operation between physics and other fields not only holds great promise but will become essential in the coming decades.

If you could travel through time, what would society look like in 2030 through your eyes?

Predictions are always difficult, especially when they concern the future! Who could have predicted 30 years ago the advent of personal computers, of communication technologies, of quantum leaps in health care or the new possibilities for human recreation and entertainment, such as satellite television, compact disks, mobile phones or the current volume of air traffic. Science and research hold new surprises for us but the big question will be whether the moral and ethical attitude of people progresses at the same pace as the technology. The responsibility for whether we use future progress for the benefit or detriment of humankind will lie with politicians. The greatest challenge of all will be to ensure that the less fortunate also reap the rewards of an industrially developed world.

This interview by Susan Schneegans was conducted for UNESCO's quarterly science magazine, "A World of Science," Vol. 3, No. 1, January-March 2005.

Notes

1. One early example of mass manufacturing was the Model T car. In 1914, Henry Ford ordered his Model T factory in Michigan (USA) to use black paint exclusively: black enamel paint dried faster than other colours, meaning more cars could be turned out daily at a lower cost. Low production costs enabled Ford to raise wages and make his Model T more affordable: the sales price dropped from $850 at introduction to less than $300 by the early 1920s. As a result, annual sales soared from roughly 300 000 units initially to a peak of more than 1.8 million.

2. Faraday (England, 1791-1867) was among those who developed electromagnetism. He was a truly gifted experimenter with a talent for physical intuition and visualization. His talent is attested to by the fact that his collected laboratory notebooks do not contain a single equation. In the 19th century, he introduced the idea of electric fields as the space around a charged body filled with lines of force, now usually called electric field lines. He is most famous for Faraday's law of induction, one of the fundamental explanations of electromagnetism. His work laid the foundations for the later development of such devices as electric motors, television transmitters and receivers, telephones, fax machines and microwave ovens.

3. The discovery and characterization of atoms is perhaps the pre-eminent triumph of 20th century physics. It is now widely known that the atom consists of electrons, protons and neutrons. The atom is 10^{-8} m wide and 99.9% of its mass resides in the nucleus. The electron has a mass 1/1837th that of a hydrogen nucleus and is negatively charged. One or more electrons can be dislodged by exposing the atom to sufficient energy. The nucleus is about 10^{-5} the size of the whole atom and of the order of 10^{-14} m wide. The proton which resides in the nucleus is the electrical counterpart of the electron with an identical but opposite charge. Scientists have devised sophisticated ways of probing deeper into the secrets of matter. Particle accelerators give particles very high speeds and energies which, in collisions, have revealed the detailed inner structure of the atom. These investigative techniques have led to practical inventions that revolutionized biology, chemistry and medicine. Among them are the electron microscope, the scanning tunnelling microscope and nuclear magnetic resonance. By the end of the 20th century, physicists were able to study the behaviour of atoms in exquisite detail.