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Einstein Session of the Pontifical Academy

On 10 November 1979 a meeting of the Pontifical Academy of Sciences was held in Rome in honor of the centenary of the birth of Albert Einstein. The session was presided over by Pope John Paul II. This issue includes most of the text of the four speeches given on that occasion.

The Pontifical Academy is an outgrowth of the Academy of the Lincei, founded in 1603, and the Pontifical Academy of the New Lincei, dating from 1847. It is a different organization from the "Accademia Nazionale dei Lincei," which has figured as the Italian National Academy of Sciences since 1871. The Pontifical Academy was renewed in 1936 by Pope Pius XI under the title Pontifical Academy of Sciences. It is composed of 70 Academicians in the fields of mathematical, physical, and natural sciences from all over the world, chosen without religious or racial discrimination. Its purpose is to promote progress in the sciences and the study of epistemiological problems.

The Einstein session was historical in three ways. It was the first time the Pope presided over a session of the Pontifical Academy. It was the first such session to be attended by the cardinals, many of whom were in Rome at the time. Finally, the content of the Pope's talk was remarkable, particularly his emphasis on the autonomy of scientific truth and its independence of religious truth.

Address of Carlos Chagas

In the course of this century science, working in two directions, has completely changed human life. One of these directions is basic research; the other is technological applications. It matters little that basic research is often regarded with mistrust in many circles, or that technological applications have not always been pursued with prudence and wisdom. Man's irrationality cannot take away from science and technology their role as powerful levers to serve our society, guided by spiritual, moral, and ethical values, to help overcome the obstacles to man's progress produced by a materialistic and opportunistic civilization, where existence destroys essence and possessions take the place of love.

Albert Einstein's work is in the realm of pure research. It contemplates the laws of nature at the level where the supreme harmony of the Divine Creation reigns. For the importance of his works, Einstein is compared to the greatest minds in the field of universal thought. I might mention among his predecessors only Galileo Galilei, who applied the keen edge of his genius to the development of science and, like Einstein, became the symbol of an era.

In studying the existing information regarding Einstein, we find, together with the great scientist, an exceptional human being, whose chief concern was with justice. And yet no one is more outstanding for his constant modesty and unceasing faithfulness to his moral principles. If he is sometimes accused of occasional self-contradiction, this is only superficial and rather the result of a firm attachment to his convictions. One thing certain is that he radiated an extraordinary intellectual force and a charisma that age only increased.

If Einstein the scientist was completely absorbed in seeking a unifying theory of the forces at work in the universe, Einstein the citizen served the cause of justice with the same zeal and courage. From 1914 until his death he fought against militarism, the abuse of power, and racial discrimination, and he staunchly defended peace.

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Einstein's Early Years

Born in Ulm on 14 March 1879, Einstein lived in Munich until he was fifteen. In Munich he began his study of mathematics; the geometry of Euclid became his bedside breviary. He also immersed himself in Kant. During this period his mother made him study music and the violin—a genuine Ingres violin—which would serve as his refuge in moments of relaxation, distress, or trial. The family environment helped to form his values; at home he learned modesty and simplicity, so well exemplified in his manner of dress and his indifference to material wealth. "Men's lowly objectives—possessions, apparent success, luxury—have always seemed to me despicable."

After his elementary studies, Einstein matriculated at the Luitpold Gymnasium. His stay at the Gymnasium was for him decisive. He could not tolerate the Prussian discipline there and what he called the "methods of fear, force, and artificial authority." At the Gymnasium were born his lifelong rebellion against authoritarianism and classical school discipline and the roots of his antimilitarism. Also, he began to feel the need to reconsider the importance of evidence that had been considered irrefutable.

Einstein did not complete his course in Munich. Interrupting his studies there, he joined his parents in Milan for a year before going to Switzerland, where he completed his secondary schooling in Aarau. He became enthusiastic over the democratic climate which had been established for centuries in the Swiss Confederation, as well as the absence of a professional army. Making a decision that was surprising in a young man of sixteen, he gave up his German citizenship to become a Swiss citizen. He entered the Ecole Polytechnique Fédérale, where in 1900 he received his diploma. The years he lived in Zurich were of great importance because they laid the foundations for the scientist.

His faithful companions—Michelangelo Besso, Konrad Habicht, and Maurice Solovine among others—tell of the astonishment and admiration of everyone in the presence of his great intelligence and his mastery of physics. Those were the years when he studied the works of Maxwell, and learned from a lecture by Henri Poincaré that it may not be possible to maintain the concepts of absolute space and absolute time and even the geometry of Euclid to be valid in mechanics. Besso brought him Mach's book *The Science of Mechanics*, which even more deeply described the difficulties of the interpretation of the two concepts of Newton. He thus began to prepare himself for relativity.

The pupil was not popular with his teachers. A very serious student, he was nonetheless irregular in class attendance. Also he was critical, sometimes arrogant, always impulsive in his comments, often hurting feelings. Consequently, he was unable to realize his dream of joining the teaching staff of the Ecole Polytechnique, or even that of other faculties. A stroke of good fortune led to his entry into the Patent Office in Bern, where he found calm and leisure and could so develop his unusual scientific theories. In 1905 he published four basic papers, in which he treated the theory of special relativity, explained Brownian motion, introduced the idea of quanta, and established the relationship between mass and energy.

After 1911 Einstein was sought by numerous universities. Following a brief period at the German University of Prague, he returned to Zurich as a professor at the very school that had scorned him, but finally in 1914 he could not resist the intellectual attraction of Berlin, where Planck and Nernst, among others, lived. He abandoned Zurich and went to become part of the heart of German physics, on terms that bear witness to the prestige he had achieved. He was named director of the Kaiser Wilhelm Institute of Physics, professor without specific teaching obligation at the University of Berlin, and member of the Prussian Academy of Science on exceptional terms. The period when he lived in Berlin permitted him to complete his theory of general relativity and establish his theory regarding the structure of the universe.

Influence of Political Developments

In Berlin, Einstein was no longer the scientist limited to science, but became involved in the political life of his period. Soon his sense of justice was sharpened and he played an active role as pacifist and began his battle against anti-Semitism.

During his youth in Zurich Einstein had been interested briefly in Judaism, but it was in Prague, when by chance he came upon a Jewish cemetery of the 5th century, that he came face to face with the centuries-old history of his people and found himself integrated with them. In Berlin he was surprised by the anti-Semitic positions taken by the university and the government, which foreshadowed a movement that was to reach its full force with the Nazi regime. He saw that the war of 1914 to 1918 was in the making and that it was awaited, if not hoped for, in certain military, political, and economic circles. He was astounded.

When war was declared, he was surprised to see his scientific friends offer their services as experts and take an active part in the war effort. He was thrown into the struggle, however, by the "Manifesto to the Civilized World," which was published in October 1914 and signed by 83 German scientists, among them several of the most outstanding. The Manifesto relieved Germany of all blame, justified the invasion of Belgium and, in terms that were to fail later, spoke of the annihilation of the white race by the Slavic hordes. Einstein readily signed an "Anti-Manifesto," which he helped to write. One of its sentences was prophetic: "No one will win the battle that rages today; all the nations that are engaged in it will pay a very high price." This antiwar declaration had only four signers, but Einstein did not lay down his arms. He immediately joined a movement started by Ernst Reuter, who was to become mayor of Berlin. The aim of the movement was to obtain an early peace and create an international organization for the preservation of peace, an ideal to which Einstein was devoted for the rest of his life.

The years that followed World War I were not easy ones for Einstein. Scientifically, he achieved great fame. The theory of general relativity was established by the direct observation of one of its principles. In 1919, during a total eclipse of the sun, the deflection of the light of the stars by the gravitational field of the sun, as Einstein had foreseen, was verified. However, Einstein was unhappy with the turn of international events. He refused to attend the 4th Solvay Congress in 1924 because the German scientists were not invited. Reaffirming his internationalism, he wrote to Marie Curie: "I understand that the Belgians and the French are not psychologically prepared to meet the Germans. But when I learned that the German scientists were excluded as a matter of principle, because of their nationality, I realized that by going to Brussels I would be lending my support to such a decision." At the time of the capture of the Ruhr Valley by the French army, Einstein, notwithstanding the anti-German feeling that he so often expressed, vigorously condemned the Allies.

The development of geopolitics and the recourse to armaments at that time so increased Einstein's preoccupation that he often joined pacifist movements, which used his name. His desire to contribute to world peace reached its height in the 1930's. In New York in 1930 he made a speech in which he said that "if 2 percent of the citizens refused to be drafted" governments would lose their ability to wage war. The speech—for which he was insultingly nicknamed "the 2 percent man"—was used against him by the followers of McCarthy even after he had obtained his American citizenship. His disillusionment with the efforts of the League of Nations and the slowness with which the Disarmament Conference held in Geneva in 1932 carried on its work led him to a new tirade. In a press interview before 60 foreign correspondents he appealed to the workers of the world to abandon their work in the armament factories and cease all activity related to the transport of armaments. Again he urged them to oppose the draft.

However, with the events in Germany after Hitler's rise to power, which led to an increase in militarism and armaments and a reappearance of anti-Semitism, Einstein was obliged to reexamine his pacifist position and change his ideas. Only force could win over the power of evil. He wrote to King Albert: "In the heart of Europe there is a power, Germany, which is preparing for war by all possible means. This has created such danger for the Latin countries, Belgium, and especially France, that they are necessarily forced to use their armies."

During World War II, he served the American war effort and played a role, which is sometimes exaggerated and sometimes belittled, in the organization of the Manhattan Project and the development of the atom bomb. Since the Hitler regime had made it impossible for Einstein to return to Germany in 1938, he established himself at the Institute for Advanced Study in Princeton, where he worked until his death on 25 April 1955. In Princeton he continued his work on unified field theory and tried in vain to remove the uncertainties which the theory of quantum mechanics (for which he had paved the way) had introduced into atomic and subatomic physics. He dedicated great efforts to the cause of Zionism—to which he had been driven by the Prague incident and German anti-Semitism—and after the war resumed his efforts on behalf of peace and international understanding, which were now threatened by the horror of a nuclear war, to which he had in a way unwillingly contributed.

Philosopher of Nature

Little by little, Einstein became a wise man, a sage, whose advice was sought and whose life was cited as an example. In a country where communication was rapid, the newspapers, radio, and television brought to the public the innumerable events of his daily life, although he tried to protect his privacy. Each week he received hundreds of letters, and he tried to answer them, especially when he sensed a correspondent in distress. People lined the streets to see him pass and buses full of tourists stopped, as they still do today, in front of 110 Mercer Street, where the man lived who completely revised science in our lifetime.

Einstein became, through his international positions, a sort of conscience of a world in anguish. For many he was one of the greatest philosophers of nature, if not the most important of our time. His views of nature embodied a new Pythagorean approach. The harmony of the universe sealed by beauty was at the center of his thinking. To achieve its highest realization, Einstein had to postulate the existence of a superior being or system as the creator of a unified field of force and organizer of the mathematical harmony of the world. This concept has a pantheistic tinge and is very close to the thinking of Spinoza. Einstein himself, in reply to some questions, stated: "I believe in Spinoza's God, who reveals himself in the harmony of all things, and not in a God who is interested in the actions and the destiny of each individual."

Although he was certainly a rationalist, Einstein was not an atheist. Respect for the thought and the history of his people produced in him an underlying religious nature. He stated: "Science without religion is lame, and religion without science is blind." The idea of a God was always with him and he affirmed: "I would like to know how God created the world. I am not interested in this or that phenomenon, nor in the spectrum of a chemical element. I want to know His thoughts, the rest is a detail."

But in his search for universal harmony and the esthetics of natural laws, Einstein never lost sight of the human condition and the importance of realities which are above science. He said: "Our times are characterized by extraordinary discoveries in science and its technical applications. Who of us is not impressed by it? However, let us not forget that knowledge and technical aptitudes do not lead humanity to a happy and dignified life. . . ." To Queen Elizabeth of Belgium, stricken by a dual grief, he sent a message of consolation, from which I quote: "After all, there is something eternal which remains, beyond tomorrow, beyond destiny and human disappointments."

Einstein was a sower and, as Saint Paul said, because he sowed generously the fruits of his activity are found abundantly in our thoughts and our activities.

Address of P. A. M. Dirac

Einstein has had a tremendous influence in many fields of activity. He was a great fighter for peace and freedom and has rendered inestimable service to mankind. But here I want to talk about his influence on physics, which is the most fundamental and far-reaching of all his work and shows him to have had a most unusual mind.

Einstein's work was essentially of a pioneering character. He started new lines of thought in unexpected directions. He introduced surprises. Other physicists then developed his ideas. There are three main innovations that Einstein made: (i) special relativity, (ii) the relation between waves and particles, and (iii) general relativity. Each of these meant the dawn of a new era. Any one of them would have ensured an immortal place in the history of science. We owe all three to Einstein.

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Special Relativity

With special relativity, Einstein showed that such commonplace ideas as space and time need to be modified. The traditional views do not provide an adequate basis for an accurate description of physical processes. They have to be replaced by a picture in which space and time are intimately related and are united in a four-dimensional continuum. Elementary notions of kinematics and of dynamics are altered.

People sometimes say that special relativity was discovered by Lorentz or Poincaré and refer to work that was published by these authors before Einstein published his famous paper on relativity in 1905. But these statements give only part of the truth and not the main part. Lorentz and Poincaré believed in the ether. They obtained some of the relativity equations working within the framework of the ether, which was always at the back of their minds.

Einstein destroyed the ether, and so the framework on which the others built was gone. He introduced a new symmetry principle between space and time. For Einstein the symmetry principle was all-important. This was his great achievement and here he stands alone. Symmetry principles are now very important in a large part of physics. Many of the symmetry principles in use nowadays are only approximate, and they are broken. The symmetry principle introduced by Einstein connecting space and time is an exact principle in physics and plays a dominant role over the others.

The difference between Einstein's attitude and that of Lorentz and Poincaré is shown by their different reactions to experimental results. Lorentz had set up a model for the electron based on his transformation equations and agreeing with Einstein's symmetry requirement. It was to replace the previous spherical model of Abraham. Experiments were done by Kaufmann to distinguish between the two models. Kaufmann's results supported Abraham. Lorentz and Poincaré were completely knocked over. Einstein was not much disturbed. He was confident in his symmetry principle. It was so beautiful it had to be right, and he felt sure there was some mistake in Kaufmann's experiments. And after some years that was found to be so.

Special relativity led to a long line of development. It led to a large rest energy associated with any mass, $E = mc^2$. It led to a square root in the formula for the energy of a moving body, so that mathematically the energy could be negative. This did not matter at first; one could just say that negative energy states do not occur. But with the arrival of quantum theory, one had the possibility of a particle jumping from a positive to a negative energy state and one was forced to look for a meaning for the negative energies. This led to antimatter, which is thus a direct consequence of Einstein's special relativity.

Special relativity provided many problems for the world's physicists—to express all the equations in a form exhibiting four-dimensional symmetry. This usually proved to be fairly easy. There are some basic difficulties concerned with quantum mechanics, which have not yet been completely resolved.

Waves and Particles

By 1905, the wave theory of light based on Maxwell's equations was well established, but certain phenomena would not fit in. It seemed that emission and absorption of light occur discontinuously. This led Einstein to the view that the energy is concentrated in discrete particles. It was a revolutionary idea, very hard to understand, as the successes of the wave theory were undeniable. It seemed that light had to be understood sometimes as waves, sometimes as particles, and physicists had to get used to it. The idea was incorporated into Bohr's theory of the hydrogen atom and forms an essential part of it.

The statistics of an assembly of light-particles was studied by Bose, who found that ordinary statistics was not applicable. The laws for the new statistics were formulated jointly by Bose and Einstein. By studying an atom in statistical equilibrium, Einstein saw the necessity for the phenomenon of stimulated emission of radiation. This effect is, in the first place, extremely small, but it can be very much enhanced with a suitable apparatus, because of the new statistics. This has led to the laser, a useful tool in present-day technology, which we owe to Einstein.

The appearance of waves connected with particles was shown by de Broglie to be applicable to all particles, not just those having the velocity of light. De Broglie worked out the mathematical relations between waves and particles, using only the requirements of special relativity. He found that the waves move faster than light. However, they cannot be used to transmit signals faster than light, which is an important feature of special relativity.

De Broglie's theory was extended by Schrödinger and led to wave mechanics, which is fundamental for modern atomic theory. Here, again, we have a long line of development of physics, originated by Einstein.

General Relativity

Einstein provided a geometric picture of gravitation and thereby started an entirely new direction for physics. Previously, there were two pictures of physical forces in general use: action at a distance and action through a field. With Newtonian gravitation both pictures are possible. With electric and magnetic forces the action at a distance concept is useful, but action through a field provides a more complete picture since it allows electromagnetic waves. With Einstein, gravitation is interpreted in terms of the curvature of space, and only the field picture is possible.

There were some small differences between the predictions of Einstein's and Newton's theories, which provided several lines of work for astronomers and physicists and enabled them to make checks. First, there was the motion of the planet Mercury, which was anomalous according to Newton but was brilliantly explained by Einstein. Then there was the bending of light passing close by the sun, which can be observed during a total eclipse of the sun. Observations were made in 1919 that confirmed Einstein's theory. These observations have been repeated many times since and his theory is always confirmed.

With the discovery of radio stars one can check on the deflection of radio waves passing close by the sun, for which one does not need a total eclipse. There is also a slowing of such radio waves, and Einstein's theory is again always confirmed.

The theory of general relativity also predicts effects concerning the shifting of spectral lines of light emitted in a gravitational field. The opportunities here are usually not very good for accurately testing the theory, but the results have supported the theory as well as could be expected.

Besides all these astronomical and physical developments following from general relativity, there has been an extensive stimulus to mathematical work. The simple kind of curved space that Einstein used, Riemannian space, which can be embedded in a flat space with a higher number of dimensions, proved so successful with gravitation that people have wondered whether more elaborate kinds of curved space might not similarly account for the other fields of physics, in particular the electromagnetic field. Einstein himself worked on this problem for many years.

But these efforts have not had any definite success. Whereas Einstein's original curved space was brilliantly successful, the more complicated spaces, on which an excessive amount of work has been done, have not led to results of physical importance so far.

There is also the problem of cosmology, the understanding of the universe as a whole. This is necessary for getting the boundary conditions at great distances in applications of Einstein's field equations. A cosmological model was first proposed by Einstein, but it was not satisfactory. Then a model was proposed by de Sitter, also not satisfactory. Then many other models were worked out, by Friedmann, Lemaitre, and others, based on Einstein's equations. This is a large subject that was initiated by Einstein's general relativity. The simplest acceptable model is one that was proposed jointly by Einstein and de Sitter, and it may very well be the one that is used in the future.

In all the fields of work I have discussed, Einstein's influence has been enormous. We can be sure that it will extend far into the future.

Address of Victor F. Weisskopf

In order to appreciate the tremendous significance of Einstein's thought for our understanding of nature, let us look at two important insights gained before Einstein, in the 19th century:

1) The recognition that electricity, magnetism, and light are the same; light is a wave of electric and magnetic force.

2) The recognition of the existence of atoms and molecules made up of electrically charged particles as constituents.

These discoveries revealed two serious contradictions. Einstein resolved them and turned them into a deeper understanding of nature.

Galileo and Newton developed the laws of motion of objects under the influence of forces; they showed that a force changes the state of motion of an object. The effect is governed by the mass of the object. The greater the mass, the smaller the change of motion by a force. Nevertheless, in principle, if a force acts long enough on an object it accelerates the object to any speed, even greater than the speed of light.

Here is the first contradiction: According to the laws of electromagnetism an electrically charged particle cannot move faster than light because it would produce infinitely strong electric forces. But matter is made of charged particles.

The second contradiction is quite different. It concerns the surprising stability of atoms and molecules and their characteristic features. An oxygen molecule in air suffers a million times a million collisions every second, but remains unchanged in all its specific properties as an oxygen molecule. Ordinary mechanics is totally inadequate to explain this stability and specificity of systems made of charged particles, such as atoms that consist of electrons moving around atomic nuclei like planets around the sun.

Einstein brought about the solution of both contradictions in a way typical of him—that is, not by making a few little improvements and additions to the established theories, but by creating new foundations for our views of nature. He solved the first contradiction by a thorough revision of our concepts of space, time, and energy. He gave the decisive impetus to the solution of the second contradiction by introducing the wave-particle duality to physics.

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Unification of Electromagnetism and Mechanics

The solution of the first contradiction is embodied in so-called special relativity theory. In it, electromagnetism and mechanics are unified in one great conceptual system. To achieve this, our ordinary concepts of space and time had to be thoroughly changed. The simultaneity of events at different places has become a relative relation depending on the state of motion. Two events that appear to happen at the same time for one observer who does not move appear to happen at different times for a moving observer. The course of time also depends on the state of motion. Incredible as it may seem at first, this fact has been shown clearly in experiments with some fast-moving entities; their course in time was shown to be retarded compared to the course in time of the same entities remaining at rest. In a famous experiment with decaying particles, the fast-moving ones lived much longer than the same sort of particles at rest. Finally, any form of energy acquires a mass, and every mass is a form of energy. A moving body appears heavier than a body at rest because its energy of motion adds to its mass. In some modern particle accelerators electrons acquire masses more than 20,000 times their original mass when they are accelerated, an effect that is clearly observed when they collide with an obstacle. All these properties affect the motion of fast electrons in electric and magnetic fields. Indeed, many practical applications of electronics are based on these properties.

This unification of mechanics and electrodynamics by Einstein was not a revolutionary opening of new vistas, but rather a unification of seemingly contradictory ideas. It was a crowning consolidation of classical physics in a new conceptual framework of space and time.

Wave-Particle Duality

Now, to the second contradiction, or rather inadequacy of classical concepts: the stability and specificity of atoms and molecules. Here, Einstein's idea started a truly revolutionary development in physics: quantum mechanics. It opened up wide new horizons and clarified many outstanding problems in our view of the structure of the matter. Quantum mechanics is based on the idea of wave-particle duality. Einstein first applied this idea to the nature of light, but it was soon applied to the nature of elementary entities such as electrons and other constituents of matter.

The idea was that all these entities exhibit both wave and particle properties. This double nature taxes our imagination; few things differ as much as a beam of particles and a running wave. In a beam of particles, matter is concentrated in small units, whereas a wave spreads continuously over space. Still, wave and particle properties are observed for electrons and other fundamental entities.

The wave nature of electrons explains so many previously unexplained facts for the following reason. If waves are confined to a finite region of space, they form characteristic shapes and patterns that are specific to the nature of the confinement. Figure 1 shows waves in space confined to the neighborhood of a central point. Only those and no other patterns can develop in this sort of confinement. But this is just the confinement that electrons suffer when they are confined around the atomic nucleus by electric attraction. The electron waves in atoms must assume some of these patterns. The simple patterns are "lower" than the more complex ones; they are lower in energy. Indeed, the electrons in an atom assume the lowest possible patterns.

This is the explanation of the stability of atoms—it takes energy to change to the next higher pattern. For example, the energy of molecular collisions in air is not sufficient to change the electron patterns in oxygen. Thus oxygen survives unchanged the many million collisions in air.

The typical shapes of the electron patterns determine the specific properties of atoms. For example, in the oxygen atom the electrons fill the lowest patterns up to the fourth one. The resulting pattern combination is characteristic for oxygen and is responsible for its properties; it determines how oxygen combines with other atoms (forming water with hydrogen, for example) and how the atoms fall into a symmetrical crystalline order when they form solids, such as ice crystals.

The electron patterns are the primal shapes of nature. Fundamentally, all of nature's shapes can be traced to such patterns. Even the properties of living substances are based on them—in particular, the properties of the molecules that carry the hereditary code. In the final scientific analysis, the stability of electron wave patterns causes the same flowers to bloom every spring and makes children similar to their parents.

Einstein started this great development as early as 1905 by an almost unimaginable act of vision, when he concluded that the concept of an electromagnetic wave does not suffice to explain important properties of light. He drew the revolutionary conclusion that there must exist light-particles, the photons. The particle-wave duality was born. Einstein recognized the fertility of his idea, but he was never completely satisfied with the conceptual basis of quantum mechanics. The lack of complete causality and the frequent use of probability instead of certainty were always a matter of deep concern for him.

Matter-Antimatter Symmetry

The next great development in physics was again an outgrowth of Einstein's ideas. Dirac was not satisfied with the fact that early quantum mechanics did not fit into the framework of relativity theory. The velocities of electrons in ordinary atoms are so small compared to the speed of light that the neglect of relativity theory did not matter much. But what about wave mechanics of particles that move much faster? Dirac was able in 1927 to unite relativity with quantum mechanics.

In doing so, Dirac discovered a new symmetry in nature, the matter-antimatter symmetry. He discovered it, not by experimenting, but solely by putting together the two great ideas of Einstein: the space-time unity of relativity and the wave-particle duality of quantum mechanics. He saw that for every particle there must be an antiparticle with opposite charge. Although in our own environment we find only negatively charged electrons and protons with positive charge, which is ordinary matter, Dirac concluded that nature must also admit the opposite. Such antimatter, he predicted, would not be stable in the presence of ordinary matter; it would annihilate when in touch with it, in a sort of explosion where the masses would be

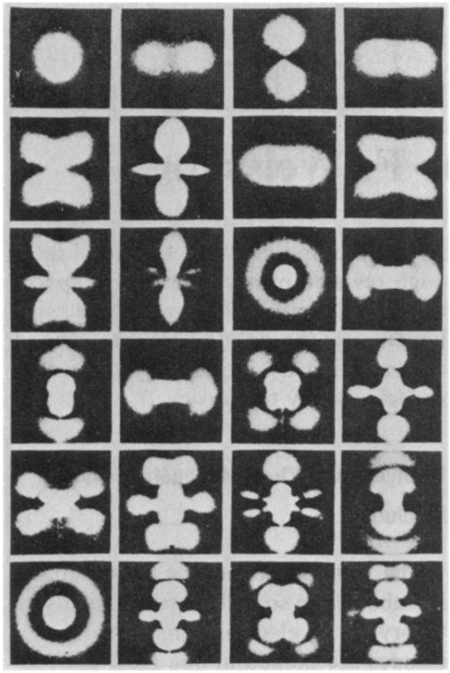

Fig. 1. Patterns of electron wave functions of different quantum states.

transformed into energy—a direct manifestation of Einstein's equivalence of mass and energy.

A few years later the antielectron was found, and almost 30 years later, the antiproton. Antimatter indeed exists in nature, as Dirac predicted from Einstein's work. This theoretical prediction was one of the greatest intellectual achievements of science. Today, beams of antimatter are produced in many laboratories; they run in carefully evacuated tubes in order not to hit any ordinary matter until they reach their target, where they annihilate with the target substance.

Theory of Gravitation

Dirac has discussed the third great contribution of Einstein in 1917: the general theory of relativity. It was a new way to understand gravity, as a warping of space and time. The consequences of Einstein's third contribution are staggering. Many of its predicted consequences have been observed—for example, the bending of light beams by the sun. One of the most interesting consequences is what happens if a large star collapses after having used up all its internal energy sources. Then the space around it collapses too, and something is formed that the astronomers call a black hole, an entity that engulfs everything in its neighborhood and does not allow even light to escape. Objects that may indeed be such black holes have been observed recently.

Einstein's theory of gravity as a deformation of the space-time structure had an enormous influence on our ideas of the structure of the universe, its beginning, its evolution, and its extension. The modern view that the universe originated from an infinitely compressed hot assembly of primal matter in the big bang and the subsequent expansion of the universe are ideas that were spawned by Einstein's conception of space and time. This view of the origin of the world was recently supported by the observation of an unmistakable faint optical echo of that grand explosion, an echo that still fills the universe with infrared radiation.

The three great insights of Einstein—the unity of space and time and all its consequences, the wave-particle duality, and the theory of gravitation—have each opened up and clarified new vistas for our view of reality. Einstein was called the Copernicus of the 20th century. He created three independent and interdependent structures of ideas, each comparable in intellectual size to Copernicus's insight.

Philosophical Implications

I would like to add two more remarks about the character of Einstein's ideas. One has to do with a widely held opinion that Einstein's ideas have undermined our belief in absolute values since he introduced relativism into our thinking. A similar widely held opinion also maintains that quantum mechanics has destroyed our belief in an objective world of nature, and that the famous uncertainty relation of Heisenberg is an illustration of a vague and unreal conception of nature in modern science. Nothing is further from the truth and from Einstein's own philosophy. Einstein believed in an ordered universe with absolute universal laws and symmetries. His concept of relativity is nothing else but a deeper recognition of absolute values in nature, such as space-time symmetries and the value of the velocity of light. Heisenberg's uncertainty relation is a logical device to make it possible that an entity may possess simultaneously wave and particle properties. This is the precondition of the existence of definite shapes and patterns of which nature abounds.

What is called uncertainty is only an expression of the limits of our old ideas. The new concepts of quantum mechanics are quite well defined and lead to a deeper understanding of the stability of nature's forms and patterns; in the last instance, they give a scientific basis for the possibility of life itself.

The second remark concerns Einstein's belief in the explicability of nature. He thought that it will be possible to attain the final aim of natural science—that is, to discover a fundamental law of nature from which everything follows. He believed that there is a fundamental principle which regulates all natural processes. Other great scientists shared this belief. Heisenberg, for example, searched for a world formula that contains all fundamental particles and interactions.

There is also another view. It is that the deeper we penetrate into the structure of matter, the more unexpected phenomena appear; these phenomena are dormant and invisible until we apply very high energies, much higher than those prevalent under terrestrial conditions. According to this view, nature is inexhaustible; our concepts, theories, and ideas only fit what we have observed so far, but any new decisive step into deeper layers of nature will reveal a wider variety of phenomena. Only further attempts to understand and to observe nature can provide answers to such fundamental questions.

Address of Pope John Paul II

Along with Your Excellency [Dr. Chagas] and with Drs. Dirac and Weisskopf, both illustrious members of the Pontifical Academy of Sciences, I rejoice in this solemn commemoration of the centenary of the birth of Albert Einstein. The Apostolic See also wishes to render to Albert Einstein the honor that is due him for the eminent contribution he has made to the progress of science—that is, to the knowledge of the truth present in the mystery of the universe.

I feel myself in full agreement with my predecessor Pius XI, and with those who succeeded him to the Chair of Saint Peter, in inviting members of the Pontifical Academy of Sciences, and all other scientists, to bring about "the progress of the sciences ever more nobly and more intensely, without asking anything more of them; this excellent aim and this noble effort represent a mission of serving the truth with which we entrust them" (*Motu proprio In multis solaciis*, 28 October 1936, on the Pontifical Academy of Sciences: *Acta Apostolicae Sedis* 28, 1936, p. 424).

Science and Religion

The search for truth is the task of basic science. The researcher who moves into this primary area of science feels all the fascination of the words of Saint Augustine: "*Intellectum valde ama*" (*Epist.* 120, 3, 13: *Patrologia Latina* 33, 459)—that is, to "love intelligence greatly" and its function, to know the truth. Basic science is a good, worthy of being very much loved, for it is knowledge and therefore the perfection of man's intelligence. Even more than its technical applications, it must be honored for itself, as an integral part of our culture. Fundamental science is a universal good that all people must be able to cultivate in complete freedom from every form of international servitude or intellectual colonialism.

Basic research must be free with regard to political and economic powers, which must cooperate in its development without impeding its creativity or subjugating it to their own ends. Like any other truth, scientific truth must render account only to itself and to the supreme truth that is God, creator of man and of all things.

In its second aspect, science turns to practical applications, which find their full development in the diverse technologies. In the area of its concrete applications, science is necessary to humanity in order to satisfy the just requirements of life and to overcome the various evils that threaten it. There is no doubt that applied science has rendered and will render immense services to man if it is inspired by love, ruled by wisdom, and accompanied by the courage that defends it against undue interference by all tyrannical powers. Applied science must be allied with conscience so that through the triad science-technology-conscience, the true good of humanity will be served.

Unfortunately, as I had occasion to say in my encyclical *Redemptor hominis*, "Man today seems always menaced by what he produces. . . . This seems to constitute the principal act of the drama of human existence today" (No. 15). Man must emerge victorious from this drama, which threatens to degenerate into tragedy, and he must rediscover his authentic kingship over the world and his full dominion over the things he produces. Today, as I wrote in the same encyclical, "the fundamental meaning of this 'kingship' and of this 'dominion' of man over the visible world, which is given him as a task by the Creator, consists in the priority of ethics over technology, the preeminence of people over things, and the superiority of spirit over matter" (No. 16).

This triple superiority is maintained to the extent that the sense of the transcendence of man over the world, and of God over man, is preserved. The Church, by carrying out her mission of guardian and advocate of both transcendences, believes that she is assisting science to keep its purity in the area of basic research and accomplish its service to man in the area of practical applications.

On the other hand, the Church willingly recognizes that she has benefited from science. It is to science, among other things, that we must attribute what the Council has said concerning certain aspects of modern culture: "New conditions have their impact finally on religious life itself. The rise of a critical spirit purifies it of a magical view of the world and of superstitions that still circulate, and exacts a more personal and explicit adherence to faith; as a result, many persons are achieving a more vivid sense of God" (*Gaudium et spes*, No. 7).

The collaboration between religion and modern science is to the advantage of both, without in any way violating their respective autonomy. Just as religion requires religious freedom, science legitimately claims freedom to carry on research. The second Vatican Council, after reaffirming with the first Vatican Council the just freedom of the arts and human disciplines in the area of their own principles and their own methods, solemnly recognizes "the legitimate au-

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This article is based on the address by Pope John Paul II at the Einstein session of the Pontifical Academy of Sciences, Vatican City, 10 November 1979. The Pope's speech, which was given in French, was translated for *Science* by Professor Robert Nicolich of the Catholic University of America, Washington, D.C. 20064.

Pope John Paul II thanking Victor Weisskopf for his contribution. In the center is P. A. M. Dirac.

tonomy of human culture and especially of the sciences" (*Gaudium et spes*, No. 59). On the occasion of this solemn commemoration of Einstein, I would like to confirm again the Council's declaration on the autonomy of science in its function of searching for the truth inscribed during the creation by the finger of God. Filled with admiration for the genius of the great scientist, in whom is revealed the imprint of the creative spirit, without intervening in any way with a judgment on the doctrines concerning the great systems of the universe, which is not in her power to make, the Church nevertheless recommends these doctrines for consideration by theologians in order to discover the harmony that exists between scientific truth and revealed truth.

The Case of Galileo

Mr. President, you said very rightly that Galileo and Einstein each characterized an era. The greatness of Galileo is recognized by all, as is that of Einstein; but while today we honor the latter before the College of Cardinals in the apostolic palace, the former had to suffer much—we cannot deny it—from men and organizations within the Church. The Vatican Council has recognized and deplored unwarranted interferences: "We cannot but deplore—it is written in number 36 of the Council's constitution *Gaudium et spes*—certain attitudes found, too, among Christians insufficiently informed of the legitimate autonomy of science. Sources of tensions and conflicts, they have led many minds to think that science and faith were opposed." The reference to Galileo is expressed clearly in the note joined to this text, which cites the volume *Vita e opere di Galileo Galilei* by Monsignor Pio Paschini, published by the Pontifical Academy of Sciences.

To go beyond this stand taken by the Council, I hope that theologians, scientists, and historians, imbued with a spirit of sincere collaboration, will more deeply examine Galileo's case, and by recognizing the wrongs, from whatever side they may have come, will dispel the mistrust that this affair still raises in many minds, against a fruitful harmony between science and faith, between the Church and the world. I give all my support to this task, which will honor the truth of faith and of science and open the door to future collaboration.

Permit me to submit to your attention and consideration some points that seem to me important for viewing Galileo's case in its true light. In this matter, the points of agreement between religion and science are more numerous and above all more important than the lack of understanding that has led to a bitter and painful conflict drawn out over the following centuries.

He who is rightly called the founder of modern physics declared explicitly that the two truths, of faith and of science, can never contradict each other. "Holy Scripture and nature proceed equally from the divine Word, the former as it were dictated by the Holy Spirit, the latter as a very faithful executor of God's orders," as he wrote in his letter to Father Benedetto Castelli on 21 December 1613 (national edition of the works of Galileo, vol. V, pp. 282-285). The second Vatican Council does not express itself otherwise; it even uses similar expressions when it teaches: "Methodical investigation in every branch of learning, if carried out in a genuinely scientific manner and in accord with moral standards, never truly conflicts with faith: for earthly matters and the concerns of faith derive from the same God" (*Gaudium et spes*, No. 36).

Galileo feels in his scientific research the presence of the Creator who inspires him and aids his intuition, acting in the inmost recesses of his spirit. With regard to the invention of the telescope, he writes at the beginning of *Sidereus Nuncius*, recalling several of his astronomical discoveries: "*Quae omnia ope Perspicilli a me excogitati divina prius illuminante gratia, paucis abhinc diebus reperta, atque observata fuerunt*" (*Sidereus Nuncius*, Venetiis, apud Thomam Baglionum, MDCX, fol. 4). "All of this has been discovered and observed these last days thanks to the 'telescope' that I have invented, after having been enlightened by divine grace."

The Galilean confession of divine illumination of the mind of the scientist finds an echo in the text of the Council's constitution, on the Church in the modern world: "Whoever labors to penetrate the secrets of reality with a humble and steady mind is being led by the hand of God, even if he remains unaware of it" (*loc. cit.*). The humility stressed by the Council's text is a virtue necessary both for scientific research and for commitment to the faith. Humility creates a climate favorable for a dialogue between the believer and the scientist; it calls for enlightenment by God, recognized as such or not, but valued in both cases by one who humbly seeks the truth.

Galileo formulated important norms of an epistemological character that are indispensable for reconciling Holy Scripture and science. In his letter to the Dowager Grand Duchess of Tuscany, Christine of Lorraine, he reaffirms the truth of Scripture: "Holy Scripture can never lie, provided its true meaning is understood, which—I do not think it can be denied—is often hidden and very different from what a simple interpretation of the words seems to indicate" (national edition of the works of Galileo, vol. V, p. 315). Galileo introduces a principle of interpretation of the sacred books that goes beyond the literal meaning but is in accord with the intention and type of exposition proper to each of them. It is necessary, as he affirms, that "the wise men who explain it should bring out their true meaning."

Ecclesiastical authorities admit that there is more than one way to interpret the Holy Scriptures. In fact, it was explicitly stated in the encyclical *Divino afflante Spiritu* of Pius XII that there are different literary styles in the sacred books and therefore interpretations must conform to the character of each.

The various points of agreement that I have brought to mind do not only resolve all the problems of Galileo's case, but they contribute to creating a favorable starting point for their honorable solution, a state of mind propitious for an honest and straightforward resolution of old conflicts.

The existence of the Pontifical Academy of Sciences, with which Galileo was, in a sense, associated through the old institutions that preceded the one to which eminent scientists belong today, is a visible sign that shows to the people of the world, without any form of racial or religious discrimination, the profound harmony that can exist between the truths of science and the truths of faith.

Lead in Albacore: Guide to Lead Pollution in Americans

Dorothy M. Settle and Clair C. Patterson

Summary. Lead contamination in canned tuna, exceeding natural concentrations 10,000-fold, went undiscovered for decades because of analytical error. The magnitude of this pollution effect helps explain the difference between the lead concentration in the diets of present-day Americans (0.2 part per million) and in the diets of prehistoric peoples (estimated to be less than 0.002 part per million). It also explains how skeletal concentrations of lead in typical Americans became elevated 500-fold above the natural concentrations measured in bones of Peruvians who lived in an unpolluted environment 1800 years ago. It has been tacitly assumed that natural biochemical effects of lead in human cells have been studied, but this is not so because reagents, nutrients, and controls used in laboratory and field studies have been unknowingly contaminated with lead far in excess of naturally occurring levels. An unrecognized form of poisoning caused by this excessive exposure to lead may affect most Americans because magnitudes of biochemical dysfunctions are proportional to degrees of exposure.

Tuna are the only large carnivorous fish that have been carefully analyzed for lead in academic laboratories so far. It has been found that albacore muscle fresh from the sea contains the smallest concentration of lead yet measured in any biological tissue—about 0.3 nanogram per gram of fresh tissue (*1*, *2*). The nutrient medium of food precursors of tuna fish, seawater, contains the smallest concentration of lead yet measured in any natural substance on the earth—in the North Pacific, 0.005 ng per gram of biologically productive seawater and ~ 0.001 ng per gram of deep water (*3*). Still, the surface waters of the North Pacific, including a thermocline layer 0.5 kilometer thick, are believed to contain about ten times more lead than in prehistoric times (*3*) as a consequence of atmospheric inputs from smelter fumes and exhaust from combustion of leaded gasoline. The natural concentrations of lead in fresh tuna muscle and in surface seawater are estimated to have been ~ 0.03 and 0.0005 ng/g, respectively. Even with the tenfold contamination of the sea and tuna, the relatively low concentration of lead in tuna muscle makes it possible to determine the effects of additional lead contamination from food processing operations. These effects include a 20-fold increase in lead contamination from butchering and packing in unsoldered cans, a 400-fold increase from butchering, grinding, and air-drying, and a 4000-fold increase from butchering and packing in cans soldered with lead.

Administrators in the Food and Drug Administration (FDA) disregarded the discovery, published 6 years ago (*1*), that lead concentrations in fresh albacore muscle were many orders of magnitude lower than levels commonly thought to be present in fish muscle. The discovery simply had no meaning within the context of their latest aims and procedures with respect to lead in foods, and it was devalued by the largely inconsequential or inaccurate data concerning lead pollution being issued in thousands of papers, reports, reviews, and books by applied chemical and engineering research workers. This situation reached a climax in 1978, when we found that the National Marine Fisheries Service (NMFS) laboratory in Maryland had made a serious mistake in analyzing lead in tuna muscle while studying lead in seafoods on behalf of the FDA. It reported an average lead concentration of 400 ng/g [0.4 part per million (ppm)] in fresh tuna muscle (*4*) and 700 ng/g (0.7 ppm) in canned tuna (*5*), with the first value too high by a factor of 1000. This report reinforced the erroneous belief, held by the FDA, that cans soldered with lead elevate lead levels in foods only a few times above so-called normal levels.

This was not an isolated incident. The federal surveillance laboratory mentioned above is but one of thousands that analyze lead concentrations incorrectly

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