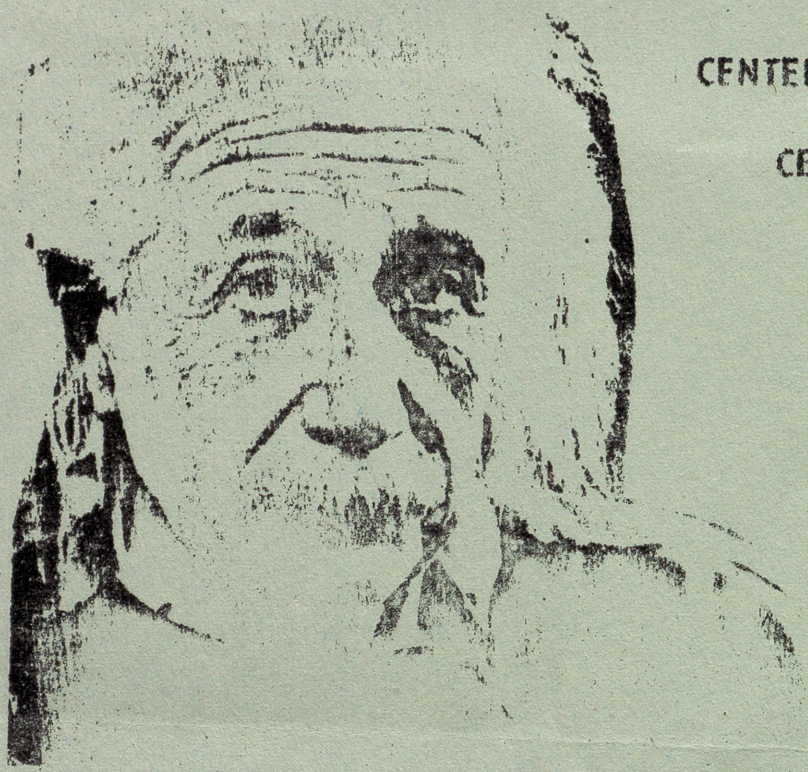
SCIENCE INFORMATION NOTES

A collection of articles on scientific and technological matters, research policies, science and society, higher learning etc.

CENTENNIAL

CELEBRATIONS



ALBERT EINSTEIN

1879–1979

INDIAN NATIONAL SCIENCE ACADEMY
BAHADUR SHAH ZAFAR MARG, NEW DELHI - 110001

OCTOBER 6, 1979

Limited Circulation

ON MARCH 14, PEOPLE ALL OVER THE WORLD CELEBRATED THE 100TH ANNIVERSARY OF THE BIRTH OF ONE OF THE GREATEST REVOLUTIONARIES OF THE 20TH CENTURY. THIS REVOLUTIONARY, WHO DID SO MUCH TO RESHAPE THE WORLD WE LIVE IN, NEVER HELD A GUN IN HIS HAND. HE WAS A PERSON WHO ENJOYED THE QUIET PURSUITS OF MUSIC, BICYCLE RIDING, HIKING AND SAILING. HE TOOK PLEASURE IN HELPING CHILDREN WITH THEIR ARITHMETIC PROBLEMS - AND OFTTIMES GOT THE WRONG ANSWER. YET THIS SERENE AND DEDICATED MAN STRICTLY THROUGH HIS ABSTRACT INTELLECTUAL POWERS, REVOLUTIONIZED PHYSICS AND HELPED USHER IN THE NUCLEAR AGE. HIS NAME -- ALBERT EINSTEIN. HE BECAME A CITIZEN OF U.S.A. IN 1940.

EINSTEIN'S INTELLECTUAL ACCOMPLISHMENTS HAVE USUALLY EVOKED FEELINGS OF AWE, AND IT HAS BEEN CLAIMED FACETIOUSLY THAT AT ONE TIME ONLY THREE PEOPLE IN THE WORLD UNDERSTOOD HIS THEORY OF RELATIVITY.

WHEN EINSTEIN PUBLISHED HIS SPECIAL THEORY OF RELATIVITY IN 1905, PHYSICS HAD COME TO A STANDSTILL. SIR ISAAC NEWTON'S MECHANISTIC LAWS OF ABSOLUTE SPACE AND TIME WERE NO LONGER ABLE TO ANSWER MANY OF THE NEW PROBLEMS THAT INCREASINGLY SOPHISTICATED EXPERIMENTATION WAS RAISING. EINSTEIN'S WORK, HOWEVER, AND HIS GENERAL THEORY PUBLISHED IN 1916, SOLVED MANY OF THE DIFFICULTIES.

ANYONE WHO KNEW THE YOUNG EINSTEIN COULD HARDLY HAVE IMAGINED THAT HE WOULD BECOME ONE OF THE GREATEST MINDS OF OUR AGE. YOUNG ALBERT, WHO WAS BORN IN ULM, GERMANY, BUT SHORTLY THEREAFTER MOVED TO MUNICH WITH HIS PARENTS, WAS, TO PUT IT KINDLY, SLOW. HE DID NOT LEARN TO SPEAK UNTIL THE AGE OF THREE AND WAS SUCH A POOR STUDENT THAT WHEN HIS FATHER ASKED HIS SON'S HEADMASTER WHAT PROFESSION ALBERT SHOULD PURSUE, THE ANSWER WAS SIMPLY : "IT DOESN'T MATTER; HE'LL NEVER MAKE A SUCCESS OF ANYTHING."

A FREE, INDEPENDENT SPIRIT, IN REBELLION AGAINST AUTHORITY, WHO STUDIED WHAT HE WANTED AND IGNORED SUBJECTS HE DISLIKED, ALBERT WAS EXPELLED FROM SECONDARY SCHOOL ON THE GROUNDS THAT "YOUR PRESENCE IN THE CLASS IS DISRUPTIVE AND AFFECTS THE OTHER STUDENTS." WHEN HE TOOK THE ENTRANCE EXAMINATION FOR THE SWISS FEDERAL POLYTECHNIC SCHOOL IN ZURICH, HE FAILED THE FIRST TIME BECAUSE, AS HE READILY ADMITTED, HE MADE NO ATTEMPT TO PREPARE HIMSELF. EVEN AFTER BEING ACCEPTED IN 1896, HIS ICONOCLASTIC AND SOMETIMES COCKY ATTITUDE DIDN'T CHANGE. ONE PROFESSOR CALLED HIM A "LAZY DOG" AND HIS PHYSICS PROFESSOR SUGGESTED HE MIGHT BE HAPPIER STUDYING MEDICINE, LAW OR PHILOLOGY. WHEN HE GRADUATED IN 1900, HE WAS THE ONLY MEMBER OF HIS CLASS NOT TO RECEIVE AN APPOINTMENT AT THE POLYTECHNIC.

ONLY THROUGH THE INTERVENTION OF FRIENDS WAS HE ABLE TO GET AN APPOINTMENT AS A TECHNICAL EXPERT (THIRD CLASS) AT THE SWISS PATENT OFFICE. (HE HAD MEANWHILE TAKEN OUT SWISS CITIZENSHIP)

IT WAS THERE, HOWEVER, THAT HE WAS ABLE TO SPEND HIS FREE TIME IN PREPARING THE SCIENTIFIC PAPERS THAT WERE TO BRING HIM WORLD FAME. HIS 1905 PAPER ON RELATIVITY, WHICH WAS ONLY ONE OF THREE PAPERS HE PUBLISHED THAT YEAR, TOOK HIM OUT OF THE PATENT OFFICE AND BACK TO THE ACADEMIC LIFE. AFTER A NUMBER OF INTERIM APPOINTMENTS HE RETURNED TO HIS OLD SCHOOL AS PROFESSOR OF THEORETICAL PHYSICS IN 1912 AND A YEAR LATER WAS INVITED TO JOIN THE PRUSSIAN ACADEMY IN BERLIN.

HIS FAME FINALLY BURST ON THE WORLD WHEN, IN 1919, A TEAM OF BRITISH SCIENTISTS CONFIRMED HIS GENERAL THEORY BY SHOWING THAT LIGHT BENT AS IT PASSED THE SUN.

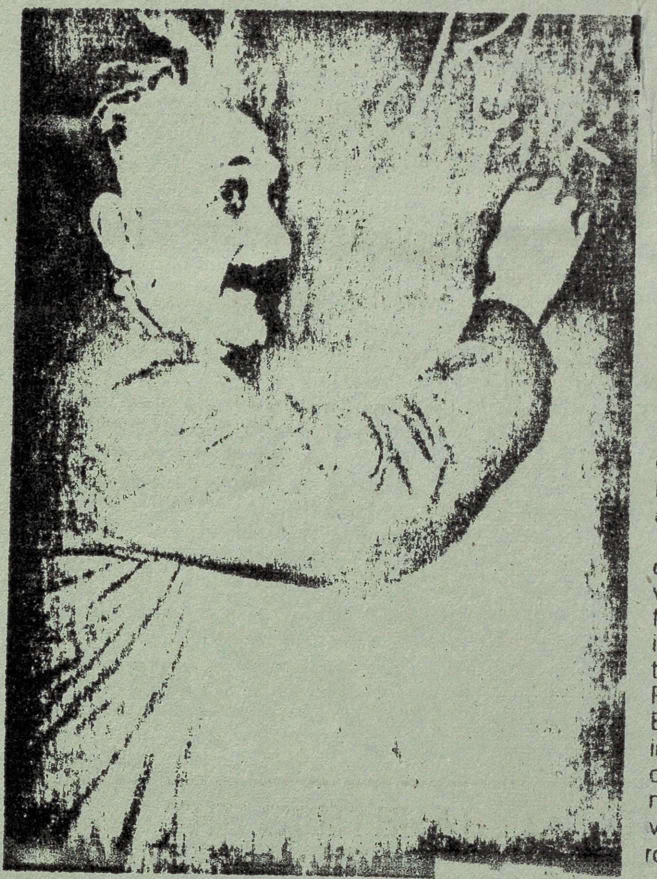
IN 1921, HE WAS AWARDED THE NOBEL PRIZE, NOT FOR HIS RELATIVITY PAPERS, BUT FOR HIS THEORY OF THE PHOTO-ELECTRIC EFFECT. THIS THEORY STATED THAT LIGHT COULD BE CONSIDERED BOTH A WAVE AND A PARTICLE THUS ENDING A LONG DEBATE BETWEEN PROPONENTS OF EACH VIEWPOINT.

"MY SCIENTIFIC WORK", HE SAID, "IS MOTIVATED BY AN IRRESISTIBLE LONGING TO UNDERSTAND THE SECRETS OF NATURE AND BY NO OTHER FEELINGS. MY LOVE FOR JUSTICE AND THE STRIVING TO CONTRIBUTE TOWARDS THE IMPROVEMENT OF HUMAN CONDITIONS ARE QUITE INDEPENDENT FROM MY SCIENTIFIC INTERESTS."

ANYONE WITH THESE POLITICAL PREDILECTIONS, ESPECIALLY A JEW, FOUND HIMSELF IN AN UNTENABLE POSITION IN HITLER'S GERMANY, SO WHEN HE WAS INVITED TO JOIN AMERICA'S INSTITUTE FOR ADVANCED STUDY IN 1933, HE READILY ACCEPTED. FROM THEN UNTIL HIS DEATH IN 1955, HE WAS A FAMILIAR FIGURE ON THE STREETS OF PRINCETON IN HIS BAGGY TROUSERS, SWEATER, TOUSLED HAIR AND PIPE.

IN 1939, URGED BY TWO FELLOW PHYSICISTS WHO HAD READ REPORTS THAT NAZI GERMANY WAS CARRYING ON EXPERIMENTS THAT COULD LEAD TO AN ATOMIC BOMB, EINSTEIN WROTE TO PRESIDENT ROOSEVELT URGING THAT THE UNITED STATES SPEED UP EXPERIMENTAL WORK IN THIS FIELD. AS HE GREW OLDER, EINSTEIN COULD NOT ACCEPT SOME OF THE LATER DEVELOPMENTS IN PHYSICS. HE SAW THE PHYSICAL UNIVERSE AS A PLACE IN WHICH ORDER PREVAILED AND HE BELIEVED THE ROLE OF THE SCIENTISTS WAS TO DISCOVER THE LAWS GOVERNING THAT ORDER. TO HIM, THE NEW WORLD OF INDETERMINACY - IN WHICH OUR KNOWLEDGE OF THE PHYSICAL UNIVERSE CAN BE ONLY A STATISTICAL PROBABILITY - WAS INTELLECTUALLY REPUGNANT. "GOD DOES NOT PLAY DICE WITH THE UNIVERSE," HE SAID AGAIN AND AGAIN. IN LATER LIFE, HE ATTEMPTED TO DEVELOP A UNIFIED FIELD THEORY THAT WOULD UNITE, UNDER A SINGLE SET OF EQUATIONS, GRAVITY AND ELECTROMAGNETISM - BUT HE FAILED. DESPITE THIS SHORTCOMING, HE IS RECOGNIZED AS A MONUMENTAL FIGURE IN MODERN PHYSICS WHO, EVEN IN OLD AGE, NEVER LOST HIS BOYISH IMPISHNESS.

THE CENTENARY OF THE BIRTH OF A GENIUS



Albert Einstein, the thinker who turned the scientific world upside down with three original papers, published in *Annalen der Physik* in 1905 at a time when he held no academic post (he was a clerk in the Swiss Patent Office), was born on 14 March 1879 in Ulm, Germany. By the time of his death on 18 April 1955 he had become surely a rarity among mathematical physicists: a man whose name was a household word throughout at least the developed world.

Einstein spent his early years in Germany, where he achieved a distinction of leaving the Luitpold Gymnasium in Munich without a diploma and in circumstances which are still unclear. Ronald Clark, in a re-issue of his good book *Einstein, the Life and Times** quotes a remark said to have been made by the school authorities: "Your presence in the class is disruptive and affects the other students". Clark adds: "This should be taken with caution but the general lines of the incident have the ring of truth. For the kindly, gentle Einstein who is remembered today, the friend of all mankind (except the Prussians), a saint insulated from the rest of the world, is largely a figure of his later years; it is a figure very different from the precocious, half-cocksure, almost insolent Einstein of youth and early manhood. Einstein was the boy who knew not merely which spanner to throw in the works, but also how best to throw it."

The full account of Einstein's 'life and times' is spelled out in fascinating detail in Clark's book. Here it is enough to refer the interested reader to it, and to recall some of the seminal ideas Einstein introduced to the world of physics. He completed his education in Switzerland, having renounced his German nationality, and after a couple of years in which he took temporary jobs and did some private teaching, took a job at the Swiss Patent Office in Berne. In his spare time he thought about physics. The notion that absolute motion in the Newtonian sense was meaningless had already been proposed a few years earlier by Henri Poincaré; Einstein had thought so since about the age of 16. In 1905 he took the imaginative leap which was to place him in the limelight which bathed him for the rest of his life. If only the motions of things relative to each other had physical significance, surely the notion of absolute time flowing "equably without relation to anything external" as Newton had it in his *Principia* was equally meaningless? Clocks were needed to measure it, and they were physical objects which could and did move relative to each other. From there to the writing of one of his three 1905 papers, on the theory of special relativity, took him only a few weeks. It was this paper which contained that mathematical expression with which even schoolchildren are now familiar: $E = mc^2$.

The other two papers contained in Volume 17 of *Annalen der Physik* have had less to do with the shaping of the modern world, but they were equally important in their own way. In the first, Einstein took Planck's quantum theory of 1900 and used it to discuss the nature of light, deriving a way of explaining the photoelectric effect. This work won Einstein the Nobel Prize in 1922. The second paper dealt with the theory of Brownian motion — the observable motion of small particles in liquid which is the most direct evidence for the existence of molecules and the interpretation of heat as the energy of molecules. Einstein showed that the average distance travelled by a Brownian particle is proportional to the square root of the elapsed time.

Special relativity predicted the second-order Doppler effect (or transverse Doppler effect); the gravitational red shift; and the equivalence of mass and energy, $E = mc^2$. The first two of these effects were tested at Harwell by Dr Ted Cranshaw and colleagues in the Nuclear Physics Division in 1961, using the very narrow γ-ray lines of the Mössbauer Effect and a rotor originally designed for use in a neutron chopper, and by passing Mössbauer γ-rays up the Harwell water tower. (We hope to be able to publish a less opaque description of these experiments in a later issue.) The third, that of mass equivalence, was of course vital in the interpretation of the mass defect of nuclei which leads to energy release in fission and fusion: the physical mechanism underlying both nuclear weapons, and the world's growing and increasingly valuable nuclear power programmes.

Einstein wrote a mass of other papers and held a succession of academic appointments, spending most of his later life at the Institute of Advanced Study at Princeton. His second paper on the theory of relativity, the *Grundlage der Allgemeinen Relativitätstheorie* (Basis of the General Theory of Relativity) was published to a storm of controversy in 1916. In it, Einstein attempted to move on from the 'flat' special theory of relativity, which considered only uniform gravity and acceleration in a straight line, to a generalised way of handling curved and rotary motion in a universe in which matter and space interact. Experimenters are still trying to test some of the elements in this theory; Einstein himself tried to the end to find a way of bringing together gravity and electromagnetism in a 'unified field theory' publishing each failure — as he put it — "to save another fool from wasting time on the same idea".

If he was a fool, what hope is there for the rest of us?

J. Daglish

On the moral obligation of the scientist

We are living in a period of such great external and internal insecurity and with such a lack of firm objectives that the mere confession of our convictions may be significant even if these convictions, as all value judgments, cannot be proven through logical deduction.

There arises at once the question: should we consider the search for truth—or, more modestly expressed, our efforts to understand the knowable universe through constructive logical thought—as an autonomous objective of our work? Or should our search for truth be subordinated to some other objective, for example, to a "practical" one? This question cannot be decided on a logical basis. The decision, however, will have considerable influence upon our thinking and our moral judgment, provided that it is born out of deep and unshakable conviction. Let me then make a confession: for myself, the struggle to gain more insight and understanding is one of those independent objectives without which a thinking individual would find it impossible to have a conscious, positive attitude toward life.

It is the very essence of our striving for understanding that, on the one hand, it attempts to encompass, the great and complex variety of man's experience and that, on the other, it looks for simplicity and economy in the basic assumptions. The belief that these two objectives can exist side by side is, in view of the primitive state of our scientific knowledge, a matter of faith. Without such faith I could not have a strong and unshakable conviction about the independent value of knowledge.

This, in a sense, religious attitude of man engaged in scientific work has some influence upon his whole personality. For apart from the knowledge which is offered by accumulated experience and from the rules of logical thinking, there exists in principle for the man in science no authority whose decisions and statements could have in themselves a claim to "Truth." This leads to the paradoxical situation that a person who devotes all his strength to objective matters will develop, from a social point of view, into an extreme individualist who, at least in principle, has faith in nothing but his own judgment. It is quite possible to assert that intellectual individualism and the thirst for scientific knowledge emerged simultaneously in history and have remained inseparable ever since.

Someone may suggest that the man of science as sketched in these sentences is no more than an abstraction which actually does not exist in this world, not unlike the *homo oeconomicus* of classical economics. However, it seems to me that science as we know it today could not have emerged and could not have remained alive if many individuals, during many centuries, had not come very close to the ideal.

Of course not everybody who has learned to use tools and methods which directly or indirectly appear to be "scientific" is to me a man of science. I refer only to those individuals in whom the scientific mentality is truly alive.

What, then, is the position of today's man of science as a member of society? He obviously is rather proud of the fact that the work of scientists has helped to change radically the economic life of men by almost completely eliminating muscular work. He is distressed by the fact that the results of his scientific work have created a threat to mankind since they have fallen into the hands of morally blind exponents of political power. He is conscious of the fact that technological methods, made possible by his work, have led to a concentration of economic and also of political power in the hands of small minorities which have come to dominate completely the lives of the masses of people, who appear more and more amorphous. But even worse: the concentration of economic and political power in the hands of a few has not only made the man of science dependent economically, it also threatens his independence from within; the shrewd methods of intellectual and psychic influences which it brings to bear will prevent the development of independent personalities.

Thus the man of science, as we can observe with our own eyes, suffers a truly tragic fate. Striving in great sincerity for clarity and inner independence, he himself, through his sheer superhuman efforts, has machined the tools which are being used to make him a slave and to destroy him also from within. He cannot escape being muzzled by those who have political power in their hands. As a soldier he is forced to sacrifice his own life and to destroy the lives of others even when he is convinced of the absurdity of such sacrifices. He is fully aware of the fact that universal destruction is unavoidable since historical development has led to the concentration of all economic, political and military power in the hands of national states. He also realizes that mankind can only be saved if a super-national system, based on law, were created to eliminate for all time the methods of brute force. However, the man of science has slipped so much that he accepts the slavery inflicted upon him by national states as his inevitable fate. He even degrades himself to such an extent that he helps obediently in the perfection of the means for the general destruction of mankind.

Is there really no escape for the man of science? Must he really tolerate and suffer all these indignities?

Is the time gone forever when, aroused by his inner freedom and the independence of his thinking and his work, he had a chance of enlightening and enriching the lives of his fellow human beings? In placing his work too much on an intellectual basis has he not forgotten about his responsibility and dignity? My answer is: while it is true that an inherently free and scrupulous person may be destroyed, such an individual can never be enslaved or used as a blind tool.

If the man of science of our day could find the time and courage to think honestly and critically over his situation and the tasks before him and if he would act accordingly, the possibilities for a sensible and satisfactory solution of the present dangerous international situation would be considerably improved.

ALBERT EINSTEIN
October 1952

INDIAN NATIONAL SCIENCE ACADEMY

SCIENCE INFORMATION NOTES

(EINSTEIN CENTENARY ISSUE)

October 6th, 1979

CONTENTS

EINSTEIN ON NEHRU

We, the worshippers of science, are today looking up to Jawaharlal Nehru the heir to Gandhi and captain of the Indian people for leadership in mankind's resolute stand to the implications of the Atomic War. He has earned for himself this responsibility by keeping India aloof from cold war and away from the 'power camps'; thereby leading her towards peace, firmly .... This is an era of extreme disorderliness. And, perhaps, Nehru was born to fashion order out of this chaos.... Today, the world is off its track. But, we have not even a little doubt that this earth will regain its own orbit in this very age of—Gandhi and Nehru.*

ALBERT EINSTEIN

** This passage is a translation of a Bengali version of Einstein's tribute by Shibdas Burman*

Einstein, most eminent among scientists, tells us that 'the fate of the human race was more than ever dependent on its moral strength today. The way to a joyful and happy state is through renunciation and self-limitation everywhere'. He takes us back suddenly from this proud age of science to the old philosophers, from the lust for power and the profit motive to the spirit of renunciation with which India has been so familiar. Probably most other scientists of today will not agree with him in this or when he says: 'I am absolutely convinced that no wealth in the world can help humanity forward, even in the hands of the most devoted workers in the cause. The example of great and pure characters is the only thing that can produce fine ideas or nobel deeds. Money only appeals to selfishness and always tempts its owners irresistibly to abuse it'.

The Discovery of India, p.683.
by Jawaharlal Nehru

Russell-Einstein Manifesto signed by Einstein on April 11, 1955, exactly one week before his death.

In the spring of 1955, Einstein and Bertrand Russell launched, with typical youthful enthusiasm, a project aimed at starting a worldwide movement among scientists to reverse the Cold War trends toward nuclear war. The credo of this movement was the Russell-Einstein Manifesto, signed by Einstein on April 11, 1955, exactly one week before his death. The other signers were: M. Born, Germany; P.W. Bridgman, United States; L. Infeld, Poland; F. Joliot-Curie, France; H.J. Muller, United States; L. Pauling, United States; C.F. Powell, United Kingdom; J. Rotblat, United Kingdom; and H. Yukawa, Japan.(All but two were Nobel Prize winners in science). The Manifesto led to the convening, in July 1957, of the first Pugwash Conference on Science and World Affairs, an institution which continues to work for the achievement of the aims expressed in the Manifesto.

The text serves well to sum up Einstein's view of the state of the world, and of the responsibilities of scientists as world citizens:

"In the tragic situation which confronts humanity, we feel that scientists should assemble in conference to appraise the perils that have arisen as a result of the development of weapons of mass destruction....

We are speaking on this occasion, not as members of this or that nation, continent or creed, but as human beings, members of the species of Man, whose continued existence is in doubt. The world is full of conflicts; and, overshadowing all minor conflicts, the titanic struggle between Communism and anti-Communism.

Almost everybody who is politically conscious has strong feelings about one or more of these issues; but we want you, if you can, to set aside such feelings and consider yourselves only as members of a biological species which has had a remarkable history, and whose disappearance none of us can desire.

We shall try to say no single word which should appeal to one group rather than to another. All, equally, are in peril, and, if the peril is understood, there is hope that they may collectively avert it.

The general public, and even many men in positions of authority, have not realized what would be involved in a war with nuclear bombs. The general public still thinks in terms of the obliteration of cities. It is understood that the new bombs are more powerful that the old, and that, while one A-bomb could obliterate Hiroshima, One h-Bomb could obliterate the largest cities, such as London, New York and Moscow.

No doubt in an H-Bomb war great cities would be obliterated. But this is one of the minor disasters that would have to be faced. If everybody in London, New York and Moscow were exterminated, the world might, in the course of a few centuries, recover from the blow. But we now know, especially since the Bikini test, that nuclear bombs can gradually spread destruction over a very much wider area than had been supposed.

It is stated on very good authority that a bomb can now be manufactured which will be 2,500 times as powerful as that which destroyed Hiroshima.

Such a bomb, if exploded near the ground or under water, sends radioactive particles into the upper air. They sink gradually and reach the surface of the earth in the form of a deadly dust or rain. It was this dust which inflected the Japanese fishermen and their catch of fish.

No one knows how widely such lethal radioactive particles might be diffused, but the best authorities are unanimous in saying that a war with H-bombs might quite possibly put an end to the human race. It is feared that if many H-bombs are used there will be universal death-sudden only for a minority, but for the majority a slow torture of disease and disintegration.

Many warnings have been uttered by eminent men of science and by authorities in military strategy. None of them will say that the worst results are certain. What they do say is that these results are possible, and no one can be sure that they will not be realized. We have not yet found that the views of experts depend in any degree upon their politics or prejudices. They depend only, so far as our researches have revealed, upon the extent of the particular expert's knowledge. We have found that the men who know most are the most gloomy.

Here, then, is the problem which we present to you, stark and dreadful and inescapable: Shall we put an end to the human race; or shall mankind renounce war? People did not face this alternative because it is so difficult to abolish war.

The abolition of war will demand distasteful limitations of national sovereignty. But what perhaps impedes understanding of the situation more than anything else is that the term mankind feels vague and abstract. People scarcely realize the imagination that the danger is to themselves and their children and their grandchildren, and not only to a dimly apprehended humanity. They can scarcely bring themselves to grasp that they, individually, and those who they love are in imminent danger of perishing agonizingly. And so they hope that perhaps war may be allowed to continue provided modern weapons are prohibited.

This hope is illusory. Whatever agreements not to use the H-bombs had been reached in time of peace, they would no longer be considered binding in time to war, and both sides would set to work to manufacture H-bombs as soon as broke out, for, if one side manufactured the bombs and the other did not, the side that manufactured them would inevitably be victorious.

Although an agreement to renounce nuclear weapons as part of a general reduction of armaments would not afford an ultimate solution, it would serve certain important purposes.

First: Any agreement between East and West is to the good in so far as it tends to diminish tension. Second: The abolition of thermonuclear weapons, if each side believed that the other had carried it out sincerely, would lessen the fear of a sudden attack in the style of Pearl Harbor, which at present keeps both sides in a state of nervous apprehension. We should, therefore, welcome such an agreement, though only as a first step.

Most of us are not neutral in feeling, but, as human beings, we have to remember that, if the issues between East and West are to be decided in any manner that can give any possible satisfaction to anybody, whether Communist or anti-

Communist, whether Asian or European or American, whether white or black, then these issues must not be decided by war. We should wish this to be understood, both in the East and in the West.

There lies before us, if we choose, continual progress in happiness, knowledge and wisdom. Shall we, instead, choose death, because we cannot forget our quarrels? We appeal, as human beings, to human beings: Remember your humanity and forget the rest. If you can do so, the way lies open to a new paradise; if you cannot, there lies before you the risk of universal death".

Albert Einstein

(b. 14 March, 1879 ; d. 18 April, 1955)

Quotations from Einstein's Writings
(By Courtesy of Dr. D.S. Kothari)

On Scientific Truth

I. It is difficult even to attach a precise meaning to the term "scientific truth". Thus the meaning of the word "truth" varies according to whether we deal with a fact of experience, a mathematical proposition, or a scientific theory, "Religious truth" conveys nothing clear to me at all.

II. Scientific research can reduce superstitution by encouraging people to think and view things in terms of cause and effect. Certain it is that a conviction, akin to religious feeling, of the rationality or intelligibility of the world lies behind all scientific work of a higher order.

III. This firm belief, a belief bound up with deep feeling, in a superior mind that reveals itself in the world of experience, represents my conception of God. In common parlence this may be described as "pantheistic" (Spinoza).

Iv. Denominational traditions I can only consider historically and psychologically; they have no other significance for me.
(1929) (A.Einstein, Ideas and Opinions; Crown Pub. 1954, p 261)

The true value of a human being is determined primarily by the measure and the sense in which he has attained liberation from the self. (1934) (ibid p.12)

I am absolutely convinced that no wealth in the world can help humanity forward, even in the hands of the most devoted worker in this cause. The example of great and pure individuals is the only thing that can lead us to noble thoughts and deeds. Money only appeals to selfishness and irresistibly invites abuse.

Can anyone imagine Moses, Jesus, or Gandhi armed with the money-bags of Carnegie? (1934) (ibid p. 12)

The Most Beautiful Experience

We can have is the mysterious. It is the fundamental emotion which stands at the cradle of true art and true science. Whoever does not know it and can no longer wonder, no longer marvel, is as good as dead, and his eyes are dimmed. It was the experience of mystery-even if mixed with fear-that engendered religion. A knowledge of the existence of something we cannot penetrate, our perceptions of the profoundest reason and the most radiant beauty, which only in their most primitive forms are accessible to our minds-it is this knowledge and this emotion that constitute true religiosity; in this sense, and in this alone, I am a deeply religious man. I cannot conceive of a God who rewards and punishes his creatures, or has a will of the kind that we experience in ourselves. Neither can I nor would I want to conceive of an individual that survive his physical death; let feeble souls, from fear or absurd egoism, cherish such thoughts. I am satisfied with the mystery of the eternity of [illegible] existing world, together with the devoted striving to comprehend a portion, be it ever so tiny, of the reason that manifests itself in nature. (1931) (ibid p. 11)

Science without religion is lame:

Science can only be created by those who are thoroughly imbued with the aspiration toward truth and understanding. This source of feeling, however, springs from the sphere of religion. To this there also belongs the faith in the possibility that the regulations valid for the world of existing are rational, that is, comprehensible to reason. I cannot conceive of a genuine scientist without that profound faith. The situation may be expressed by an image. Science without religion is lame, religion without science is blind. (1939) (ibid p.46) (italics added)

Nothing which cannot be dispensed with:

When asked (during a serious illness) whether he was at all afraid of death, Einstein said, "I feel such a sense of solidarity with all living things that it does not matter to me where the individual begins and ends". And he said, "There is nothing in the world which I could not dispense with at a moment's notice". (Max Born, Einstein Letters, Macmillan).

Strange is the lot of mortals:

How strange is the lot of us mortals. Each of us is here for a brief sojourn, for what purpose he knows not, though he sometimes things he senses it. But without deeper reflection one knows from daily life that one exists for other people-first of all for those upon whose smiles and wellbeing our own happiness is wholly dependent, and then for the many, unknown to us to whose destinies we are bound by the ties of sympathy. A hundred times every day I remind myself that my inner and outer life are based on the labors of other men, living and dead, and that I must exert myself in order to give in the same measure as I have received and am still receiving. I am strongly drawn to a frugal life and am often oppressively aware that I am engrossing un undue amount of labor of my fellow men. I regard class distinctions as unjustified and, in the last resort, based on force. I also believe that a simple and unassuming life is good for everybody, physically and mentally.

I do not at all believe in human freedom in the philosophical sense. Everybody acts not only under external compulsion but also in accordance with inner necessity. Schopenhauer's saying, "A man can do what he wants, but not want what he wants," has been a very real inspiration to me since my youth; it has been a continual consolation in the face of life's hardships, my own and others", and an unfailing well-spring of tolerance. This realization mercifully mitigates the easily paralyzing sense of responsibility and prevents us from taking ourselves and other people all too seriously; it is conducive to a view of life which, in parcicular, gives humor its due. (1931) (ibid p.8)

On Freedom:

Only if outward and inner freedom are constantly and consciously pursued is there a possibility of spiritual development and perfection and thus of improving man's outward and inner life. (1940) (ibid p. 32)

On God:

'Rabbi Herbert S. Goldstein of New York cabled Einstein (April 1929): "Do you believe in God?" Einstein cabled back: "I believe in Spinoza's God, who reveals himself in the harmony of all being, not in a God who concerns himself with the fate and action of men". It would have been impossible for Einstein to give the rabbi a more pointed reply or one which came closer to his own innermost convictions. Manya time, when a new theory appeared to him arbitary or forced, he remarked: "God doesn't do anything like that." I have often felt and occasionally also stated that Einstein stands in particularly intimate relation to the God of Spinoza'. (A. Sommerfeld in Albert Einstein, Philosopher-Scientist. The library of Living Philosophers Editor Paul A. Schilpp, 1949, p 103)

Einstein on Mahatma Gandhi:

On the Occasion of Gandhi's seventieth birthday in 1939. (Published in Out of My Later Years, New York: Philosophical Library, 1950).

A leader of his people, unsupported by any outward authority: a politician whose success rests not upon craft nor the mastery of technical devices, but simply on the convincing power of his personality; a victorious fighter who has always scorned the use of force; a man of wisdom and humility, armed with resolve and inflexible consistency, who has devoted all his strength to the uplifting of his people and the betterment of their lot; a man who has confronted the brutality of Europe with the dignity of the simple human being, and thus at all times risen superior.

Generations to come, it may, be, will scarce believe that such a one as this ever in flesh and blood walked upon this earth. (Ideas and Opinions, ibid, p 77.

Einstein on Mach:

The impact on Einstein of the views of Ernst Mach is well known. To quote Einstein (Albert Einstein: Philosopher Sciehtist: Editor P.A. Schilpp p. 21 (1949) :

"We must not be surprised, therefore that, so to speak, all physicists of the last century saw in classical mechanics a firm and final foundation for all physics, yes,t indeed, for all natural science... It was Ernst Mach who, in his History of Mechanics, shook this dogmatic faith; this book exercised a profound influence upon me in this regard while I was a student. I see Mach's greatness in his incorruptible scepticism and independence; in my younger years, however, Mach's epistemological position also influenced me very greatly, a position which today appears to me to be essentially untenable".

It is noteworthy that Mach was influenced to a considerable degree by Indian Philosophic thought. Erwin Schroedinger observes (My view of the World, Cambridge University Press (1964) p.37): "If, finally, we look back at that idea of Mach, Avenarius and Schuppe which we outlined earlier on, we shall realize that it comes as near to the orthodox dogme of the Upanisheds as it could possibly do without stating it expressis verbis".

In his The Analysis of Sensations (Dover Publication), Mach argues that the two view points - stationary earth, and the sun and the fixed stars in motion, [illegible] opposite equally well-adapted to their special purposes". But to accept this equivalence is nothing, as he points out, in comparision to the simple truth based on straightforward psychological analysis that the "ego" the "I", is nothing at all but a transitory connexion of changing elements. He says (p.25): "The ego must be given up. It is partly perception of this fact, partly the fear of it, that has given rise to the many extravagances of pessimism and optimism, and to numerous religious, ascetic, and philosophical absurdities. In the long run we shall not be able to close our eyes to this simple truth, which is the immediate outcome of psychological analysis... We shall then be willing to renounce individual immortality, and not place more value upon the subsidiary elements than upon the principal ones. In this way we shall arrive at a freer and more enlightened view of life, which will preclude the disregard of other egos and the over-estimation of our own".

Mach especially refers to Buddhism. He says (footnote p. 356) "For thousands of years post Buddhism has been approaching this conception from the practical side". He speaks of "the wonderful story unfolded" in Paul Carus's Karma, A story of Early Buddhism, Chicage (1694); also The Gospel of Buddha (1954)

Message from Einstein for the Physics Laboratory of Delhi University (February 24,1940)

"This is the sentence expressing my good wishes for your new Physics Laboratory:

Keep good comradeship and work with love and without pre-conceived ideas and you will be happy and successful in your work."

A. Einstein

ALBERT EINSTEIN: 14 MARCH, 1879 - 18 APRIL, 1955

By

Kenneth Brecher

Nature Vol. 278 15 March 1979

This brief collection of direct and indirect quotations by or about Albert Einstein is offered as a tribute in honour of the centenary of his birth. The selection makes no attempt to be complete but does try to be representative of his attitude towards science and mathematics. As this selection is addressed to a primarily scientific audience, his views concerning his two most important creations, quantum theory and relativity, are particularly stressed toward the end.

The most beautiful experience we can have is the mysterious. It is the fundamental emotion which stands at the cradle of true art and true science. Whoever does not know it and can no longer wonder, no longer marvel, is as good as dead, and his eyes are dimmed.

from The World as I See it,
by A. Einstein (Philosophical
Library; New York, 1934)

I believe with Schopenhauer that one of the strongest motives that lead persons to art and science is flight from the everyday life, with its painful harshness and wretched dreariness, and from the fetters of one's own shifting desires. One who is more finely tempered is driven to escape from personal existence and to the world of objective observing and understanding. This motive can be compared with the longing that irresistibly pulls the town dweller away from his noisy, cramped quarters and toward the silent, high mountains, where the eye ranges freely through the still, pure air and traces the calm contours that seem to be made for eternity.

With this negative motive there goes a positive one. Man seeks to form for himself in whatever manner is suitable for him, a simplified and lucid image of the world, and so to overcome the world of experience by striving to replace it to some extent by this image. This is what the painter does, and the poet, the speculative philosopher, the natural scientist, each in his own way. Into this image and its formation, he places the centre of gravity of his emotional life, in order to attain the peace and serenity that he cannot find within the narrow confines of swirling, personal experience.

from the Scientific Imagination
Case Studies (page 231), by
G. Holton (Cambridge
University Press: Cambridge, 1978)

Kenneth Brecher is Professor of Physics at the Massachusetts Institute of Technology. Cambridge, Massachusetts,

The most incomprehensible thing about the universe is that it is comprehensible.

in Albert Einstein: Creator and Rebel (page 18), by Banesh Hoffman (Viking: New York, 1972; Hart-Davis, MacGibbon: London, 1973; Paladin: London, 1977)

Out yonder there was this huge world, which exists independently of us human beings and which stands before use like a great, eternal riddle, at least partially accessible to our inspection.

from "Autobiographical Notes", in Albert Einstein: Philosopher-Scientist edited by E.A. Schilpp (Harper and Row: New York, 1959)

To the sphere of religion belongs the faith that the regulations valid for the world of existence are rational, that it is comprehensible to reason. I cannot conceive of a genuine scientist without that profound faith. The situation may be expressed by an image: Science without religion if lame, religion without science is blind.

in Einstein: His Life and Times, by P. Frank (Knopf: New York, 1947)

Of all the communities available to us, there is not one I would want to devote myself to, except for the society of true searchers, which has very few living members at any time.

in letter to Max Born, April 29, 1924, from the Born Einstein Letters, by M. Born (Walker: New York, 1971)

In every true searcher of Nature there is a kind of religious reverence; for he finds it impossible to imagine that he is the first to have thought out the exceedingly delicate threads that connect his perceptions. The aspect of knowledge which has not yet been laid bare gives the investigator a feeling akin to that experienced by a child who seeks to grasp the masterly way in which elders manipulate things.

in Conversations with Einstein, by A. Moszkowski (Horizon New York, 1970)

What I'm really interested in is whether God could have made the world in a different way; that is, whether the necessity of logical simplicity leaves any freedom at all.

to Ernst Straus, quoted in The Scientific Imagination Case Studies, by G. Holton (Cambridge University Press: Cambridge, 1978)

I want to know how God created this world. I am not interested in this or that phenomenon, in the spectrum of this or that element. I want to know His thoughts, the rest are details.

in Einstein: The Life and Times, by R.W. Clark (World Publishing: New York, 1971: Hodder and Stoughton: London 1979)

God is cunning but He is not malicious (Raffiniert ist der Herr Gott aber boshaft ist Er nicht.)

inscribed at Princeton

Physics is essentially an intuitive and concrete science. Mathematics is only a means for expressing the laws that govern phenomena.

from Lettres a Maurice Solovine, by A. Einstein (Gauthier - Villars: Paris 1956)

God does not care about our mathematical difficulties. He integrates empirically.

in Quest (page 279), by L. Infeld (Gollancz: London 1942)

How can it be that mathematics, being after all a product of human thought which is independent of experience, is so admirably appropriate to the objects of reality? Is human reason, then, without experience, merely by taking thought, able to fathom the properties of real things? In my opinion the answer to this question is, briefly, this; as far at the propositions of mathematics refer to reality, they are not certain; and as far as they are certain, they do not refer to reality.

from "Geometry and Experience". in Ideas and Opinions (page 233), by A. Einstein (Crown; New York, 1954)

In the matter of physics, the first lessons should contain nothing but what is experimental and interesting to see. A pretty experiment is in itself often more valuable than twenty formulae extracted from our minds; it is particularly important that a young mind that has yet to find its way about in the world of phenomena should be spared from fomulae altogether. In his physics they play exactly the same weird and fearful part as the figures of dates in Universal History.

from Conversations with Einstein, by A. Moszkowski (Horizon: New York, 1970)

What applies to jokes, I suppose, also applies to pictures and to plays. I think they should not smell of alogical scheme, but of a delicious fragment of life, scintillating with various colours according to the position of the beholder. If one wants to get away from this vagueness one must take up mathematics. And even then one reaches one's aim only by becoming completely insubstantial under the dissecting knife of clarity. Living matter and clarity are opposites-they run away from one another. We are now experiencing this rather tragically in physics.

in letter to Max Born, January 15, 1927, from The Born-Einstein Letters, by M. Born (Walker: New York, 1971)

It is in fact, nothing short of a miracle that the modern methods of instruction have not yet entirely strangled the holy curiosity of enquiry; for this delicate plant, aside from stimulation, stands mainly in need of freedom; without this it goes to wrack and ruin without fail.

from "Autobiographical Notes", in Albert Einstein: Philosopher-Scientist, edited by E.A. Schilpp (Harper and Row: New York, 1959)

The only rational way of education is to be an example - if one can't help it, a warning example.

To punish me for my contempt for authority, Fate made me an authority myself.

in Albert Einstein: Creator and Rebel (page 24), by Banesh Hoffman (Viking: New York, 1972; Hart-Davis, MacGibbon: London, 1973; Paladin: london, 1977)

Great spirits have always encountered violent opposition from mediocre minds.

I remember a beautiful remark of his when he criticized a well-known American physicist. Einstein said he "couldn't really understand how anybody could know so much and understand so little"! Einstein always emphasized that you could know too many facts and get lost among them.

E. H. Hutten, in Einstein: The Man and His Achievement, edited by G.J. Whitrow (Dover: New York, 1973)

About ten years ago I spoke with Einstein about the astonishing fact that so many ministers of various denominations are strongly interested in the theory of relativity. Einstein said that according to his estimation there are more clergymen interested in relativity than physicists. A little puzzled I asked him how he would explain this strange fact. He answered, a little smiling, "Because clergymen are interested in the general laws of nature and physicists, very often, are not." Another day we spoke about a certain physicist who had very little success in his research work. Mostly he attacked problems which offered tremendous difficulties.

By most of his colleagues he was not rated very highly, Einstein, however, said about him, 'I admire this type of man. I have little patience with scientists who take a board of wood, look for its thinnest part and drill a great number of holes where drilling is easy'.

Philipp Frank, "Einstein's Philosophy of Science", in Reviews of Modern Physics, 21, 349 (1949)

I might begin with a true story that some of you may know concerning a conversation between Einstein and the French poet Valery. When Einstein first came to Paris, a well know hostess achieved the triumph of having both Einstein and Valery in her drawing-room, and arranged for a conversation between the two that everone else could listen to. As you know, Valery's mania was to say that he was more interested in the process of creation than in the actual opus which came out of this creative process .... and he started asking questions of Einstein about how he worked.

"How do you work, and could you tell us something of this?" Einstein was very vague about it.
He said, "Well, I don't know .... I go out in the morning and take a walk."
"Oh", said Valery, "Interesting, and of course you have a notebook and whenever you have an idea you write it out in your notebook."
"Oh", said Einstein, "No I don't".
"Indeed, you don't?
"Well you know, an idea is so rare."
That is really as much as I think can be said as to really great creativity.

J. Monon, in the Creative Process in Science and Medicine, edited by H.A. Krebs and J.H. Shelley (Elsevier: New York, 1975)

He was asked whether he thought that everything could ultimately be expressed in scientific terms. Einstein replied: "Yes, that is conceivable, but it would make no sense. It would be as if one were to reproduce Beethoven's Ninth Symphony in the form of an air pressure curve."

G. Born, in The Creative Process in Science and Medicine, edited by H.A. Krebs and J.H. Shelley (Elsevier: New York, 1975)

During his Zurich stay the woman doctor, Paulette Brubacher, asked the whereabouts of his Laboratory. With a smile he took a fountain pen out of his breast pocket and said: "Here".

from Albert Einstein: A Documentary Biography, by C.Seelig (Staples: London, 1956)

The most important tool of the theoretical physicist is his wastebasket.

told by P. Morrison

Just as it is the pride of many people never to have any time, so it has been Einstein's always to have time. I recall a visit I once paid him on which we decided to visit the astrophysical observatory at Potsdam together. We agreed to meet on a certain bridge in Potsdam, but since I was a good deal of a stranger in Berlin, I said I could not promise to be there at the appointed time.
"Oh", said Einstein, "that makes no difference; then I will wait on the bridge."
I suggested that that might waste too much of his time.
"Oh" no," was the rejoinder, "the kind of work I do can be done anywhere. Why should I be less capable of reflecting about my problems on the Potsdam bridge than at home?"

in Einstein, His Life and Times (page 118), by P. Frank (Knopf: New York, 1947)

The friendship of my thesis professor, Rudolf Ladenbury, and Einsteinwas a long one. They had been together in Berlin before coming to Princeton. Ladenburg liked to tell of their first meeting about 1908, when he called upon Einstein in the Swiss Patent Office. Einstein told him that he was the first physicist that he had seen in five years. During these years Einstein had done much of his important work. He pulled out one drawer of his desk and said that it was his theoretical physics office. His duty of reading patents book little time, and he worked upon physics whenever he was free.

Y. Beers, Am. J. Phys.,
46, 506 (1978)

I never think of the future, it comes soon enough.

Who would have thought around 1900 that in fifty years time we would know so much more and understand so much less ... Nowadays, one can be happy if one is not trampled down by the stampede of the buffalos.

in Albert Einstein and the
Cosmic World Order, by C.
Lanczos (Wiley: New York, 1965)

A theory is the more impressive the greater the simplicity of its premise is, the more different kinds of things it relates, and the more extended is its area of applicability. It (thermodynamics) is the only physical theory of universal content concerning which I am convinced that, within the framework of applicability of its basic concepts, it will never be overthrown

from "Autobiographical
Notes", in Albert Einstein:
Philosopher-Scientist, edited by
E.A. Schilpp (Harper and Row:
New York, 1959)

It was therefore quite a shock when he said, "But why should anybody be interested in getting exact solutions of such an ephemeral set of equations?". I remember very well this work "ephemeral". It meant that he did not consider his gravitational equations as the last word.

by C. Lanczos, in Einstein:
The Man and His Achievement
(Page 49), edited by G.J.
Whitrow (Dover: New York, 1973)

But it (general relatively) is similar to a building, one wing of which is made of fine marble (left part of the equation), but the other wing of which is built of low grade wood (right side of the equation). The phenomenological representation of matter is, in fact, only a crude substitute for a representation which would do justice to all known properties of matter.

from "Physics and Reality"
(1936), reprinted in Ideas and
Opinions (page 311), by Albert
Einstein (Crown:
New York, 1954)

I can, if the worst comes to the worst, still realise that the Good Lord may have created a world in which there are no natural laws. In short, chaos. But that, there should be statistical laws with definite solutions, i.e., laws which compel the Good Lord to throw the dice in each individual case, I find highly disagreeable.

in Albert Einstein: A Documentary Biography, by C. Seelig (Staples: London, 1956)

You believe in a dice-playing God and I in perfect laws in the world of things existing as real objects, which I try to grasp in a wildly speculative way.

from letter to Max Born, quoted in Albert Einstein: Philosopher-Scientist (page 176), edited by E.A. Schilpp Harper and Row: New York, 1959)

The present theory of relativity is based on a division of physical reality into a metric field (gravitation) on the one hand, and into an electromagnetic field and matter on the other hand. In reality space will probably be of a uniform character and the present theory be valid only as a limiting case. For large densities of field and of matter, the field equations and even the field variables which enter into them will have no real significance. One may not therefore assume the validity of the equations for very high density of field and of matter, and one may not conclude that the "Beginning of the expansion" must mean a singularity in the mathematical sense. All we have to realise is that the equations may not be continued over such regions.

in the Meaning of Relativity (page 129), fifth edition, by Albert Einstein (Princeton University Press: New Jersey, 1956)

Quantum mechanics is certainly imposing. But an inner voice tells me that it is not yet the real thing. The theory says a lot, but does not really bring us any closer to the secret of the 'old one'. I, at any rate, am convinced that He is not playing at dice.

from a letter to Max Born, December 4, 1926, from The Born-Einstein Letters, by M. Born (Walker: New York, 1971)

The Heisenberg-Bohr tranquilizing philosophy - or religion? - is so delicately contrived that, for the time being, it provides a gentle pillow for the true believer from which he cannot very easily be aroused. So let him lie there.

in a letter of E. Schrodinger, May 31, 1928, from Letters on Wave Mechanics (page 31), edited by K. Przibram (Philosophical Library: New York, 1967)

Is it conceivable that a field theory permits one to understand the atomistic and quantum structure of reality? Almost everybody will answer this question with "no". But I believe that at the present time nobody knows anything reliable about it. This is so because we cannot judge in what manner and how strongly the exclusion of singularities reduces the manifold of solutions.......

We can give good reasons why reality cannot at all be represented by a continuous field. From the quantum phenomena it appears to follow with certainty that a finite system of finite energy can be completely described described by a finite set of members (quantum numbers). This does not seem to be in accordance with a continuum theory, and must lead to an attempt to find a purely algebraic theory for description of reality. But nobody knows how to obtain the basis of such a theory.

in The Meaning of Relativity (page 165), fifth edition, by Albert Einstein (Princeton University Press: New Jersey, 1956)

You imagine that I look back on my life's work with calm satisfaction. But from nearby it look quite different. There is not a single concept of which I am convinced that it will stand firm, and I feel uncertain whether I am in general on the right tract .... I don't want to be right ..... I only want to know whether I am right.

from Lettres a Maurice Solovine, by Albert Einstein (Gauthier-Villars: Paris, 1956)

One thing I have learned in a long life: that all our science, measured against reality, is primitive and childlike - and yet it is the most precious thing we have

frontispiece to Albert Einstein: Creator and Rebel, by Banesh Hoffman (Viking: New York, 1972: Hart-Davis, MacGibbon: London, 1973: Paladin: London, 1977:

The assence of a man like me lies just in what he thinks and how he thinks - not in what he does or suffers.

from "Autobiographical Notes", in Albert Einstein: Philosopher-Scientist, edited by E.A. Schilpp (Harper and Row: New York, 1959)

Am J Psychiatry 136:1, January 1979

Einstein's Creative Thinking and the General Theory of Relativity: A Documented Report

BY ALBERT ROTHENBERG, M.D.

A document written by Albert Einstein has recently come to light in which the eminent scientist described the actual sequence of his thoughts leading to the development of the general theory of relativity. The key creative thought was an instance of a type of creative cognition the author has previously designated "Janusian thinking." Janusian thinking consists of actively conceiving two or more opposite or antithetical concepts, ideas, or images simultaneously. This form of high-level secondary process cognition has been found to operate widely in art, science and other fields.

ALBERT EINSTEIN was clearly one of the world's most creative scientists. Among his many accomplishments, the formulation of the general theory of relativity stands out as one of the most far-reaching scientific events in the modern era. As a new theory of gravitation, it embraced Newton's classic theory as a special case and allowed for extensive and grand conclusions about the universe as a whole. At the very least, the accomplishments and accumulated knowledge of modern astrophysics can be traced to this theory and the dramatic confirmations of its predictions in 1919 from data collected during a solar eclipse.

Because of his importance and the exalted nature of his accomplishments, many speculations have arisen about the roots of Einstein's genius and creativity (1–7). Much has been made of the rather remarkable but now generally known facts that Einstein learned to speak late, did not perform well in his early school years, and was not highly proficient in verbal skills throughout his life. Emphasis has been placed on the visual nature of his thinking, which he reported to his colleague Hadamard (8) and to Wertheimer (7). Because of Einstein's gentle and somewhat introverted personality and because visual thinking is often erroneously considered more primitive and more characteristic of childhood than verbal thinking, some have asserted that Einstein thought as a child thinks. This type of conclusion roughly coincides with many psychoanalytic formulations about creativity that postulate the regressive, primitive roots of creative thinking (9–11).

Tracing specific factors of creative thinking is highly complex and difficult, especially in science. Scientists rely so heavily on the contributions of their colleagues and predecessors and so much good scientific work derives directly from perseverance, memory, and logical capacity that it is hard to isolate and identify special kinds of thinking or skills in an individual discovery. Moreover, even when something is known about a scientist's personality, cognitive modes, and outlook, specific data are needed before it is possible to connect any particular personality factors or modes to a specific attainment or discovery. The assertions of childish, primitive thinking in Einstein's discoveries are especially based on surmise and speculation. Even the emphasis on visual and geometric thinking, plausible as it may be, derives only from Einstein's sketchy and general descriptions to Hadamard. As with most scientists, Einstein gave out very little information during his lifetime about the circumstances or specific sequences of thought connected with any of his attainments.

An important document has recently come to light, however. This document provides a direct and detailed account by Einstein himself of the actual thinking that led to his discovery of the crucially important general theory of relativity. Still unpublished in its entirety, it was written in Einstein's own hand in approximately 1919 and titled by him (in translation from the German) "Fundamental Ideas and Methods of Relativity Theory, Presented in Their Development." It was found after Einstein's death among his personal effects and includes an unusually explicit personal statement by a man whose writings are almost invariably scientific or impersonal. Even Einstein's autobiographical notes, written at age 67, consist primarily of an exposition of his theories (12).

The section I shall quote was subtitled by Einstein The Fundamental Idea of General Relativity in Its Original Form. Prof. Gerald Holton published other

Presented at the 130th annual meeting of the American Psychiatric Association, Toronto, Ont., Canada, May 2–6, 1977. Received May 9, 1977; revised Dec. 1, 1977; accepted March 29, 1978.

Dr. Rothenberg is Professor of Psychiatry and Behavioral Sciences, University of Connecticut Health Center, Farmington, Conn. Address reprint requests to him at 139 Webb Circle, Monroe, Conn. 06468.

The author would like to acknowledge the Estate of Gladys B. Fiske, Ralph F. Colin, Trustee, for support of this research, and the Estate of Albert Einstein, Otto Nathan, Trustee, and Prof. Gerald F. Holton for the use of the Einstein material quoted. Professor Holton is responsible for the discovery of the Einstein material and for its translation.

translated versions and portions of these passages in 1973 (5) and 1975 (13). The entire document is in the Einstein Archives at the Princeton Institute for Advanced Study. The section I shall quote was translated by Professor Holton and was made available to me by the executors of the Einstein Estate, Otto Nathan and Helen Dukas. The section begins with Einstein's discussion of considerations involved in his discovery of special relativity theory, the theory he expanded and applied to gravitation in his general theory of relativity. These considerations involve a seeming discrepancy of interpretation arising from the Maxwell-Lorentz theory explaining Faraday's work on electromagnetic induction:

> In the development of special relativity theory, a thought—not previously mentioned—concerning Faraday's work on electromagnetic induction played for me a leading role.
>
> According to Faraday, when a magnet is in relative motion with respect to a conducting circuit, an electric current is induced in the latter. It is all the same whether the magnet moves or the conductor; only the relative motion counts, according to the Maxwell-Lorentz theory. However, the theoretical interpretation of the phenomenon in these two cases is quite different. . . .
>
> The thought that one is dealing here with two fundamentally different cases was, for me, unbearable [*war mir unerträglich*]. The difference between these two cases could not be a real difference, but rather, in my conviction, could be only a difference in the choice of reference point. Judged from the magnet there certainly were no electric fields; judged from the conducting circuit there certainly was one. The existence of an electric field was therefore a relative one, depending on the state of motion of the coordinate system being used, and a kind of objective reality could be granted only to the electric and magnetic field together, quite apart from the state of relative motion of the observer or the coordinate system. The phenomenon of the electromagnetic induction forced me to postulate the (special) relativity principle.
>
> When, in the year 1907, I was working on a summary essay concerning the special theory of relativity for the Yearbook for Radioactivity and Electronics I tried to modify Newton's theory of gravitation in such a way that it would fit into the theory. Attempts in this direction showed the possibility of carrying out this enterprise, but they did not satisfy me because they had to be supported by hypotheses without physical basis. At that point there came to me the happiest thought of my life, in the following form:
>
> Just as in the case where an electric field is produced by electromagnetic induction, the gravitational field similarly has only a relative existence. *Thus, for an observer in free fall from the roof of a house there exists, during his fall, no gravitational field* [Einstein's italics]—at least not in his immediate vicinity. If the observer releases any objects, they will remain, relative to him, in a state of rest, or in a state of uniform motion, independent of their particular chemical and physical nature. (In this consideration one must naturally neglect air resistance.) The observer is therefore justified in considering his state as one of "rest."
>
> The extraordinarily curious empirical law that all bodies in the same gravitational field fall with the same acceleration immediately took on, through this consideration, a deep physical meaning. For if there is even one thing which falls differently in a gravitational field than do the others, the observer would discern by means of it that he is falling in it. But if such a thing does not exist—as experience has confirmed with great precision—the observer lacks any objective ground to consider himself as falling in a gravitational field. Rather, he has the right to consider his state as that of rest, and his surroundings (with respect to gravitation) as field free.
>
> The fact, known from experience, that acceleration in free fall is independent of the material is therefore a mighty argument that the postulate of relativity is to be extended to coordinate systems that are moving non-uniformly relative to one another.

The happiest thought of Einstein's life as described here was the formulation that provided the foundation for the general theory of relativity. From the exposition, it is clear that this "happiest thought" was his underscored (here italicized) phrase, "*Thus, for an observer in free fall from the roof of a house there exists, during his fall, no gravitational field.*" Einstein was not referring to the analogic thought in the immediately previous sentence because, in earlier paragraphs, he had made it clear that he had had in mind for some time the idea of an analogy between electromagnetic induction and gravity. The analogic thought, in other words, was the formulation of the problem, and the underscored idea was the solution. It is important to emphasize this because the exposition indicates many factors pertaining to Einstein's capacity to make this discovery, such as his full and complete knowledge of theories and facts, his extraordinary intelligence and lucidity, his passionate devotion to solving the problem, and his emotional involvement in the substance of the matter—seen in his statement, "The thought that one is dealing here with two fundamentally different cases was, for me, unbearable." All this is worthy of attention and analysis, but Einstein's creative leap of thought is discovered here for the first time clearly specified, and it is this thought—the happiest one of Einstein's life—which requires explication. The leap of thought Einstein described is an instance of a psychological process I have previously (in 1969 and 1971) defined, discussed, tested experimentally, and designated "Janusian thinking" (14–18).

JANUSIAN THINKING

Janusian thinking consists of *actively conceiving two or more opposite or antithetical concepts, ideas, or images simultaneously*, both as existing side by side and/or as equally operative or equally true. In order to clarify the creative nature of this type of thinking, I shall first briefly review the research that led to its discovery and then return to show how it is manifest in Einstein's dramatic formulation.

Janusian thinking was discovered through empirical studies of the creative process consisting of extensive and intensive psychiatric research interviews focused on creative work in progress (19), analyses and reconstructions—both statistical and psychological—of literary creative processes of the past with predictions assessed in other types of research interviews (14) and experimental studies (17, 18). In the research interviews focused on work in progress, I regularly and systematically met with creative individuals over an extended period—usually months or years—and, in a collaborative effort (not a treatment or a psychotherapy), we explored the thoughts, feelings, fantasies, dreams, and events in their lives that were connected to the creative work they were engaged in at the time.

On the basis of these interviews, which total 1,665 hours to date, new experimental techniques were constructed and particular controlled experiments designed to elicit cognitive patterns were performed, both with the individuals who had participated in the interviews and with 149 other creative individuals and control subjects (17, 18, 20). Although differing criteria were used for assessing the creativeness of the individuals involved in the various researches, selection of individuals for the interview series was based primarily on two factors: high creativity ratings by peers and endorsement by society at large. For the creative writers and scientists who were my interview subjects, this meant roughly that they had achieved some major honor or award, such as the Nobel Prize, Pulitzer Prize, National Book Award, Bollingen Poetry Prize, membership in the American Academy of Arts and Letters, in the National Institute of Arts and Letters, in the American Academy of Arts and Science, or in the National Academy of Sciences, and that they were considered highly creative through an objective survey of their writer and scientist peers.

The term "Janusian thinking" is based on the Roman god Janus, whose multiple faces (two, four, or six) [illegible] were turned in several opposite directions at once. In apparent defiance of logic or matters of physical impossibility, the creative person formulates two *or more* opposites or antitheses coexisting and simultaneously operating, a formulation that leads to integrated concepts, images, and creations. This form of thinking, apparently unique to creative people, plays a constant role in diverse types of creative processes. From the reports of my subjects and from other documented sources, it clearly operated during the creation of poems, novels, plays, paintings, or sculptures, and it operated during the creation of new scientific theories and creative leaps of thought connected to very important scientific discoveries (20). Occurring at crucial moments during the process of creating, usually at the moment of inspiration, this form of thinking has effects that are not always overtly manifest in the final product. The Janusian formulation, in other words, is often a crucial step or way station that later undergoes a good deal of transformation and revision.

Before I describe the revisions and transformations as well as the functions of Janusian thinking, it is important to note that many untransformed Janusian formulations are clearly manifest in some of the great creations of the world. In religious creations, for instance, there is the Yin and Yang formulation of the oriental Taoist religion: two opposite and universal forces or principles operating together as a single force. Nirvana and Samsara are the dominant unified principles of Buddhist theology. Nirvana, the end of the cycle of rebirth, is opposed to and simultaneous with Samsara, the endless series of incarnations and reincarnations of living things. In the Middle East Zoroastrianism, the major religion of the vast Persian Empire, had as its basic tenet the simultaneous presence from the beginning of all things of the twin but opposite gods Ormazd, the god of light and goodness, and Ahriman, the god of darkness and evil. The precepts and descriptions in various aspects of Western theology of a simultaneous operation of God and the Devil, insofar as they are theological creations of the human mind, are also direct manifestations of Janusian formulations.

In philosophy simultaneous opposition and antithesis are manifest in the pre-Socratic conceptions pertaining to Being and Becoming, Nietzsche's Dionysian and Apollonian principles, Kierkegaard's belief by virtue of the absurd, and Sartre's representation of Being and Non-Being. In psychology there are Freud's formulations of the conscious operating together with the unconscious and the theory of the dually functioning but opposed instincts of sex and aggression. Direct manifestation of simultaneous opposition is probably most apparent in the poetry produced by great creators throughout the world and throughout the ages. Many major poets and critics, including William Blake, Samuel Taylor Coleridge, Cleanth Brooks, Robert Graves, Amy Lowell, Robert Penn Warren, Allen Tate, and John Crowe Ransom, have emphasized that poetry is fundamentally based on elements of opposition or a close relation, paradox.

All these examples suggest the workings of Janusian thinking in diverse types of creations, but my evidence is not based merely on consideration of these final created products. It is derived from experimental data and empirical observations of the constant use of this type of thinking in the achievement of creative ideas. For instance, plagued all his life by the suicide of a roommate in his youth, a suicide apparently precipitated by the roommate's wife's infidelity, a great playwright came to realize that the suicide was also motivated by guilt over a simultaneous but opposite wish—the man had wanted his wife to be unfaithful. The formulation resulting from this realization—the idea that his former roommate had both wanted and not wanted his wife to be unfaithful—instigated the writing of one of this playwright's most highly esteemed plays, and the idea directly influenced that play's structure and substance (14). Another noted playwright decided to write a comedy shortly after his father's death. He structured this highly successful play around characters who were both living and dead at the same time.

These characters were not to be represented as ghosts but as lost persons struggling to survive and to understand what had happened to them (20). Another subject of mine, a novelist, during an early phase of thinking about a novel's plot, conceived of a revolutionary hero as responsible for the deaths of hundreds of people but killing only one person with his own hand, a person who had been kind to him and whom he loved. Much of the subsequent novel became an elaboration of this early idea.

One subject, who was a poet, conceived the central image of a poem when he thought of horses as both human and beasts simultaneously, that is, horses were beasts but they lived human lives, they were not human and were human at the same time (20, 22). Another poet, walking on a beach, came on some rocks and thought: the rocks are heavy, they are weapons of violence but, *at the same time*, they feel like human skin. This inspiration led to the construction of a poem concerning the relationship between sex and violence in the world. That sex and violence have much in common was an immediate formulation at the time of perceiving the antithetical qualities of the rocks. For an example from painting, a careful analysis of Picasso's drawings and the successive stages of his creation of the great mural *Guernica* leads to the conclusion that his earliest conception, visually formulated, was of a woman (holding a torch in the completed mural) looking both inside a room and outside onto a courtyard at the same time (20). In context, all of these creative constructions involved high-level, conscious, abstract thinking. As a psychological process, Janusian thinking is a complex, nonprimitive form of cognition.

EINSTEIN'S CREATIVE COGNITION

The sentence following Einstein's underscored and happiest thought is, "The observer is therefore justified in considering his state as one of 'rest.'" Adding this, Einstein clarified the essence of his thought. As he surely knew, the observer falling from the roof of a house is in a state of motion, he is moving during his fall. However, as Einstein conceived it in this formulation, the observer is simultaneously in a state of rest; the observer is thus *in motion* and *at rest* at the same time. This was Einstein's observation about a physical circumstance that allowed him to modify Newton's theory of gravitation so that it would fit into relativity theory. It imbued the "extraordinarily curious empirical law that all bodies in the same gravitational field fall with the same acceleration" with a "deep physical meaning." From the formulation that an observer in free fall is both at rest and in motion at the same time, Einstein was able to postulate the relativity of motion in coordinate systems. Thus, the crucial step in the development of the general theory of relativity, Einstein's creative leap, was a formulation of the opposite states of motion and rest operating simultaneously, an instance of Janusian thinking.

That Einstein knowingly formulated a condition of simultaneous antithesis is clear from the discussion in context. In ordinary experience, falling or being in motion and being at rest are completely antithetical. He therefore devoted several sentences to explaining the particular considerations allowing the moving observer to—as he states twice—"consider his state as that of rest." As Einstein knew, it was a rather shocking and dramatic breakthrough.

The complete development of the general theory of relativity depended on the previous conception of the special theory, as Einstein here made clear, and that theory depended, as Gerald Holton has shown (5), on the direct and indirect influence of Maxwell, Lorentz, Mach, Poincaré, and Föppl as well as important scientific, sociological, and philosophical currents of the time. Other factors included Einstein's enormous capacities for deductive and inductive logic, for combining and separating categories and symbols, and for intense concentration as well as his profound understanding of the rubrics of science and mathematics. As Einstein made clear in this passage, however, the key creative step consisted of finding a way to connect gravitation to relativity on the basis of empirical or physical reality. This key step was formulated all at once as a simultaneous antithesis.

As an instance of Janusian thinking, the formulation was not developed through a stepwise weighing of physical or conceptual alternatives, such as drawing cumulative inferences from a series of observations or deriving conclusions directly from a theory. Nor, as is intrinsic to a dialectical process (dialectical and Janusian thinking are not the same), did Einstein consider the opposites or antitheses in systematic fashion in order to synthesize or combine them. Although he may have engaged in such systematic thinking about the problem at other times, he stated he was working on a summary yearbook essay when he conceived the entire idea.

There was nothing primitive, childlike, or regressive in the creative leap. Absent from the account are any suggestions of an altered state of consciousness or the intrusion of ego-alien material. There is nothing to suggest primary process material appearing in consciousness; no sudden idea followed afterward by critical and logical evaluation. Einstein was fully aware of the logic and reality of the issue at the moment he had, in his words, his "happiest thought." He did not magically conceive of the equivalence of opposites. Visual thinking, which Holton (5, 13) and others (7, 8) have emphasized, and imagery seem to have been present. The idea of a person falling from the roof of a house suggests a visual conception. Rather than the primary process visual imagery emphasized by regression theories of creativity, however, Einstein's probable visualization in this case very likely involved another type of high-level creative thinking (Homospatial thinking), which I have described extensively elsewhere (22).

Einstein's account also clearly conveys both the aesthetic orientation and emotional investment ("Th thought that one is dealing here with two fundamentally different cases was, for me, unbearable.") connected with his scientific thinking that has been emphasized by Holton (5). An interest in economy and simplicity and what Holton has described as a sensitivity to asymmetry and an interest in symmetry seem to play a general role. Janusian thinking is related in an instrumental and critically facilitative way to these general factors. As it is extensively operative in aesthetic creation, as it has definite and specific connections with emotional sources and emotional goals (15, 20), and as simultaneous antitheses or oppositions are intrinsically symmetrical, Janusian thinking is a more primary creative factor than the general ones. Holton's observations are important; aesthetic goals operate ubiquitously in scientific creation. Looking for economy or rejecting asymmetry or being emotionally invested are not, however, the same thing as deriving the particular formulation of simultaneous antithesis that provides key conceptions and dramatic creative leaps.

In its fully worked-out form, the general theory of relativity presented what physicists today consider the principle of equivalence of gravitation and inertia. According to this principle, there is no way to distinguish the motion produced by inertial forces—acceleration, deceleration, centrifugal forces—from motion produced by gravitational force. In blind-flying in an airplane, for instance, it is impossible to separate the physical sensation of pulling out of a dive and that of executing a steeply banked turn at high speed; one cannot separate the effects of inertia from those of gravitation. In both cases blood is drawn away from the brain and the body is pulled down heavily into the seat. The fully worked-out theory, moreover, gave a picture of the universe as a four-dimensional space-time continuum, a construct that changed previous conceptions such [illegible] island of matter in a sea of space. Revolutionizing science, philosophy, and man's view of the nature of physical experience, this construct is the basis for [illegible] mological conceptions. The theory not only allowed for predictions about deflections of the light of stars seen in a solar eclipse, it explained an observation about the behavior of the planet Mercury that had not been accounted for by Newton's laws. It provided a means of dealing with high speed velocities and intense gravitational fields, and it provided an understanding of the shape and size of the universe. Much elaboration, deduction, and calculation went into the development of the entire general theory of relativity, and there has been much empirical testing and conceptual elaboration since it was first constructed. However, as Einstein's exposition now makes clear, the key thought allowing for the formulation, the creative leap giving his incomplete ideas a physical basis and bringing them together in a meaningful formulation, was the specific conception of opposites operating simultaneously—an observer being in motion and at rest at the same time. Such a formulation is a cardinal instance of the creative cognitive process of Janusian thinking.

The cognitive process I have described is not the same as that [illegible] by other investigators. It is not at all merely a manifestation of Guilford's "divergent thinking" (23), Koestler's "bisociation" (3), DeBono's "lateral thinking" (24), or Mednick's formulation of the bringing together of remote associates (25). It is a directed thought process involving active formulation rather than association or bisociation. Moreover, it involves active espousal of specifically antithetical or oppositional entities rather than only divergent or "lateral," unrelated, or remote ones. Nor is Janusian thinking an illogical or prelogical process. In distinction to schizophrenic thinking or the thinking in dreams, for instance, it is a logical postulating of what, on the surface, seems illogical. It is not a form of primary process thinking nor does it derive directly from the unconscious. The creative person actively brings together opposites and antitheses as a means of formulating scientific and other problems, initiating and facilitating aesthetic tasks, creating theories, making discoveries, and constructing works of art.

As seen in Einstein's description, during the creative process the creative person is in neither a trance nor an altered state of consciousness, nor is there any indication that unconscious material erupts directly into consciousness. This is not primary process or free association material brought into consciousness by suspension of secondary process thinking and/or logical and critical judgment. Nor is it correct to say that Janusian thinking consists of unconscious or preconscious material appearing in consciousness during an altered state and then later subjected to logic and critical judgment. Critical assessment and logical elaboration are always necessary to construct and articulate a full theory, discovery, or work of art, but, as Einstein's description again makes clear, the creator is also fully logical and capable of full critical judgment at the moment [illegible] the Janusian formulation. Janusian thinking is a form of secondary process cognition. Creative individuals are fully aware that the elements of their thought would be, in a particular context, antithetical, but they engage in what may be called a logic-transcending or "translogical" leap of thought.

Einstein and general relativity: Historical perspectives

S. Chandrasekhar
The Enrico Fermi Institute, University of Chicago, Chicago, Illinois 60637
(Received 22 September 1978; accepted 20 November 1978)

Editor's Note: This paper was presented as the 1978 Oppenheimer Memorial Lecture at Los Alamos Scientific Laboratories on August 17, 1978.

Einstein's place in the physics of the 20th century is generally considered unique. And one may ask, Why? For, one could name several whose fundamental contributions to the physicist's common stock of knowledge may be considered even more relevant than Einstein's—at any rate, comparable to his. Here are the names of some: Lorentz, Poincaré, Rutherford, Bohr, Fermi, Heisenberg, Dirac, and Schrödinger.

Einstein's contributions to that part of physics with which all students of physics, without exception, would be familiar are those derived from his three famous papers of 1905: dealing with his founding of the special theory of relativity, the theory of Brownian motion, and the concept of the photon. While all these contributions, singly, and even more, together, place Einstein among the foremost physicists of our time, one cannot be confident that on these accounts his place is one of exceptional uniqueness. After all, Lorentz, and even more Poincaré, were not that far behind Einstein in formulating the principles of special relativity; and it is to Minkowski that we turn for the deepest formulation of the concepts of special relativity. Smoluchowski, independently of Einstein, discovered the theory of Brownian motion; and it is to Smoluchowski that we turn for the unraveling of all the multifarious aspects of that theory. And in the formulation of his concept of the photon, Einstein was preceded by Planck and followed by Bohr. And let us not forget the great figure of Poincaré who looms behind so much of the mathematics of the 20th century and of physics, indirectly.

Why, then, is Einstein unique? To this question the answer undoubtedly is that besides all his contributions that have been enumerated, he was the sole and the lonely discoverer of the general theory of relativity.

With that assessment, I agree.

But Einstein's unique fame deriving from his development of the general theory of relativity has many paradoxical aspects. Perhaps the most striking of these is the exalted place which Einstein was given for his discovery of the general theory of relativity by some of the early investigators, who were eminent men of science themselves, and the benign neglect to which his theory was consigned by the professional scientific community for some 50 years—not to mention the active hostility to which his theory has been subjected over the years. The unraveling of the many conflicting strands of opinion with respect to general relativity is not an easy task. It is made somewhat easier for me since I share and endorse Weyl's assessment of general relativity: "As the greatest example of the power of speculative thought."

Let me begin by describing in the most general terms the basic ideas which led Einstein to his theory of gravitation by the sheer power of his speculative thought. It should be emphasized first that Einstein's replacement of the Newtonian theory of gravitation by his own theory did not arise in any of the normal ways in which new physical theories emerge.

It is almost invariably the case that new theories in physics, or novel generalizations of the old, result from a definite conflict with experience; and the ideas for the new theory are distilled from the need to incorporate the facts, which appear to conflict with what is already known, in a harmonious whole. Further, the success of the new ideas is judged by the extent to which they can account for new phenomena. The general theory of relativity did not originate in this fashion.

Einstein started with the premise that Newton's theory required a reformulation, since it was in manifest conflict with his own special theory of relativity. The basic tenet of the special theory of relativity is that in physics there can be no instantaneous action at a distance: no signal of any kind can be propagated with a velocity exceeding that of light. And, of course, Newton's laws of gravitation postulate instantaneous action at a distance. Besides, at the base of Newton's laws of gravitation is an enigmatic fact—well established, but not understood, before Einstein. The enigmatic fact goes back to Galileo's well-known demonstration from the leaning tower at Pisa that all bodies, large or small, are accelerated equally in the local gravitational field of the earth. From this equality of acceleration of different masses, one concluded that mass as a measure of the quantity of matter and mass as a measure of its weight are identically the same. This identity is commonly referred to as the equality of the inertial and the gravitational masses of a body. But this equality had no theoretical basis before Einstein: it is an empirical fact which requires experimental evidence. Newton was well aware of the need for experimental evidence for this crucial fact. Thus, in the opening paragraph of his *Principia*, Newton wrote:

> "Air of double density, in a double space, is quadruple in quantity; in a triple space, sextuple in quantity ... It is the quantity that I mean hereafter, everywhere, under the name of body or mass. And the same is known by the weight of each body, for mass is proportional to the weight, as I have found by experiments on pendulums very accurately made."

(May I parenthetically note that this equality of inertial and gravitational masses to which Newton makes reference, has in recent years been established to an accuracy of one part in several billions.)

The extremely general facts I have stated provided Ein-

 0002-9505/79/030212-06$00.50

stein with the entire basis for his formulating the general theory.

Even given these bases for generalizing Newton's theory, there really was no compelling need for an exact theory of gravitation. For, on general grounds, one could have argued that the Newtonian theory should be valid so long as the velocity of a planet or a satellite is small compared to the velocity of light. Even Mercury, the planet closest to the Sun, describes its orbit around the Sun with a velocity which is 6000 times smaller than the velocity of light. Accordingly, any departures from the predictions of the Newtonian theory can be estimated to be no more than a few parts in a billion. On this account, it would have been entirely sufficient to generalize the Newtonian theory to allow for such small departures which may arise from the finiteness of the velocity of light since we expect the Newtonian theory to be exact if the velocity of light could be considered as infinite. And that would have been the normal way.

But Einstein did not proceed in that way. He searched for an exact theory which would be valid even if the velocities of the gravitating bodies approached that of light. Certainly, an exact theory, even if one should succeed in formulating it could never be confirmed by experimental or observational features which as I have stated, must be minute, by all criteria, in the solar system; moreover, when Einstein sought for a new theory, he had no prior conception as to what the nature of the departures may be that the new theory would be asked to account for. But as was stated by one of his early associates, Lanczos, by a combination of constructive mathematical thinking, philosophical imagination, and a nonerring aethestic sense, Einstein arrived at his exact equations governing the theory of gravitation, a theory in which the three fundamental entities, space, time, and matter, were unified.

As a rule, Einstein generally refrained from any emotional exclamation marks in his publications but he overcame his reticence in the concluding sentence of his first communication in November 1915 to the Berlin Academy in which he announced the basic equations of his theory. He wrote:

> "Scarcely anyone who has fully understood this theory can escape from its magic; the theory represents a genuine triumph of the method of the absolute differential calculus of Christoffel, Ricci, and Levi Civita."

Weyl and Eddington, who wrote the first serious expositions of relativity, responded to Einstein's magic. Thus, in the preface to his *Space, Time, and Matter*, published in the spring of 1918, Weyl wrote:

> "It is as if a wall which separated us from the truth has collapsed. Wider expanses and greater depths are now exposed to the searching eye of knowledge, regions of which we had not even a presentiment. It has brought us much nearer to grasping the plan that underlies all physical happening."

And in Eddington's *Space, Time, and Gravity*, published in 1920, the opening sentence reads:

> "By his theory of relativity, Albert Einstein has provoked a revolution of thought in physical science."

Others of comparable eminence, who have studied general relativity and made contributions to it have written similarly. Thus, Landau and Lifshitz in their well known book on *Classical Theory of Fields* in introducing the general theory of relativity, state that it "represents probably the most beautiful of all existing physical theories." And Dirac has said that Einstein's generalization of the special theory of relativity to include gravitation "is probably the greatest scientific discovery that was ever made."

From these statements of the eminent men of science who have studied the theory of relativity and made important contributions to it, one might conclude that the general theory of relativity is an accepted theory and that only cranks would doubt its validity. But that is not the case. A great number of eminent men have either given faint praise or have considered Einstein's theory as just plainly incorrect. Let me quote some varying shades of opinion.

Born, who was an assistant of Einstein's in Berlin during the very years when Einstein was developing his general theory of relativity, in 1955, on the occasion of the 50th anniversary of Einstein's great paper on special relativity, stated:

> "The foundation of general relativity appeared to me then, and still does as the greatest feat of human thinking about Nature, the most amazing combination of philosophical penetration, physical intuition, and mathematical skill. But its connection with experience is slender. It appealed to me like a great work of art, to be enjoyed and admired from a distance."

But what are we to make of this seeming praise of general relativity? Has it only to be admired from a distance? Does it not then require study and development like any other branch of the physical sciences? And a cynic might add that the description of Einstein's work as a work of art is often the cloak in which physicists disclaim the relevance of general relativity to the advance of physics. Here is J. J. Thomson:

> "Einstein has given a second theory known as 'general relativity' and includes the theory of gravitation. This involves much very abstruse mathematics, and there is much of it I do not profess to understand. I have, however, a profound admiration for the masterly way in which he has attacked a problem of transcendant difficulty."

And here is Rutherford:

> "The theory of relativity of Einstein, quite apart from its validity, cannot but be regarded as a magnificent work of art."

The description of general relativity as a work of art is double edged. One senses that in describing the theory in this way, one is trying not to dissociate oneself from the general acclaim that is accorded to Einstein. But the matter is not that simple. It is, in fact, the case that the literature dealing with theories alternative to Einstein's are as numerous as the positive contributions devoted to exploring the content of the theory itself. It is not merely that cranks and pseudoscientists have written tracts disputing Einstein. Several eminent men of science, whom we all respect, have also considered Einstein's theory as scientifically unsound. Let me list the names of some of those who have written books and tracts presenting theories which they consider as viable alternatives to Einstein's theory. Whitehead, the distinguished philospher and mathematician, Birkhoff, the distinguished mathematician, Milne, the distinguished astrophysicist, and Hoyle and Narlikar. Besides several earlier adherents of Einstein's theory have now discerned either flaws or grave crises: e.g., Rosen and Møller.

While I shall not give any account—I could not do so dispassionately—I will quote a few sentences from Whitehead, whose many writings on science and philosophy many of us have admired.

In 1922, Whitehead published a book entitled, *The Principle of Relativity*, an alternative to Einstein's theory. Whitehead starts by quoting with approval an aphorism of Thomson: "I have no doubt whatever that our ultimate aim must be to describe the sensible in terms of the sensible." After this quotation, Whitehead goes on to say, "I do not agree with Einstein's way of handling his discovery," meaning that Einstein's theory does not describe sensible things in a sensible way. Here are some other quotations from Whitehead which will give you a flavor of his reasoning:

> "So many considerations are raised that we are not justified in accepting blindfolded the formulation of principles which guided Einstein."

Or, again:

> "In the comparative absence of applications, beauty, generality, and even Truth, will not save a doctrine from neglect in scientific thought . . . To expect to reorganize our ideas on Time, and Space, and Measurement without some discussion, which must be ranked as philosophical, is to neglect the teaching of history and the inherent possibilities of the subject."

[illegible] Einstein's formulation of space time, as a Riemannian manifold with a metric is invalid on philosophical grounds, Whitehead goes on to develop a detailed theory of his own. But unfortunately for Whitehead some of the implications of his theory have been shown to be blatantly contrary to experience in several instances in which Einstein's theory succeeds admirably. Whitehead's philosophical acumen has not served him well in his criticisms of Einstein.

I said a little earlier that I was making an exception of Whitehead's criticisms of Einstein. But I cannot desist quoting the reaction to relativity of one of my personal friends, the late Milne. In developing his kinematical theory of relativity, Milne stated:

> "Einstein's law of gravitation is by no means an inevitable consequence of the conceptual basis given by describing phenomena by means of a Riemannian metric. I have never been convinced of its necessity . . . General relativity is like a garden where flowers and weeds grow together. The useless weeds are cut with the desired flowers and separated later."

Milne goes on to say, referring to his own theory: "In our garden we grow only fowers."

I think that I have stated enough to convince you that the general theory of relativity did not receive [illegible] acceptance from many respected scholars, who have apparently tried to understand the theory. But one may ask, What was the attitude of a serious physicist (of the period say from 1925 to 1965) to general relativity? Born's remark, that the [illegible] relativity with experience is slender, is representative. I have been told that at a dinner in honor of Einstein's 70th birthday, held at the Institute for Advanced Study in 1948, Oppenheimer made remarks to the effect that general relativity had been singularly without influence in the development of physics during the period 1925–1950. Indeed, general relativity as a discipline in physics was simply ignored or at any rate neglected benignly in most institutions devoted to its study. As an illustration of this fact I might refer to the circumstance that from 1936, when I joined the faculty of the University of Chicago, to 1961, no courses in general relativity, not even for one single quarter, were given at the University. And the University of Chicago is not atypical. And I am not sure how well the principles of general relativity, as laid by Einstein, are appreciated by the common physicists of today. Where, then, does Einstein's fame come from?

It will be presumptuous of me to suggest an answer of my own to the question I have just raised. But I will give an answer given by Rutherford, during a conversation 45 years ago, at which I was present.

The conversation took place in the Senior Combination Room in Trinity College, after dinner, during the Christmas recess of 1933. During the Christmas recess, very few people normally dine in the College. On this particular occasion there were only five of us: Rutherford, Eddington, Amos (at one time, during the 1920s, the Chief Judicial Advisor to the Egyptian government), DuVal (a distinguished geometer), and myself. After dinner, we all sat around a fire and in the ensuing conversation Rutherford was in great form.

At some point during the conversation, Amos turned to Rutherford and said:

> "I do not see why Einstein is accorded a greater public acclaim than you. After all, you invented the nuclear model of the atom; and that model provides the basis for all of physical science today and it is even more universal in its applications than Newton's laws of gravitation. Whereas granted that Einstein's theory is right—I cannot say otherwise in the presence of Eddington here—Einstein's predictions refer to such minute departures from the Newtonian theory that I do not see what all the fuss is about."

Rutherford, in response, turned to Eddington said: "You are responsible for Einstein's fame." And more seriously, he continued:

> "The war had just ended; and the complacency of the Victorian and Edwardian times had been shattered. The people felt that all their values and all their ideals had lost their bearings. Now, suddenly, they learned that an astronomical prediction by a German scientist had been confirmed by expeditions to Brazil and West Africa and, indeed, prepared for already during the war, by British astronomers. Astronomy had always appealed to public imagination; and an astronomical discovery, transcending worldly strife, struck a responsive cord. The meeting of the Royal Society, at which the results of the British ex-

peditions were reported, was headlined in all the British papers; and the typhoon of publicity crossed the Atlantic. From that point on, the American press played Einstein's [illegible]

I could see from Eddington's reaction that he agreed with Rutherford; and he, in turn, recalled some events of that time.

Let me go back a little to tell you about the circumstances which gave rise to the planning of the British expeditions. I learned of the circumstances from Eddington (in 1935) when I expressed to him my admiration of his scientific sensibility in planning the expeditions during "the darkest days of the war." To my surprise, Eddington disclaimed any credit on that account—indeed, he said that, left to himself, he would not have planned the expeditions since he was fully convinced of the truth of the general theory of relativity! And he told me how the expeditions came about.

In 1917, after more than two years of war, England enacted conscription for all able-bodied men. Eddington, who was then 34, was eligible for draft. But as a devout Quaker, he was a conscientious objector; and it was generally known and expected that he would claim deferment from military service on that ground. Now the climate of opinion in England during the war was very adverse with respect to conscientious objectors: it was, in fact, a social disgrace to be even associated with one. And the stalwarts of Cambridge of those days—Larmor (of the Larmor precession), Newall, and others—felt that Cambridge University would be disgraced by having one of its distinguished members a declared conscientious objector. They therefore tried through the Home Office to have Eddington deferred on the grounds that he was a most distinguished scientist and that it was not in the long-range interests of Britain to have him serve in the army. (The case of Moseley, who discovered the concept of atomic number and who was killed in action at Gallipoli, Turkey, was very much in the minds of the British scientists at that time.) Larmor and the others nearly succeeded in their efforts.

A letter from the Home Office was sent to Eddington; and all he had to do was to sign his name and return it. But Eddington added a postscript to the effect that, if he were not deferred on the stated grounds, he would claim it on conscientious objection any way. This postscript, naturally, placed the Home Office in a logical quandary: a confessed conscientious objector "had to be sent to a camp." Larmor and others were much annoyed. Eddington told me that he could not understand their annoyance; and as he expressed himself, many of his Quaker friends found themselves in camps in northern England "peeling potatoes" for holding the same convictions and he saw no reason why he should not join them. In any event, at Dyson's intervention—as the Astronomer Royal, he had close connections with the Admiralty—Eddington was deferred with the express stipulation that if the war should have ended by 1919, he should lead one of two expeditions that were being planned for the express purpose of verifying Einstein's prediction with regard to the gravitational deflection of light.

In any event, Eddington clearly realized the importance of verifying Einstein's prediction with regard to the deflection of the light from the distant stars as it grazed the solar disc during an eclipse. It is best that I continue the story in Eddington's own words:

"In a superstitious age a natural philosopher wishing to perform an important experiment would consult an astrologer to ascertain an auspicious moment for the trial. With better reason, an astronomer today consulting the stars would announce that the most favorable day of the year for weighing light is May 29. The reason is that the sun in its annual journey round the ecliptic goes through fields of stars of varying richness, but on May 29 it is in the midst of a quite exceptional patch of bright stars—part of Hyades—by far the best starfield encountered. Now if this problem had been put forward at some other period of history, it might have been necessary to wait some thousands of years for a total eclipse of the sun to happen on the lucky date. But by strange good fortune an eclipse did happen on May 29, 1919 . . .

Attention was called to this remarkable opportunity by the Astronomy Royal (Sir Frank Dyson) in March 1917; and preparations were begun by a committee of the Royal Society and the Royal Astronomical Society for making the observations.

Plans were begun in 1918 during the war, and it was doubtful until the eleventh hour whether there would be any possibility of the expeditions starting . . . Two expeditions were organized at Greenwich by Sir Frank Dyson, the one going to Sobral in Brazil and the other to the Isle of Principe in West Africa. Dr. A.C.D. Crommelin and Mr. C. Davidson went to Sobral; and Mr. E. T. Cottingham and the writer went to Principe.

It was impossible to get any work done by instrumentmakers until after the armistice; and as the expeditions had to sail in February, there was a tremendous rush of preparation. The Brazil party had perfect weather for the eclipse; through incidental circumstances, their observations could not be reduced until some months later, but in the end they provided the most conclusive confirmation. I was at Principe. There the eclipse day came with rain and cloud-covered sky, which almost took away all hope. Near totality the sun began to show dimly; and we carried through the program hoping that the conditions might not be so bad as they seemed. The clouds must have thinned before the end of totality, because amid many failures we obtained two plates showing the desired star-images. These were compared with plates already taken of the same star-field at a time when the sun was elsewhere, so that the difference indicated the apparent displacement of the stars due to the bending of the light-rays in passing near the sun.

As the problem then presented itself to us, there were three possibilities. There might be no deflection at all; that is to say, light might not be subject to gravitation. There might be a 'half-deflection,' signifying that light was subject to gravitation, as Newton had suggested, and obeyed the simple Newtonian law. Or there might be a 'full deflection,' confirming Einstein's instead of Newton's law. I remember Dyson explaining all this to my companion Cottingham, who gathered the main idea that the bigger the result, the more exciting it would be. 'What will it mean if we get double the deflection?' 'Then,' said

Dyson, "Eddington will go mad, and you will have to come home alone."

Arrangements had been made to measure the plates on the spot, not entirely from impatience, but as a precaution against mishap on the way home, so one of the successful plates was examined immediately. The quantity to be looked for was large as astronomical measures go, so that one plate would virtually decide the question, though, of course, confirmation from others would be sought. Three days after the eclipse, as the last lines of the calculation were reached, I knew that Einstein's theory had stood the test and the new outlook of scientific thought must prevail. Cottingham did not have to go home alone."

It was some months before the two expeditions returned to England and the participants were able to measure their plates and collate their results. But rumors of the successful confirmation of Einstein's prediction reached Einstein in early September 1919. And on September 22, 1919, the Dutch physicist, Lorentz, sent Einstein a telegram confirming the rumors to which Einstein replied (also by telegram), "Heartfelt thanks to you and Eddington. Greetings." Einstein's own satisfaction with the outcome of the British expeditions is shown by the postcard dated September 27, 1919) to his ailing mother in Switzerland. It said:

"Dear Mother: Good news today. H. A. Lorentz has wired me that the British expeditions have actually proved the light deflection near the Sun . . ."

There is a further anecdote relative to Einstein's reaction to the news from England which I should like to recall. Rosenthal-Schneider, a student of Einstein in 1919, recalls that Einstein showed her the cable from Eddington informing him of the successful verification of his prediction. And she asked him, what if there had been no confirmation of his prediction? Einstein's response was: "Then I should have been sorry for the dear Lord but the theory is correct."

The Times of London for November 7, 1919, carried two headlines: "The Glorious Dead, Armistice Observance. All Trains in the Country to Stop," and "Revolution in Science. Newtonian Ideas Overthrown." The second of these headlines referred to the meeting of the Royal Society in London on November 6 at which Dyson had reported on the results of the British expeditions.

Whitehead's account of this meeting of the Royal Society has often been quoted. It is worth quoting once again:

"The whole atmosphere of tense interest was exactly that of the Greek drama: we were the chorus commenting on the decree of destiny as disclosed in the development of a supreme incident. There was dramatic quality in the very staging—the traditional ceremonial, and in the background the picture of Newton to remind us that the greatest of scientific generalizations was now, after more than two centuries, to receive its first modification. Nor was the personal interest wanting: a great adventure in thought had at length come safe to shore."

The meeting of November 6, 1919 of the Royal Society also originated a myth that persists even today (though in a very much diluted version): "Only three persons in the world understand relativity." Eddington explained the origin of this myth during the Christmas-recess conversation with which I began this account.

Thomson, as President of the Royal Society at that time, concluded the meeting with the statement: "I have to confess that no one has yet succeeded in stating in clear language what the theory of Einstein's really is." And Eddington recalled that as the meeting was dispersing, Ludwig Silberstein (the author of one of the early books on relativity) came up to him and said: "Professor Eddington, you must be one of three persons in the world who understands general relativity." On Eddington demurring to this statement, Silberstein responded, "Don't be modest Eddington." And Eddington's reply was, "On the contrary, I am trying to think who the third person is!"

The myth that general relativity is a difficult theory to understand has done immeasurable harm to the development of the theory. The fact is that the theory of general relativity is no more difficult than many other branches of physics. General relativity, at the time it was founded, required familiarity with a mathematical discipline which physicists had not encountered before that time. But that has also been the case with several other branches of physics, including quantum mechanics.

I cannot conclude this account, relating to the verification of Einstein's prediction concerning the deflection of light by a gravitational field and how that was responsible for his becoming "a focus of widespread adoration," without remarking that the history might well have been very different.

In 1911, Einstein had calculated, on the basis of his principle of equivalence, the deflection that light, grazing an object, such as the sun, will experience. The principle of equivalence correctly accounts for the slowing of a clock in a gravitational field; but it gives for the deflection of light only half the value predicted by general relativity. Roughly speaking, one might say that one-half of the predicted effect is the result of the slowing down of the time-measuring process; and that the other half is due to the spatial curvature of space time. The latter effect is an essential aspect of general relativity.

The German astronomer, Freundlich, had planned to test Einstein's prediction of 1911 at an eclipse of the Sun which occurred in Russia in 1914. But the war intervened; and Freundlich was unable to make the observations he had planned. As Hoffmann and Dukas have said:

"Suppose the war had not come and Finaly Freundlich had been able to observe the 1914 eclipse and had found a deflection of 1.7 seconds of arc at a time when Einstein was predicting a deflection of only 0.83 seconds of arc. Imagine how tame Einstein's 1915 calculation of 1.7 seconds of arc would have seemed . . . He would have been belatedly changing the value after the event, having first been shown to have been wrong . . . and the deflection of light would have lost the tremendous impact that it had as a prediction."

But the war had in fact intervened; and the predicted deflection had been confirmed under circumstances described by Rutherford. And as Eddington wrote to Einstein in December 1919:

"All of England has been talking about your theory. It has made a tremendous sensation . . . It is the best possible thing that could have happened for scientific relations between England and Germany."

Are we to conclude then that the unique place in physics which Einstein is accorded is an accident of circumstances? I do not think so. The testimony for his uniqueness comes from those who, serious students of science themselves, are caught in the web of the magic of Einstein's theory and feel, as Weyl felt, that a wall obscuring truth collapses when we explore the richness of his theory.

In saying this, I do not wish you to conclude that those who marvel at the content of Einstein's theory form a cult of some sort. That would be the case, if one's admiration for the theory was derived from a distance, as Born has stated, or as a "work of art" as Rutherford and Thomson have stated. The simple fact is that Einstein's theory is incredibly rich in its content and presents glittering faces at every turn. Let me be specific and illustrate what I mean in a concrete way.

I am sure that all of you are familiar with the role black holes have been publicized to play in current astronomical developments. Let me say at once that I do not associate myself with those who consider black holes as exotic objects predicted by general relativity. Exotic means grotesque, bizarre; and there is nothing grotesque or bizarre about black holes.

We are all aware that a body projected from the earth, for example, cannot escape the earth's gravitational field unless it is projected with a sufficient speed; otherwise, it will simply fall back. Once we grant that light is deflected by a gravitational field—as, indeed, we must—then it is a matter of simple arithmetic to calculate how strong the gravitational field must be if a particle, projected with a velocity equal to that of light, cannot escape. This calculation was, in fact, made by Laplace as long ago as 1798, even though he had no reason to suspect that light is affected by gravity.

We have seen that light grazing the Sun is deflected by the minute amount of 1.[illegible] sec of arc. But if the Sun, instead of its present radius of 700000 km should be compressed to a sphere of radius $2\frac{1}{2}$ km, then at that radius, the gravitational field would be strong enough to prevent light from escaping from the surface; and we should cease to see it; it would have become a black hole.

The contraction of a star with a solar mass to a radius of $2\frac{1}{2}$ km does not require us to postulate physical conditions with which we are not familiar. The mean density of matter at that radius is no different than in ordinary atomic nuclei. The physical conditions required for the occurrence for stellar masses to become black holes are, therefore, entirely within the realm of reason. The question is rather whether such physical conditions can be realized in nature and in the natural course of events. Let me categorically state that very simple and quite elementary considerations relating to the last stages in the evolution of massive stars, i.e., stars with masses exceeding say five solar masses, require the formation (barring accidents in every case) of black holes. This is a story which is fascinating in itself, but is not the story I wish to tell now. Rather I want to turn to what the general theory of relativity has to say with regard to black holes.

One might think, that if all that is required for black holes to occur are sufficiently strong gravitational fields, then black holes of diverse shapes, forms, and sizes should be possible. For example, the external shape and size that a gravitating object can have in Newtonian theory are infinitely diverse: they will depend on the mass, the stratification of density, and temperature in the interior, whether it is rotating or not; and if it is rotating, whether it is rotating uniformly or not, and how fast it is rotating; and a whole variety of other factors. But very remarkably, on the general theory of relativity, black holes belonging to one family and of only one kind can occur. This family of solutions was discovered by Kerr, a New Zealand mathematician, in 1962. Kerr's solution provides the basis for an exact representation of all black holes that can occur in the astronomical universe.

It is not only that Kerr's solution is unique: there is an explicit formula which one can write for it. This is a startling and an unexpected consequence of the general theory of relativity. Besides, the geometry of the space-time around a Kerr black hole has many remarkable features. For example, in Kerr geometry all the standard equations of mathematical physics can be solved exactly; and we are also led to [illegible] of a kind one had never suspected.

I do not know to what extent the foregoing remarks appear convincing to you. But the point I wish to make is that the general theory of relativity is incredibly rich in its content; and as I said, one finds a glittering face at almost every turn. Einstein was certainly correct in his prediction of 1915 that "anyone who fully understands the theory" cannot escape from its magic. If some remote and presently unforeseen development requires a modification of Einstein's theory within its own well defined framework of validity, then we should indeed have reason to "be sorry for the dear Lord."

Coherence, abstraction, and personal involvement: Albert Einstein, physicist and humanist

Yuval Ne'eman

After reviewing Einstein's main contributions to physics in the light of present-day results, the author analyses the need for and the importance of a coherent body of theory, and cases in which this body may not be attainable. The role of invariance principles is reviewed, as well as the method of abstraction. Finally, the author touches upon Einstein's involvement in non-scientific issues-pacifism, the anti-Nazi struggle, nuclear disarmament, and Zionism.

Stature of the man

I can't help but feel deeply moved whenever I look at Herblock's cartoon in The Washington Post published on a certain day of April, 1955. The cartoon is a wide-angle view of the universe, showing scores of planets floating by. One of these is special, carrying a sign which reads, 'Albert Einstein lived here'.

In the procession of minds which have led and shaped the progress of mankind since the beginning of recorded history, Albert Einstein does stand out uniquely. Herblock has replaced the earth's family album of two hundred historical generations, and only one Einstein, by a congruent set of two hundred Einsteinless planets less one. This poetic abstraction manages to convey a moving message, more subtle and more powerful than a direct statement. (Such mechanisms are being studies in the modern theory of linguistics.) In my view, the broader and deeper impact is due to the abstracted message's capability of evoking an abundant and resonant set of thought associations. In what will follow, we shall be able to assess and juxtapose the force of abstraction in the scientific context.

It is worthwhile providing the non-physicist reader with some indication of the man's achievements in physics, justifying Herblock's cartoon-poem. Indeed, whatever Einstein's impact on the non-physics world, be it pacifism, Zioism, nuclear preparedness or nuclear disarmament, all world-important as they may be, his special place in history is due solely to his physics. The rest constituted an important part of this personality-that of an involved scientist-but its effectiveness was due first and foremost to his stature as a physicist. This is also true of his other intellectual pursuits, including philosophy and music. In the case of philosophy, it is true even though that discipline's specific historical role as an ersatz-science suffered major collapse at his touch(in the matter of the conception of time and of space-time)similar to that of the Church after its collision with Copernicus and Galileo. The Church later wisely retreated into the domain of ethics, where it may be safe for a while as a source of doctrine. (Of course, it has to be attentive to scientific and technological developments-birth control, biological engineering, etc.- and try hard to find the best ethical answers; otherwise it will loss ethics to some more efficient humanism). Likewise, post-Einstein philosophy has abandoned metaphysics and the direct weighing of natural concepts, leaving them to the relevant sciences, and entrenching itself in epistemology and the study of the scientific method. In this field, it is doing well and has enriched our understanding. As to the rest of philosophy, logic has been reshaped after Cantor as a branch of mathematics. In the last century, politics has been replaced by the social sciences. Aesthetics and ethics are still there, in that region where the scientific method has not yet found its [illegible]

Brownian motion and relativity

Had Einstein's contributions to physics been less outstanding in their originality, depth and overall importance, they would still have put him in the first row, considering their number and versatility. They straddle most topics and fields which were being dealt with up to the 1930s. In thermodynamics, he co=invented the modern statistical mechanics approach, independently and simultaneously with W. Gibbs. In quantum theory, he elaborated on Planck's idea of the quantum of action, and relaunched the corpuscular theory of light in what later became its dual particle-wave nature. In this programme, he conceived identical-particle statistics (simultaneously with S.N. Bose, but independently) and explained the photo-electric effect (which we deactivate and reactivate every time we cut the beam at the entrance to a bank or a lift). These are just some examples of his less epoch-making work. Recently, I was talking to a professor of material science about the modern 'composite materials' which have become very important in aeronautics, for instance. It turns out that the formalism utilized in the study of these materials is based on the young Einstein's first paper, on Brownian motion (in both cases one is dealing with cores of material A embedded in a background matrix of material B).

Einstein's most important contributions came under the headings of the special and general theories of relativity. We shall discuss the epistemological and metaphysical lessons from these principles in detail in what will follow, but what is relevant to Einstein's personal achievement is the fact that both dealt with the fundamental properties of space and time, and modified them completely. As to the role of Einstein, it has been said that special relativity would have been discovered within a year by either Lorentz or Poincare, if Einstein had not done it. The subject was on the highest priority list of the scientific frontier,; there was a negative experimental result to be explained (the failure of Michelson and Morley in their attempt to measure the ether's drift velocity); G.F. Fitzgerald and Lorentz had already calculated the "Apparent" contraction of lengths in a moving coordinate frame, and Poincare was aware of the mathematical group-structure required from such transformations. The difficulty lay in the missing time-dilations, which were the hardest conceptually. Einstein supplied them, together with a change in the interpretation of the entire set of transformations. Rather than think of artificial 'apparent' or 'effective' changes in matter, due to internal collapse forces, he realized that these were just the specific properties of space-time, the geometrical manifold in which we exist, the geometrical manifold in which we exist, Instead of a Euclidean or Galilean structure, this manifold preserves the velocity of light (philosophers could never have guessed at this preferred role of the velocity of light, as against that of sound, for instance). Einstein's former teacher H. Minkowski soon gave the system its formal geometric characterization. Everything stems from the requirement that the speed of light be the same for all observers moving at constant velocities with respect to each other. Einstin's 1905 contribution (he was twenty-six in that year in which he launched a series of five articles of the highest-impact model) was thus most important, but it is plausible to assume that by 1908 or 1910 it would have been done by others.

An intellectual pursuit

The story of Einstein's theory of gravitation(the general theory of relativity) is very different. He worked on it for ten years, and published it in 1916. He had got some partial answers several years earlier and published them. He had been helped by Marcel Grossmann, a former fellow student and now a mathematician, and by David Hilbert, one of the greatest mathematicians of this century. Still it was Einstein himself who was obstinately pursuing the goal and building his theory step by step. In the outcome, general relativity is probably the finest achievement ever produced by a scientific mind. Note that the urge to resolve the problem of adapting Newton's gravitation and mechanics to the requirements of special relativity was an entirely intellectual pursuit. There was no pressing experiment to be explained. The topic appeared to most scientists as too far-fetched at that stage.

And when it came to the formulation of the new theory, the 1905-1906 conceptual understanding of space-time and of matter residing in it had to be changed again One clue used by Einstein was a Newtonian 'coincidence', i.e. the equality of inertial mass to gravitational mass. It had indeed been checked experimentally with great precision, and thus strengthened Einstein's motivation. His intuitive understanding required the new theory of produce 'Mach's principle', a scientifically unsubstantiated but philosophically appealing view, published by Ernst Mach before relativity, in which the inertial forces should themselves result from a gravitational interaction with the distant masses of the universe. With all this, it can be said that another fifty years at least might have passed before the advent of general relativity-had Einstein himself not done it. It might even never have been done at all, though it does resemble some of our current theories(which have, however, general relativity as their model).

From relativity to cosmology

Consider that we have nowadays several similar incompatibilities, e.g. since 1925 between gravitation itself and quantum mechanics. We have not solved the latter problem in fifty-four years, with very many people working on it-although we may be very close now. I believe that bridging the gap between Newtonian physics and the new kinematics of special relativity (which were obeyed by the electromagnetic theory of Faraday and Maxwell) was a comparable task, and it was done almost single-handedly within ten years. Moreover the theory has withstood every experimental test in the last sixty-three years. It has stayed unmodified while everything else has had to be changed or supplemented. Intrinsically, it has a tremendous aesthetic appeal, beyond Chartres or the Taj Mahal in its monumental simplicity, together with an overwhelming power. One very rarely comes across the words 'aesthetic', beauty, etc., in textbooks of theoretical physics. It is thus noteworthy that the feelings

I express here must have been felt by many, if not all, physicists—as witnessed by this line in a famous and excellent textbook by L.D. Landau and E.M. Lifshitz (otherwise written in an extremely dry and unpersonalized style):

The theory of gravitational fields, constructed on the basis of the theory of relativity, is called the general theory of relativity. It was established by Einstein (and finally formulated by him in 1916), and represents probably the most beautiful (my emphasis) of all existing physical theories. It is remarkable that it was developed by Einstein in a purely deductive manner and only later was substantiated by astronomical observations.

After general relativity, Einstein invented cosmology in 1917. This is a field which has been very lively in the last fifteen years, thanks to new observational material. An alternative approach to cosmology, modifying Einstein's theory, was suggested by a British group in 1948. Though it became very popular at the time, the 'steady-state theory', as it was called, has not been vindicated by observations, and Einstein's equations for cosmology still hold.

Einstein's last twenty years were spent in an attempt to unify electromagnetism with gravitation. He idid not achieve that aim, but since 1976 the prospects of such a unification have improved, and a look at Einstein's results shows he was on the right track, anticipating some features of work in progress.

The coherence of science.

We have thus seen that Einstein's greatest contribution has consisted in the construction of a more general and more fundamental theory, removing the incompatibility between Newtonian mechanics, based on Galilean kinematics with no preferred velocity (and on action at a distance), and the Einsteinian Kinematics of special relativity, discovered by Einstein himself, as well with those of Faraday-Maxwell electromagnetism. Incidentally, these two clashing theories themselves had been considered, prior to Einstein's achievement, as realizing the final axiomatic-deductive and aesthetic ideals required of a physical theory.

Most developments in theoretical physics deal with the removal of an incompatibility, but on a different scale. Generally, one has a theory and comes across a new observation which appears not to fit. Often, the observation itself results from an attempt to test the theory, in the spirit defined by Karl Popper as 'falsification'. The results is generally a modification of the theory, a weakening of one of its postulates. A new free parameter is allowed. In some cases (such as the discovery of time-reversal asymmetry at the fundmental level in 1964), it may require the introduction of an entirely new force. For the Michelson-Morley negative result, it even required a fundamental change in bur conception of space-time. But in the case of general relativity, the problem was of another magnitute: to remove the basic incompatibility between two full-fledged and well-grown theories. This is why the answer had to reach that deep. That an answer could be found is in itself an extremely important epistemological clude.

The entire scientific programme is based on this success. There is little a priori understanding of why the physical world should obey a mathematical description, even if we believe in the strength of logic and know that mathematics is its most direct realization. The world could still be inextricably complicated and self-interacting, and there would then be no way of guaranteeing the existence of a coherent and complete mathematical system describing it, based upon human observations. Indeed, the gap between disciplines is generally to be found in such regions.

For example, we now have in E. Schrodinger's equation (1925) of quantum mechanics an equation capable in principle of describing correctly any atom (even uranium with 239 protons and neutrons and ninetytwo orbiting electrons) of molecule (even DNA with its millions of atoms). Thus the whole of chemistry and perhaps biochemistry are contained in this one equation. However, the actual calculations become unmanageable beyond two or three electrons or nucleons (protons and neutrons). We have to rest satisfied with the knowledge that the problem is not one of principle but of practical computation, and chemistry continues to evolve at its own composite-structure level. Indeed, G.F. Chew had suggested in the early 1960s that such a situation had arisen for the strong interactions (the nuclear glue). Happily, the 1970s have brought some answers which may resolve those difficulties.

Gaps and more gaps

Conceivably, unbridgeable gaps might exist between various theories dealing with diffent elements or aspects at the fundamental level. Einstein's achievement encourages us to think that this is not so, and that if we explore deeply enough, we might well achieve a coherent structure. There are nowadays several such gaps which seem to us like real abysses, and it is good to know that one should persevere and not rest satisfied with disconnected theories.

Such a gap existed between quantum mechanics and special relativity. It was effectively bridged in 1948, after twenty years of hard labours. But though this was done by some of the greatest physicists of that period- Dirac, Pauli, Weisskopf, Feynman, Schwinger, Tomonaga, Dyson, to cite just a few names-it was left without the Einsteinian 'polish'. To this day, the theory lacks a proper mathematical foundation. It is operationally wonderful, yielding the most precise results in any science, yet every such calculation involves a cancellation of infinities on both sides of an equation, i.e. a mathematically unsound operation. Surely, the theory deserves a better foundation, which probably would still yield the same operational results. The search has been on since 1948, and more intensely since the mid-195os, but the end is still not in sight.

Another such gap exists between gravitation and the other interactions (or forces) in nature: electromagnetism, the Fermi (short-range) weak interactions (such as radioactive beta decay) and the strong interactions (also short ranged, responsible for the glueing together of nucleons in the nucleus). This is related to Einstein's last and unfinished programme. We have recently witnessed (1960-73) what may possibly be the ad hoc operational merger of weak and electromagnetic interactions into a coherent 'electroweak' interaction. The evidence in 1979 is highly favourable, but the crucial test will be available around 1982. Again this is at present a very ad hoc wedding, with none of the aesthetic impact of Einstein's work. This success has [illegible] many of us to renew the search for the other missing connections between interactions. In particular, many of us are studying a possibly new link between gravity and the other forces, which may at the same time resolve the incompatibility of general relativity and quantum mechanics. This approach, called supergravity, has intrinsic beauty, but it has not yet led to the correct operational wedding, so to speak; the search goes on.

Invariance principles
and geometrization

One tool which was used by Einstein in both special and general relativity is the application of invariance principles. E. Whittaker has named them 'postulates of impotence', though they are highly potent in their results. 'It is impossible to pick a preferred frame of reference in space-time' is the wording of the Einstein invariance postulates, first for 'inertial frames' only (special relavitity), then 'non-inertial' (i.e. accelerated) frames for general relativity. The first resulted in kinematical restrictions which are expressed by ten conservation laws (energy-momentum and generalized angular momentum). Indeed, a theorem proved by E. Noether, a female student of Hilbert and later his colleague (though the Gottingen faculty refused to grant her a professorship, finally using the argument that there was a only a men's room in the Senate building), states that for every invariance (or symmetry) there will be a conservation law and vice-versa.

The negative content of the postulate of impotence is in fact the bold step of generalization taken by the new theory. To achieve coherence one has to look for a more general foundation, i.e. for simplicity. Simplicity is then achieved by this indistinguishability. One frame of reference is as good as another: here is the simplicity. However, for the laws of nature to obey such sweeping generalizations, tremendous sophistication may be needed in the dynamics. In general relativity-and in all the more recent 'gaugetheories' inspired by it-this is indeed the situation. These are stronger, local invariance principles-local in the sense that we may even change our preferred frames of reference at different points in space-time. Any such local invariance postulate then requires the existence at every point of a new 'field' which compensates for and cancels completely the changes we are producing in arbitrarily applying our freedom of choice at each point. Such is the role of the gravitational field, and a similar part is played by the electromagnetic field, or perhaps the electroweak, combining electromagnetism and weak interactions. We experience these forces directly, but the justification for their presence, and the understanding of their full action, required this identification of their role as guardians and preservers of simplicity through a Leibnitzian relativity (or indistinguishability) applied locally in spacetime.

The other key feature introduced by Einstein was geometrization. In his theory of gravitation, all of physics could be represented as motions in curved space-time. The curvature is another embodiment of the same stresses and compensating forces mentioned in the previous paragraph. Indeed, we have recently learned that such a picture is in the background of all our new gauge theories. Einstein had set up this idea of a geometrized theory and, for some sixty years, it looked as if only gravitation would be affected-with all other forces moving in different directions. Suddenly, the light on the scene has changed. It seems that we are all heading for geometry.

Abstraction

A physicist's mind undergoes a constant struggle between (a) the wish to remain close to the perceptions and observations and (b) the need to look for abstract formulation, required by generalization. If one had to provide one theory for each observation one could stay at that level. For a theory to encompass the largest possible set of observations, it has to abandon the actual observables and move to a deeper and more abstract level. Aristotle was trying to avoid abstraction in his physics, and studied motions which were all taken from daily experience and thereby entailed forces of friction. In such a milieu, force is proportional to the 'final' velocity, as was calculated in the first half of the last century by G.G. Stokes. Aristotle thus postulated such a law-which was superficially simple but described a non-simple situation. This law of force-velocity proportionality could not be generalized, and obstructed progress.

simple formalism fitted this/

Newton imagined a vacuum, and stated his laws in this 'unnatural' background. His/simple picture-and Newton's abstraction won. 'Force is proportional to acceleration' is a generalizable statement and does not involve one particular force (friction in Aristotle's case). Einstein followed the same path and started from a highly abstract picture of a generalized manifold. His theory did achieve the aims he had set, including Mach's principle, but its abstract structure made it capable of going even beyond that image. Einstein's theory handles situations (such as Godel's 'universe', a universe in which time is cyclic) which go beyond Einstein's intuitive goals (including non-Machian universes). Indeed, Einstein himself started this testing of his theory as a theory of the universe (cosmology), beyond its role as a theory of gravitation.

In this abstractive jump, the creative scientist sometimes has to free himself-and us-from some preconceived notion, whether based on sense perceptions or on conditioning and prejudice. It has happened many times-e.g. accepting that the world is round (an ancient Greek discovery, forgotten in mediaeval times until it was re-established in the Age of Discovery). Copernicus and Galileo had to struggle hard to replace the earth by the sun at the center of the system of planets. Darwin had to fight prejudice when he announced the common ancenstry of men and apes. Einstein's original shock action was his dethronement of Chronos, immutable time. To this very day you will find some partisans of 'common sense' time who still have not absorbed the message, after a huge amount of direct observational evidence. Remember, indeed, that although the good theory requires abstraction, it also has to be experimentarlly testable, 'falsifiable' in Popper's words. A theory which can never be tested is devoid of any scientific value. Einstein's gravitational theory, general relativity was accepted only after it had passed several such tests: the deflection of light when passing near the sun, the advance of the perihelion of Mercury, etc.

Does the scientific abstraction have anything to do with the artistic one we mentioned earlier? It may require similar imaginative capabilities, although its motivation and effects are very different. Somehow, the one reasonates in the subconscious whereas the other is tested by precise computation. However, that aesthetic quality of the great theories affects us in the subconscious, too. Traditionally, the scientist resides in his ivory tower. Undoubtedly a certain disconnection is essential at the conceptual stage, and mathematician, the theoretical physicist and perhaps many others could not function if they were to take part in the [illegible] the action and worries of one's surroundings. In many cases, the process is irreversible. However, both the decision to leave the ivory tower and that of returning to it are the individual scientist's personal problem.

With Einstein, the sense of justice and worry about his fellow men were strong motivations which led him out of his personal tower after 1914. The outbreak of the First World War caused him to lend his name and energies to pacifism. He could see no sense in that war which was fought mostly for 'honour' or because of the assassination of an archduke. From Berlin itself, he joined Georg Nicolai in a manifest to the 'Europeans', transcending the various nationalisms.

Around 1920, he involved himself in Zionism. I shall discuss this aspect in more detail, having been personally interested in it for obvious reasons. To come back to pacifism, the outbreak of the Second World War brought a different response. Nazi Germany was our nemesis; it was extending its domination over the whole of Europe and bringing in its wake prejudice and persecution, mostly racial. It was every free man's duty to help stop Nazism and (we hoped) break its power. At the suggestion of Szilard and Wigner he sent his famous letter to Roosevelt which influenced the decision to start the American nuclear project. There is no doubt that he was right in fearing for the fate of the world in case the Nazis should succeed with their own atomic energy programme. Hitler had the right intuition about the development of weapons, to the point where one new weapon could win the war. (I shall always remember the speeches in which he mentioned Germany's 'secret weapon'. It turned out that he erred in the actual choice, putting all his weight behind rockets instead of nuclear weapons.

After the fall of Nazi Germany, Einstein's sense of human responsibility made him an initiator of nuclear disarmament, an aim which led him to the Russell- Einstein manifesto. It is invigorating to see how he could be moral and at the same time pragmatic. He was not a starry-eyed intellectual dealing with an unfamiliar world. He understood the realities and reassessed the situation at each stage, rather than taking one dogmatic stand throughout.

Einstein and the political life

He could be courageous and daring in his decisions, as exemplified by his stand against Joseph McCarthy. There was a time when Einstein's was one of the relatively few dissenting voices to be heared in the United States.

We now come to Zionism. Einstein espoused this cause between 1914 and 1919, coming to the conclusion that the creation of the Jewsih State in Palestine was indeed the only way of saving his fellow jews. To be sure, the League of Nations mandate to Great Britain, with the explicit aim of making Palestine the Jewsih 'national home', made him very happy. 'What pleases me the most is the realizing of the Jewsih State in Palestine', he wrote to Ehrenfest. His forst visit to America, in 1921, was as a Zionist emissary, together with Chaim Weizmann, the future first president of Israel. Einstein's role was to collect the people and the means for the creation of the Hebrew University in Jerusalem. He was later the first chairman of its board of trustees.

After 1921 Einstein took an active part in the general Zionist effort by writing a large number of articles and addresses. Beyond physical salvation for the persecuted (which finally came too late for six million Jews of Central and Eastern Europe), he was considering the effect on the Jew of the Diaspora: 'I am a national Jew in the sense that I demand the preservation of the Jewish nationality as of every other. I look upon Jewish nationality as a fact... I regard the growth of Jewish self-assertion as being in the interests of non-Jews as well as Jews. That was the main motive in my joining the Zionist movement' (from a speech made in the United Kingdom in 1921 upon his return from the American trip). Again: 'I have always been annoyed by the undignified assimilationist cravings and strivings which I have observed in so many of my friends' (from the same speech).

In 1923, Einstein visited Palestine. He kept a dairy which reflects his emotions. In Jerusalem he gave a lecture and laid the cornerstone of the future university. He was asked to stay and settle in Jerusalem and noted in his dairy 'the heart says yes, but the mind says no'. Retrospectively, I am not sure he made the right decision at that point. True, Palestine was still an intellectual desert as far as the sciences were concerned, but his own immigration-perhaps by the 1930s-might have accelerated that development and still enabled him to continue his work.

The temptations of leadership

In Tel Aviv he was taken by the local enthusiasm and joined a group of young German Zionists who were laying bricks in an apartment building. He enjoyed this experience of creative manual labour, though he later often wondered whether the Jewish return to the land would not inhibit the intellectual capacities developed in the Diaspora.

During the 1930s and 1940s he was active in fund-raising but was also interested in the political developments. In 1932 he said in a speech in Los Angeles that 'the Zionist goal gives us an actual opportunity to put into practice, through a viable solution of the Jewish-Arab problem, those principles of tolerance and justice that we owe primarily to our Prophets'. Often he pressed for compromise -but there was no response from the other side, which considered Zionism as an intrusion. In the onslaughts of 1936-39, and in the six-nation Arab invasion of 1948, he stood for firmness and the absolute necessity of defeating aggression.

In 1952, upon Weizmann's death, it was only natural that Einstein should be asked to succeed him as president of Israel. He had indeed become a symbol to all Jews and Israelis, a unifying personality and a central link. He declined the offer, fearing over-involvement, and wrote: 'I am the more distressed over these circumstances because my relationship to the Jewish people has become my strongest human bond, every since I became aware of our precarious situation among the nations of the world'.

. . . .

The excellence of Einstein's theory of gravitation

P.A.M. Dirac

Einstein gave us a new theory of gravitation connected with the curvature of space. He started a new line of activity for physicists. He set them working with non-Euclidean space. The particular kind of space that Einstein introduced was Riemann space, a space that can be embedded in a flat space of a larger number of dimensions.

Under the stimulus of Einstein various people have considered introducing other kinds of space into physics, but so far without any real success. So far as is known at present, the space introduced by Einstein is the one used by Nature.

Einstein's theory of relativity remained unknown, except to a few specialists, until the end of 1918, when the First World War came to an end. It then came in with a terrific impact. It present the world with a new style of thinking, a new philosophy.

It came at a time when everyone was sick of the war, those who had won as well as those who had lost. People wanted something new. Relativity provided just what was wanted and was seized upon by the general public and became the central topic of conversation. It allowed people to forget for a time the horrors of the war they had come through.

Innumerable articles about relativity were written in newspapers, magazines and everywhere. Never before or since has a scientific idea aroused so much and such widespread interest. Most of what was said or written referred to general philosophical ideas and did not have the precision required for serious scientific discussion. Very little precise information was available. But still people were happy just to expound their views.

I was an engineering student at Bristol University at the time, and of course the students took up this subject and discussed it extensively among themselves. But the students as well as the professors did not have precise information about it and knew nothing of the underlying mathematics. We could only talk about the philosophical implications and accept the universal belief that it was a good theory.

Three early ways to test the theory

In great Britain we had one man, Arthur S. Eddington, who really understood relativity and became the leader and the authority on the subject. He was very much concerned with the astronomical consequences of the theory and the possibilities of checking it by observations. There were three possibilities for testing the theory, which everyone soon became familiar with from the publicity given by Eddington.

Test number one involved the planet Mercury. It had been known for a long time that there was a discrepancy between the motion of this planet and the Newtonian theory. Its perihelion was observed to be advancing by the amount of 42" per century, which could not be explained by the Newtonian theory. The Einstein theory required such an advance and gave the correct amount, 42" per century. It was a wonderful success for the theory. It is said that Einstein himself was not unduly elated when he heard of this success. He was so confident that his theory had to be right.

The Einstein theory of gravitation requires that light passing close by the sun shall be deflecting. The Newtonian theory also requires a deflection, but only half the amount of the Einstein theory. So by observing stars on the far side of the sun, whose light has passed close to the sun to reach us, we can test the Einstein theory. This is test number two.

The observations can be carried out only at the time of a total eclipse of the sun; otherwise the sun's light makes it impossible to see the stars. There was a suitable eclipse in 1919. Two expeditions were sent out to observe it, organized by Eddington and one led by the astronomer. Both expeditions obtained results supporting the Einstein theory and against the Newtonian theory. The accuracy of the confirmation was only moderate, owing to the inherent difficulty of the observations. Since then, similar observations have been made at various later total eclipses. Einstein's theory has always been confirmed, although the accuracy has not been as great as one would desire.

There are redundancies to the tests.

The discovery of radio stars provided an alternative way of checking on test number two, using radio waves instead of light waves. One needs a radio source behind the sun. One just has to wait until the sun passes close in front of a radiostar and then observe whether the apparent position of the star is deflected. One does not need a total eclipse for such observations, as the sun is not a strong radio source.

The use of radio waves instead of light waves brings in a complication because radio waves are deflected by the sun's corona. But one can make observations for two different wave lengths, for which the deflection caused by the corona is different, so that it can be separated from the Einstein effect. The result is that the Einstein theory is confirmed with an accuracy much greater than that attainable with lightwaves.

The third effect which provides a means of testing the Einstein theory is the red-shift of spectral lines caused by a gravitational potential at their point of origin. The obvious place to look for this effect is in light from the surface of the sun. But the effect here is obscured by the Doppler effect coming from motion of the emitting matter. By estimating the Doppler effect one gets rough support for the Einstein theory, but it is too rough to be an effective test.

The discovery of white dwarf stars provides a better way of testing for this effect. In a white dwarf the matter is so highly condensed that the gravitational potential at the surface is very large, and so the Einstein red-shift is large. When one knows enough about the white dwarf to determine its mass and radius one can make a good test of the Einstein theory. One finds that the theory is well confirmed.

This effect can also be checked by terrestrial experiments, as was shown by R.V. Pound and G.A. Rebka. One sets up in the laboratory an emitter of electromagnetic waves and observes them at a place lower than the place of emission, where the gravitational potential is less, It is best to use gamme rays of a definite frequency for this experiment. One finds that the frequency is increased by the change in gravitational potential. The amount of this increase confirms the Einstein theory, with an accuracy greater than any astronomical test for this effect.

Recently a fourth test has been added to the three classical ones. This is concerned with the time taken by light to pass close by the sun. The Einstein theory requires a delay. This can be observed if one projects radar waves to a planet on the far side of the sun, and then observes the time taken for the reflected waves to get back to earth. With the use of radar waves the retardation is affected by the sun's corona and, again, one has to use two different wavelengths to disentangle the corona effect from the Einstein effect.

The observations have been carried out by I.I. Shapiro, and he gets good confirmation of the Einstein theory.

One can also get evidence about the Einstein theory from the observation of binary pulsars. A pulsar emits pulses of radio waves which normally have extremely high regularity. However, if the pulsar forms part of a binary system, its rotation around the other star introduces irregularities- coming from the Doppler effect associated with its motion and also from the Einstein precession effect-like the effect in rest number one in the orbit of the pulsar around its companion. This effect is very large, much larger than in the case of Mercury.

The observations give qualitative support to the Einstein theory, but one cannot make a quantative check because one does not know enough about the parameters of the binary system.

I have enumerated the success of the Einstein theory of gravitation. It is a long list, quite impressive. In every case the Einstein theory is confirmed, with greater or less accuracy depending on the precision with which the observations can be made and the uncertainties that they involve.

Can Einstein's theory always be right?

Let us now face the question. Suppose a discrepancy had appeared well confirmed and substantiated, between the theory and observations. How should one react to it? How would Einstein himself have reacted to it? Should one then consider the theory to be basically wrong?

I would say that the answer to the last question is emphatically no. The Einstein theory of gravitation has a character of excellence of its own. Anyone who appreciates the fundamental harmony connecting the way nature runs and general mathematical principles must feel that a theory with the beauty and elegance of Einstein's theory has to be substantially correct. If a discrepancy should appear in some application of the theory, it must caused by some secondary feature relating to this application which has not been adequately taken into account, and not by a failure of the general principles of the theory. One has a great confidence in the theory arising from its great beauty, quite independent of its detailed successes.

It must have been such confidence in the essential beauty of the mathematical description of nature which inspried Einstein in his quest for a theory of gravitation.

When Einstein was working on building up his theory of gravitation he was not trying to account for some results of observations. Far from it. His entire procedure was to search for a beautiful theory, a theory of a type that nature would cho[ose]. Of course it needs real genius to be able to imagine what nature should be like, just from the abstract thinking about it. Einstein was able to do it.

. . . .