[1]Einstein's Last Dream: The Space – Time Unification of Fundamental Forces

Abdus Salam

1. From the earliest times, man's dream has been to comprehend the complexity of nature in terms of as few unifying concepts as possible. In this context, in the history of physics, three names stand together; those of Newton, Maxwell and Einstein, as among the greatest synthesisers and unifiers of all times. *Newton*, some three hundred years ago, identified and unified terrestrial gravity (the force which makes apples fall) with celestial gravity (the force which keeps planets in orbit around the sun). *Maxwell*, two hundred years later, unified the forces of electricity and magnetism. He further showed that light was one manifestation of this unification. *Einstein,* in 1905, unified the concepts of space and time. Eleven years later, he could show that Newton's gravity was a manifestation of this audacious unification in the sense that Newtonian gravity signified a curvature of the united space-time manifold. The question which Einstein then asked was this: Could *Maxwell's electromagnetism* be united with *Newtonian gravity* in the same way that Maxwell had united electricity and magnetism? If so, was Maxwell's electromagnetism also a manifestation of some other geometrical property of the space-time manifold; just as Newtonian gravity was a manifestation of its curvature? This was Einstein's last dream, about which I have been asked to speak today. In 1979, it appears that Einstein's was a very valid dream and there is progress towards its realization, which I am sure he would have rejoiced to see.

2. To set the scene, let us summarize what we have known since around 1935, regarding the ultimate building blocks of which all matter in the Universe is made and the forces which govern the behaviour of matter. I shall forego introducing some concepts which are irrelevant to my theme today: stated in its simplest form, essentially all matter we see around us is made up of *four* building blocks, four basic particles. These are the two nuclear particles, the proton (*P*) and the neutron (*N*) and the two so-called light particles, the electron (*e*) and the neutrino (ν). There are *four* basic forces which govern the behaviour of these particles, when they come close to each other. These four forces are the following:

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(i) *The Gravitational Force:* All four particles (P, N, e, ν) attract each other with a force which is proportional to their *mass* . This is the force which controls the behaviour of planets, stars, galaxies and which determines the overall features of the Universe we live in.

(ii) *The Electromagnetic Force:* Of the four particles, two, the proton and the electron are electrically charged. The other two are electrically neutral. Protons attract electrons, the strength of the electromagnetic force between them being proportional to their electric charges. The proton-electron force is responsible for holding atoms together. It is this force which chiefly governs all known phenomena of life on earth.

(iii) *Weak Nuclear Force:* All particles P, N, e, ν also interact with each other through a weak nuclear force provided they are closer to each other than 10^{-16} cm, and are in a state of left polarisation. This force was discovered in the early part of this century; it gives rise to the phenomenon known as β-radioactivity and is principally responsible for the existence of heavy elements on earth and other parts of the Universe.

(iv) *Strong Nuclear Force:* Protons and neutrons carry a strong nuclear charge (in addition to the weak nuclear charge). These particles attract each other strongly when closer than 10^{-13} cm. The strong nuclear force is responsible for holding the nuclei of He, Li, Be, C, U, etc., together. The phenomena of fusion, responsible for making the sun shine, and fission which powers present generation of nuclear reactors are aspects of this force.

The picture presented above of *four* basic entities and *four* basic forces between them represents a remarkable economy in concepts. But even this remarkable economy is not enough for the physicist. Just as Maxwell and Faraday had shown that the seeming distinction between electricity and magnetism depended on whether electric charges producing these forces were stationary or in motion, in a like manner the physicist has hoped that he could unify the four seemingly distinct forces into one single basic force of which the four known ones are different facets. Einstein went further; he wished to comprehend this single unified force – assuming that it existed – as a geometrical property of the space-time manifold we live in. If this dream of unification is true, there would, of course, be measurable consequences, which would follow from the unification of forces and their enshrinement within space-time structure.

What exactly does the unification of forces mean, can be illustrated by a historical survey of the unification ideas.

3. *History of Unification Ideas in Physics*

(i) We start with the Islamic physicist Al-Biruni (working in the 11th century) and Galileo: they declared that laws of physics, discovered here on earth, apply equally to phenomena occurring elsewhere in the Universe. Galileo in particular made the concept more precise, by his observations regarding the mountains on the moon. This faith in the unity of nature now underlies the whole of science.

(ii) Newton (born the year of Galileo's death) quantitatively realized some 300 years ago, Galileo's ideas, by recognizing and postulating the law of universal gravity; in particular by showing quantitatively that the terrestrial force which governs falling bodies on earth is identical with celestial gravity – the force which keeps planets in orbits around the sun.

(iii) One hundred and fifty years after Newton, Faraday and Ampere showed that magnetic forces are produced by electric charges in motion. This was the beginning of the unification of the till-then two disparate forces of nature – electricity and magnetism.

(iv) The work of Faraday culminated with Maxwell, the centenary of whose death will fall this year in November. Maxwell showed that a manifestation of the unification of electricity and magnetism must mean the production by accelerating electric charges of electromagnetic radiation – in the form of radiant heat, light, radio and X-rays. These radiations are nothing but aspects of the electromagnetic force.

(v) Fifty years later the work of Heisenberg, Schrödinger and Dirac showed that chemical forces – among which are included all forces which govern life and neurological functions – are yet another manifestation of electromagnetism plus quantum theory.

(vi) In 1905, Einstein unified the concepts of space and time. In 1906, building on this, and generalizing the unification concepts still further, he showed that Newtonian gravity was a manifestation of the curvature of the space-time manifold. This audacious concept of a dynamic space - time led to spectacular advances in cosmology; predicting on the one hand an expansion of the universe (substantiated by the observed red shift of distant galaxies) and on the other hand predicting the 3 K remnant of a big bang which signalled the 'birth' of the Universe some 10^{10} years ago.

(vii) Finally, as the culmination of his life work, Einstein wished to see a unification of gravity and electromagnetism as aspects of one single force. In modern language he wished to unite electric charge with the gravitational charge (mass) into one single entity. Further, having shown that mass – the gravitational charge – was connected with space-time curvature, he hoped that the electric charge would likewise be so connected with some other geometrical property of space-time structure.

(viii) But where did the weak and the strong nuclear forces – and the weak and the strong nuclear charges – come into this? Gravity and electromagnetism are but two out of the four basic forces. It is here that the recent post Einsteinian developments I wish to describe are relevant.

We believe that the electromagnetic charge and the weak and the strong nuclear charges, are so akin to each other – in the fact recently shown that all these charges can only exist in discrete units – that the first stage of unification would bring electromagnetism and the nuclear forces together. Once this is accomplished a second stage of unification would unify this combined force with gravity and possibly also realize Einstein's dream of comprehending the final unified force within the geometry of space-time.

It is difficult to describe the theoretical arguments which have led us to this conclusion. But there are experimental consequences which follow from the suggestion of the unification of the electromagnetic with the weak nuclear force.

The most spectacular prediction, verified last year at the Stanford Linear Accelerator Centre was the following. If indeed the weak nuclear force is nothing but a different facet of a basic force whose other facet is electromagnetism, electromagnetism – the force between electrons and protons – when carefully examined should show some characteristics which one had in the past associated with the weak nuclear force only. One such characteristic is the distinction of force experienced by left-spinning versus right-spinning electrons. The SLAC experiment, measuring this deflection with an accuracy never before attempted, demonstrated that left-spinning electrons indeed are deflected one part in ten thousand times more than right-spinning electrons when scattered off heavy water. To one part in ten thousand – just as the theory predicted – what was previously thought of as the distinct weak nuclear force intrudes into the hitherto separate domain of electromagnetism, clinching the hypothesis that the two forces are indeed facets of one basic fundamental force and are intertwined one with the other.

There is a second prediction, even more spectacular. It states that the apparent differences – short-range character of the weak nuclear versus long-range character exhibited by the electromagnetic force – are simply a consequence of the circumstance that we happen to live in an epoch some 10^{10} years after the big bang, when the Universe has cooled to a temperature of 3 K. If we had been privileged to live and experiment one tenth of a second after the birth of the Universe, both forces, the weak-nuclear and the electromagnetic would be long range. Of course we cannot travel backwards in time; but we can quantitatively predict the precise difference in range of the weak nuclear force versus the electromagnetic. The precise prediction is that if these two forces are truly facets of a basic 'electroweak' force, then there must exist two new heavy elementary particles with masses ~ 80 and 90 times proton mass, the first charged, the second electrically neutral. The particles are predicted to be the mediators of the weak nuclear force just as the photon is the mediator of the electrical force. The European Nuclear Research Laboratory (CERN) which UNESCO helped to found in 1954, is tooling itself just now to produce the requisite energetic beams of protons and antiprotons with its new accelerator, commissioned five years ago. If suitably energetic beams can be produced, one may expect that during 1982, experiments to check if the predicted particles exist will be carried out. If such energetic beams are impossible to produce – and there are formidable difficulties in attaining the requisite intensity – one shall need a new particle accelerator with verifying energies and intensities still higher to clinch the matter. This experiment – the existence of the electroweak particles and in particular the heavy photon – is in some ways on par with the 1919 eclipse measurement of deflection of light which established Einstein's theory of gravity. This time it is the unification of the weak nuclear force with the electromagnetic which is at stake. At present all indirect experimental evidence already points in the direction that the electroweak unification hypothesis is correct, that the predicted particles do indeed exist. There are not four, but three basic forces of nature.

After this experiment is done, or perhaps simultaneously with it, there will be a test of the possible unification of the strong nuclear force with the electroweak force – reducing the four basic forces to just two. This test consists of storing 10,000 tons of water in a mine one mile deep, shielding the water from all external sources of radiation. This mass of water will be surrounded by light-detecting devices. One proton out of the 10^{33} protons which make up this mass of water will turn (in the span of a year) into a positron, emitting light of a characteristic wavelength. This will be the signal of the grand unification into one force of three of the four forces – electromagnetic, weak-nuclear and the strong-nuclear.

But what of Einstein's first dream of finally unifying this electro-nuclear force with gravity – and then the second dream of this new unified force being a manifestation of the structure of space-time? Amazingly, in the optimistic climate of physics today, these dreams also seem near to realization. It could be that space-time has extra dimensions besides the four that we are conscious of – it could be that the extra dimensions are associated with the electric and the nuclear charges just as the gravitational charge is associated with the curvature of the four space-time dimensions we are familiar with. It could be that, as suggested by Wheeler, the electric and nuclear charges are telling us about the small scale structure of space-time, of foam-like granularities, which are smoothed out when one observes coarsely. Space-time may be like some varieties of cheese with holes at places where charges are located. Some of these ideas were already formulated when Einstein lived. On some of these he worked himself. Somehow, today with the electroweak unification already in the offing, they appear near to being realized.

I was amused to read the Science and Technology section of the prestigious British journal, *The Economist,* the issue of 10 March 1979, commemorating Einstein's birthday. *The Economist* discusses the unification of forces I have described above and then goes on to say: "If nature is really that simple, and there is only one fundamental force, then industry should be thinking about its long-term research programmes. It may eventually prove sensible to harness the other forces to new technologies, by manipulating them with electromagnetism. Nobody can predict just what the applications might be. But then, when Maxwell realized over a hundred years ago, that electricity and magnetism were just different aspects of the same electromagnetic force, nobody foresaw that this would help lead to radios, telephones, televisions and the whole of electronics." Surely, Einstein never bargained for this when he dreamt about uniting Maxwell's theory with Newton's through the crucible of a dynamic space-time.

4. I wish to conclude with one thought which I would like to share with you.

There has been no one like Einstein in this century; perhaps never in the whole history of human thought, so far as physical sciences are concerned. Certainly there never has been anyone so singly responsible for so much revolutionary thinking in physics.

But how easily may Einstein have been lost, particularly if he had been born in a developing country. At the age of fifteen he was summoned by one of his teachers at the Luitpold Gymnasium in Munich; the teacher expressed the wish that Einstein leave the school. In Einstein's words "To my remark that I had done nothing amiss, he replied only, "Your mere presence spoils the respect of the class for me." This was a reference to Einstein's independence.

At the age of sixteen and a half, Einstein wished to enter the Zurich Polytechnic. He took the Entrance Examination for Engineering and, fortunately for physics, he failed. A year later, he succeeded, but by now he had given up all thought of becoming an engineer. Einstein graduated from the Zurich Polytechnic in the year 1900; he sought university positions, but failed "for I was not in the good graces of my former teachers." Einstein maintained himself by finding temporary jobs, performing calculations, private tutoring at 3 francs an hour, school-teaching. In November 1901 he submitted a research paper as a thesis for a doctorate's degree – a necessary passport for university teaching. Although this paper – his second – was accepted by the prestigious journal, *Annalen der Physik*, the University of Zurich rejected it as inadequate for a Ph D.

According to Banesh Hoffmann, Einstein felt himself sinking hopelessly in the quagmire of a world that had no place for him. A poignant episode during 1901 will illustrate what I mean. In 1901 Einstein's first research paper had been published in *Annalen der Physik*. Einstein sent a copy of this to Professor Wilhelm Ostwald – later a Nobel Laureate – with the letter:

"Since I was inspired by your book on general chemistry ... I am taking the liberty of sending you a copy of my paper. I venture also to ask you whether perhaps you might have use for a mathematical physicist... I am taking the liberty of making such a request only because I am without means..."

In spite of a second reminder there was no response from Ostwald, nor from Professor Kamerlingh-Onnes in Leiden to whom Einstein sent a similar request.

At this stage, in Banesh Hoffmann's words, a beautiful event occurred in Einstein's life of which he knew nothing. Einstein's father, an unsuccessful merchant, in ill health, and a stranger to the academic community, took it upon himself to write to Professor Ostwald. Here is his letter:

"I beg you to excuse a father who dares to approach you, dear Professor, in the interest of his son... My son Albert Einstein is 22 years old... Everybody who is able to judge praises his talent.... My son is profoundly unhappy about his present joblessness, and every day the idea becomes more firmly implanted in him that he is a failure in his career and will not be able to find the way back again... Because, dear Professor, my son honours and reveres you... I permit myself to apply to you with the plea that you read his article... and hopefully that you will write him a few lines of encouragement so that he may regain his joy in life and his work....

My son has no idea of this extraordinary step of mine."

There was still no reply. Eventually as is well known, in 1902 Einstein did find a job at the Swiss Patent Office – first as Probationary Technical Expert, Third Class and then with a promotion to Engineer, Second Class. It was here – far from adequate scientific libraries, far from the stimulating research atmosphere of a conventional university physics department, snatching precious morsels of time for his own surreptitious calculations, which he guiltily hid in a drawer when footsteps approached, Einstein produced his revolutionary papers on quantum theory of light and the unification of space and time, during 1905. And during all this time, he was without the precious Ph D. "I shall not become a Ph D . . . the whole comedy had become a bore to me". Thus wrote Einstein, for a second attempt at this degree made in 1905 had also failed. A third attempt did eventually succeed, but by then he did not need the Ph D any more for he had already become famous.

I have told this story in detail; for the simple reason that every one of the discouragements he suffered from are a norm for a scientist in a developing country. And even in a developed country today, would an Einstein, with his commitment to science for its own sake, fare any better? I shall quote first from Einstein and then quote a comment from Professor Reimar Lüst, President of Max-Planck Society.

"My scientific work is motivated by an irresistible longing to understand the secrets of nature and by no other feeling. My love for justice and striving to contribute towards the improvement of human conditions are quite independent from my scientific interests".

Professor Lüst's comment made during the Einstein celebrations at Bern was:

"These words may sound strange in the ears of those who are responsible for science policy all over the world today, looking for social relevance, immediate applicability and cost-benefit-analysis in supporting scientific research."

I rejoice that UNESCO, representing the world community of culture and scholarship is commemorating in a befitting manner the centenary of Einstein - the greatest figure in the scientific culture of our times - perhaps all times. I am confident UNESCO will not forget Einstein's ideal regarding the preciousness of search for knowledge for its own sake, nor will it forget the comments of Professor Lüst, when UNESCO's counsels are sought on science policy for developing countries.

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Extract from Salam's Nobel Prize Acceptance Speech, Stockholm, December 8, 1979.

Scientific thought and its creation is the common and shared heritage of mankind. In this respect, the history of science, like the history of all civilization, has gone through cycles. Perhaps I can illustrate this with an actual example.

Seven hundred and sixty years ago, a young Scotsman left his native glens to travel south to Toledo in Spain. His name was Michael, his goal to live and work at the Arab Universities of Toledo and Cordova, where the greatest of Jewish scholars, Moses bin Maimoun, had taught a generation before.

Michael reached Toledo in 1217 AD. Once in Toledo, Michael formed the ambitious project of introducing Aristotle to Latin Europe, translating not from the original Greek, which he knew not, but from the Arabic translation then taught in Spain. From Toledo, Michael travelled to Sicily, to the Court of Emperor Frederick II.

Visiting the medical school at Salerno, chartered by Frederick in 1231, Michael met the Danish physician, Henrik Harpestraeng – later to become Court Physician of Eric IV Waldemarssön. Henrik had come to Salerno to compose his treatise on blood-letting and surgery. Henrik's sources were the medical canons of the great clinicians of Islam, Al-Razi and Avicenna, which only Michael the Scot could translate for him.

Toledo's and Salerno's schools, representing as they did the finest synthesis of Arabic, Greek, Latin, and Hebrew scholarship, were some of the most memorable of international assays in scientific collaboration. To Toledo and Saleron came scholars not only from the rich countries of the East, like Syria, Egypt, Iran and Afghanistan, but also from developing lands of the West like Scotland and Scandinavia. Then, as now, there were obstacles to this international scientific concourse, with an economic and intellectual disparity between different parts of the world. Men like Michael the Scot or Henrik Harpestraeng were singularities. They did not represent any flourishing schools of research in their own countries. With all the best will in the world their teachers at Toledo and Salerno doubted the wisdom and value of training them for advanced scientific research. At least one of his masters counselled young Michael the Scot to go back to clipping sheep and to the weaving of woollen cloths.

In respect of this cycle of scientific disparity, perhaps I can be more quantitative. George Sarton, in his monumental five-volume *A History of Science,* chose to divide his story of achievement in sciences into ages, each age lasting half a century. With each half century he associated one central figure. Thus 450 BC - 400 BC Sarton calls the Age of Plato; this is followed by half centuries of Aristotle, of Euclid, of Archimedes, and so on. From 600 AD to 650 AD is the Chinese half century of Hsüan Tsang, from 650 to 700 AD that of I-Ching, and then from 750 AD to 1100 AD – 350 years continuously – it is the unbroken succession of the Ages of Jabir, Khwarizmi, Razi, Masudi, Wafa, Biruni, and Avicenna, and then Omar Khayam – Arabs, Turks, Afghans, and Persians. After 1100 appear the first Western names: Gerard of Cremona, Roger Bacon – but the honors are still shared with the names of Ibn Rushd (Averroes), Moses Bin Maimoun, Tusi, and Ibn-Nafis – the man who anticipated Harvey's theory of circulation of blood. No Sarton has yet chronicled the history of scientific creativity among the pre-Spanish Mayas and Aztecs, with their re-invention of the zero, of the calendars of the moon and Venus and of their diverse pharmacological discoveries, including quinine, but the outline of the story is the same – one of undoubted superiority to the Western contemporary correlates.

After 1350, however the developing world loses out except for the occasional flash of scientific work, like that of Ulugh Beg – the grandson of Timurlane, in Samarkand in 1400 AD; or of Maharaja Jai Singh of Jaipur in 1720 – who corrected the serious errors of the then Western tables of eclipses of the sun and the moon by as much as six minutes of arc. As it was, Jai Singh's techniques were surpassed soon after with the development of the telescope in Europe. As a contemporary Indian chronicler wrote: "With him on the funeral pyre, expired also all science in the East." And this brings us to this century when the cycle begun by Michael the Scot turns full circle, and it is we in the developing world who turn westward for science. As Al-Kindi wrote 1100 years ago: "It is fitting then for us not to be ashamed to acknowledge truth and to assimilate it from whatever source it comes to us. For him who scales the truth there is nothing of higher value that truth itself; it never cheapens nor abases him."

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