MATSCIENCE REPORT 107

PROCEEDINGS OF THE NINETEENTH ANNIVERSARY

SYMPOSIUM ON A BIOGRAPHICAL APPROACH TO MODERN PHYSICS

(Planck to Salam, the Quantum to the Quark)

JANUARY 17—21, 1981

MATSCIENCE
THE INSTITUTE OF MATHEMATICAL SCIENCES
MADRAS-600 020, (INDIA)
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Madras
January, 17-21, 1981

Convener:

Professor Alladi Ramakrishnan
Director, MATSCIENCE

THE INSTITUTE OF MATHEMATICAL SCIENCES, MADRAS-20
(India)
February 1982

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PREFACE

This report contains the lectures given during the 19th Anniversary Symposium held at the Institute during 17th to 21st January 1981.

Some years back, we started displaying the portraits of great scientists and mathematicians of the world on the walls of the Institute. Besides offering our admiration and respect to these great men, the portraits undoubtedly give us great enthusiasm and definitely keep our plane of thinking very high. To appreciate the fact that they were also people like us and they had to strive hard to get their discoveries recognized by other pioneers in their fields, Professor Ramakrishnan suggested that we may discuss in this anniversary symposium about the biographical background of these scientists, especially the circumstances which made them to think of such original and fundamental problems and [illegible] the fortituous background which empowered them tackle and solve such problems.

We are really fortunate that Professor C.J.Eliezer from La Trobe University, Australia is with us. He worked in Cambridge, U.K. with Professor Dirac. He is telling us about some of his personal experience with Professor Dirac. I do hope that the proceedings will give us great strength to persue on problems of great depth.

I thank the lecturers for putting their great efforts, Professor R.Parthasarathy for all organizational assistance and Mr.N.S.Sampath for his great enthusiasm in bringing out the Matscience Report in the present form.

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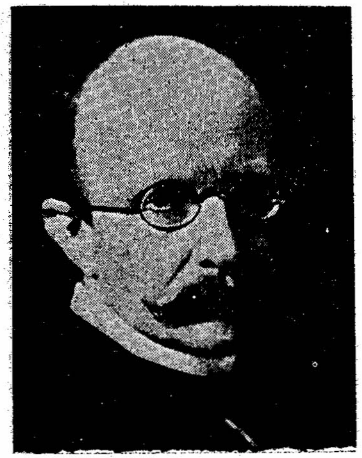
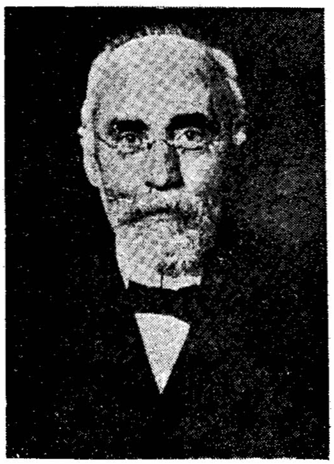
The Nineteenth Matscience Anniversary Symposium was held at Matscience from 17th to 21st January 1981 with the theme 'A Biographical Approach to Modern Physics - Planck to Salam, the Quantum to the Quark'. The symposium was inaugurated by His Excellency Mr.Sadiq Ali, the Governor of Tamil Nadu. The portraits of Sin-Itiro Tomonoga and Hideki Yukawa were unveiled by Mr.Masanari Ozaki, Consul General of Japan, Madras and the portaits of Julian Schwinger and Emilio Segre were unveiled by Mr.Christopher L.Sholes, Director, USICA, Madras. The present report contains a collection of articles by some of the participants of the symposium who discussed the historical perspectives of physics from the time of Planck at the beginning of this century to the present era of Salam through the contributions of the various outstanding scientists who developed modern physics.



Max Planck

Albert Einstein



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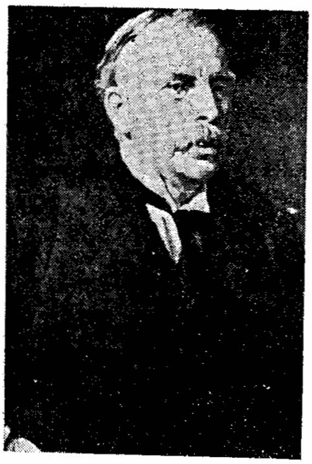

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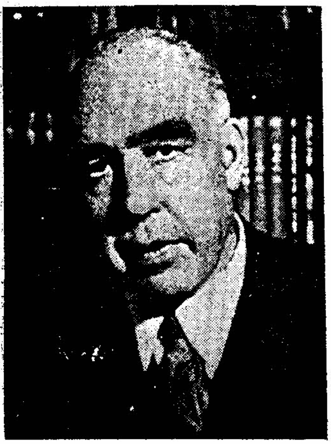

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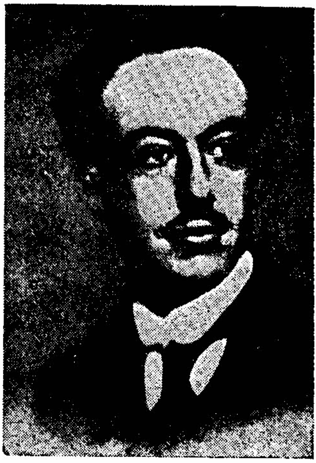
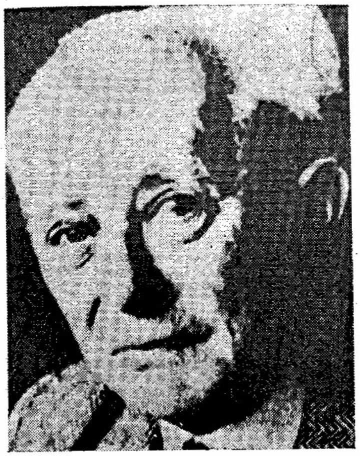


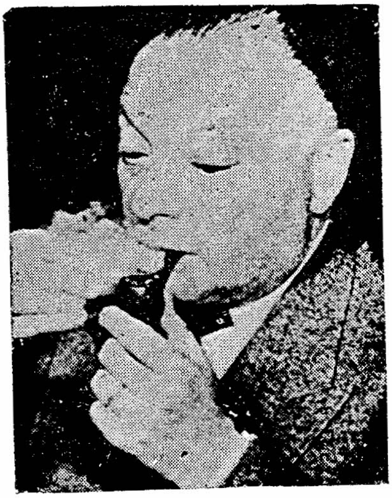
Louis de Broglie

Werner Heisenberg

Erwin Schrodinger



Max Born



Wolfgang Pauli

P. A. M. Dirac

Hideki Yukawa

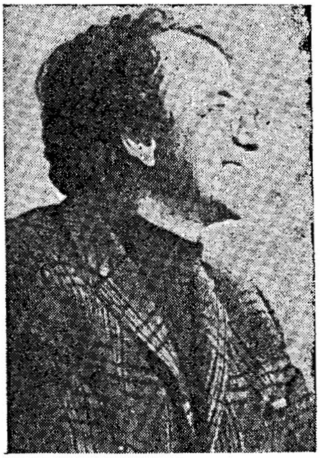
Sin-itiro Tomonaga

L. D. Landau

C. V. Raman

S. W. Hawking

Steven Weinberg



Sheldon Lee Glashow

Abdus Salam

ALBERT EINSTEIN - MAGIC OR LOGIC

Alladi Ramakrishnan
Director, MATSCIENCE, Madras-20.

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Albert Einstein - there is a magic about the name which has become synonymous with mathematical genius, physical intuition, a wide understanding, humanity and a sublime simplicity that goes with true greatness. How is it that in this age of science, in a world used to the greatness of Nobel Prizemen and the prestige of Ivy League, Harvard and Princeton, Oxford and Cambridge, Gottingen and Heidelberg, Einstein should have acquired a reputation which transcends those of the intellectual giants of all time, Newton and Maxwell, Gauss and Riemann, Galileo and Copernicus, Euclid and Archimedes? What were the circumstances that made the incredible possible? Was it a gradual rise or a sudden blaze to unrivalled fame?

It all happened due to the publication of three papers in one year in 1905 when Einstein was just a patent office civil servant, not working in a University as an academician. The three papers changed the face of modern physics, each giving him a right to immortality. One dealt with the Brownian motion of particles, another with the quantum nature of light, which won for him the Nobel Prize and the third with the special theory of relativity, which earned for him a unique place in human history. It was the theory of relativity that rocked the world and dazzled the minds of every one from the novice to the Nobel Laureate. Every human being is concerned with space and time and feels it obvious that these two are distinct, one having no influence on the other.

Script used in the Television Programme on 'Einstein' on March 1979 to think of them as part of the same mathematical physical structure confounded the imagination and staggered the senses. Similarly, one is used to the concept of indestructibility of matter, though aware of the release of energy by combustion which is interpreted as a rearrangement or recombination but not a destruction of atoms. That matter could just disappear and become energy and what is more that a small amount of matter could release an enormous amount of energy, excited the imagination of the world. How is it that the concept of the unity of space and time occurred just to one man, when so many first rate minds were concerned with problems which were solved at one stroke by his discovery? How is it that a patent office executive decided to go ahead and publish his ideas when established scientists of eminence were puzzled to distraction by the insoluble nature of the problems? How is it that the scientific world accepted his work without delay and with unrestrained enthusiasm? We shall attempt to answer these questions and understand the life of a man, the like of whom the world will not see for centuries to come.

Einstein was born on March 14, 1879 in Ulm, a lovely old German city on the Danube at the foot of the Swabian Alps. The Einsteins were jews hailing from Bachau, a small town between Lake Constance and Ulm. The father, Hermann, who owned a small electrical workshop 'was a jovial man fond of beer and good food, Schiller and Heine.' He was of such good nature that his business suffered and the Einsteins shifted to Munich within a year of Albert's birth. It was as though his birth in Ulm was just to justify the tradition that the people of that city were mathematicians.

In Munich he studied in a Catholic school from five to ten and then in the Luitpold Gymnasium. As a boy he did not openly reveal or perhaps no one noticed the precocity of a genius who enlightened the world twenty years later. However there occurred an incident which has now become famous in the light of his fame. He was impressed and excited that a magnetic needle always pointed to the same direction. What was it that 'existed' in empty space which constrained the needle to a particular direction? It was just like any other question by an intelligent inquisitive boy, but obviously it turned out to be the unnoticed starting point of the greatest intellectual revolution of our times! Even as a boy he was troubled by this question. How did God create the universe?

The other early influence was music, through his mother, particularly the violin which was to become the symbol of his greatness.

The Gymnasium was just a conventional school and young Einstein seems to have despised educational discipline which he felt interfered with the radical enquiring mind, essential to a scientist. Though there was no visible evidence of precocity, from 'hindsight' we could trace the origins of his achievement to his spirit of dissension and obsession with the nature of the universe.

The family moved to Italy, in 1894, where he studied in a Swiss school in Milan. Very soon due to the precarious financial situation in the family, his father urged him to forget the 'philosophical nonsense' which engaged his mind and turn to the sensible trade of electrical engineering by entering the famous Federal Institute of Technology (E.T.H.) at Zurich. He could not at first qualify in the entrance examination and had to stay in Aarau for a year before obtaining admission to the E.T.H. During this period he sent a 'paper' to his uncle 'concerning the investigations on the state of Aether in magnetic fields' - hardly a suitable subject for a budding electrical engineer.' But it was a remarkable paper for a boy of sixteen in which posterity would discern the seeds of relativity after its discovery in 1905.'

Life in Aarau had the tranquil charm of the Swiss countryside and young Einstein liked it so much that he renounced his German nationality to express his detestation of the violent anti-semitic feeling growing in his native country. Since he was only sixteen this renunciation had no legal consequence. He passed the entrance examination for the E.T.H. and shifted to Zurich. Among his teachers there were Minkowski, the famous mathematician and Weber, the physicist. Minkowski who at that time felt that Einstein was 'a lazy dog who never bothered about mathematics at all', was to become the most ardent and effective supporter and protagonist of relativity after its discovery by Einstein'. Under Weber, Einstein studied physics getting familiar with the work of Maxwell, Faraday and Hertz.

For a few years after graduation Einstein was unemployed when he published his earlier papers in the Annalen der physik entitled 'Inference to be drawn from capillary phenomenon.' It was then through the good offices of his friend Marcel Grossman he got the job of a class III Civil servant in a patent office in Berne on a salary of 4000 francs a year. While working there in early 1905 he got his Ph.D. by presenting his thesis to the University of Zurich entitled 'A new definition of molecular dimension' and dedicated it to his friend Marcel Grossman. He just made it despite 'crudeness in style and slips of pen' through the mastery of mathematical methods.

In Berne he lived in a small room and walked to his office. He did his work with diligence and efficiency but found time to contemplate on the real question that worried him to the depths of his being, the existence or the nonexistence of aether. Between 1901 to 1904 he published five papers, like any other competent student of theoretical physics, on statistical concepts in liquids and gases, work which in time proved to be as significant as that of Gibbs. During this period he acquired two pupils one Solovine and other Marie who soon became his wife. They spent hours discussing various questions in physics but there was nothing to herald the bursting of the blazing rocket of an idea which would illumine the whole domain of physics. Obviously during these years Einstein spent many hours of intense contemplation with ferocious concentration not noticed by others. Out of this womb of thought emerged the charmed triad of papers comparable only to that of Newton's triple discovery of Calculus, the spectrum of light and the law of gravitation.

What was the state of physics which stimulated the conception of these ideas? What were the questions that troubled Einstein first to distraction then to contemplation and finally to achievement?

At the turn of the century the world of physics saw the birth of the Quantum Theory due to Max Planck. Though it had its origin in a statistical phenomenon, the composition of black body radiation, it was a total break from the past and the starting point of twentieth century physics. That light energy was 'quantized' or divided into discrete packets, each packet being proprtional to the frequency, a concept at variance with the age old idea that energy could assume continuous values, an astounding hypothesis forced on the physical world by experiment and observation. It took about twenty five years before this could be imbedded into a complete theory of quantum mechanics at the hands of Bohr, Heisenberg, and Born, Schrodinger and Dirac.

Planck's quantum hypothesis dealt with light or electromagnetic radiation. There was another even more challenging problem regarding light, a legacy from the days of Newton and the earliest measurements of its velocity by Fizeau and Foucalt. It was established beyond doubt that the velocity of light was constant in all frames of reference moving with uniform velocity with respect to one another. This looked like a 'violation' of intuition and even reason for it seems obvious to anyone that things move slower relative to a person who is chasing them and faster relative to one moving away from them.

But the constancy of light velocity was an experimental fact as demonstrated by Michelson and Morley. If light is transmitted through the hypothetical medium aether, the medium should have very special features to maintain the constancy of the velocity of light. But the Maxwell equations were consistent with experiment and Lorentz noticed their invariance with respect to a mathematical transformation of space and time coordinates, the meaning of which he did not comprehend at that time. The equations did not need the postulate of aether for their validity but only their invariance under Lorentz transformation.

Einstein, as an unknown physicist concerned himself with the almost insoluble problem which baffled the masters like Lorentz and Poincare. What is the physical significance of the invariance of equations under the Lorentz transformation? What has this transformation got to do with the constancy of light velocity? What would happen if we chase light by riding on a particle as fast of light?

The insurrection in the mind of Einstein continued till 1905 when in a sudden flash he realised that the Lorentz transformation was applicable to the motion of massive particles and that space and time occurring in the transformation

$$x' = \frac{x - vt}{1 - v/c^2} \qquad t' = \frac{t - x\, v/c^2}{1 - v/c^2}$$

c = velocity of light.

referred to the intervals between events relating to the observation of these massive particles* With a vaulting leap of imagination, intuition, courage and confidence he arrived at the conclusion that the same transformation would apply also to energy and momentum leading to the fantastic conclusion that mass increases with velocity and that the mass of a particle was equivalent to its energy'. These conclusions were published in the famous paper entitled 'Electrodynamics of moving media'

$$m = \frac{m_0}{1 - v^2/c^2}, \qquad E = mc^2 \qquad p = mv$$

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* The language used is not the same as in Einstein's papers. But the author has recently shown that if an event is defined as the observation of a massive point particle, needless confusion due to meaningless paradoxes which still persist could be avoided.

Within two years of its publication, the theory of relativity was accepted by the scientific world, for it answered all the puzzling questions relating to light and electromagnetic phenomena. Lorentz, the father of the electron and of the transformation that bears his name, realized that Einstein had formulated a single law valid both in mechanics and in electromagnetism. The merit of Einstein's theory was that it preserved the mechanics of Newton for phenomena involving ordinary velocities and made spectacularly new predictions for very fast particles. He did not overthrow Newton but in every sense he stood on his shoulders and so was able to look much farther - far enough to realise a new feature of nature - the convertibility of mass into energy. The logic of it was so compelling that it was accepted by the leading physicists of the time with obvious enthusiasm and approbation. Einstein with a modesty characteristic only of purest genius stated that it was a 'systematic extension of the electrodynamics of Maxwell and Lorentz'. The conversion of mass into energy explained the energtics of particles in radioactive transformations. To many, the actual possibility of the conversion of matter into large amounts of energy, either for military purposes or for harnessing for peaceful purposes seemed very remote. Rutherford the architect of the nuclear model of the atom till the end of his life felt it was 'moonshine' to hope to release the energy locked in the atom. Hahn's discovery of fission and the Manhattan project under the stress of war were still to come before the 'dream' or 'nightmare' of atomic energy had to be realised.

With the establishment of relativity theory Einstein was appointed Associate Professor in Zurich or a modest salary of 4500 francs a year, augmented by lecture fees. But he was indifferent to material ewards and was more concerned with his mission to understand the ature of the universe around him. It was said that a man who had evolutionised the concept of time could not afford adecent clock n his room and did not mind it.' Anyway, within a few years of he publication of the triumphant triad of papers he was acknowledged he foremost physicist of his time by the community of physicists, hough it took some time before the 'mystic aura' of transcendent enius **surrounded** his name. It was a fact he never worried about oney and was quite casual about 'creature comforts'. What he needed as leisure to be busy with his own thoughts, for the greatest was ct to come - the general theory of relativity.

Einstein was popular as a lecture who had the habit of stopping nd asking whether he was understood. He was precise and clear, arely using notes and spoke with a touch of humour. He brushed houlders and pitted his brains with Planck in Berlin, Rutherford in ngland and Poincare in Paris. He just needed pencil, paper, pipe eace and relaxation and he found it in Switzerland. He was a Swiss itizen at home with the tranquil surroundings of that 'Schonste land'.

It was then that he was offered a full professorship in Prague n a fine institute with a magnificent library'. One of his students as Otto Stern who was to follow him to various centres in Europe, ater to America, and play a significant part during the Second World ar. At Prague he enjoyed the solemn sounds of the organs in the atholic Cathedrals, the chorales in Protestant churches, the mournful

Jewish melodies, and the folk music and works of the German, Czech and Russian composers. Here germinated the first ideas of general relativity and the principle of equivalence to take the shape of a complete theory when he shifted later to Berlin.

He was invited to Leiden by Lorentz and then to the first Solvay Congress in 1911. Einstein the ex-German Swiss attended it as an Austro-Hungarian from Prague. All the leading lights of Europe were there - Planck, Poincare, Curie, Langevin, Jeans, Rutherford and others, with Lorentz presiding. Einstein also met Lindemann, later Lord Cherwell, the scientific adviser to Churchill. Everyone found the greatest genius of the century a pathetic *naivette* in the ordinary affairs of life. In 1912 he accepted the chair for mathematical physics at the ETH, in Zurich, offered to him on the recommendation by Madame Curie and Poincare.

Einstein's participation in the Solvay Congress had one major consequence. Planck and Nernst became interested in redeeming Einstein for Germany where a new research Institute was being started in Berlin in the name of the Emperor. The Physics faculty at Berlin compared favourably with the 'incomparable' Cavendish under J.J. and Rutherford, Planck and Nernst met Einstein at E.T.H. and pleaded with him to take up the professorship which he did at the new Kaiser. Wilhelm Institute on a special salary of 12000 Marks a year. He was also elected to a special chair of the Prussian Academy of Sciences.

As stressed by Sommerfeld the leisure afforded to him in Berlin was responsible for the successful completion of the general theory of relativity. When the first world war broke out the philosopher pacifist found himself isolated with his work in Berlin. Einstein's war-time contacts outside Germany were Lorentz and Ehrenfest. He retained the privileged position of a critic of war whose presence was to be tolerated though his views were disliked. The redemption from this delicate situation came only with the end of the war and the total defeat of Germany.

During the war there was a great change in his domestic life. He and his wife, Mileva, were first separated and then divorced and Einstein, with characteristic indifference to his personal needs, agreed to make over to her the proceeds of the Nobel Prize which he hoped to win within a few years. He fulfilled his promise, an act of triple significance - that he was generous, that he was man of his word and that he had faith in his work which deserved a Nobel award!

It was during the war years that the General theory of relativity was taking shape in his mind. Just as the constancy of light worried him leading to the discovery of special relativity, the following question held his mind and led him to the general theory: An external force acting on a mass produces acceleration and for a given force if we increase the mass the acceleration decreases. However the acceleration of mass due to gravitation is <u>independent of mass</u> (Galileo). So the force is proportional to mass which is identical with the rest mass occurring in special relativity! This principle of equivalence led him to the famous postulate that we could think of <u>gravitation as a property of space</u> in the presence of matter or more precisely: there is a curvature of space due to the existence of matter.

In 1916, in Volume 49 of the Annalen der Physik was published 'The foundation of the General Theory of Relativity', the greatest feat of human thinking about nature, the most amazing combination of philosophical penetration, physical intuition and mathematical skill. It deals with structure of space in the presence of matter, the essence of gravitation. Space is no longer flat but curved and consequently light is beng in the presence of a gravitational field. With characteristic humour Einstein spoke with a humility born out of confidence. 'When the blind beetle crawls over the surface of a globe he does not notice that the track he had covered is curved. I was lucky enough to have spotted it'! Thus he had to invoke not Euclidean but Riemannian geometry which was already there waiting for Einstein's call! Einstein's paper was received by DeSitter at Leiden who passed it on to Eddington, the Plumian Professor of Astronomy at Cambridge, who with his superb mathematical ability and mastery over the Calculus of Rici Levi Civita realised the profound significance of Einstein's theory. In the Einstein universe, the curvature produced by matter turned space back on itself so that of light starting on its journey in the universe will return to its starting point. There must be no favoured location in the universe.' Just as the laws of nature are the same for all the observers so must the view of the universe.' - no preferred centre, no preferred boundary all must see the universe alike. To Einstein's eyes, the whole universe has a diameter of 100 million light years, 700 trillion miles. It is a closed continuum as far as distances are concerned. The curvature of space decreases with time and this implies an expanding universe. The work of Hubble and others was verified at Mt.Wilson by observing the redession of Galaxies and the expansion of the universe.

What a strange irony that all this effort at international cooperation in science and exchanges of ideas between Berlin and Cambridge, Leiden and Zurich should be taking place against the tragic reality of a world was in which Germany and England were engaged in a death struggle?

About this time the physical world was startled by the contributions of a young Danish physicist, Niels Bohr who brought Rutherford's nuclear concept of the atom within the framework of quantum theory. The decade 1920 to 30 saw the development of quantum mechanics based upon the hypothesis of Planck and Bohr's successful theory of the atom. It was a mathematical scheme, developed by Heisenberg and Schrodinger and perfected by Dirac incorporating relativity into it, accepted as an adequate description of the universe around us. Srangely Einstein who confirmed Planck's quantum theory found himself a 'conscientions objector' to the view of intrinsic indeterminacy' in Nature. Contrary to Bohr's view he felt that the probabilistic interpretation was only an approximation. This controversy was to assume importance in the thirties in the later stages of his life.

He did not believe in quantum mechanics as a <u>final</u> description of matter since he felt strongly that God would not play dice in the world! This controversy came to the force in the Solvay Congress in 1927 attended by Lorentz from Holland, William and Lawrence Bragg from England, Heisenberg from Gottingen, Einstein from Berlin, Schrodinger from Stuttgart and Bohr from Copenhagen. The famous controversy was to enliven and enlighten the whole of physics in the years to come. Bohr and Einstein were separated by a 'chasm in faith' that was not be closed in their life times.

The triumph of the quantum theory of Planck was complete with Bohr's model and Einstein, as expected by him and by the scientific world was awarded the Nobel Prize mainly for his quantum theory of the photoelectric effect. But in the citation his other contributions to statistical mechanics and his special theory of relativity were explicitly mentioned. What is more, in his Nobel lecture Einstein elaborated on the meaning of relativity, the unity of space time structure and the applicability of the Lorentz transformation to the mechanics of particles. After the war Einstein responded to invitations to visit and lecture in various countries. He married again and visited Japan in 1922 and also made a journey to Palestine which consolidated is interest in the Hebrew University. Back in Berlin, he was invited to California by the Chairman of Caltech and in the Golden state where elebrities were made overnight and lionised for life time, many come ust to see him as if he was a glamorous film star. With the celebrities e visited the <u>premiere</u> of 'All quiet on the western front'. He et the aged Michelson of the famous experiment at a dinner in honour f both.

While Einstein was being overwhelmed by the tidal wave of fame nd glory he found himself confronted, along with millions of his ewish comrades, by the real and present danger of the inhuman wrath nd thirst for Semitic blood, of Hitler and his Nazi Government. No w was spared - young or old, infants or infirm, the flower of youth or gifted manhood - all were treated alike as fodder for the Moloch of Nazi tyranny and oppression. Einstein was to be no exception. The madness reached such a degree that relativity was condemned as a Jewish doctrine by Nazi fanatics, among whom were the Aryan German Nobel Prizemen like Lenard and Stark. Even in times of such mortal stress, Einstein still retained his sense of humour. When he was told that a hundred professors wrote a book condemning his theory, Einstein remarked 'If I were wrong, one professor would be enough.'

Germany was indeed organising a bargain sale of intellectual merchandise at reduced prices. Lindemann was keen on acquiring one or two theoretical physicists for Oxford and he offered Einstein a research studentship at Christchurch on 400 £ per annum - an academic honour despite the modest sum for the nomenclature 'studentship was peculiar to Christchurch like 'fellowship' to other Oxford Colleges, well understood by those aware of the Oxbridge tradition of conscious understatement when implying something very significant. Einstein accepted it and he was received in England with warmth and esteem. During his stay there he expressed his moral indignation at Nazi crimes and inhuman lust for blood and conquest. He lectured on the German military menace at Albert Hall when Lord Rutherford was in the chair and others in the platform included Sir James Jeans, Sir William Beveridge and Sir Austin Chamberlain. The hall was packed with 10,000 eager listeners, part of the crowd coming to verify whether there was to be an attempt on Einstein's life! In England he liked the solitude of the countryside and its monotony which stimulated active work!

Among the scientists who fled from Germany was Max Born who first migrated to Cambridge and settled down in Edinburgh. Schrodinger who went to Oxford and then to Dublin. Szilard, Teller, Wigner, Peierls, Frisch, Stern, Bethe and Weisskopf who sought their home in the hospitable United States.

When Einstein was in Christ Church, Abraham Flexner informed him of a new Institute for Advanced Study being created at Princeton through funds provided by Bamberger and Fuld amounting to five million dollars. It was to be a haven of research for scholars and scientists who make the blackboard and lecture room their laboratory, paper and pencil their instruments and who work without regard to immediate gain or desire for instant applause. Flexner was fascinated by Einstein's noble bearing and charming manner and genuine humility. He made the offer of a professorship at the Institute to Einstein who wanted just 3000 dollars a year inquiring whether he could live on less! Flexner replied that he would arrange such matters with Mrs.Einstein, making an offer of 16,000 dollars a year, an immense sum in those prewar years.

In 1934 Einstein arrived in Princeton, the most illustrious immigrant since the birth of the American republic as a nation of enterprising immigrants. It was not surprising that he wished to settle there permanently being impressed by its quality of life and the hospitality and friendliness offered to him in that lovely university town.

At first he lived in a small rented building 12, Library Place and attended the Institute which was located in the University to be later shifted to the Fuld Hall. He later bought a lovely old house 112, Mercer Street which became one of the famous residences in the world.

in the world.

He became the instant legend of Princeton where even the trees and the grass feel the breath of mathematical thought . The man who changed the view of the universe became the idol of its population, from a school girl who wanted his help to complete her home work to the Nobel Prizemen who could share their ideas with him. All his personal habits became the talk of the town. It was well known that he was no respecter of the dress shirt or lounge suit. His loose sweater obviated the necessity of a tie or jacket and his long hair spared him wasteful visits to the barber. He had to live with the legend and he did it with disarming simplicity and natural modesty. He also responded to the invitation from great places dined with Presidents but found enough time to teach school girls and enjoy an evening of music. The Government of United States conferred its citizenship on him in a manner which amounted to a rare and significant honour. Congressman Kenney of New Jersey proposed a Joint Resolution in the House of Representatives to admit Einstein to U.S. citizenship in a citation which ran as follows:

> Whereas Professor Albert Einstein has been accepted by the scientific world as a savant and a genius; and
>
> Whereas his activities as a humanitarian have placed him high in the regard of countless fellowmen; and
>
> Whereas he has publicly declared on many occasions to be a lover of the United States and an admirer of its Constitution; and
>
> Whereas the United States is known in the world as a haven of liberty and true civilisation: Therefore be it
>
>> Resolved by the Senate and House of Representatives of the United States of America in Congress assembled.
>> That Albert Einstein is hereby unconditionally admitted to the character and privilege of a citizen of the United States.

The following day, by an ironic coincidence, it was officially announced in Berlin that Einstein and been formally deprived of his German citizenship.

The U.S. had given not just an asylum to a scientist in distress, but gave Einstein the most exalted position the nation could offer - a professorship for life and without condition in the most prestigious institution in the country and a social status which rivalled that of the President of the United States.

Einstein, without design or compulsion, repaid the generous gesture when the time and occasion required it in 1939 - when Germany unleashed the holocaust of war on a dismayed world. He then wrote his famous letter to President Roosevelt at the suggestion of Wigner and Teller, warning him that Germany had the resources, the intention and perhaps the programme of producing the atomic bomb and so America should initiate without delay an effort to forestall these developments in the interest of its defence. On his advice America soon initiated the Manhattan project under Robert Oppenheimer who was assigned a task, undefined in its scope, unpredictable in its consequences, the creation of the atomic bomb.

Einstein was not directly involved in this awesome project while Bohr under the name of John Baker was more closely associated with its development. During this period he was voyaging in strange seas of thought speculating on a unified field theory to discern the grand design of the Maker by surmise and reason.

The publication of this theory in 1950 did not meet with success like his earlier work but as Oppenheimer stated he had the right to failure, for his eminence would be least affected by it.

The successful explosion of the atomic bomb in the desert of New Mexico came as startling news to Einstein as it did to the world outside. He was perplexed and tormented by the moral ambiguities emerging from the success of an endeavour which brought the world to an end but blasted two populous cities Hiroshima and Nagasaki out of existence. Left to himself, he would have wished that his greatest gift to humanity, the mass energy relation, should play its primary role only in the understanding of nature - in the Dirac equation and Fermi interaction, in the study of Black Holes and White Dwarfs, in deciding between the 'Big Bang' origin of the universe and continuous creation of matter. But his work and what followed placed in the hands of Man a weapon of incredible power either to make the world a happier place with new sources of energy or to meet his doom through fission or fusion.

The brain, the seat of thought, which gave the world the view of God's universe without a preferred centre or a static boundary , came to rest as the mighty heart made its last beat on 18th April, 1955. Einstein had become a name of immortal fame as enduring as space, time and matter. His last years were spent in tranquil leisure, the most fertile source of creative thought, that gift of God given only to His chosen few who are destined to explain to humanity the mysteries of His Creation.

We must consider ourselves fortunate to be alive in a post Einsteinian world for now we can comprehend the integral nature of the spatial, temporal and material constitution of the universe around us. Even more fortunate are those who are trained to understand his work and drink deep the fountains of his equations and perhaps add a colour, a <u>flavour</u> or a <u>charm</u> to the understanding of Creation from the deepest recesses of confined Quarks to the fleeing galaxies of an expanding universe.

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I begin with a comment of Einstein (which I read when I was a student over forty years ago) that in Einstein's opinion Dirac was the greatest genius of our times. Years later in 1954 when Professor and Mrs. Dirac were visiting Ceylon I mentioned this remark to my journalist sister-in-law, just to give some background information of our distinguished visitor. At dinner that night at our home in Colombo, much to my embarassment, the journalist quoted this statement to Dirac and asked if he would comment. Dirac's comment was typical :- 'Einstein would never exaggerate like that'.

Born in 1902 in England, of British and French parentage, Dirac went to school and university in Bristol, and graduated in Engineering. He then found that he could not get a job as an engineer. England was heading towards the depression. He then started trying for post-graduate scholarships and eventually got a scholarship to do Ph.D. at Cambridge. (Dirac once commented to me that he valued his Engineering training, as it made him tolerant of approximations). At Cambridge, his genius blossomed. He was to live and work there for the next forty three years. retiring from the Cambridge chair at the compulsory age of sixty seven, he accepted an invitation from the University of Florida where he still continues to be active in lecturing and in research, in semi-retirement.

As research student at Cambridge, he was guided by R.H.Fowler in the field of Analytical Mechanics. The research started off somewhat slowly, then came one break through, followed by an increasing pace of front line research, startling results following one after another, which were to revolutionise physical theory and our concepts of the physical world. By 1932, that is, within eight years at Cambridge, he had formulated abstract quantum mechanics, unifying Heisenberg's matrix mechanics and Schrodinger's wave mechanics, make the δ-function an accepted working tool, unified quantum mechanics and special relativity, then obtaining the relativistic wave equation of the electron. This equation is a good example of 'the unreasonable but sweet success' of mathematics in describbing physics'. For that equation constructed with one thing in mind had many unexpected bonus results, such as the spin and magnetic moment of the electron, prediction of the existence of the positron, and the notion that each charged particle had a twin with the same mass but with a charge of the opposite kind - - all surprisingly verified by experiment soon after. Then he extended quantum mechanics of particles to quantum mechanics of fields and formulated quantum electrodynamics.

I picked on 1932 as a land mark - for by then, he had become a Fellow of a Cambridge Collge, Fellow of the Royal Society, been appointed to the Lucasian Chair (a famous chair once occupied by Newton) and won the Nobel Prize - just about the age of thirty. The importance of his work till then may be gauged from a Bakerian lecture he gave that year to the Royal Society where he put down a set of wave equations of interacting particles and said 'In these equations are contained the whole of chemistry and a good deal of physics'. A remarkable phrase : the whole of chemistry and a good deal of physics.

Dirac has given an account of his first discovery, when after Heisenberg's first paper, he asked himself if $q\rho - pq$ was not zero, what was it ? The solution came to him when walking along the old Cambridge road that the Poisson bracket of classical mechanics is what should correspond to the commutator in quantum mechanics.

Heisenberg has spoken of his first meeting with Dirac in Cambridge (I hope this account is in print somewhere, I heard Heisenberg say this at an informal Cambridge dinner). After Heisenberg's first paper, he was invited to lecture in England. At Cambridge, he spoke at an after-dinner meeting (of probably the $\nabla^2 V$ Club) when in the front were J.J.Thomson, Rutherford, Astin and many famous physicists. During his lecture he could see they were not receiving his ideas well. At question time, however, a young tall fellow at the back (this was Dirac) asked him one question which purzzled him, but he gave some sort of an answer, and then came further puzzling questions. After the meeting Heisenberg went over to Dirac and talked for a while. Dirac indicated the lines along which he was working, and asked if he could write for his comments if anything interesting turned up. Heisenberg said he would delighted.

After the lecture tour Heisenberg was back in Germany and looked out for a few weeks for a possible letter from Dirac, but none came and he soon forgot all about it. Then after three months came a packet, which was Dirac's first draft of what was to become the famous treatise in quantum mechanics. Before finishing, let me describe how I happened to become Dirac's Ph.D. student. It was in 1941. It had not been his practice to take on students.

Before going down for the long vacation, it had been arranged that Dr. A. H. Wilson would supervise my research programme which would begin when the new academic year began in October 1941. Dr. Wilson had given me a number of papers to read for the long vacation. These were all about the meson, the particle proposed by Yukawa as the carrier of nuclear force. Theories about the meson, the particle proposed by Yukawa as the carrier of nuclear force. Theories about the meson were just coming into vogue. In early September I wrote to Wilson asking for an appointment to see him to clarify some of the points in the papers. No reply came for some weeks, and then came a short note saying he was out of Cambridge on national service, would not be able to supervise me, but he had arranged with Professor Dirac to take me on. So due to the exigencies of war time I became Dirac's research student. I was mightily pleased but overawed as well. The next day I had a letter from Dirac himself: 'as I am now your supervisor you should come and see me some time. I lecture on Tu, Th, S at 10. The best time to catch me is immediately after a lecture in my room in the arts School'.

And so at the earliest opportunity I presented myself. I showed him the reprints which Dr. Wilson had given and I had been reading. He looked over them and then said: These concern mesons which are interesting particles but which are more complicated than electrons. There are difficulties which still confront the theory of electrons. It seems better to face up to the difficulties of the simpler particle first before proceeding with the complicated ones. Then he gave me a reprint of his paper on the classical theory of radiating electrons, and suggested that I could perhaps apply the theory to the hydrogen atom.

The problem is to select from the whole family of solutions of the equations of motion the one which was physically allowable. Unfortunately the equations of motion were of the third order and were non-linear and to find an analytical solution was impossible. Eventually I concentrated on the one-dimensional problem, where an electron is projected towards a stationary proton. I summised that in a non-physical solution, the electron would hit the proton too hard or too slowly, while the physical solution would be some intermediary motion. The problem came to examining the behaviour of a non-linear second order differential equation for the velocity as the distance between the particles approached zero. After getting help from Miss Cartwright and Professor Littlewood on how to handle non-linear differential equations, the conclusion emerged that in whatever way the electron is projected initially towards the proton, it would be brought to a halt before it could reach the proton.

When this unexpected conclusion seemed inevitable I told Dirac about it. He seemed puzzled for a while, and then he asked: if the electron gets stopped what happens to it then ? Stupidly I had not asked myself this obvious question, so I had to hazard a guess. I said probably the electron moves away from the proton but comes to a halt, and moves back towards the proton until it halts again, thus repating this type of motion but getting closer and closer to the proton each time, Dirac's eyes let up. 'That is a beautiful and complete solution to the problem' he said.

I left in high spirits, but this was to be short lived. When back in my room and I calculated to find what happend to the electron after it came to a halt, I found that the electron shot away from the proton without coming to a halt again. I went to Dirac to tell him thus, but he too had worked it out and got the same result. You may write about these results in a paper he said.

From there one moved on to other problems. After the Ph.D. was completed, and I had become a fellow of a Cambridge College, Dirac once stopped me after a seminar and said he was going to be away in the U.S. the following academic year and asked if I would give his usual Quantum Mechanics courses. I was delighted. It was a demanding course of three lectures a week for two terms. About thirty to forty students attended, and I recollect some who are now famous, like G.A.Dirac and Abdus Salam. These were some of the high points of my association with Professor Dirac.

Dirac married Maritt, Wigner's sister. They have three daughters. Paul Blackett has told of the episodo when working in London he received a telephone call from Paul Dirac asking if he was very busy that day. Blackett replied it was busy as usual, but not that busy as not be able to see Dirac. Dirac said he was getting married that afternoon and would Blackett be his best man ?

Of my impressions of Dirac two qualities stand out. Firstly, he was a very direct and forthright person, modest and gentle, and completely free of promposity. Secondly, he had the capacity to go to the heart of the matter in almost a flash, and pick out the important from the rest. The important had to be simple, beautiful and fascinating. If these elements were not there, Dirac would let the matter pass by in silence. But when something caught his attention he was like a house on fire.

PRINCE LOUIS VICTOR DE BROGLIE

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Louis de Broglie was awarded the Nobel Prize in Physics for the year 1929, for 'his discovery of the wave nature of electrons'.

Born in a famous aristocratic family on 15th August 1892 in Dieppe, France was attracted to theoretical physics nearing the age of 30 and within two years submitted his doctoral thesis, which contained the idea for which he was awarded the Nobel Prize. He was interested in solving the mystery surrounding the structure of matter and radiation. The stage was such that wave nature as well as corpuscalar nature was recognized for light through the interference. and diffraction experiments as well as the photo-electric effect, explained by Einstein. Einstein had to evoke, the corpuscular nature on one hand and at the same time accepted Planck's relation in attributing to it an energy   for a frequency   , thereby the wave nature. The light corpuscle, the photon was to yield all its energy to the matter electron. In the theory of atoms, the matter, the electron could execute stable motion, which was determined by eigen values, which occured as quantum numbers. Eigen values, were of frequent occurence in physical problems involving periodic vibrations. This suggested to him that electrons also should be attributed both a corpuscular nature as well as a wave native; very much the same way the light was treated. So he tried to find a relationship between the wave aspect of electron and the corpuscular nature. The latter was to be described in terms of energy, velocity momentum etc. while the former by wave-length, frequency etc. At the same time special theory of relativity has to be respected. Two frames of references A and B are chosen such that B moves with respect to A with uniform velocity v along OZ axis of frame A., the axis of B being parallel to those of A. The particle is at the origin of frame B, and the particle, electron was at rest in frame B; so that to the observer in frame A, the electron appears to move with uniform velocity along the Z axis. Since the particle is at rest in frame B, its energy $W = m_0c^2$ and momentum zero. If a wave is to be associated with it in frame B; it has to be

$$\psi_B = a_B \exp(2\pi i \nu_B t_B)$$

where the amplitude a_B is a constant that is independent of spatial coordinates. If now the postulate is made that $W = h\nu_B$ then at once $h\nu_B = m_0 c^2$, m_0 being the rest mass of the electron. By a Lorentz transfomation, the wave is described in the frame A as,

$$\psi_A = a_0 \exp\left[2\pi i \nu_A \left(t - \frac{z}{V}\right)\right]$$

where

$$\nu_A = \frac{\nu_B}{\sqrt{1-\beta^2}}, \quad \beta = \frac{v}{c}, \quad V = \frac{c^2}{v}$$

The phase velocity of the wave is V. Therefore the wave appears to move as seen from frame A, with a phase velocity V, while the particle with a velocity v. Throughout the motion $(V - v)$ remains constant, that is the particle is always in phase with the wave. That is, the particle appears as though dragged by the wave. Since $V = \nu_A \lambda_A$, $\lambda_A = \frac{h}{p}$, where $p = \frac{Wv}{c^2}$ the the momentum. λ_A is called de-Broglie wavelength for the electron whose momentum is p, and h is Planck's constant. For relativistic particle, $v = V = c$, so that, $\lambda_A = \frac{c}{\nu_A}$. Therefore

$$\psi_A = a_0 \exp\left[\frac{i}{\hbar}(Wt - \vec{p}\cdot\vec{r})\right]$$

in general for motion in arbitrary direction $\vec{r}$. The phase is essentially $\frac{1}{\hbar}$ times Hamilton Action of the particle. De Broglie recognized the need for developing a new mechanics to describe this wave. Such a wave mechanics was soon put forth by Schrodinger; which was established to be equivalent to the quantum mechanics proposed by Heisenberg and developed by Born, Dirac, Jordan, Bohr, Pauli and others. According to this, description the motion of the particle could not be described in a deterministic way, as in classical mechanics, but only with the help of probability. This was not satisfactory to de Broglie, who was in the company of Einstein and several other scientists, who believed that it should be possible to obtain deterministic description, but non could provide such a theory of universal acceptance De Broglie hoped to develop a wave field theory, along Einstein's ideas, such that particle would appear as singularities or inhomogenity in the field, and hoped to obtain a completely deterministic description. This attempt he called 'Theory of the double solution', and emphasised nonlinearityin the equations' was inevitable. To get a start in this direction he relaxed the condition that the amplitude a_0 was constant, and instead took

$$u(x,y,z,t) = f(x,y,z,t)\exp\left[\frac{i}{\hbar}\varphi(x,y,z,t)\right]$$

where the phase φ is exactly the same as before. The constant could be some sort of averaged value of f(x,y,z,t) so that the probability interpretation could also be given to compare it with conventional quantum mechanics. If one considers a spinless particle, one can substitute u into Klein-Gordon equation,

$$\Box u + \frac{m_0^2 c^2}{\hbar^2} u = 0$$

and get, $\Box f = 0$ for determining f(x,y,z,t). Going over to the proper system of the particle, t dependence is removed and equation reduces to $\nabla^2 f = 0$, which has the singular solution $f = \frac{c}{r}$, singularity being at the origin, where the particle is situated.

De Broglie has also treated likewise, a spin $\frac{1}{2}$ particle by using Dirac equation and has obtained expressions for $f(x,y,z,t)$.

Though de Broglie could not achieve his goal, his ideas, especially introducing nonlinearities in the equation should be investigated further.

On the works of
BORN and PAULI

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MAX BORN (1882 - 1970): German physicist. Won the Nobel prize in physics in 1954 for his fundamental research in Quantum Mechanics. As a teacher he inspired a generation of brilliant young theoretical physicists like Heisenberg, Fermi and Oppenheimer. He was born in Breslau, Germany on December 11, 1882 and was educated at the Universities of Breslau, Heidelberg, Zurich and Gottingen. Received his Ph.D. at Gottingen in 1907. Taught at Berlin and Frankfurt and became Professor in 1921 at Gottingen, the leading center of theoretical physics at that time. In the early days of Quantum Theory and Relativity Born worked out many difficult mathematical formalisms for the behaviour of atoms, which became the basis for all subsequent developements in the field. He also showed how to reconcile mathematically the random behaviour of subatomic processes with the deterministic postulates of electromagnetic theory. He went to England in 1933 as a refugee from Nazism and taught at the Cambridge University. He became the Tait Professor of Natural Philosophy at the University of Edinburgh in 1936. Soon, as the world war II broke out he became a British subject and also a Fellow of the Royal Society. After retirement in 1953, he returned to his native Germany and lived near Heidelberg. A long with Bothe he was awarded the Nobel Prize in Physics in 1954 for the work he did more than twenty five years earlier. Died on 5th

January 1970 in Gottingen.

Born's contributions to scattering theory, theory of molecular structure, crystallography, optics, kinetic theory of fluids, etc., are well known. Ofcourse when we think of Max Born, the most important thing that comes to our mind is his probalistic interpretation of the basis of quantum theory. As he says the published work for which the honour of the Nobel Prize was accorded to him does not contain any discovery of a new phenomenon of nature but rather a newway of thinking about the phenomena of nature. Now we know that this way of thinking has permeated all branches of experimental and theoretical physics. So I shall recall briefly here the history of the birth of this new way of thinking in physics, basing my account almost verbatim on his own writings ('Physics in my generation', Max Born, Pergamon Press, 1956)

At the beginning of the 1920's every physicist was convinced that Planck's hypothesis was correct, according to which light waves of definite frequency w contained finite quanta of size $E(w) = \hbar w$. Furthermore Einstein's assertion that light quanta carry momentum E/c was well supported by experiment. This meant a new lease of life for the corpuscular theory of light for a certain complex of phenomena whereas for other processes the wave theory was appropriate. Physicists accustomed themselves to this duality and learned to handle it to a certain extent. In 1913 Niels Bohr solved the riddle of line spectra using quantum theory leading to a marvellous explanation of the main features of the wonderful stability of atoms, the structure of their electronic shells and the periodic system of elements. Fully aware of the conflict of classical mechanics with his model of atomic structure, Bohr fused his new ideas with the old boldly through his correspondence principle, on which theoretical physics lived for the next ten years. But the major problem was this: a system like the harmonic oscillator possesses not only frequency but also intensity as well. How is the by considerations of the correspondence principle latter to be found/? This period was brought to a sudden end in the summer of 1925 by Heisenberg, the young assistant of Born Heisenberg demanded that instead of describing the motion of electrons in atoms by specifying the quite unobservable coordinates as functions of time one ought to determine an array of transition probabilities (q_{mn}). Based on experience with known examples he was able to guess certain rules and apply them with success to simple cases like harmonic and anharmonic oscillators. Recognising the deep significance of Heisenberg's paper Born immediately communicated it to Z. Phys. (<u>33</u>, 879, 1925) Then in the absence of Heisenberg due to hay fever, Born applied the theory of matrices, he had learned from his teacher Rosanes in Breslau, to the quadratic arrays and their multiplication rules discovered by Heisenberg and derived the formula

$$pq - qp = h/2\pi i$$

now famous as Heisenberg's commutation relation which is the essence of quantum theory. This meant that coordinates and momenta are not tobe represented by the values of numbers but by symbols whose product depends on the order of multiplication. Born's excitement over this result was like that of the mariner who after long voyaging sees the desired land from afar and his only regret was that Heisenberg was not with him. Soon there followed a hectic period of collaboration of Born and his pupil Jordan with Heisenberg through a lively exchange of letters. The most important principles of quantum mechanics including its extension to electrodynamics were enunciated in the joint paper by Born and Jordan (Z. Phys. <u>34</u>, 358, 1925) and the famous three-man paper (Born, Heisenberg and Jordan, Z. Phys. <u>35</u>, 557, 1926) brought the formal side of the investigstion to a certain degree of cpmpleteness. But before the publication of the paper the first surprise came- the paper by Dirac on the same subject (Proc. Roy. Soc. <u>A109</u>, 642, 1925). The stimulus received through a lecture by Heisenberg in Cambridge led him to similar result with the difference that he had discovered for himself and elaborated the doctrine of such noncommuting observables without having recourse to matrix theory.

The first nontrivial and physically important application of quantum mechanics was soon made by Pauli (Z. Phys. 36, 1926) who calculated the stationary energy levels of the hydgogen atom using the matrix method in complete agreement with the results of Bohr for the same. From this moment no longer there was any doubt about the correctness of the theory. But the real significance of this formalism was not clear. Mathematics is often wiser than interpretative thought. While Born and his collaborators were discussing the various aspects of their matrix mechanics the second dramatic surprise came- the papers of Schrodinger in the Ann. der Physik of 1926 which followed a totally different line of thought derived from deBroglie's idea on matter waves. The first quantitstive proof of deBroglie's idea was provided independently by Elsasser, Davisson and Germer and G.P.Thomson. Actually Elsasser's investigation on electron waves was arranged by his teachers Born and Frank, following a letter to Born in 1925 from Davisson containing the singular results on the reflection of electrons from metallic surfaces, which made them conjecture that those waves of Davisson were crystal-lattice spectra of deBroglie's electron waves.

For a short while in 1926 it looked as if there were suddenly two self-contained but entirely different modes of explanation of the natural phenomena: Matrix mechanics and wave mechanics. Wave mechanics enjoyed much greater popularity than matrix mechanics and Schrodinger himself soon established the complete equivalence of the two systems. But Schrodinger's interpretation abandoning the particle picture totally and speaking of particles as continuous density distribution $\psi^*\psi$ appeared unacceptable at Gottingen, in the face of the experimental facts that particles or electrons can be counted by means of the Geiger and other counters and their tracks are seen in Wilson's cloud chamber. Now to Born it appeared that it was not possible to arrive at a clear interpretation of ψ by considering bound electrons and so he was at pains as early as in 1925 to extend the matrix method to aperiodic processes i.e. collissions. At that time he went to M. I. T. in U.S.A. as a guest and there he and Norbert Weiner replaced the matrix by the general concept of an operator and in that way made possible the description of aperiodic processes (Z. Phys. 36, 1926). Yet they missed the true approach which was reserved for Schrodinger Soon Born took up Schrodinger's method. Once more an idea of Einstein gave the lead. Einstein had sought to comprehend the particle-wave duality of light quanta by interpreting the square of the optical wave amplitude as the probability density for the occurrence of photons. Based on this picture of the duality of light quanta now Born was able to establish the extension of Einstein's idea to the ψ-function i.e. $\psi^{*}\psi$ represents the probability, with the help of the analysis of atomic scattering processes.

WOLFGANG PAULI (1900 - 1958) Austrian physicist. Born on 25,April 1900, in Vienna where his father was Professor of Physical Chemistry He obtained his doctorate in 1921 under the guidance of Arnold Sommerfeld contributing to the old quantum theory by a thesis on the hydrogen molecule ion submitted to the University of Munich. In 1922 Pauli spent a year at Copenhagen with Bohr himself. In 1923 he returned to the University of Hamburg as a lecturer. In 1928 he became Professor of Theoretical Physics at the Federal Technical High School in Zurich. Beginning in 1930's Pauli visited the United States as alecturer on several occasions and served as visiting Professor of Theoretical Physics at the Institute for Advanced Study at Princeton. He died on December 15, 1958 in Zurich.

Practically there is no branch of physics in which Pauli's have not had a significant role. His penetrating insight and critical judgement were evident even when he was only twenty yearsold.

His famous article on relativity published at that time in the Encyclopaedie der Mathematischen Wessenschaften is still one of the most valuable expositions of the basis and scope of Einstein's original conceptions. His article on the foundations of quantum mechanics in the Hand buch der physik (1933) retains a similar position in physics literature.

When we think of Pauli, the first thing that comes to our mind is the famous Pauli's Exclusion Principle. So on this occasion let me trace briefly the events leading to the formulation in 1925 of this basic principle of quantum theory which won him the Nobel prize of 1945. While the theory of relativity, both as regards the principles and their applications had already reached a high degree of completion in the hands of Einstein the situation in quantum theory was different indeed. Phenomena in the atomic domain presented a confusing picture and Planck's discovery of the 'quantum' posed a challenge to incorporate an entirely new elementary feature, quite contradictory to the then well established classical classical mechanics, into a consistent description of physical phenomena. As we have already seen while discussing the work of Max Born, the way to this goal was paved only gradually by the collaboration of a whole generation of physicists. After his school days in Vienna Pauli came to Munich to study under Sommerfeld who exerted a deep influence on all his students with his great mastery over mathematical physics. After getting his doctor's degree in Munich and working for sometime in Gottingen with Born Pauli went in 1922 to spend a year in Copenhagen with Bohr. There Pauli became at once a great source of stimulation to the group with his acutely critical and untiringly searching mind. In discussions he expressed his dissatisfaction with the weak argumentation underlying the attempt to explain the peculiar stability of closed electron shells so decisive for the arrangement of elements in the periodic table. Yet his mastery of such arguments of old quantum theory based on the correspondence principle of Bohr is illustrated by his beautiful analysis of the Compton scattering of light by free electrons along almost the same lines followed in the general dispersion theory formulated by Kramers which was to prove very important for subsequent great developements. To Pauli with his abhorence for any kind of ambiguity in physical theories the advent of the new quantum thèory of Heisenberg, Born, de Broglie and Schrodinger excluding all irrelevant use of classical pictures was a tremendous relief. With this aim Pauli continued his work in the following years resulting in 1925 in the enunciation of the Exclusion Principle.expressing a fundamental property of a system of identical particles for which classical physics presents no analogy as for the quantum of action itself. In this formulation of the Exclusion principle an earlier work of Pauli (Z. Phys. 16, 155, 1923) on analomous Zeeman effect was to play a significant role. Following this he first observed in Z. Phys. 31, 373 (1925) that the doublet structure of alkali spectra as well as the deviation from Larmor theorem is due to a particular two valuedness of the quantum theoretic properties of the electron which cannot be described from the classical point of view. While writing this paper an interesting paper by Stoner had appeared in Phil. Mag. 48 in which besides improvements in the classification of electrons in closed shells and nonclosed shells in subgroups an important remark had been made that for a given value of the principal quantum number the number of energy levelsof a single electrons in the alkali metal spectra in an external field is the same as the number of electrons in the closed shell of the rare gases which corresponds to this principal quantum number. This remark, Pauli says in his Nobel lecture, was of decisive importance and on the basis of his own earlier results on the classification of spectral terms in a strong magnetic field the general formulation of the exclusion principle became clear to him. Thus he finally enunciated in Z. Phys. 31, 765 (1925) his famous principle in the form: There can never be two or more equivalent electrons in an atom for which the values of all the quantum numbers are the same. If an electron is present in the atom for which all the quantum numbers have definite values, this state is occupied.

Pauli gave several applications of his principle and at the end of the paper he expressed his hope that sometime a deeper understanding of quantum mechanics might enable us to derive the exclusion principle from more fundamental hypotheses. Later ofcourse we know that Pauli himself was able to show that the connection between the exclusion principle and the more general principle of antisymmetry (Dirac, Heisenberg, 1926) follows from the fact that electrons have half integral spin and relativistic invariance (Phys. Rev. 58, 716 (1940)).

In the formulation of the exclusion principle in 1925 Pauli introduced besides the three quantum numbers n, l, and m_l the fourth one m_s to the atomic electron with a peculiar two valuedness without any classical analog. This fourth degree of freedom turned out to be associated with the 'spin' as it is well known and Pauli himself gave the famous spin matrices named after him in 1927 (Z. Phys. 43, 601) to represent the quantum mechanical spin operators. The events leading to this discovery of spin form another very interesting story (for details see 'Theoretical Physics in the 20th Century' Ed. Fierz and Weiskoff, Interscience Pub. New York, 1960)

From the beginning Pauli took a prominent part in the formulation of the quantum theory of electromagnetic fields and his contributions to the relativistic theory of the electron helped very much the full understanding of its implications. In subsequent years Pauli became deeply interested in the problems of of elementary particle physics. The introduction of the concept of the 'neutrino' by him was the fundamental contribution which ensured the upholding of the conservation laws in the beta decay of atomic nuclei (Mentioned first in a letter to Geiger and Meitner in Dec. '30. Made it public at the American Physical Society meeting in Pasadena in June '31. Pauli made his bold proposal on the 'neutrino' finally in 33 in the Solvay Congress in Brussels) In this connection it is also interesting to recall that Pauli was the first (Naturwissenschaften, 12, 741, 1924) to point out how the hyperfine structure of spectral lines offered information about nuclear spins and electromagnetic moments. According to Peierls it is not exaggeration to say that the modern electron theory of metals was started by Pauli's paper on the paramagnetism of electron gas (Z. Phys. 41, 81, 1927). Thus there are many instances in the history of Physics when it was Pauli who made the first decisive step.

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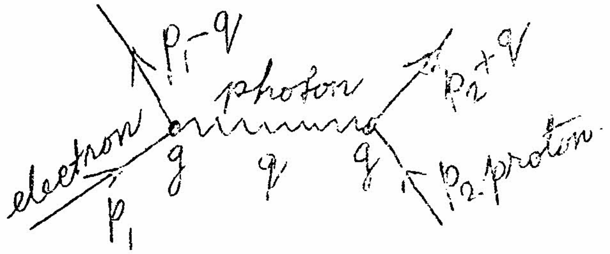
Was born in Tokyo, Japan, on 23rd January 1907. He graduated from University of Kyoto, where his father was the professor of geology. Next six year 1929-1935 he bestowed his attention on the theory of elementary particles. The only elementary particles known at that time were Neutron, Proton, electron and Photon. During this period theory of Atom was undergoing radical changes. The quantum mechanics was established by Heisenberg, Dirac, Born, Jordan, Pauli, Schrodinger and Bohr. With the help of this new mechanics Atomic spectroscopy was developed in Europe to a remarkable degree, which could be considered satisfactory. In the atom, the nucleus occupied only a very negligible volume as shown by Rutherford, but the electrons being very light, most of the mass of the atom was there, contributed by the nucleus. As Heisenberg pointed out Neutron and Proton were the consituents of the nucleus, the former a neutral particle and unstable, against β decay, while the latter stable and charged with one unit of positive charge, equal in magnitude to the charge on the electron, but of opposite nature. The nucleus has a charge that is the sum of the positive charges on the Protons it contained, and since an atom has to be electrically neutral, must contain an equal number of electrons about it. The masses of nutrons and Protons are practically the same, and both have intrinsit spin 1/2 . Since nutron and proton were enclosed in a stable fashion within a very tiny volume and former carrying no electric charge, obviously some other type of attractive force must keep them stably together. This unknown force was therefore named nuclear force - which even upto this day not only understood. This nuclear force, differed from the electromagnetic force between Proton and electron, in two characteristics. The range of former is extremely small while that of the latter infinite. The strength of the former is much larger. The qualitative features of nuclear force which keeps the nutrons and Protons stably together in the nucleus of the atoms, are therefore, a short range, say of order 10^{-13} cm, (1 Fermi unit) and extremely strong.

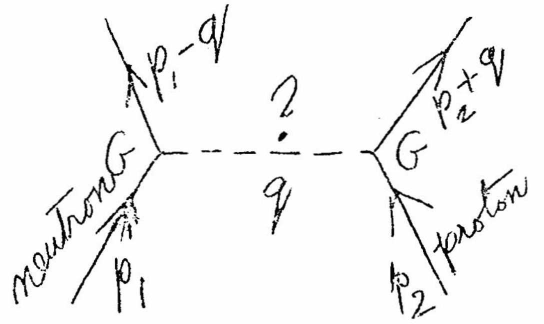
These were the facts available to Yukawa who was attempting to solve the mystery of this nuclear force and putforth his ideas in 1935 which won him the Nobel Prize for Physics in 1949. We shall here briefly outline his theory, which was developed in close anology to Electromagnetic forces. The electromagnetic force between two electrically charged particles, varying as $\frac{1}{(\text{distance})^2}$ vanishes only when the particles are infinitely seperated, and has an unpleasant singularity when the distance is reduced to zero. The force is believed to be arising from the charged particles exchanging between them photons. The photons have zero rest mass, and the force infinite range. In Feynmandiagram this process can be depicted as



q is the electromagnetic coupling constant

$p \rightarrow (p_1, p_2, p_3, p_4)$

Obviously, if we want to develop in close anology with this, a theory for nuclear forces, we should use the same Feynman diagram,



but with different coupling constant G which should give the much larger strengthand the exchanged particle must be something different from photon, and should correctly give the very short range 10^{-13} of nuclear force. Obviously, this unknown particle must have a nonzero rest mass to give a finite range. Larger the rest mass shorter would be the range of the force. This can be seen by writing down the matrix element M for this Feynman diagram

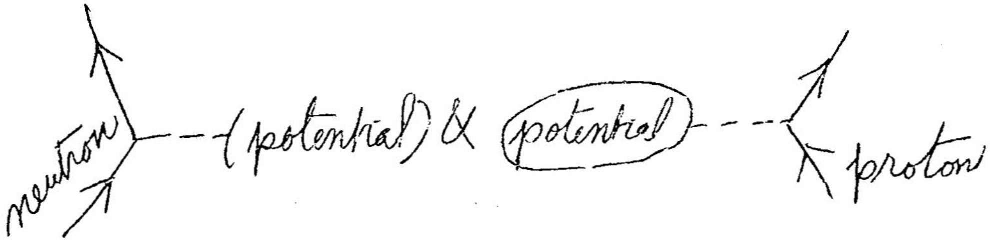
$$M \sim G^2 \left(\frac{1}{q^2 - \mu^2 + i\epsilon} \right)$$

where the quantity inside the bracket is the propagator or the Greens function corresponding to the exchanged particle, denoted by dotted line, between the two vertices. Here μ is the rest mass of the particle. By Fourier transforming the propagator we can see the effect of μ on the range. If we neglect the recoil effects of the nutron and proton while exchanging this particle, $q^2 \approx - |\vec{q}|^2$, so that $M \approx - \frac{G^2}{|\vec{q}|^2 + \mu^2}$, keeping only the real principal part. Now four transforming this expression one obtains

$$- \frac{G^2 e^{-\mu r}}{r} , \quad r = |\vec{r}|$$

distance between the nutron and proton. Negative sign shows the force is attractive.

If we regard this as though each particle, neutron and proton feels the

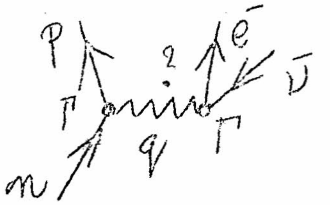


effect of each other as though the other is providing a Force due to a potential, then the potential is $V_Y(r) = G^2 \frac{e^{-\mu r}}{r}$.

This is the celebrated Yukawa potential. Note that as μ becomes larger and larger, the numerator becomes very small exponentially fast, for smaller and smaller values of r, that is the range is made smaller and smaller. Now it remains only to adjust the two parameters G, correspond to the strength and μ to the range of 10^{-13} cm.

Yukawa thus obtained $\mu \sim 200$ MeV. Thus Yukawa predicted the existence of a new particle, which was named 'meson' of mass around 200 MeV. The correct particle, the π meson was experimentally detected in 1947, that is 12 years after Yukawas prediction, very soon his great work was acknowledged by the award of the Nobel Prize in 1949. Yukawa has tried to develop a theory for the weak interaction also. The famous Fermi theory, developed essentially for the β decay appeared as a suitable basis for other decays, as well so that it was named Universal Fermi interaction, to describe the weak interactions.

The process of β decay can be also written



$$n \Rightarrow p + e^- + \bar{\nu}$$

$$M \sim \frac{\Gamma^2}{q^2 - m^2},$$

In the estreme limit, if q^2 is neglected with m^2 then M reduces to constant and the diagram collapses into a contact interaction

which can also be written symmetrically to yield the Fermi interaction.

I have mentioned this weak interaction also due to two reasons, One, that Yukawa himself had interest in this, and secondly to emphasize how the strong, electromagnetic, and weak interaction all in their very rudimentary form, have great similarity, and historically evolved that way too. Therefore in the present days effort to unify the three interactions, one should remember that the pioneer workers like Yukawa and Fermi well realised that a deep underlying unity in the three interactions, though they could not develop a unified theory themselves.

Now I will conclude by mentioning another effort by Yukawa, to develop a Non-local field theory of elementary particles. After winning the Nobel Prize in 1949 he was a visiting professor at Columbia University in U.S.A. during 1949-1953. Here he published a series of papers in which he expounded his non-local field theory. He returned to Japan in 1953 as the Director of Research Institute for Fundamental Physics, Kyoto University, and established the well-known journal Progress of Theoretical Physics for which he is the editor.

Due to the limitation on time I give a few references to the Non-local field theory papers of Yukawa.

Phy. Rev. 77, 219, 1950

Phy., Rev. 80, 1047, 1950

Phy. Rev. 91, 415, 1953

The conventional field theory dealing with point particles is local in character as the field operator is function of only one space time coordinate (x_μ), was facing difficulties of divergent expressions in calculations such as self energy etc. The basic difficulty is evident in classical theory itself when the particles are assumed to be point particles. Example the electromagnetic force between two charged point particles, being $\frac{1}{r^2}$ became infinite if r, the distance between them is zero, which is possible as the particles are point particles. This can be evaded by ascribing a finite size to the particles. Then a particle cannot be described by just one coordinate x_μ, but with more parameters describing the finite extent. This amounts to introducing a cut off of the forces at certain distance, corresponding to the size of the particles. This is not easy to do, when the calculations are to be subjected to relativistic invariance Feynman has devised schemes in his treatment of achieving this in quantum electrodynamics. The basic question is, if a finite radius r_o is ascribed to a particle in one Lorentz frame, it will be different in another frame. Then one must write a relativistic equation for this varying quantity in addition to the usual wave function. On the other hand if one demands r_o remains constant in all Lorentz frame, then, one conflicts with the situation that interaction must propagate through this distance instantaneously, that is with velocity greater than that of light in vaccum.

On account of these difficulties non-local field theory, as developed by Yukawa, or as developed by few workers in different ways earlier, never got established. Yukawa himself did not universe it further during later years. However, it may be that it is worth the effort to re-examine his papers on Non Local field theories in new angles. He has specified how to obtain equations for non local theory, in relativistic way, and has indicated how to generate the 'mass spectrum' of elementary particles and has also critically examined the conclusions.

To get a feeling for this theory a sketch can be given here.

For a scalar non local field theory the wave function is taken as

$$\varphi(X_\mu, r_\mu) = (x'_\mu | \varphi | x''_\mu) \quad \mu = 1,2,3,4.$$

$$X_\mu = \frac{x'_\mu + x''_\mu}{2}, \quad r_\mu = x'_\mu - x''_\mu .$$

The free particle equation is supposed to have a general form

$$F\left(\frac{\partial}{\partial X_\mu}, r_\mu ; \frac{\partial}{\partial r_\mu} \right) \varphi (X_\mu, r_\mu) = 0. \qquad (1)$$

F is not to contain X_μ so that to preserve invariance under any inhomogenous of $\frac{\partial}{\partial X_\mu}$ r_μ, $\frac{\partial}{\partial r_\mu}$ should involve such invariant combinations, and also F(....) is linear

$$F \equiv \frac{\partial^2}{\partial X_\mu \partial X_\mu} + F^{(r)}\left(r_\mu r_\mu ,\ \frac{\partial^2}{\partial r_\mu \partial r_\mu} ,\ r_\mu \frac{\partial}{\partial r_\mu} \right) \qquad (2)$$

The eigen solutions are obtained by method of separation as usual.

$$\varphi \equiv U(X)\ \chi(r),$$

with

$$\left(\frac{\partial^2}{\partial X_\mu \partial X_\mu} - \mu \right) u(X) = 0 \qquad (3)$$

$$\left(F^{(r)}(\ldots) - \mu \right) \chi(r) = 0 \qquad (4)$$

μ appearing as the separation constant. The masses of the free particles are given as the eigen values of $\sqrt{\mu}$ in equation (4), for the internal eigen function χ. If one chooses $F^{(r)}$ such that the eigenvalues $m_n = + \sqrt{\mu_n}$ are positive and discrete one can write then,

$$\varphi(X, r) = \sum_n u_n(X)\chi_n(r) \qquad (5)$$

To deal with interaction Yukawa's papers referred to above can be consulted.

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Sin-Itiro Tomonaga was awarded the Nobel Prize in Physics for the year 1965, which he shared with Richard Feynman and Julian Schwinger. Tomonaga is noted for his work in Quantum Electrodynamics, though his interests in research were wide. Born in Tokyo Japan on March 31, 1906, he got educated in Kyoto, where he met Hideki Yukawa, about the same age, and it can be stated that these two were greatly responsible for establishing a strong school of Theoretical Physics in Japan.

Tomonaga, while at Kyoto, had the opportunity to attend the lectures of Nishina fresh from Europe, and got to know the rapid developments taking place in theoretical physics in Europe. He worked for some time with Nishina on quantum electrodynamics at Tokyo, but left for Germany in 1937 to work with Heisenberg. The work done at this time formed his D.Sc. thesis, submitted in Japan later in 1939.

During 1941-43, while he was Professor at Bunrika University, Tokyo, developed his well known paper on the covariant formulation of quantum field theory, which was published in 1943 in Japanese but translated into English and appeared in Progress of Theoretical Physics, Vol.I, 1946, a journal then started by Yukawa. This paper is included in the collected papers in quantum electrodynamics, edited by Julian Schwinger and published as Dover edition.

Tomonaga was interested in meeting the criticism by Yukawa (1942) and Dirac (1933) that a fully covariant formalism of quantum field theory had not been formulated. It was known that in Heisenberg Representation equal time commutators were employed which singled out a specific Lorentz frame and hence not covariant. In order to get over this difficulty Stukelbergs' (1934) Interaction Representation was employed, wherein, the temporal evolution being governed by free field Hamiltonian, covariant commutation rules could be prescribed. In this representation the state vectors evolved according to the Schrodinger equation,

$$i\hbar \frac{\partial \psi(t)}{\partial t} = H_I(t)\psi(t)$$

which involved non-covariant operation $\frac{\partial}{\partial t}$. The solution $\psi(t)$ with its probability interpretation of $|\psi(t)|^2$ involved non-covariant nature, as stressed by Yukawa and Dirac as mentioned above. Tomonaga replaced $\psi(t)$ by the functional $\psi[C]$ where C is a space-time surface which is space-like. Tomonaga replaced the conventional equation by the functional differential equation

$$i\hbar \frac{\delta \psi[C_p]}{\delta C_p} = H_I(p)\psi[C_p]$$

where C_p is the space-time surface passing through C_p.

Julian Schwinger, quite independently employed this equation in his papers on quantum electrodynamics (1948,1949) so that this equation is called Tomonaga-Schwinger equation. Thus Tomonaga achieved in 1943 the covariant formulation of the quantum field theory and answered the questions raised by Yukawa and Dirac.

Tomonaga concludes his paper by remarking "no new contents are added and the well known divergences remain still. More profound modification of the theory is required."

Another contribution of Tomonaga, namely the one-dimensional model of electron gas, has acquired importance recently. Following Little's suggestion that high temperature superconductors could be found among one-dimensional or quasi one-dimensional organic systems, great efforts in synthesising such compounds followed. Recently TCNQ complexes have been synthesised, which are quasi one-dimensional. For such systems Tomonaga's model could form a good starting point.

STEVEN WEINBERG, ABDUS SALAM, SHELDON GLASHOW

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GENERAL INTRODUCTION.

Symmetry principles and the principle of renormalizability govern the field of elementary particle physics. It was Einstein who made the appearance of symmetry principles in the twentieth century phsycis in 1905 by the identification of the invariance group of space and time in his theory of Relativity. With some difficulty, the internal symmetries were realised in 1930's . As early as 1920, it has been recognised by Fock, and Weyl that Quantum electro dynamics has a powerful kind of symmetry, namely the 'local' symmetry under which the electron field suffers a phase change that can vary freely from point to point in space-time and the electromagnetic vector potential undergoes a corresponding gauge transformation. The electromagnetic field is recognised to be the gauge field of U(1) gauge transformation. In other words, electromagnetism arises from the requirement of local gauge invariance. The generalization of local gauge invariance to non-abelian groups had been carried out in a seminal papers by Yang and Mills (1954) and Ronald Shaw (1955). However the gauge invariance required the vector bosons to be massless. Only photon is the massless vector boson. The problem of giving masses to the vector bosons remained for a long time. It was in 1964, Higgs and Kibble independently showed in the theories with spontaneously broken symmetry (the Hamiltonian and commutation relations could possess an exact symmetry but the physical states might nevertheless not provide a neat represtnation of the symmetry), if the broken symmetry is local, then although the Goldstone bosons (inevitable consequences of spontaneously broken symmetry) exist formally and are in some sense real, they can be elimited by a gauge transformation so that they do not appear as physical particles. The missing Goldstone bosons appear as zero helicity states of the gauge bosons which hereby acquire mass. This is a new development in theoretical physics and should be viewed as the foundation for the edifice of unified electro-weak theory. It is really a surprise how Higgs and Kibble who actually found the key for the renormalization of weak interactions did not use for opening the treasure box. It was left to the grand masters Weinberg and Salam who were very keenly looking for such a key during their stranous search for a renormalizable theory of weak interactions. As Weinberg remarked in his Nobel lecture, "... changed the role of Goldstone bosons from that of unwanted intruders to that of welcome friends". What made Salam and Weinberg to jump over the Higgs' mechanism as the right candidate for providing a successful theory of weak interactions ? What made them to propose the gauge group as $SU(2)_L \otimes U(1)$? These are the questions which I shall try to explore to receive his earlier thoughts on the fourth Quark and its deep connection with the electroweak theory will be covered at the end.

S. WEINBERG

As a graduate student, Weinberg learned about the renormalization theory mostly from Dyson's articles. He was impressed by the derivation of 'QED' from symmetry principles and the constraint of renormalizability. Although Dirac formulated QED in a different way, the only Lorentz invariant and gauge invariant renormalizable Lagrangian for photons is exactly the same as that of Dirac's original Lagraigina. The minimal coupling of photon field to the Dirac field '$e A_{\mu}(x)\ \psi(x)$' introduced by Dirac for simplicity came natural in gauge invariant formulation. Enthused by this, Weinberg wrote his Ph.D. thesis under S.Treiman in 1957 on the use of limited version of renormalisability to set constraints on the weak interactions. Subsequently he completed the proof of Dyson and Salam that ultra violet divergences really do cancell to all orders of perturbation in renormalizable theories. He remarked that none of these helped to formulate a renormalizable theory of weak interactions. What is to be noted here is the familiarity of Weinberg with renormalization in 1957 and his intellectural thirst in formulating a renormalizable weak interaction theory.

In 1960-61 , the idea of 'broken symmetry' - a symmetry of Hamiltonian but not of the vacuum, has been borrowed from solid state physics to particle physics by Heisenberg, Nambu and Goldstone, and Weinberg 'fell in love with this idea'. He had long discussions with Goldstone at Madison in 1961 (vide his Nobel Lecture) and then with Salam at Imperial College. The three physicsts jointly wrote the article in 1964 showing that the Goldstone bosons are inevitable whene whenever a continuous symmetry is spontaneously broken and their masses zero in all orders of perturbation theory. Commenting upon this, Weinberg writes " I remember being so discouraged by these zero masses that when we wrote our joint paper, I added an epigraph to underscore the futility of supposing that anything could be explained in terms of a non-invariant vacuum state, it was Lear's retort to cordelia, 'Nothing will come of nothing, speak again'. Of course the Physical Review protected the purity of Physics literature and removed the quote. So when the exception to the Goldstone theorem was found by Higgs and Kibble, and when the gauge bosons acquired mass, Weinberg naturally felt at home with these new developments. He could immediately view the Adler-Weissberger sum rule in a different way different from current algebraic method. By assuming approximate symmetry for strong interactions based upon $SU(2) \otimes SU(2)$ which is spontaneously broken giving mass for nucleons and identifying pion as the Goldstone boson (with small but non-zero mass), the Adler-Weissberger sum rule can be obtained. Weinberg published a series of papers in 1965-67 on the implication. of spontaneous symmetry breaking for strong interaction. According to Weinberg, it was this work that led him to his 1967 paper on weak and electromagnetic unification. Actually the idea was that perhaps $SU(2) \otimes SU(2)$ symmetry of strong interactions was a local not a global one and that strong interactions could be described by Yang-Mills type theory. Soon he realized (in the fall of 1967 while driving to his office at MIT) that he had been applying the right ideas ideas to a wrong problem. In his description of strong interactions, ρ mesons were from Yang-Mills theory and in addition there could be axial vector A_1 mesons. He inserted a common ρ and A_1 mass term in the Lagrangian and the spontaneous breakdown of $SU(2) \times SU(2)$ woul would split the ρ and A_1 by a mechanism similar to that of Higg's. When applied to the theory of leptons, the massless ρ meson has photon and A_1 has massive intermediate vector boson as their counterparts. And what he achieved is the marvellous unification of weak and electromagnetic interactions. This theory was conjectured to br renormalizable like QED because it is gauge invariant. How did he arrived at $SU(2)_L \otimes U(1)$. group ?

It is well known that left-handed leptons only participate in the weak interaction. Naively speaking the V-A from $(\psi_1 \gamma_\mu (1-\gamma_5) \psi_2)$ is simply $\psi_{1L} \gamma_\mu \psi_{2L}$ with chiral projections. As the neutrinos are believed to be massless, one has two left handed electron type leptons ν_{eL} and e_L and one right handed lepton e_R to account for e.m. interactions and mass for electron. Weinberg first started with $U(2) \otimes U(1)$, all unitary 2 x 2 matrices acting on left-handed components and with all unitary 1 x 1 matrices acting on e_R. By breaking up U(2) into unimodular transformations and phase transformations the group could be SU(2) x U(1) x U(1), He identified one of the U(1) with ordinary lepton number and since lepton number is conserved with no massless vector particle coupled to it, he excluded that U(1) for lepton number, leaving behind the four parameter group SU(2) x U(1). The spontaneous breakdown of SU(2) x U(1) to N(1) of electromagnetic gauge invariance would give masses to the guage bosons of the broken gauge group SU(2) namely $W^\pm$ and an orthogonal combination remains massless, identified as the photon. The theory has one parameter, the orthogonal mixing angle or γ-z^0 angle, θ_W. The theory predicted weak neutral currents which are discovered later. To quote Weinberg, The naturalness of the whole theory is well-demostrated by the fact that much the same theory was independently developed by Salam in 1968.

Returning to the question of renormalizability both Weinberg and Salam conjectured the renormalizability on the basis of gauge invariance. It is illuminating to read the dialogue between Sudarshan and Salam in the later's contribution to the Nobel symposium in 1968. Weinberg admits in his Nobel lecture that he did not know how to prove that the renormalizability was not spoiled by spontaneous symmetry breakdown. However he attempted to prove by using unitary gauge which while exhibiting the three particle spectrum made the renormaliziability obsecure. It was ' t Hooft who invented a gauge like Feynman gauge in which the Feynman rules manifestly lead to only a finite number of ultra-violet divergences and proved the renormalizability. Weinberg write that he was not convinced of 't Hooft's paper and only after the canonical quantization procedure of the same proof due to Ben Lee, he regarded the renormalizability of the unified theory as essentially proved.

Weinberg did not stop with the unification of weak and electromagnetic interactions and in 1971 he studied the experimental possibilities to detect neutral current effects. Of course neutral weak currents were speculated by very many (Glashow, Salam-Ward and Bludman) but the electro weak theory predicted definitely the strength. He contributed to the field theory of strong interactions, the Quantum Chromo Dynamics. He and independently Gross and Wilczek in 1973 gave the unbroken strong interaction symmetry version of QCD in which the gluons are massless leading to the remarkable property of asymptotic freedom.

It is inevitable to mention about his monumental book on Gravitation which exposes the subject in terms of gauge fields and will be the starting point for the Great Grand unification.

A. SALAM

Professor Abdus Salam had been associated with weak interaction almost from the very beginning and his contributions to the early weak interaction theory and renormalization of meson theories were of very fundamental importance. I will be concentrating upon his contributions to the unification of e.m. and weak forces and the various circumstances that led him to propose the electro weak theory.

He started physics research around 1950 asn an experimental physicist in the Cvendish Laboratory on tritium - deuterium scattering. However perhaps due to the presence of the eminent man Dirac, soon he stated to work on Quantum Field theory with Kemmer. That was the time of the famous Quantum Electro Dynamics - renormalized Maxwell-Dirac Gauge theory and the successful attempts of Tomonaga, Schwinger and Dyson enthused every theoretical physicist. With P.T.Mathews, Salam started exploring the renormalizability of meson theories and found that the renormalizability was possible only for spin zero mesons, which gave the hope of explaining the origin of nuclear force. However the renormalizable spin zero theory for pions was not a gauge field theory and hence there was no conserved charge. Thus it remained off being a fundamental theory.

According to Salam, the trek to gauge theoreies as the candidates for fundamental interactions started in September 1956, when he heard the idea of parity violation in weak nuclear force from Yang and Lee, at the Seattle conference. This had a deep impact on him. He recalled in his Bobel lecture how sleepless he was during his flight back to London on an American Air Force transportation, reflecting on why Nature should violate left-right symmetry in weak interactions. Professor Peierl's question to Salam during his Ph.D.

examination about the reason for the masslessness of neutrino had been in his mind too. Combining the masslessness of neutrino and violation of parity, Salam could see the connection between the two. The existence of γ_5 symmetry for massless Dirac particles must imply a combination $(1 \pm \gamma_5)$ for neutrino interactions and all leptonic or semi-leptonic weak interactions are accompanied by neutrino. When Salam presented this to Professor Peierls he replied saying that he did not believe in the violation of parity in weak interactions. Similar reply came from Pauli as 'Give my regards to my friend Salam and tell him to think of something better'. However when Mrs.C.S.Wu et. al. showed experimentally the violation of parity in the beta decay of ^{56}Co, Pauli wrote an apologetic letter to Salam on 24-1-1957 However when Salam sent his papers on the extension of chiral symmetry to electrons and muons with the suggestion of spin 1 mesons mediating the weak forces, Pauli wrote (30-1-1957 '.... Iam very much startled on the title of your paper, universal Fermi Interaction. For quite a while I have for myself the rule if a theoretician says Universal it just means non-sense. This holds particularly in connection with Fermi interaction, but otherwise too and now you too Brutus, my son, came with this word'. Regarding the vector meson field, Pauli questioned 'If the rest mass is infinite (or very large) how can this be compatible with gauge transformation $B_\mu \rightarrow B_\mu - \partial_\mu \Lambda$?' Salam admits in his Nobel lectures that although he was taken aback by Pauli's fierce prejudice against universalism, he did not take this too seriously. However Salam could see Pauli's point on the gauge field B_μ that one could not obtain a mass without wantonly destroying the gauge symmetry one had started with. Salam's ideas on gauge fields were similar to that of Yang and Mills and his own student Ronald Shaw's thesis contained these.

Before turning to the generation of mass for Yang-Mills fields by Higgs-Kibble mechanism, let me briefly sketch the consequences of adopting Yang-Mills theory to weak interaction. Yang and Mills conjectured the renormalizability of their theory relying on the masslessness of spin one intermediate vector bosons. Once Yang-Mills Shaw fields are identified with weak interaction, on the gauge group SU(2), what could be the meaning of the third component of SU(2) triplet of which the charged weak currents were the two members. Bludman (1958) suggested (however he had global SU(2) invariant triplet) that there could be weak neutral currents, this has nothing to do with electromagnetism and corresponds to $\theta_W \to 0$ case of the Standard theory (For a comparitive study see my article in 18th Anniversary Symposium of Matscience). The idea of unification of weak and e.m. forces was developed by Glashow in 1959 and Ward and Salam in 1959. Earlier Schwinger (1956) was convinced of the unity of weak and electromagnetic forces. Glashow being a student of Schwinger wrote in 1958 in his Harvard thesis 'It is of little value to have a potentially renormalizable theory of beta processes without the possibility of a renormalizable electrodynamics. We should care to suggest a fully acceptable theory of these interactions may only be achieved if they are treated together'. Salam and Ward (1961) realized that it should be possible to generate strong, weak and electromagnetic interaction terms with all their correct symmetry properties by making local gauge transformations on the kinetic energy terms in the free Lagrangian for all particles. They, motivated by the beauty of gauge theories arrived at the gauge group SU(2) x U(1), to build a unified theory accommodating parity violation for weak and parity conservation for e.m. interactions.

When Higges (1964) and others showed how the spontaneous breakdown of gauge symmetry could generate vector boson masses, at the same time eliminating the unwanted Goldstone bosons, it just gave what one needed for formulating a gauge invariant unified theory of weak and electromagnetic interactions. The works of Glashow, Salam and Ward were published and known to physicists working on weak interactions. Then, why Higgs or Kibble or others failed to connect the Higgs mechanism with SU(2) x U(1) in formulating the weak interaction theory based upon Yang-Mills fields, now acquiring mass ? I think that it is better to quote Glashow on this point. These workers never thought to apply their work on formal field theory to a phenomenologically relevant model. I had many conversations with Goldstone and Higgs in 1960. Did I neglect to tell them about my $SU(2) \otimes U(1)$ or did they simply forget ? Salam and Weinberg had considerable experience informal field theory and had collaborated with Goldstone. It is not surprising that it was they who first used the key'.

Salam writes, 'What strikes me most about the early part of this story is how unninformed all of us were, not only of each others work but also of work done earlier'. He recalls the work of Wentzel in in 1937 on neutral currents and that of Klein (1937) on a theory similar to that of Yang-Mills-Shaw. Salam gives a series of very interesting questions which may be answered in future years.

(1) To the level of energy explored at present, one understands

$$\text{Family I}\qquad \underset{SU(3)_c}{\left\{\begin{matrix} u_R & u_Y & u_B \\ d_R & d_Y & d_B \end{matrix}\right\}} \quad \underset{SU(2)}{\left\{\begin{matrix} \nu_e \\ e \end{matrix}\right\}}$$

Family II $$\left\{\begin{matrix} c_R & c_Y & c_B \\ s_R & s_Y & s_B \end{matrix}\right\} \quad \left\{\begin{matrix} \nu_\mu \\ \mu \end{matrix}\right\}$$

Family III $$\left\{\begin{matrix} t_R & t_Y & t_B \\ b_R & b_Y & b_B \end{matrix}\right\} \quad \left\{\begin{matrix} \nu_\tau \\ \tau \end{matrix}\right\}$$

R - Red, Y - Yellow, B - Blue.

Are there more families ? Is there a basic layer of structure underneath ?

(2) All known baryons and mesons are singlets of colour $SU(3)_c$ Colour is confined. What is the mechanism of confinement ?

(3) Why does nature favour the simple SU(2) x U(1) ? Is there one just Higgs particle ? What is the mass ? Is Higgs elementary or composite ?

(4) The grand unification scheme in which letons and Quarks come in the same multiplet predicts the decay of proton. In such a scheme, with Planck's mass as natural mass scale in particle physics, the great unsolved problem is the natural emergence of mass hierarchies, m_p, αm_p, $\alpha^2 m_p$ .... .

(5) The idea of pre-quarks due to Pati, Salam and Strathdee poses the problem of confinement of preons inside Quarks. Is there a stage where this scratching of layer ends ? (According to Salam two pre-preons may suffice).

(6) With all this, the meaning of the charge is not clear. Einstein's dream to comprehend the nature of electric charge in terms of space-time geometry in the same manner as he had successfully comprehended the nature of gravitational charge in terms of space-time curvature, is not fulfilled so far.

The real unification in the Einsteinian sense is yet to arrive.

S. GLASHOW

Sheldon Lee Glashow made outstanding contributions to the understanding of weak interaction of leptons and to the hadronic world. He started his research career in 1956 as the student of Schwinger. His Ph.D. thesis (in Harvard) contains a suggestion to treat weak and electromagnetic interactions together. This could be seen as a natural consequence of his association with Schwinger who (in 1956) believed in the unity of these two fundamental interactions. In 1961 he realised the need for a larger group larger than SU(2) for the unification of weak and e.m. forces. While Salam and Ward (1964) were guided by the beauty at gauge theories, Glashow was interested in renormalization. In the 1950's QED and meson theory were only known to be renormalizable. Glashow wrote in 1959 that a softly broken gauge theory with symmetry breaking procided by explicit mass terms was renormalizable which he himself admitted later to be false.

Although Glashow had his SU(2) x U(1) theory, he did not connect with the developments on formal field theory like the broken symmetry and Higgs mechanism. He admits in his Nobel lecture 'In pursuit of renormalizability I had worked diligently but I completely missed the boat'. Nevertheless, he had speculated on a possible extension to include hadrons because the weak processes mostly involved hadrons. It is wellknown that charged hadronic weak current contains both strangeness conserving and violating parts appropriately weighted by Cabibbo angle and so if the weak neutral current, consequence of his SU(2) x U(1) theory existed would have strangeness violating piece as well. Unlike the situation is charged hadronic weak current, the neutral currents violating strangeness were absent or heavily suppressed. Glashow to account for this made Z^0 very massive than $W^{\pm}$ thereby solving the problem of strangeness violating neutral currents - infact he suppressed all neutral currents '. He writes commenting upon this , 'The baby was lost with the bath water'. With Gell-Mann (1961) he showed by using current algebra that a gauge theory of weak interaction would inevitably run into the problem of strangeness changing neutral currents.

Glashow from 1961-64 worked with S. Coleman devoting to the exploition of unitary symmetry. Bjorken and Glashow based on rather wrong notions of hadron spectroscopy but enforcing quark-lepton symmetry (two weak doublets of leptons $\begin{pmatrix}\nu_e\\ e\end{pmatrix}$ and $\begin{pmatrix}\nu_\mu\\ \mu\end{pmatrix}$ suggest two doublets of quarks $\begin{pmatrix}u\\ d\end{pmatrix}$ $\begin{pmatrix}?\\ s\end{pmatrix}$) suggested that the Gell-Mann-Zweig system of three quarks should be extended to four. There were others who suggested a similar extension, at the same time. (Amati 1964, Hara 1964, Okun 1964, Maki and Ohnuki 1964, Nauenberg 1964, Teplitz and Tarjanne 1963). The weak current with four Quarks introduced by Bjorken and Glashow was exactly the GIM current. However the same person who attempted to solve strangeness violating neutral weak currents, now failed to connect itwith his four Quark theory. Glashow writes 'I had apparently quite forgotten my earlier ideas of electroweak synthesis .... the problem explicitly posed in 1961 was solved in principle in 1964 ..... we were perhaps befuddled by the chimera of relativistic SU(6).... to cloud the minds of theorists'.

In 1970, John Iliopoulos and Luciano Maini jointly with Glashow wrote the famous GIM paper. This was fully after three years of the important work of Weinberg and Salam. Yet when GIM wrote, none sensed the connection between the two theoretical developments.

Glashow and Georgi contributed much fundamental ideas to Grand Unified theories. Their Grand Unifying group SU(5) $\supset$ SU(3)$_c$ x SU(2) x U(1) the simple gauge group seems to be preferred by many.

The charm quark came into light after the disconvery of J/ψ particle - $c\bar{c}$ bound state. Soon another quark was suggested, the bottom one and there are evidences for bb bonnd state. While most of the people just accepys the 6 Quark 6 lepton model with no experimental evidence for the top quark. Glashow and Georsi proposed models without t-quark. In Grand Unified theories where one treats Quarks and leptons in one multiplets, it is possible to assume b and τ share a quantum number like baryon number which is conserved. How far this is true remains to be seen.

Glashow aptly describes the present day standard theory as an integral work of art - the patch work quiet has become a tapestry. He says 'Let me stress that I donot believe that the standard theory will long survive as a correct and complete picture of physics: There is no grand unification unless Gravitation is included. 'If standard theory is correct, this age has come to an end. Only a few important particles remain to be discovered whose properties are known in advance. Surely this is not the way things willbe, for Nature must still have some surprises in store for us'.

LORENTZ, PLANCK AND HAWKING

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I am grateful to you all assembled here, and from varied walks of life, to listen to me on the origins of 'modern' physics starting with the works of Lorentz and Planck and upto this researches of Salam-Weinberg-Glashow on the one hand and of Hawking on the other. The subtitle of the symposium being 'Planck to Salam', we have the sequence PQRS, where R would for Ramakrishnan who has initiated these proceedings, and Q for 'queue of us all', who are going to follow and contribute our might in this effort.

Many among you in the lay public (pardon me for saying so) may value science, not for how well it explains nature, but much as would a vedic love vedic hymns for how they sound - obscure and mysterious. This may give some scientists a feeling of satisfaction. But science is no more objective or mysterious than any other human activity. Perhaps every scientist realises this consciously or subconsciously. It is time that this realization is extended to the public at large. According to Einstein

> 'In my view there is but one way to bring a great scientist to the attention of a large public, it is to discuss and explain the problems and solutions which have characterised his life work. Otherwise the result is a banal hero-worship based on emotion and not on insight'.

This advice is particularly true in the Indian context, I hope in the following talk to live upto it.

LORENTZ

Hendrick Antoon Lorentz was born of dutch protestant parents in Arnhem, Netherlands on July 18, 1853. Though he did attend church, he remained of independent denomination till the end on February 4, 1928. Like Einstein, as a child he learnt to speak late and at three could hardly articulate, in contrast (also to Einstein) he fared rather well in school and invariably was on top of the class, much to his embarrassment ! As a celebrated son of his country he had many memorials: monuments, busts, statues, many schools, streets and squares in several dutch towns bear his name and so do a fund, a medal, a scholarship and a chair in a University. He was well honored during his life and even in death, by people in all walks of life. In human relations, he was a person of considerable tact, though socially inclined, a good companion and rather well liked inspite of his formidable academic reputation even as a student, he could keep his distance. This stood him in good stead as a presiding officer in a variety of organizations and conferences. Thus (Kuhn, p.195) according to Planck

> 'Lorentz' " rich knowledge and experience in all fields of physics together with his skill in handling men and situations equipped him far more than others for the role of mediator during discussions at scientific meetings"

and Einstein said

> " I admire that man more than anyone else; I might even say I love him".

Joining Leydon University in 1870, he passed his candidates examination summa cum laude in a year and returned to Arnhem as evening high school teacher and continue his Ph.D. work independently. His dissertation 'On the Reflection and Refraction of Light', publicly defended in 1875 traces the ideas of Fresnel and Young to show the insufficiency of both longitudinal and transverse pictures taken alone, with their associated others, he concludes that Maxwell's electromagnetic theory, with an everywhere pervading ether sensitive only to the electromagnetic fields, stood the data very well. Prophetically, he also speculated on implications of the theory of heat, and emphasised the use of Newtonian space-time concepts in relation to electromagnetic phenomena.

In 1878 he was invited to the chair of professor of theoretical physics at Leydon. He continued his investigations on various aspects of electromagnetic phenomena, such as chromatic dispersion, polarization, the Zeeman effect, the Lorentz force, the action of convection currents and the problems of ether hypotheses, culminating in his electron theory, first published in 1892.

Already in 1878, with his inaugural lecture at Leyden he started work on the molecular-kinetic theory of Maxwell-Boltzman, going on to their studies (and of Gibba) on thermodynamics, entropy and statistical thermodynamics (1887) clarifying various aspects of these in the literature, together with applications. This work naturally led him in 1900 (1901,1903) to the problems of thermal radiation. His careful analysis of the electromagnetic mechanism of the classical process of radiation, led him in 1903 to the expression for the spectral distribution of the black body radiation, independently obtained by other means by Raylergh (1900) Jeans (1905) and Ehrenfest (1905) (and of course Einstein 1905). He was further able to show, in agreement with the results of Ehrenfest and Einstein (1908-1910), that the spectral distribution function for thermal radiation obtained by Planck, though empirically satisfactory, was contrary to the tenets of classical statistical mechanics and electrodynamics, which involved continuous emission processes. He thus had an important and influential part in unravelling of the deeper significance of Planck's formula, which was the forerunner of Quantum theory.

I now come to his work, for which he is most known, viz. the Lorentz transformations. He was naturally led to these because of his concern for clarifying the role of ether. Thus in his 1904 paper he refers to Michelson's experiment and Trouton-Noble experiment on ether drift, and also gives detailed comparison with Kaufman's (1902) experiments on mass of a moving charge. Incidently, Poincare coined the word Lorentz group in 1906, pointing out also an error in Lorentz's expression of the transformation formulas known after him. It is to be noted that formal expressions, identical to Lorentz transformations had also been derived by Voigt and Larmor in different physical motifs. Rather than go into the details of this well-worked topic, I quote Einstein who puts Lorentz's contribution in a proper perspective (H.A.Lorentz-Impressions of His Life and work by G.L.De Haas-Lorentz, North Holland, 1957, p.7).

'H.A.Lorentz even discovered the 'Lorentz transformation', so named after him - though ignoring its group - like quality. For him, Maxwell's equations concerning empty space applied only to a given system of coordinates, which, on account of its state of rest, appeared excellent in comparison to all other existing systems of co-ordinates. This was a truly paradoxical situation, since the theory appeared to restrict the inertial system more than classical mechanics. This circumstance, proving as it did quite incompatible with the emprical standpoint, simply had to lead to the special relativity theory".

Lorentz contributed also to many surely aspects of physical sciences. For instance, already before his thesis he obtained experimental result of Kerr effect. He was even chairman of the committee for studies on building enclosure of the Zuiderzee, so as to dam and push back the sea over a distance of about fifty miles. Even though several engineers were associated, Lorentz demonstrated his unique talents as a physicist by making independent calculations and insisting on checking and rechacking the various assumptions made in the estimates.

Lastly I would like to mention that Lorentz also obtained equations of the General Theory of Relativity of Einstein's 1916 paper, independently, and is acknowledged by Einstein. In this of course he was following Einstein's earlier attempts, as did Hilbert.

MAX PLANCK

Max Planck was born at Kiel, Germany in 1858; his father was a Professor of Law; this stood him in good stead in later obtaining position at Kiel. After early education, principally at Munich, he went to Berlin in 1878 for a year where lectures of Helmotz and Kirchhoff greatly inspired him; he thus submitted a dissertation in 1879 to the University of Munich on Clausius' formulation of thermodynamics (1876), suggesting a fundamental reformulation of approach. He phrased the second law as the principle of increase of entropy: for entropy S_t at time t, $S_t - S_{t_0} \geqslant 0$ for $t > t_0$; and applied it later to problems in physical chemistry (1882; 1887-1894) made exciting by the researches of Arrhenius and Van't Hoff. In 1885he was appointed to a special chair of mathematical physics at Kiel and then moved in 1889 to Berlin as a successor to Kirchhoff. It was therefore fitting that in 1894 he turned to the problems of black body research.

In 1891, he had expressed skeptism regarding the use of statistical mechanics of Maxwell-Boltzman to thermodynamics asserting that their 'remarkable physical insight and mathematical skill.... is inadequately rewarded by the fruitfulness of the results gained". He felt that according to Maxwell-Boltzman view the second law would not be exact but would rather have a statistical validity. In 1895 his assistant Ernst Zermelo (1871-1923) developed the socalled "recurrence paradox", that in such a mechanical systems "...irreversible processes are impossible since (aside from singular initial states) no single-valued continuous function of the state variables, such as entropy, can continuously increase;...". In this controversy Planck at first sided with zermelo, but slowly veered round to Boltzman's view that such a system is not merely mechanical but statistical, and that probability arguments play a crucial role in obtaining an irreversible mechanical system as a complex of reversible ones (1897). He was already at that time in the midst of his black body researches and maintained that his method of showing irreversibility by resorting to continuum applied equally to electromagnetic radiation and to acoustic resonators in a continuous medium.

In his first paper in 1895 he considers, following closely Hertz, the case of resonators capable of linear oscillations in equilibrium with an incident field of a spherical wave train, and finds the (secondary) solutions corresponding to a wave emitted by the resonator in terms of the amplitude and phase. He next considered energy balance between this secondary wave of the resonator with the primary radiation, to compute the ratio of their amplitudes at equal phase at equilibrium as a function of wavelength only. In the next paper 1896 he dropped the assumption of equilibrium and obtained differential equation for the resonator and its natural period exhibiting dissipative term. He then attempted to give a proof of irreversibility by considering in a series of five papers, starting in 1897-99, the behaviour of a system as a whole consisting of one or more resonators interacting with a field. He first treated the resonator free case, obtaining "radiation intensity J at time t" by introducing a distinction between slowly and rapidly varying quantities relative to an averaging procedure. By his second instalment he had extended this to the case of radiation in a cavity with a resonator at the origin. At this point he realised the role of initial conditions. A critique by Boltzman on this work in 1897 pointed out that laudable though Planck's work was, the programme would fail in obtaining irreversibility since both Maxwell equations and the boundary conditions of their solutions were time-reversal invariant. By his third instalment Planck realized the validity of Boltzman's point. In his fourth instalment he starts by hypothesising that radiation in a cavity is an electromagnetic analogue of Boltzmann's molecular disorder, and its development would involve explicit recourse to averages over resonator bandwidth. He therefore looks for monotonically varying function like Boltzmann's H approaching stationary value in time. Following Boltzmann closely on heels he obtains the differential equation

$$\frac{dU_0}{dt} + 2\nu_0 \sigma U_0 = \frac{c^3 \sigma}{4\pi \nu_0} u_0$$

between the resonator energy U_0 and the energy density of radiation u_0 ($= 3J_0/4\pi$, J_0 = radiation intensity at resonator frequency $\nu_0 = \frac{1}{4\pi}$ times the mean square of the electric field $\underset{\sim}{E}$ parallel to the resonator axis). Since at equilibrium $dU_0/dt = 0$, he obtained for equilibrium between resonator and field energies at frequency ν, $\mathcal{U}_\nu = 8\pi\nu^2 U_\nu c^{-3}$ He next *defines* the entropy of a resonator of frequency ν and energy U as $S = -\frac{U}{a\nu} \log \frac{U}{cb\nu}$ by putting its variation $\delta S/\delta U$ a constant θ^{-1}, he obtains

$$U_\nu = b\nu \exp(-a\nu/\theta), \mathcal{U}_\nu = \frac{8\pi b\nu^3}{c^3} \exp(-a\nu/\theta)$$

and the distribution function for the radiation intensity of wavelength λ as

$$K_\lambda = (2c^2 b\lambda^{-5}) \exp(-ac/\lambda\theta);$$

this he identifies with Wiens Law obtaining for θ the interpretation of temperature. This result which he got in 1899 suffered from the criticism of non-uniqueness of his definition of entropy. At this point O-Lummer and E-Pringsheim pointed out (1899) Wien's Law was not the last word, as it disagreed with their experimental results which showed a symmetric variation of the constants in (Wiens formula) with temperature and wavelength and considerable deviation for longer wavelengths irrespective of temperature. In February 1900 Max Thiesen suggested the formula $K_\lambda = \lambda^{-5} f(x) = T^5 \psi_m \left[(x_m/x) \exp(1 - x_m/x) \right]^a$

where the subscript m denotes the value of $x = \lambda T = \lambda\theta$ at which K_λ attains a maximum, and the constant a = 4.5, for agreement with Lummer-Pringsheim data. Since both Wien and Thiesen expressions had local maxima, in a paper in March 1899, Planck proposed to find a characteristic function S(U) with that property. Using his previous work, he obtained for entropy deviation dS_t from maximum value in a time interval dt, when the resonator energy deviates by ΔU from the equilibrium value U the expression

$$dS_t = dU\,\Delta U\,\frac{3}{5}\left(\frac{\partial^2 S}{\partial U^2}\right)_0$$

where dU is the change in resonator energy during dt, and

$$\frac{dU}{dt} \neq 2\sigma\nu\,\Delta U = 0\;;\; \Delta U = U - 3c^3 J_0/32\pi^2\nu^2$$

Since ΔU and dU must have opposite signs, he obtains

$$\frac{3}{5}\frac{\partial^2 S}{\partial U^2} = -f(U),$$ $f(U)$=positive function of U.

He next assumes that if one considers n such resonators, one must have $f(nU) = f(U)/n$, leading to his previous result $\partial^2 S/\partial U^2 = -\alpha/U$.

In a paper submitted to the Physical Society on 19th October 1906, he argued that the entropy of n oscillators must depend not only on the total energy, but also on that of the single oscillator; this would require replacing $-\alpha/U$ by a more complex expression. He noted that $-\alpha/U(\beta+U)$ "is the simplest by far of all the expressions which yield S as a logarithmic function of U (a condition which probability theory suggests) and which besides coincides with the Wien Law for small values of U." With the standard condition $\partial S/\partial U = T^{-1}$ and $\partial^2 S/\partial U^2 = -\alpha U^{-1}(U+\beta)^{-1}$ he obtains on rising the Wien displacement Law

$$K_\lambda = \frac{c\lambda^{-5}}{e^{c/\lambda T} - 1}$$

and the average resonator energy as $U = b\nu(\exp a\nu/T - 1)^{-1}$

Though these expressions furnished a good fit to experiments, Planck realised that the criticism by Wien and Lummer of its physical arbitrariness was justified, and therefore tried to seek an answer in a combinatorial derivation, following the work of Boltzman. This he did in a subsequent paper submitted to Annalen der Physik in early January 1901. Kuhn has discussed in detail the possible manner in which Planck could have worked backwards, from his earlier results to arrive at this derivation, which appeared to be obscure to his contemporaries. Lorentz latter derived the result in 1910 in close parallel with Boltzman's distribution law for gases and Planck gave a similar derivation in his 'Lectures' published in 1913.

Along with his first announcement Planck also gave the values of the constants a = 4.818 x 10^{-11} deg. sec., b = 6.885x 10^{-27} erg. sec., and felt that they offered a natural system of units with b = h(= 6.55 x 10^{-27} erg. sec.) and Boltzman constant

$k = h/a (= 1.346 \times 10^{-16}$ erg/deg). Planck's contribution was to emphasise the importance of the constant k by analysing its significance in his 1906 Lectures. He thus found Loschmidt's number as 2.76×10^{19} (modern $2\text{-}69 \times 10^{19}$) and electric charge as 4.69×10^{-10} esu (modern 4.803×10^{-10}). But it is to be noted that his 1906 lectures were fully classical relying on a close parallel with gas theory, and its incompatibility with "quantization" of the resonator energy was not clear to Planck-Kuhn has noted that

> "In Planck's theory, resonator emission and absorption are governed in full by Maxwell's equations...though the structure of the energy continuum is fixed by the energy element $h\nu$-nothing in Planck's published papers, known manuscripts, or autobiographical fragments suggest that the idea of restricting resonator energies to a discrete set of values had even occurred to him as a possibility until others forced it upon him during 1906 and the years following"

On the other hand Kuhn suggests that emphasis on the natural constants was Planck's main contribution. Thus in 1906 Lectures Planck says:

> "...The thermodynamics of radiation will therefore not be brought to an entirely satisfactory conclusion until the full and universal significance of the constant h is understood. I should like to label it the 'quantum of action' or the 'element of action' because it has the same dimensions as the quantity to which principle of least action owes its name."

That there was something basically contradictory between Planck's Law and classical physics came to be discussed more or less simultaneously, by several people. In England, there was a debate in Nature in 1905 regarding its contradiction with Rayleigh-Jeans Law based on classical physics. Paul Ehrenfest, a student of Boltzman who had just finished his Ph.D. in 1904, discussed the puzzling aspects of Planck's work during (1905-1906). Conclusions analogous to Ehrenfest were also arrived at by Planck in 1906 as a 'Postscript' conclusions to his 'Lectures' and perhaps owed something to Ehrenfest. In his 1905 paper "On the theory of Emission and Absorption of Light" Einstein had already obtained independently the Rayleigh-Jeans result as a consequence of his earlier work on foundations of statistical thermodynamics and recognised that Wiens Law valid at low intensities (high frequencies) was consistent with discontinuous emission and absorption of light.

In 1906, Einstein derived Planck's radiation law, clarifying for the first time its theoretical basis, its contradictions and points of departure from the classical picture (the discrete energy of the spectrum of resonators, but their continuous emission and absorption assumed!), calling for a complete re-examination thus in 1908 he rederived the Planck formula using Bohr's theory. On the other hand, Planck who immediately recognised the merit of Einstein's work on relativity, and himself contributed to it squarely opposed Einstein's Light-quantum hypothesis. Thus with Nernst, Rubens and Warburg, while proposing Einstein for full membership of Prussian Academy and describing his work in glowing terms remarked "That he has occasionally missed the target in his speculations, as for instance in his light quantum hypothesis is not something that should count too severely against him". History, however, proved them wrong as Einstein was vendicated and in fact won the Nobel prize for this in 1921.

I have already mentioned the contribution of Lorentz on clarification of physical significance of Planck's theory. With so much criticism around, Planck attempted to modify his theory by suggesting to Lorentz (1909) to abandon the electron theory, but still opposed Einstein's "quantum hypothesis"; interestingly Lorentz also considered it too outlandish. In the late 1912 edition of his Lectures, Planck modified his earlier stand to hypothesise on discontinuous emission "in accord with energy quanta and the laws of chance". He discussed several different variations of this in the succeeding years. In developing this line of thought, in 1916 he devoted much space to the notion of the conjugate coordinate and momentum space. This played, latter, a useful technical role in the Wilson sommerfeld quantization of phase space.

In conclusion let me summarize contributions of Max Planck:

1. First clear advance in the statement of the second law of thermodynamics;
2. Laying the foundations for the 'thermodynamic theory' in physical chemistry;
3. He contributed greatly to the clarification of Maxwell-Boltzman system and of the logical structure underlying classical-statistical physics.
4. Determination of the distribution function involved in Black-body theory. It is for this that he is mainly known, since this led to the great revolution in physics.
5. He stressed the importance of the use of a natural base of units based on fundamental constants, such as h and k.
6. Formal quantization of phase space, leading to its use in old quantum theory.

He also contributed to other subjects, including special theory of relativity. In all these he comes out as a supreme empiricist. Like Newton he believed in mathematical theory and was less adept at "physical picture" or "Language interpretation" it entailed. His work shows his single mindedness of purpose, and readiness to correct himself keeping in mind the dictum that in the study of natural phenomena nature is the final arbitor.

S.W. HAWKING

Whereas Lorentz and Planck were contemporaneous, Hawking is well seperated from them not only in time but in several other ways. Hawking at present occupies the chair to Lucasian professor of Mathematics at Cambridge that was at one time adorned by Newton and more recently by Dirac and Lighthill. In a certain sense this is very fitting as like Newton he too is concerned deeply with problems of astronomy. I might note that three great theoretical violations of Newtonian mechanics, Electrodynamics and Quantum theory received their finishing touches at Cambridge. And people involved in these have been totally different in temperments and attitudes one from the other.

Hawking's Adams prize Essay in 1966 was on ' singularities and the Geometry of Space-time" and he has been since concerned with properties of space-time that relate to its large scale structures. The mention of the notion of large scale structure brings to mind the subject of cosmology. But that is not necessarily so. Thus Cartan mentions in a letter to Einstein (Einstein-Cartan correspondence, ed.R.Delover, Princeton, 1979) says

> " 1. What, from the point of view of Analysis situs, is the space or the continuum in which we want to localise the phenomena?"
>
> " 2. This continuum being chosen, what are the singularity free solutions in this continuum ? It is quite possible that the existence of singularity free solutions imposes purely topological conditions on the continuum. They may require, for instance, that this continuum be closed, as in a 4-dimensional space" .

The problem that is involved here is that given a local solution of Einstein equations, what are the limits of its validity in space time and how it can be extended, if at all beyond what is given in the local coordinate system. This clearly involves the question of the large scale structure of space-time and of the structure of its underlying topology. In quantum mechanics, for instance the formalism of non-relativistic quantum mechanics shows that Cartesian system of coordinates are kind of basic to the formalism as they correspond to a unique coordinate system that is defined everywhere in the euclidean space - which is the underlying space of non-relativistic mechanics. In the general case such coordinate system are not available, hence more sophisticated tools have to be employed to gleem out information on the large scale nature of the solutions for gravitational field. Hawking, along with Roger Penrose and others (like Trautman from Poland) has pioneered efforts in this direction. Thus the book of Hawking and G.F.R. Ellis (1973) deals precisely with this topic. Hawking-Penrose theorem on singularities first clarifies the energy-momentum types into those that satisfy the positive energy condition and those that do not, the latter are unphysical. Then they show that space-times with positive energy condition invariably evolve into a singularity. A result along these lines, based purely on physical considerations and using Kasner metric have also been discussed by Khalatńikov, Belsmky, Khalab and Lifshitz (1970). In order to avoid the problems posed by an 'inevitable singularity' Hawking has introduced the hypothesis of cosmic censorship. In many cases when singularity is approached, the time-like killing vector field, responsible for bringing in information terminates and further towards singularity it may turn space-like. There is thus no input in the usual sense from beyond this point (where time-like killing vector field terminates). According to Hawking, all physical situations are of this type and the cosmic censor-- in the form of absence of future directed time-like killing vector - forbid any information regarding the singularity, which is then physically irrelevants from reaching the observer. Many solutions have been exhibited which show a naked singularity, but these are invariably unphysical and artificial - at least so far.

Another aspect of the singularity problem is the collapse of a star. In the early thirties Oppenheimer and Volkoff, and Oppenheimer and Snider had considered this question. In 1931 S.Chandrasekhar showed that for a collapsing white dwarf size star, as the collapse proceeds after exhausting its nuclear fuel, it forms in its outer layers a degenerate Fermi sea of electrons, which would explode due to Fermion degeneracy phenomena. With this discovery of the neutron, Landau (1932) obtained a similar result for a massive star, which first forms a neutron Fermi-degenerate sea. However, if mass of a star is even larger, there could result a stable rotating neutron stars. Such objects, called pulsars have recently been observed. If the mass of a star is even larger, then in principle the collapse process can go beyond this point and the entire star many disappear inside its event horizon, becoming effectively black, in the absence of a future pointing killing vector field.

Such a situation had been envisaged by the ancients. For instance Laplace (Exposition of systems of the World, Part II,p.305, May 1978, also p.608) showed that attractive force of a heavently body could be so large that light could not flow out of it. Such objects are called black holes (B.H) studies of Hawking and Christodoulsou showed that area of a B.H. can never degrease. Moreover Wheeler had shown that a B.H. may be completely characterised by its mass, spin, charge and angular momentum. This would mean that the entire information associated with a star is effectively lost down the hole. Bekenstein suggested that B.H. surface area is proportional to entropy and total outside entropy plus B.H. entropy is conserved. At this point people showed that one could extract energy from a charged or spining B.H. by sending radiation in, which then comes out enhanced (super-radiance). Zeldovich and collaborators showed that this corresponds to the quantum phenomena of induced emission. Hawking then concluded that one could go a step further to show that there must exist spontaneous emission phenomena as well. He did this in his 1975 paper in communications in Mathematical Physics, by applying quantum mechanical considerations to spherically symmetric B-H. He showed that spontaneous emission is Planckian for bosons and Fermi-Dirac for Fermions. This gave rise to a spate of different derivations of this result, which fixes the proportionality constant between surface area and entropy of a B.H. In a derivation given by me I have shown that one can slso obtain the result by considering the energy released from an incipient B.H. which is taken to be represented by a collapsing Freedman metric via the geometric meachanism of a projecture charge representing symmetry breaking in collapse.

With the success of these theoretical efforts there have been varied studies for solutions of Dirac and Klein-Gordon equations for Schwarchild and Kerr metrics. Whereas these studies are purely formal with no clear physical direction, there have been serious considerations on the interpretation of the entropy of a black hole.

Bekenstein has shown that for a compact object the ratio of its energy to entropy ($\mathcal{E}/S$) has an upper bound which is attained for a black-hole. This shows that B-H. entropy has perhaps implications for the whole of physics. Interestingly, Planck's studies on black body radiation ushered us into a new era of quantum theory. Perhaps now the study of black-body radiation of a black hole would lead us into another revolution in physics in the offing.

Associated with the notion of entropy is the notion of information lost. Hence if a B.H. can be characterised in terms of some set of elementary qualities of nature then this characterisation would correspond to a relation between the B-H. entropy and the information lost down the hole. Some time ago I had envisaged such an estimate by considering gentle fall of a small body (or a B.H.) into a large B.H. to obtain an upper limit on the number of qualities of nature as (exp 2π). Bekenstein's recent theorem on the ratio of $\mathcal{E}/S$ yields this same result More recently I have obtained this answer also by two other means. One of these envisages a model of interior of a B.H. as a compact space of negative constant curvature. By quantizing the interior configurations one again obtains this estimate for the number of qualities in nature.

Acknowledgements

The material presented above is drawn from several sources. But for any conclusions and stress I take full responsibility. The recent book T.S.Kuhn 'Black Body Theory and the Quantum Discontinuity 1894-1912' Oxford (New York, 1978) is an exhaustive study on contributing of Planck and others to this topic, and I have drawn much from it. 'H.A.Lorentz' ed. G.L.Dettaas-Lorentz, North-Holland (Amsterdam, 1957) is another good source that I have relied on.

ERNEST RUTHERFORD, later BARON RUTHERFORD OF NELSON

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Soon after my return from Bonn, when I come to know of the title of this year's Anniversary Symposium and the physicists assigned to me, I started thinking about the catchy sub-title, 'From Planck to Salam, the Quantum to the Quark', and the main title, 'Biographical Approach to Modern Physics', chosen for the Symposium by the Director. In the short 20 minutes assigned to talk about the each physicst, it is just impossible to do any justice to even the most significant contribution made by the physicist. So, only a vague outline of the times of the physicist and what he did for the advancement of physics will be attempted. I found even this a rewarding experience, for, in the words of Longfellow:

> "Lives of great men all remind us
>   we can make our lives sublime,
> And, departing, leave behind us,
>   Footprints in the sands of time"

A slight alteration to this famous annotation of Longfellow expresses, in my opinion, what can be called as the unwritten motto for each one who takes to research.

" Discoveries of great men all propel us
To make our researches more meaningful
And, departing, leave behind us
Reprints in Tomes for the mindful".

In this spirit, let me first talk about Ernest Rutherford, later Baron Rutherford of Nelson.

Ernest Rutherford was born on August 30, 1871, in Brightwater, Nelson, New Zealand. He was the second son and fourth child of a family of twelve. His father James was a farmer, a wheelwright, who in 1882 setup a flaxmill and sawmill in Havelock. When Rutherford was 15, two of his younger brothers were drowned in a boat accident and it fell to him to take the tragic news to his mother, who was a school teacher and a woman of keen intellect. The year of the tragedy Rutherford won a Marlborough Education Board Scholarship - obtaining 580 marks out of 600 and this award enabled him to go to Nelson College. Later he won a junior University Scholarship to Canterbury College, which he attended from 1890 - 1894, graduating with a B.A. in 1892 and an M.A. in 1893 with first class honours in both Mathematics and Physical Sciences.

In 1894 began the amazing career of Rutherford with a simple and ingenious experimental set-up of the first magnetic detector of wireless waves. He was able to send and receive signals first over the length of his laboratory, then across a large open common and finally, at Trinity College, Cambridge, from the laboratory to his lodgings and in 1895 he held the then world record of reception at 2 miles. He published a paper on 'A magnetic detector of electrical waves'.

Rutherford's achievements in the field of physical sciences spanned the years 1895 - 1937. Till 1895, Rutherford was in New Zealand but spent his most productive years as Professor of Physics in Cavendish Laboratory, Cambridge (1895 - 1919) and McGill University, Montreal (1898 - 1907), as Professor and Director of the Physical Laboratory at the University of Manchester (1907 - 1919) and again as Professor at Cambridge (1919 - 1937). Rutherford was awarded the Nobel Prize for Chemistry, in 1908, for 'His Researches on the disintegration of the elements and the chemistry of radiative matter'. He was knighted in 1914 and in 1931 Rutherford was created a Baron and took the title of Lord Rutherford of Nelson, revealing by his choice of the title his love for his homeland.

At present usage of words like quarks, gluons, Higgs bosons, and bags, has become acceptable as part of the increasing scientific vocabulary. When we talk of the times of Rutherford, we go back to a time when the words electron, alpha-particle, proton, neutron, Y-rays, isotppes, were equally new and mind-bogging. These words are now, however, familiar to most and are even mentioned in the press and over the radio.

In 1895, he elected to work under J.J.Thomson, at Cambridge who put forward the idea of a unit of electricity - the electron - which was a constituent part of the structure of all atoms, although only 1/1800 th the mass of the hydrogen atom. With Thomson, Rutherford investigated the conditions governing the remarkable conducting power for electricity imparted to a gas through which the Rontegen X-rays were arranged to pass. This work was published by them in 1896. Thereafter, Rutherford worked on his own, or as senior partner with others.

After Becquerel discovered, in France, that Uranium gave out rays which, like X-rays, could affect a photographic plate, Rutherford discovered that Uranium gave out two kinds of radiation which he named as alpha and beta rays. Debierne added the third, the gamma-rays. After this work at Cavendish, Ratherford moved to McGill University, Montreal, and the new radioactive substances and their radiations became his life's work. At McGill, Ratherford was at the height of his mental and physical prowess and during the years 1898-1907, he was the pioneer, the planner, the integrator of the efforts of his colleagues and the formulator of bold theories. Professor Cox unselfishly relieved Rutherford of much of the routine administration, while the tobacco millionaire Macdonald, who endowed the Professorship, also provided Rutherford with money to purchase radium and a liquid air plant which made many of his best subsequent experiments possible.

At McGill, Rutherford discovered the radioactive disintegration of Thorium. He proved that the α-particle is positively charged and that it is an atom of helium, while the beta-particle was nothing but an electron. In 1903, Rutherford calculated the enormous energy that was being released in the radioactive decay of Radium. In the same year, he was elected a fellow of the Royal Society. In 1904, Rutherford estimated the age of the earth from the heat generated throughout the ages by radioactive elements, and the publication of his book 'Radioactivity'. The crowning achievement was the unravelling of the successive radioactive changes in the radium, thorium and actinium families.

In 1906, Professor Arthur Schuster, at Manchester, a man of great moral strength and scientific and administrative ability, being reasonably wealthy, was considering retirement, so that he could devote more time to theoretical studies, to international science, and to the Royal Society. He considered Rutherford as the ideal person to take-over the reigns of the department and in a spirit of self-abnagation offered to resign his chair at Manchester, if Rutherford agreed to take his place. At the same time he offered to personally finance a readership in Mathematical Physics, which was subsequently held by Sir Charles Darwin and later by Niels Bohr. This led Rutherford eventually to move to Manchester in September 1907, where he started his experimental work in right earnest within a few weeks of his arrival. In a letter to his mother, at New Zealand, Rutherford wrote that compared with Canada and New Zealand, the Manchester students tended to look up to a Professor as somewhat of a God. During his twelve years at Manchester, 1907-1919, his research was directed principally at investigating atomic structure by using alphs-particles as projectiles. In 1908, he and Geiger constructed the first particle counter - later improved by Geiger to become the famous Geiger counter. The same year he was awarded the Nobel Prize for Chemistry, for 'His researches on the disintegrated of the elements and the chemistry of radioactive matter'. Towards the end of his life, in 1931, he expressed his unconcealed debt to Manchester in the following words: 'I owe a great debt to Manchester for the opportunities it gave me for carrying out my studies. I do not know whdther the University is really aware that the few years from 1911 onwards the whole foundation of the modern physics movement came from the physics department of Manchester University."

We have already mentioned the fact that, with Geiger, he constructed the first particle counter: A thin wire or needle point charged to a high voltage was inserted axially in a metal tube into which α-particles were allowed to enter. As each particle entered, the ionization produced was increased greatly by collision with air molecules at those high voltages and sufficed to cause a current to cross the gap and give an observable pulse on a connected electrometer. With this beautifully designed experiment, it is remarkable that they obtained a value of 'e', for example, within $2\frac{1}{2}$ % of that obtained from the methods available over 50 years later. However, at that time, their value was 40%

higher than the previously accepted value and hence the consequences of this measurement were many in all branches of physics.

Geiger and Marsden were scattering alpha-particles through thin metal foils such as Al, Ag, Au, Pt, etc., when Rutherford had a hunch and asked Marsden to 'see if you can get some effect of α-particles directly reflected from a metal surface'. This led to the startling discovery by Geiger and Marsden that a small fraction of the incident α-particles, about 1 in 20,000, were turned through an average angle of 90° in passing through a layer of gold-foil about 4×10^{-5} cm. thick. Rutherford showed that the distribution of α particles for various angles of large deflection did not follow the probability law to be expected if such large deflections were considered to be made up of a large number of small deviations.

This expectation that a series of small deflections take place as a charged particle passes through an atom is a natural consequence of the then model of the atom proposed by J.J. Thomson, according to which the atom was supposed to consist of a number N of negatively charged corpuscles and an equal quantity of positive electricity uniformly distributed throughout a sphere. Rutherford putforward the bold assumption that the deflection through a large angle is due to a single atomic encounter and for such a thing to be possible the atom must be a seat of an intense electric field. These considerations led him to propose the now famous Rutherford Nuclear atom model, in 1911, according to which an atom 'contains a charge $\pm$ Ne at its center surrounded by a sphere of electrification containing a charge $\mp Ne$ supposed uniformly distributed throughout a sphere of radius R". We all know, how Bohr improved on this model and said that the Rutherford's atomic nucleus is surrounded by electrons moving in stable, non-radiating orbits, to account for the spectrum of the hydrogen atom.

During the war years (1914-1918) he was appointed to a position on the Admiralty Board of Invention and Research to work in the field of submarine detection.

In 1919 Rutherford return to the University of Cambridge for a second period, as Professor of Experimental Physics. A light-hearted song on "An Alpha Ray" was composed by A.A.Robb, shortly after Rutherford's arrival, and it formed part of the "post-prandial proceedings of the Cavendish Society". The last few lines of the song were:

> "For an alpha ray
> Is a thing to pay
> And a Nobel Prize,
> One cannot despise,
> And Rutherford
> Has greatly scored,
> As all the world now recognize".

In June 1920, Rutherford delivered his second Bakerian lecture, before the Royal Society, and made one of his most remarkable predictions that somewhere in the atom, a neutral particle might exist, which would be very much more useful as an atomic artillery projectile than the α-particle. Twelve years later, such a particle, called the 'neutron' was discovered by Chadwick in 1932.

Also, in 1920, Rutherford suggested that the hydrogen nuclei should be called as 'protons'. In 1922, he disagreed with the suggestion that the hydrogen nucleus be called a 'positive electron', for he conjectured "a positive unit of electricity associated with a much smaller mass than the hydrogen nucleus may be discovered". Again, ten years later, in 1932, such a particle, called the positron, was discovered by C.D.Anderson.

After the discovery of the neutron in 1932, Rutherford was interested in the possibilities of producing fast particles with which to bombard nuclei and this resulted in the Cockroft-Walton machine and the subsequent era of particle accelerators.

In the August 1937 issue of Nature, Rutherford published the last of his publications, which total an astounding 340-odd in all! This paper entitled, " The search for the isotopes of hydrogen and helium of mass-3", was an account of the search for tritium in nature, by the method of electrohysis. Appropriately enough natural tritium was first detected by Dr.W.F.Eibby at Chicago University in 1951.

Rutherford died unexpectedly on the 19th of October 1937. Among his last words to his wife were: "I want to leave a hundred pounds to Nelson College. You can see to it".

The fact that in Nature of 1938, two publications appeared , which were to be respectively, his " Presidential address prepared for the Jubilee Meeting of the Indian Science Congress", and on the " Transmutation of Matter" , is a clear indication of how Rutherford was snatched away from this world before he could visit our country.

In 1961, a Rutherford Jubilee International Conference was held in Manchester to mark the Fiftieth Anniversary of the Rutherford scattering law and the discovery of the atomic nucleus. Ten years later, in 1971, the Rutherford Contennial Symposium was held at the University of Centerbury, Christ Church, New Zealand, and in this latter Symposium, Professor Alladi Ramakrishnan participated. That so many years after his death, these meetings were held to talk about the works of Rutherford is only because the scientific world wanted to acknowledge him as the " father of modern science" , who through his works wrote the " modern bible of science" .

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C. V. RAMAN [*]

by

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Chandrasekhara Venkata Raman is perhaps the only name of a scientist which is a household world in India barring the exceptions of Meganath Saha and Homi Bhabha. Raman effect is the only scientific discovery that is widely known to the public in India.

Drawing on the material on C.V.Raman's biography presented at the 50th Anniversary of the discovery of Raman effect, we know that Venkataraman was born on 7th November 1888 at Tiruvanaikaval in Trichy district, as the second child of Chandrasekhara Iyer and Parvathi Ammal. His father was a school teacher and later accepted the post of a lecturer in Mathematics and Physics in Mrs.A.V.N. College, Vizagapatnam (in Andhra Pradesh) for a salary of Rs.85/- p.m. A good collection of Mathematics and Physics books collected by his father was within the reach of young Raman.

Venkataraman matriculated at the age of 11, passed his F.A. at the age of 13, entered Presidency College, Madras for his B.A. with a scholarship for his B.A. degree course. He passed his M.A. in 1907, winning gold medals for Physics and English. I have been at Presidency College, demonstrating my weakness in experimentations and have been daily looking at his photographs in the Presidency College for 3 years during the fifties.

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[*] We have drawn much on the contributions in the Physics News of December 1970 which was devoted to honouring our great scientist.

At the age of 16 measuring the angle of a prism with a spectrometer experiment as many of us have done so many times, he observed diffraction bands which formed the subject matter of his first publication in the philosophical Magazine (London) 1906. Then followed another paper on a new experimental method of measuring surface tension.

'Nature whispers and only the gifted minds understand the message'. This is amply illustrated in the life of our hero. He did not go to England for further studies being disqualified in medical tests by the civil surgeon of Madras. He always thanked the civil surgeon for a good turn. In his 18th year he passed the civil service examinations and in 1907 joined the Calcutta office as Assistant Accountant General when he was 18 $\frac{1}{2}$ years old. Meanwhile he married Lady Raman Lokasundari, when she was 13. Story has it that she sang on the Veena the first time she saw him the Thiyagaraja Kiruthi, 'Rama ni Samanam Evero' . As a married officer he was given an addition Rs.150/- from the Finance Department and the couple settled in Calcutta off Bowbajar street.

Within a few days after settling in Calcutta he got into the Association for Cultivation of science and met Ashu Babu, who was his associate in all his scientific endeavours for the next 25 years. Amit Lal Circar, the secretary of the association promptly handed him the keys of the Institute. It was Mahendralal Circar, his father who established this association and wanted that some young researcher made use of its facilities. Raman began work tirelessly at the association both in the morning before going to the office and later after 5 p m. coming there straight from the office to work till 10 p.m. running round in taxis all the time as Mr.A.G.Narasimhan told me. He was transferred to Rangoon in 1909, to Nagpur in 1910, and posted back to Calcutta in 1911. He started the Bulletin in 1911, which later became Journal of Physics.

He has heard his father play violin. He experimented on the bowed strings. He and Ashu Babu were the only workers in the association for cultivation of science. Papers on struck strings, plucked strings, and musical flames followed. His researches on Veena, musical drums bring out the high harmonic contents of these instruments and by 1920 Raman has become the world authority on sound and musical instruments.

His work in the Finance department was praised by his superiors and there was every chance of his going up to dizzy heights, may be to the position of the Finance member in the Viceroy's Council in the impending Indianisation at that time. But he accepted the Palit chair of physics at the Calcutta University at the invitation of Sir Asutosh Makerjee, its Vice Chancellor, for a salary less than what he was getting. The endowment for that chair required that the occupant shoud have been trained abroad and Raman refused to go to England to be trained. Sir Asutosh changed the constitution.

In 1921 under presure from Sir Asutosh he went to Cambridge, Oxford and met famous scientists like Sir Thomson, Bragg and others.

As a tourist he goes to St.Paul's Cathedral in London and does experiments on the whispering gallery effect there, publishes two papers, one in Nature and the other in Proceedings of the Royal Society.

On his return voyage, he investigated the blue of the mediteranian. Again the story of his investigating what he saw. Rayleigh has explained the blue of the sky as due to light scattering by molecules of the atmosphere and he has dismissed the blue of ocean as just due to the reflection of the blue of the sky by sea. Raman demolished this idea by making observations of sea with polarizing nicol prism. He proved that the bluesness of the sea is due to the scattering of light by the moleculus of the water in the sea itself. He later concerned himself with these ideas, namely the scattering of light by liquids, the X-ray scattering and viscosity of liquids. On X-ray scattering from liquids many experiments were done, early in India as evidenced by the famous Raman - Ramanathan (1923) papers. They did not apply the Fourier transform methods which Zernicke and others applied later in 1927. He has advanced theories of viscosity, which has been used by polymer chemists.

Many of his students studied the molecular scattering of light by a large number of liquids. Raman's monograph in 1922 'On the Molecular Diffraction of Light' is a classic. He deeply considered how the quantum of light could exchange energy with the molecules. We should note that all this was before the discovery of Compton effect. In April 1923, K.R.Ramanathan, one of his distinguished students performed experiments on scattering of light from water using a system of complimentary filters. Scattered light showed a change in color. This was attributed to 'Weak flourescence'. Raman was not satisfied with this explanation. This effect persisted even after repeated distillation of the liquid to remove flouresecent impurities. This same effect was observed by K.S.Krishnan in many organic liquids. The weak flourescence was not unpolarised as it should be if it is due to real flurescence Raman gave a classical explanation of Compton X-ray scattering using the concept of fluctuations.

In 1928, Raman along with Krishnan set up detailed experiments for the study of the scattering of light in organic liquids and vapours and 7th February 1928, they found all liquids exhibited 'Weak Flourescence' which was polarised. On the 16th February they sent a note to Nature suggesting that 'the modified radiation could arise from fluctuations of the molecules of the liquid' an analogue of compton effect in the visible region. On 27th February Raman asked Ashu Babu to set up the mercury vapour lamp and used the direct-vision spectroscope to study the 'flourescent track'. Using filters to cut of all the components other than Indigo 4358 A.V. they found two sharp lines in blue-green region. Raman effect was discovered on 28th morning and the announcement was made on 29th February 1928.

Who gave the name to this effect ? In 1923 Smekal had predicted using Bohr model of the atom, that photons can be inelastically scattered. For a while this was called Smekal-Raman effect. Closely on the heels of the discovery of Raman effect, Landsberg and Mandolstam of Soviet Union reported the same effect in Quartz. They called it 'Combinatorial Scattering'. However, the name, Raman effect stuck and Nobel Prize citation in (1930) refers to the " The discovery named after him" since Raman himself identified the basic features connected with this stimulated radiation.

The physics of the process is that the incident light interacts with the medium and introduces oscillating polarisation components with frequencies which are either the sum of the incident and inherent frequencies, or their difference. These oscillating dipoles emit radiation which correspond to the stokes and antistokes lines and gives rise to Raman scattering. Talking quantum mechanically Raman scattering is related to the off-diagonal matrix elements of the polarisability operator while Raylight scattering relates to diagonal elements. Raman effect is effectively used to study oscillatory polarisability caused by molecular rotations, Vibrations and electronic motions. The widest use has been in the study of vibration spectra since these vibration frequencies of molecules and solids are in the infrared region which is not convenient for experimental study while their Raman modulated frequencies are in the visible and ultra-violet region where the photographic plate is very sensitive.

A large amount of research by physical chemists to study structure of molecules has been carried out specially for the large molecules. Then came the laser with high-power-packed monochromatic light with high directional and near perfect polarisation. Added to this are the improvements in the electronic detection of radiation signals which have led to the widespread use of Raman spectrometer now-a-days, and we list some of the important fields of laser Raman spectra.

(i) Exploring the long wavelength vibration modes of ionic crystals. These give information about electric fields and also provide a better understanding of their optical properties. While first order Raman scattering gives information about long wavelength modes, second order Raman effect gives information about short wavelength phonons. Laser Raman effect leads to investigation of damped soft modes in ferroelectrics, investigation of polaritons (Photon phonon coupling) in a lattice medium with transverse electric fields etc. Similarly in degenerate semiconductors, where the plasmons get coupled to the phonons, Raman spectra gives a clue to these modes. When the conduction electrons in a semiconductor are in a magnetic field they arrange themselves in the Landau levels and the transitions between theseselves are studied by Raman spectroscopy.

Another domain in which Raman did a lot of investigations and ran into severe controversies is the physics of crystals and their dynamics in particular. This is a field in which Einstein, Debye and Born paid a lot of attention. Einstein considered crystals as an assembly of isotropic oscillators with a single frequency. He assumed that the average energy of the oscillator is given by Planck's law rather than the Equipartition law and he found that specific heat went down to zero as temperature goes to zero. Debye considered that the crystal lattice can be replaced by an elastic continuum with a continuous frequency spectrum. Debye's formula was a better fit for specific heat data. Born-von Karman took account of lattice structure of an infinite crystal with cyclic boundary conditions. Raman did not agree with the idea that normal modes can be classified on the basis of travelling waves, and staunchly opposed the theories of Debye and Born. He favoured the Einstein idea of having normal modes and their frequencies. He worked on diamond and extensively studied its X-ray diffraction patterns. The same analysis were done by neutron spectrometry at Los Alamas in 1970. Similar work is also done at Trombay with many substances. There are many questions to be settled between these views and more experiments may be needed which may come up in future.

Raman spectra is used in petrolium industry to characterise different hydro-carbons in the petrolium fractions, i.e. characteristion of oils. A wide variety of problems in nucleic acids peptides, amino acids, especially proteins and the DNA of different types have been studied with Raman spectra with impressive results. The future of Raman polymer studies hold great prospects.

He left Calcutta in 1933, to become the Director of Indian Institute of Science, Bangalore. Finally in 1951, he set up Raman Research Institute in which he worked for next two decades of his life.

He was awarded the Nobel Prize in 1930. He was made the Fellow of the Royal Society in 1924 and was knighted by the British Government in 1929. The Soviet Union gave him the Lenin peace Prize in 1958 and he was awarded the title 'Bharat Ratna' in 1954.

A grateful world of science all over the world showed its appreciation of Raman's contribution to knowledge by showering upon him many honorary degrees and fellowship of prestigious scientific bodies. To foster the growth of scientific community within India he helped to formed the Indian Science Congress in 1951, and later the Indian Academy of Sciences in Bangalore. His greatest gift was his power of expression. He could make a scientific idea literally come alive by choice of words and imagery that will make even a layman experience the idea as his own. His greatest contribution to Indian Science was the demonstration that the essence of science is independent thinking hard work and devotion and nothing else.

HEISENBERG

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Heisenberg is undoubtedly one of greatest Physicists of this century. His name is inalienably associated with the discovery of Quantum Mechanics. Professor Dirac when he introduced Heisenberg to an audiance has said that " we were both young men at that time, working on the same problem. He succeeded where I failed".

Werner Karl Heisenberg was born on 5th December 1901 in Wurzburg in Bawaria. I had the fortune of spending a few years at the University of Wurzburg. In fact, the Wurzburg Municipality has brought out a commomoration coin in honour of Heisenberg. It is also Wurzburg where X-rays were first discovered by Rontgen. He worked for his Ph.D. in the University of Munich under Arnold Sommerfeld on a problem in classical hydrodynamics, the transition from laminar into turbulent flow. He developed his own approximation methods to deal with the non-linear problem and showed that the Poiseuille flow between two parallel walls would become unstable if the Reyunold's number connected with the problem exceeded the value of about 1000, a result which was later reconfirmed by L.H. Thomas.

Pauli and Heisenberg had the fortune of attending the lectures of Niels Bohr in Gottingen (Bohr's festival) in June 1922. Bohr explained about his atomic model, quantization and correspondence principle. He dismussed the calculation of quadratic Stark effect that was done by Kramers on the basis of correspondence considerations. Heisenberg raised a serious objection because the result did not agree with any of the classical frequencies of the atom. Bohr was very impressed with Heisenberg and invited him to join him for walks on the Hainberg in Gottingen to discuss the problems of atomic theory.

After his Ph.D., Heisenberg went to Gottingen to work under Max Born . With Born, he did a systematic study of complex atoms with the help of perturbation methods. To explain the correct ionization energy of helium atom, Heisenberg showed that one had to introduce half integral quantum number. But Bohr thought that it was the mechanics that was wrong. In the meantime other difficulties had arisen for Bohr's conception of atomic phenomena based on correspondence principle, especially the discovery of Compton effect in 1922, which proved the existence of light quanta.

Bohr, Kramers and Slater used the idea of a virtual oscillators to explain Compton effect without the light - quantum . Lademberg dispersion relations which Kramers later extended to describe transitions by taking into account both types of dispersion effects of atoms in an arbitrary state n , one in which the emission follows absorption and the second in which the reverse takes place. By 1925, Bohr-Karamers-Slater theory got into serious problems connected with the statistical independence of emission and absorption and the energy - momentum conservation. Heisenberg traced the difficulties to the breakdown of the Kinematics underlying the mechanics. He showed that the classical combination law of re frequencies has to be amended. This led him to the concluion about the non-commutativity of two dynamical variables. Born showed that Heisenberg's symbolic multiplication was nothing but matrix calculus. Further developments we made by Born, Heisenberg and Jordon in their famous paper usually referred to as " Drei-Manner arbeit".

Dirac, working on Hamiltonian formulation established the connection between classical Poisson bracket and Heisenberg's commutation brackets.

I do not have to describe to you on the great triumph of quantum theory. Heisenberg showed that the noncommutativity of dynamical variables leads to limitations on the simultaneous measurements of physical quantities like momentum and position

$$\delta p . \ \delta q \sim \frac{h}{2\pi} \quad .$$

This uncertainty relation won him the 1932 Nobel Prize. He became the Director of Max Planck Institute fur Physics in Gottingen in 1946 which was transferred to Munich in 1958. He played a leading role in the reconstruction of Science in Germany after World War II. He has made outstanding contributions to many branches of theoretical physics like theory of turbulence, of ferromagnetism, of Nuclear forces (he introduced the concept of isotopic spin), S-matrix, and non-linear theory of elementary particle interactions.

ERWIN SCHRODINGER

(Aug. 1887-1961)

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Schrodinger was born on August 12, 1887 in Vienna. He belonged to a Bavarian family settled in Vienna. He was a versatile with vast personal culture that included the study of Greek literature and philosophy and the writing of poetry. He was at the University of Vienna during 1906-1910. He was very much influenced by Frirtz Hasenohrl who was Boltzmann's successor. Schrodinger had mastery on eigenvalue problems in the physics of continuous media. He served as an artillery officer in World War I. In 1920, he joined as an assistant to Max Wien, followed by a position in Stuttgart. He spent six years in Zurich replacing Von Lane. It was in Zurich that he had the contact and friendship of Herman Weyl and Debye. In the fall of 1925, Schrodinger had become tired of his stay in Zurich and the work of Heisenberg, Born and Jordan on matrix mechanics added to his discomfort. To get over this unhappiness, he started on a scheme of atomic mechanics which served as an alternate to matrix mechanics. His work started controversial discussions that led to the physical and philosophical interpretation of quantum mechanics. In four communications to the Annalen der Physik (1926), Schrodinger developed his theory of wave mechanics, entitled " Quantization as an eigenvalue Problem" . He used his equation to solve the problem of the spectrum of hydrogen atom. In the mathematical aspects, he had invaluable help from Weyl. In Schrodinger's work the basic ideas of Einstein and Louis de Broglic found a natural place. Schrodinger soon recognized that his approach and the matrix methods of Heisenberg and Born complemented each other. He recognized the " formal, mathematical identity" of Wave mechanics and matrix mechanics. In the last stages, he moved to Dublin where he stayed until 1955. In the last bit of his service, he was working on Einstein's ideas of unifying electromagnetism and gravitation. After retirement, he came to Vienna where he died on 4th January 1961.

NIELS HENRIK DAVID BOHR

(October 1885 - November 1962)

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Besides his basic discovery of the structure of atomic and of the radiation emanating from them, we particularly remember him for as you all know that he is directly responsible for the creation of our Institute. It is the impression that he conveyed to Pandit Nehru that moved the sponsers to start our Institute. We have instituted a Niels Bohr, Visiting Professorship at the Institute and many eminent scientists like Professors Schiff and Marshak visited our Institute under this scheme.

Niels Bohr was born in Copenhagen on October 7, 1885 as the son of Christian Bohr, an eminent physiologist. He studied in Copenhagen University and took his Doctor's degree in 1911. Even as a student, he won a gold medal for his investigation of the surface tension by means of oscillating fluid jets. His stay in 1911 in Cambridge and in 1912 in Manchester laid the foundations for his interests in atomic structure. Rutherford had earlier discovered the existence of the nucleus through his work on alpha-particle scattering. By introducing conceptions borrowed from the quantum theory as established by Planck, Bohr succeeded in working and presenting a picture of atomic structure that, with later discoveries of Heisenberg explains all the physical and chemical properties of the elements. In 1916, he was appointed

Professor of Theoretical Physics at Copenhagen University, a position he occupied until his death in 1962. He was awarded the Nobel Prize for 1922. He worked on Neutron Capture and nuclear constitution and on liquid drop model. Bohr also contributed to ~~the classification of the problem encountered~~ the classification of the problems encountered in quantum physics, in particular by developing the concept of complementarity. He has authored many books. He has six sons one of whom we will know is Professor Aage Bohr, who also has won the Nobel Prize.

L.D. LANDAU

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Lev Davidovich Landau, the great Soviet theoretical physicist was born on 22nd January 1908, at Baku. His father was a Chief Engineer to an oil company and mother, a midwife. At the age of 12 he passed matriculation and entered the University at Baku and then left for Leningrad University. He was not only a child prodigy but also a singular, determined and obstinate ~~fashion~~ person, as evidenced by his remark that he would be ashamed to get a better mark than a pass for some subjects like literature etc. He shaped himself into a great physicst at Leningrad and got a nick name Dau which struck to him. Landau was one of the outstanding theoretician of our century. He had achieved unfading merit by his creation of a modern theoretical style. He was unique in being able to get to the theoretical essence of any problem and solve it by the method of theoretical physics. He could simplfy a problem and make it trivial Landau was one of the very few physicst universalist. After Fermi's death he remarked " Now I am the last physicist universalist". Before finishing the University at the age of 18, he published two papers on quantum mechanics and one of them being the density matrix formalism in quantum dynamics. Then he was a post-graduate student in the Leningrad Technological Physical Institute.

By the end of 1928, he went to Europe worked with Pauli and Dirac and stayed for a good time in Copemhagen with Bohr and the Institute which was the Mecca of theoretical Physicists. We quote Professor Bohr who said'From the beginning we got a deep impression of his power to penetrate to the root of the physical problems and his strong views on all aspects of human life" . Bohr has to repeat very often "Landau do not grumble but criticise and now let me say a few words" . The German Chemist Ostwald divided men of science into two groups - Classicists and romantics. Classicists devote themselves to one field and spend their lives in developing their own fields. Their thinking is inertial. Romantics work in various fields and their thinking is almost without inertia and they fly like birds from one to another and glide from field to field and Landau was a Romantic.

Landau was an unusual personality both as a physicist and a man and always aroused public interest and public indignation. He classified physicsts in a 5 decade logarithmic scale. A phycisist in class 1 did 10 times more physics than the physicist in class 2. In that scale he put Eihstein as 1/2, Bohr, Heisenberg, Dirac and Schrodinger etc. were assigned class 1, and adjudged himself as class $2\frac{1}{2}$. He promoted himself to class 2 after his work in phase transition.. It was during this time that he propounded his famous theory of diamagnetism of the electron gas called Landau diamagnetism.

After return from Europe, he joined Leningrad Physical and Technical Institute and had to leave it to go to Kharkov and realised his great talents as a teacher. Though his sloppy dressing was a challenge to public taste, large number of studants were attracted to his lectures. Out of these lectures grew the eight monuments of this great mind, as the eight volumes of theoretical physics written by Landau and Lifshitz, translated into 10 languages now.

It was in Kharkov, he conceived the idea of the theoretical minimum for a graduate student which consisted of mine tests, one has to get through before taking up research. Very few got through his tests and it was called the Landau barrier. Only 43 scientists surmounted the barrier. In 1934, Landau was awarded the doctorate degree without presenting a thesis. He began now to investigate the theory of phase transition and published a series of fundamental papers on this subject.

He very soon left Kharkov and began to work in Institute of Physical Problems in Moscow. This Institute was started in 1934, by Professor Kapitza, a low temperature specialist, who was with the Cavendish Laboratory for a number of years. This was an exceptional Institute and Landau found that he could flourish without any conflicts and grow to great heights for which his exceptional talents destined him. In 1938, when he was in the midst of his superfluid theories, an years interuption followed.

. After resuming at Institute of Physical Problem, he revoked his earlier principle about marriage got married in 1940, and got a son named Garik in 1946.

The post war period saw an eruption of scientific activities of Landau in the field of superfluidity and on the viscosity of liquid Helium. Then followed a number of papers on a critical re-evaluation of quantum electrodynamics, quantum field theory and theory of elementary particles. In the fifties he created his most famous contribution - the theory of the Fermi liquid.

Landau created the most influential soviet school of physics. However, Landau's role sometimes seemed controversial. He was a strange and unique mixture of simplicity, democratic behaviour and unlimited intolerance and self-confidence. About particle-hole' concept he said " <u>Quatsch</u>" in his letter to Bohr. Landau coined a new word to condemn, theories or physicists he did not like. He called it pathology. His absolute judgements produced some harmful effects as in the case of I.S.Shapiro from Moscow, in 1956. Shapiro investigated the τ-θ puzzle and came to the conclusion that it can be explained by parity non-conservation. Landau laughed at such an idea when Shapiro presented his paper and without his holy consent it could not be published before Lee and Yang published it. Soviet physics lost one Nobel Prize. His last scientific paper was on 'Fundamental Problems dealing with multification of electrical charge in elementary particles', published in the memorial volume to Pauli.

His scientific contribution covered a wide field, quantum mechanics, quantum field theory, elementary particle physics, nuclear physics, thermodynamics and statistical physics, continuum mechanics and many different parts of statistical physics. They may belisted chronologically as:-

(1)	The density matrix in quantum Meahanics and statistical Physics.	.. (1927)
(2)	Quantum theory of diagmagnetism of the electrons	.. (1930)
(3)	Phase Transitions of second order	.. (1936-37)
(4)	Domain structure of fermomagnetics antiferro-magnetism	.. (1935)
(5)	Theory of intermediate state of super conductors	.. (1943)
(6)	Statistical theory of atomic nucleus	.. (1943)
(7)	Quantum theory of superfluidity of He-II	.. (1940)
(8)	Multification of electrical charge of elementary Particles	.. (1954)
(9)	Quantum Theory of Fermi liquid	.. (1956)
(10)	Combined parity in weak interaction	.. (1957)

In 1962, November, the Swedish academy presented him the Nobel Prize for Physics for the pioneering theories, for condensed matter, especially liquid helium.

In 1946, he was elected the fellow of the USSR Academy of Sciences. He was awarded a number of orders, including the order of Lenin, the title as the Hero of socialist labour - for his work for the state and the Lenin Prize and an number of foreign honours including the F.R.S., National Academy of Sciences memberships and Max Planck Medal, London Award from U.S .

I conclude this by repating the remarks of R.E.Peierls on Landau in a symposium, on the beginnings of Solid State Physics Organized by Mott in 1979.

In the early 1930's when quantum theory of solids was very much a promising ground for the new quantum mechanics. Landau was very interested in this field to which he brought his characteristic depth of insight and insistence on fundamental understanding. His paper on diagmagnetism of free electrons is well known. He explained the domain structure of ferromagnetism. In papers with I. Pomaranchuk he discussed the effect of electron-electron interaction on the conducting of metals and showed that it will lead to a T^2 term in the resistence to be observable at low temperature. He became interested in the intermediate state of semiconductors and discussed its structure in several papers. In addition, his influence was exerted through many discussions with colleagues which often helped to extend and clarify their views.

On the 7th January 1962, he was fatally hurt in a car accident and a great physicst was snuffed out in a senseless accident. The catastrophy shook the world of physics. The physics community in Soviet Union and the world over exerted itself to drag him out from the jaws of clinical death. An international consortium of doctors, best specialists arrived in Moscow. Customs and Visa formalaties were held in abeyance. The doctors declared that 33% of his salvation as was done to doctors 33% 33% to medicines, to the physicists and 1% to God. Slowly he revived and suffered from loss of memory.

Landau the man survived, Landau the physicist for six years, and on 24th March 1968, he had a relapse and died in April. His last words were " I have not tried badly. I was always successful in everything". That marks him out as a स्थितः प्रज्ञ .