MATSCIENCE REPORT - 86

ESSAYS ON SCIENTIFIC TOPICS-II

BY

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January, 1977.

THE INSTITUTE OF MATHEMATICAL SCIENCES
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ESSAYS ON SCIENTIFIC TOPICS - II*

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*Collection of lectures on scientific topics given over the ALL INDIA RADIO and in other places during the last few years.

C O N T E N T S

ΔTalk given by Krishnaswami Alladi at the All India Radio

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EINSTEIN'S CONTRIBUTION TO HUMAN THOUGHT*

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It must be extreme madness or boldness to attempt to speak on "Einstein's contribution to human thought" at a luncheon meeting of professional groups of doctors, businessmen and industrialists. Obviously this seems too abstract and academic a subject for doctors who cure the ills of flesh and blood, magnates who produce steel and sugar and captains of industry who move ships and aircraft. However I wish to convince you that Einstein's theory of relativity is not so abstruse as it seems, for it has influenced human thought and affected human life as no idea has done before.

In its pristine form, it deals with the unity of space and time which staggers imagination for mankind has been used to thinking for ages that space and time are distinct from one another. The idea is considered so strange because it is generally stated that the concept of simultaneity of two events has been rendered meaningless by Einstein. Actually Einstein has not done anything like that. He merely stated that events which are independent of one another, or those relating to two different objects, can be separated by times less than that taken by light to travel the distance between them. In other words he altered the usual definition of 'alibi' when we say that a person is not responsible for an event if he is found at a different place at the same time. Einstein requires that it is only necessary to prove that person was found at another place at a time interval (before or after !) less than that taken by

*Talk delivered at the luncheon meeting of the Rotary Club at the Hotel Connemara on the 5th October 1976.

light to travel the distance between him and the event. This implies that no object in the world can travel faster than light and this turns out to be a very reasonable restriction on the Newtonian concept. However as regards the events relating to the same individual it is impossible to reverse the order of events. Therefore there is no change due to Einstein in the concept of age or the experiences of any individual.

A striking consequence of Einstein's theory is that energy is related to momentum as time is related to space. This mathematical equivalence inevitably leads to the convertibility of mass into energy, a physical property which when once realised in the laboratory has affected the life of man and the future of the human race. Actually this phenomenon was occurring on a microscopic scale in nature as in radio activity but when applied to matter in bulk has ushered in the atomic age when the first explosion took place in the deserts of New Mexico in 1945. It only demonstrates that the frontiers between various professions are vanishing. The mathematician, scientist, engineer, industrialist and planner - all seem to be engaged in the same enterprise of harnessing nature's resources for the use of the human race.

There is the third aspect of Einstein's theory - the existence of anti-pafticles which when colliding with particles disappear along with them to produce energy in the form of light. These phenomena are happening on a astronomical scale and have a great bearing on the evolution of the universe.

It looks therefore quite natural to contemplate why these three apparently distinct results are unified by the single thread of mathematical reasoning. Very recently in my own way I have tried to understand the magic of this logic. My efforts have led me to cast Einstein's equations in a new form which reveals, even to the layman and the novice, the extraordinary beauty of the mathematical structure and its relation to nature. If I have stimulated in you a trace of faith that the theory is not so abstract as it is thought to be it would justify the kind invitation extended to me on your behalf by my good friend Parthasarathy and endorsed by your gracious president Dr.Sundararaman.

NSS/11.10.1976

UNNOTICED SYMMETRIES OF EINSTEIN'S RELATIVITY THEORY

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"Time has not withered nor space dissipated
the colour and charm of special relativity"

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We shall show that striking symmetries are revealed by rewriting the transformation formulae in special relativity as a 'conservation law' involving n velocities. Hitherto these symmetries were obscured by the particular form of the Lorentz and velocity transformation formulae and the needless use of a multiplicity of words like - 'frame of reference', 'event', 'observer', 'light signals', 'clocks' and 'measuring rods'. In the spirit of a previous paper we assert that Einstein's theory is a perfect creation of the human mind, the elegance and beauty of which are revealed when it is understood as a 'natural completion of Newton'. We therefore recall the following conclusions of that paper which lead naturally to the 'symmetrisation of the transformation formulae'.

1. The world consists of a multiplicity of <u>massive</u> point particles moving parallel and with uniform velocity with respect to one another.
2. An observer is <u>any one</u> of these point particles. An 'observer' is congruent with a frame of reference and by definition is at rest.

3. An event is the 'occurrence or observation' of a point massive particle at a point in space and time.

4. There is an upper limit to the velocity of any massive particle with respect to another.

5. Two events separated by a space like interval relate to two (i.e. different) particles.

6. Two events separated by a time-like interval relate to a single (i.e. same) particle.

A 'conservation law' in physics is usually stated in mathematical terms as follows.

If a, b, c, d, ... e are values of a physical quantity

$$a + b + c + d \ldots\ldots = 0$$

The special theory of relativity is based on a modified conservation law:

$a + b + c$ ...... (sum of values taken singly)

$+ abc + bca$ ...... (sum of products of three values)

$+ abcde +$ .... (sum of products of five values)

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+ (sum of products of $2m+1$ values), = 0

where $2m+1$ is the largest odd number less than or equal to the total number n of values.

We can also express the above law in an equivalent form

$$(1 + a)(1 + b) \ldots\ldots = (1-a)(1-b) \ldots\ldots$$

Let us deal with n massive particles moving uniformly and parallel with respect to one another. Let us label the particles 1,2,... n. Let v^j_k represent the velocity of the j^{th}

particle relative to k. By definition

$v_k^j = -v_j^k$, $v_j^j = 0$ for all j, k. We now take n values in cyclic order

$$v_1^2 , v_2^3 , \ldots . v_{n-1}^n , \text{ and } v_n^1 .$$

Let (m / n) the sum of all possible products of m members* of the set of n values. Then we write the conservation law in Einstein's special theory of relativity as

$$(1 | n) + (3 | n) \ldots\ldots + (2m+1 | n) = 0$$

We note that

$$(m | n) = (m | n-1) + v_n^1 (m-1 | n-1)$$

Hence

$$+ v_1^n = - v_n^1 = \frac{(1 | n-1) + (3 | n-1) \ldots\ldots}{1 + (2 | n-1) + (4 | n-1) \ldots\ldots} = \frac{N}{D} .$$

We can call v_1^n the 'resultant' of the set $v_1^2, v_2^3, \ldots, v_{n-1}^n$.

It is interesting to notice that

$$\frac{1 - v_n^1}{1 + v_n^1} = \frac{1 + v_1^n}{1 - v_1^n} = \frac{(1 + v_1^2)\ (1 + v_2^3)\ \ldots\ldots\ (1 + v_{n-1}^n)}{(1 - v_1^2)\ (1 - v_2^3)\ \ldots\ldots\ (1 - v_{n-1}^n)} = \frac{N + D}{D - N}$$

and also that $D^2 - N^2$ is factorisable as

$$(D^2 - N^2) = (1 - (v_1^2)^2)\ (1 - (v_2^3)^2)\ \ldots\ldots\ (1 - (v_{n-1}^n)^2).$$

Taking the case $n = 3$

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*All velocities are normalised with respect to the velocity of light.

$$- v_3^1 = v_1^3 = \frac{v_1^2 + v_2^3}{1 + v_1^2\, v_2^3} \quad \text{or}$$

$$v_2^3 = \frac{v_1^3 - v_1^2}{1 - v_1^3\, v_1^2} \quad \text{which is the familiar form}$$

in which we express the relation between velocities of the same particle 3 with respect to the particles 1 and 2 respectively knowing the velocity of 2 with respect to 1.

Let two events relating to particles j be separated by space interval x_{j-1}^j and time t_{j-1}^j when the particle $j-1$ is the 'observer'.

$$v_{j-1}^j = \frac{x_{j-1}^j}{t_{j-1}^j} .$$

Thus $$\frac{x_2^3}{t_2^3} = \frac{x_1^3\, t_1^2 - x_1^2\, t_1^3}{t_1^2\, t_1^3 - x_1^3\, x_1^2}$$

yielding $$x_2^3 = \eta(x_1^3\, t_1^2 - x_1^2\, t_1^3)$$

$$t_2^3 = \eta(t_1^3\, t_1^2 - x_1^3\, x_1^2)$$

where η is a coefficient to be chosen suitably

$$\left\{ (t_2^3)^2 - (x_2^3)^2 \right\} = \eta^2 \left\{ (t_1^2)^2 - (x_1^2)^2 \right\} \left\{ (t_1^3)^2 - (x_1^3)^2 \right\}$$

If we choose $\eta^2 = \dfrac{1}{(t_1^2)^2 - (x_1^2)^2}$ then we find

$$(t_2^3)^2 - (x_2^3)^2 = (t_1^3)^2 - (x_1^3)^2$$

i.e. $(t^2) - (x^2)$ is conserved with respect to changes of the frames of reference and

$$x_2^3 = \frac{x_1^3 t_1^2 - x_1^2 t_1^3}{\sqrt{(t_1^2)^2 - (x_1^2)^2}} = \frac{x_1^3 - v_1^2 t_1^3}{\sqrt{1 - (v_1^2)^2}}, \quad t_2^3 = \frac{t_1^3 - v_1^2 x_1^3}{\sqrt{1 - (v_1^2)^2}} .$$

Thus the Lorentz transformations follows as a natural consequence of the velocity transformation. We have here assumed that the velocities are less than unity and therefore $(t)^2 - (x)^2$ is positive. However the extension to the case when

$(t_1^3)^2 - (x_1^3)^2$ is negative while $(t_1^2)^2 - (x_1^2)^2$ is

positive has been discussed in detail in the previous paper.

For general n we can write

$$x_n^{n+1} = \frac{D\, x_1^{n+1} - N\, t_1^{n+1}}{\sqrt{D^2 - N^2}}, \quad t_n^{n+1} = \frac{D\, t_1^{n+1} - N\, x_1^{n+1}}{\sqrt{D^2 - N^2}}$$

where N and D have been defined earlier.

Where for notational convenience we consider the spatial and time intervalsbetween events relating to the n+1th particle when particle n and particle 1 are the 'observers' respectively.

For n = 3 the conservation law takes the form

$$a + b + c + abc = 0.$$

This form for n = 3 has been noticed by L.H.Palmer but it is the case of general n that reveals the symmetries in the structure of the numerator and denominator in the expression for the 'resultant'.

For the case of $n = 4$ the conservation law can be written in the form

$$a + b + c + d = - abcd \left(\frac{1}{a} + \frac{1}{b} + \frac{1}{c} + \frac{1}{d} \right)$$

revealing tantalising symmetries between the velocities and their reciprocals.

The elegant form of the conservation law encourages us to define a physical quantity '<u>bias</u>' of a particle j with respect to k as

$$B^j_k = \frac{1 + v^j_k}{1 - v^j_k} = \frac{1}{B^k_j}, \quad B^j_j = 1$$

with the multiplicative property

$$B^n_1 = B^2_1 \, B^3_2 \, \ldots\ldots \, B^n_{n-1} \, .$$

i.e. the 'resultant bias' is the product of the 'biases'.

The multiplicative property can also be expressed in the equivalent form

$$(x^2_1 + t^2_1) \, (x^3_2 + t^3_2) \, \ldots\ldots \, (x^1_n + t^1_n)$$

$$= (t^2_1 - x^2_1) \, (t^3_2 - x^3_2) \, \ldots\ldots \, (t^1_n - x^1_n)$$

which can be compared with the conventional invariant in special relatuvity

$$(x_1^n)^2 - (t_1^n)^2 = (x_2^n)^2 - (t_2^n)^2 = \ldots\ldots = (x_{n-1}^n)^2 - (t_{n-1}^n)^2 .$$

The former case relates to spatial and temporal displacements of various particle while the later deals with the dis-placements of the same particle relative to other particles.

The quantity 'bias' admits of a very elegant interpretation. Before arriving at it we describe the circumstances under which the velocity of a particle can assume the limiting value ± 1. The particle has to 'massless' to move with velocity ± 1 with respect to a massive particle but it is meaningless to speak of a massive particle moving with respect to a massless particle since a massless particle cannot be a frame of reference. In other words a massless particle can be "observed" but cannot be an 'observer'. This is not an anomaly in the concept of relative velocity but is a consequence of the mathematical concept of a limit in a limiting process. This also implies that we can extend the concept of an event to the observation of a massless particle though we cannot treat it as a frame of reference.

Treating the (n+1)-th particle as massless we can set $V_j^{n+1} = \pm 1$ for all j. The spatial and temporal separations of two events relating to the massless particle with velocity +1 when j and k are observer are connected by the Lorentz transformation formula

$$X_{j(+)}^{n+1} = \frac{(1 - V_k^j)\, X_k^{n+1}}{\sqrt{1 - (V_k^j)^2}} = \frac{t_k^{n+1}}{\sqrt{B_k^j}}, \quad t_{j(+)}^{n+1} = \frac{(1 - V_k^j)\, t_k^{n+1}}{\sqrt{1 - (V_k^j)^2}}$$

imilarly for two events relating to a massless particle with velo-ity -1 separated by the same time interval t_k^{n+1} when k is frame f reference we have

$$X^{n+1}_{j(-)} = \sqrt{B^j_k}\; X^{n+1}_k = -\sqrt{B^j_k}\; t^{n+1}_k , \quad t^{n+1}_{j(-)} = \frac{(1 + V^j_k)\, t^{n+1}_k}{\sqrt{1 - (V^j_k)^2}}$$

he ratio

$$\frac{-X^{n+1}_{j(-)}}{X^{n+1}_{j(+)}}$$

s recognised to be the 'bias' of j with respect to k. It is to e noted that the spatial and temporal intervals are altered by the ame factor $\frac{1}{\sqrt{B^j_k}}$ or $\sqrt{B^j_k}$ as we shift from particle k to j keeping he velocity of the massless partdcle constant with respect to any rame of reference.

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PROFESSOR PAUL ERDÖS

Professor Paul Erdos the eminent Hungarian Number Theoriest visited Madras in January 1975 and gave two lectures at MATSCIENCE . This provided an opportunity for Krishnaswami Alladi a student of Vivekananda College, to consult the famous mathematician regarding the research work he did during his undergraduate studies. Therefore in this series of scientific essays a radio talk of Krishnaswami Alladi about his association with Professor Erdos has been included.

MY ASSOCIATION WITH PAUL ERDOS*

Krishnaswami Alladi[Δ]

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In the world of mathematics and in particular in number theory Professor Paul Erdos is considered a phenomenon. For little over forty years he has been continuously producing original mathematical work of the highest quality and even now in his mid-sixties is still one of the most active mathematicians in the world. But these are not just the reasons why he is regarded as unique, for it is a common feature of great scientists to contribute substantially for decades together. So before I start describing my association with Professor Paul Erdos let me first give a description of who he is, the kind of work he does and how he does it.

Paul Erdos is of Hungarian origin and is a professor at the Hungarian Academy of Sciences in Budapest. But he is rarely there. He is probably the world's most widely travelled mathematician and I am sure that even diplomats like Kissinger would be baffled by this record. Erdos believes that mathematics survives and grows essentially because of communication and constant exchange of ideas. It is his philosophy that he should never stay at one place for too long a time. In fact he seldom spends more than a couple of months at a particular centre of research during a visit and usually he visits universities only for a few days. But it is next to impossible to keep such a philosophy successful. First, one has to be a mathematician of world rank to be wanted everywhere. Secondly, Paul Erdos

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*Talk delivered at the All India Radio, Madras, on 13th Aug.1976.

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is so friendly that people feel it is always a pleasure to be his host. It would be improper to call him a namad, for a nomad by definition is a homeless man. On the other hand to Professor Erdos every University is his home. So we may justly described him as a mathematician eternally on the move from one home to another.

His friendliness brings us to another interesting side of the story. Professor Erdos has to his credit more than seven hundred original papers published regularly over the last forty years. Of these certainly more than a third are in collaboration with others, so much so that there is a well known joke about 'Erdos number' in the mathematical world. 'Erdos numbers' are defined as follows. Erdos himself has Erdos number zero. Any person who has directly collaborated with him has Erdos number one. A collaborator of a collaborator with Erdos has number two and so on. The well known joke is that any mathematician of the present day who has joint paper with another does have an Erdos number. In other words it is always possible to trace one's 'ancestry' back to Erdos. In fact somebody asked Erdos why he writes so many papers jointly with others. Erdos is supposed to have replied that it is his belief that he will live as long as half his collaborators are alive and that is why he likes to have young collaborators.

Let me now briefly mention the work that brought him fame. Probably the most important theorem in the theory of numbers is the prime number theorem. This was proved first at the end of the nineteenth century by two French mathematicians using the highly sophisticated theory of functions of a complex variable. For quite sometime mathematicins were trying hard to get an elementary proof, where the word elementary is not to be misunderstood. Elementary here means that the proof does not involve complex analysis. It was considered a sensation when in 1947. Professor Erdos along with Selberg gave an elementary proof of the prime number theorem. His contributions have been to mainly to number theory and more recently he is working on the rapidly growing subject of graph theory, where too he is an authority. I think by now you must have begun to realise that Professor Paul Erdos is doubtlessly a phenomenon. Let me now mention briefly my meeting him and how our joint paper came about.

It was in June 1973 when I participated in the International Summer Institute in Number Theory in Ann Arbor, Michigan, U.S.A. that I first heard of Paul Erdos as a phenomenon. Unfortunately I could not meet him then for I had to come away to Madras. It was however a fortuitous circumstances when in January 1975 Erdos passed through Madras enroute to Australia. He gave four lectures here, two at my father's Institute Matscience, and two more at the Ramanujan Institute. I attended all his lectures and explained to him the problems I was interested in. At that time I was working on the properties of the arithmatic function representing the sum of the prime factors of an integer. I expressed the opinion that it is rather strange that this function had not been discussed in detail before. He then went to Australia where he spent a few weeks and moved to the U.S.A. Throughout his travels we were in regular correspondence exchanging ideas on this function. In fact at about the same time he wrote a letter recommending me to UCLA and I owe my present position there to his kind letter and the efforts of my professor, Straus there.

Suddenly one day I got a letter from Professor Erdos saying that we should put our ideas together in the form of a joint paper. Naturally I was overjoyed at the idea of collaborating with one of the greatest mathematicians of the present day. According to G.H.Hardy anybody who could give a new proof of the Prime Number theorem attained immortality. Erdos had not only given a new proof but a sensationally new one, as I had mentioned before. So I seized this golden opportunity and worked hard for the next few months to complete our results.

The next task was how this joint paper is to be written. This was solved by another fortuitous circumstance. I was to join the mathematics department of the University of California, Los Angeles in early September 1975, and Erdos was any way coming there for a few weeks visit during that time. So we agreed to write the paper in Los Angeles. Little did I realise how popular he is till I saw him at UCLA. In Madras I had him for myself all the time. But there he was swarmed with mathematicians and friends most of the time. Still he was as kindly generous that he gave me two hours a day from 8 a.m. to 9 a.m. in the morning and one hour in the afternoon when we had lunch together. In the course of a fortnight we brought our plans to complexion and divided how our joint paper was to written. I recollect with pride and joy how he invited me to lunch to a restaurant just before he left. He came back again to UCLA in April 1976 and in these few months he had done to Calgary, Cambridge, Israel, Texas, New York Rochester, Berkeley and several other institutions in the U.S.A. In fact by the time he came back I had the revised version of the paper ready, and it was just in time for me to get his approval which I did of course.

The main theorem of our paper deals with a new estimate on large prime factors of an integer based on the idea of Hardy and Ramanujan that most prime factors of a number occur single, I had the opportunity to present this work on our behalf at Annual West Coast number theory conference, in December 1975, held at Asilomar beach near San Fransisco, where mathematicians from all over met in at setting of incomparable beauty.

So let me conclude by saying that Paul Erdos is one of the most romantic figures in Number Theory and in mathematics in recent time. It has been a pleasure and a privilege collaborating with him and believe me it is in education in itself to associate one-self with him. I hope in the future I could write many paper like he did but even a few of such calibre would be highly satisfactory.

NSS/6.12.76

RESEARCH IN MATHEMATICAL SCIENCES IN INDIA*

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It is as much a faith as it is a fact that the creative contributions of India in mathematics and mathematical sciences in recent years are more in keeping with international standards than in applied science and technology. I shall attempt a rapid review of the growth of mathematical sciences in India during the past sixty years starting with the solitary splendour of Ramanujan to the present day when India is providing hundreds of young emigrant mathematicians to the scientific establishments of Europe and the United States. I shall conveniently divide the sixty years into three periods - 1920-1945 the age of individual genius, 1945-1970 the Bhabha era of professionalism in science and 1970 to the present day with a peep into the future of professional mathematics.

Modern mathematics in India has a single starting point in space and time, the work of Srinivasa Ramanujan in Madras in the theory of numbers. He came out of nowhere at the dawn of this century, just a phenomenon which burst and blazed forth a light of such intensity as is still shining today with undiminished brilliance. The fact that he was recognised even at school and at college clearly showed that there was at that time an intellectual community capable of understanding such creative work and estimating such mathematical genius. However, unfortunately there was not at that time a group of persons or institutions which could benefit directly by the presence of such creative genius in the country. Today, number theory is no longer an isolated discipline, for it has ramifications over all the domains of modern mathematics. Ramanujan's contributions aro influencing the entire domain of mathematical development engaging the attention of leading minds in centres like Harvard and Princeton, Cambridge and Conttingen.

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* Talk delivered at the Madras Station of All India Radio on Monday, the 9th of August, 1976.

During the period 1920-1945 there were honours and M.Sc. courses in Indian Universities demanding high standards of performance of students who were mainly qualifying themselves for the civil service and similar professions. Creative science attracted only a few individuals and there were no institutions sponsoring systematic research. Satyen Bose, Megnad Saha, Chandrasekhar, Bhabha and Harish-Chandra are perhaps shining examples of such individual effort. Chandrasekhar left for Cambridge and then migrated to Chicago; Harish-Chandra did much the same but taking to pure mathematics after reaching the United States. Besides these, of course there were many individual mathematicians like Vijayaraghavan, Ganapathi Iyer and Vaidyanathaswamy who carried on work in lonesome glory in their respective Universities.

It has to be accepted and emphasised that systematic research at doctoral and post-doctoral level in mathematical sciences started with the creation of the Tata Institute of Fundamental Research at Bombay by Professor Bhabha. His greatest contribution to Indian science was that for the first time in the annals of Indian society, mathematical sciences became a profession changing the entire face of Indian technological and economic development.

The Bhabha era started in 1945 at Kenilworth, a beautiful little private home in Peddar Road in Bombay, the initial venue of the Tata Institute of Fundamental Research. It was my privilege to be associated with the architect of Indian science at the inception of this great effort. Within two decades after the creation of the department of atomic energy, crores of rupees were spent on research in newly constructed gigantic establishments and the Tata Institute received its full share of support from the Government of India. It was the good fortune of the Indian mathematician Chandrasekharan to join the Institute when the tide of support for basic research was at its peak. With his organising ability he was able to attract the best of talent towards mathematics in the Tata Institute of Fundamental Research.

During the past twenty five years that Institute has produced about a dozen first rate mathematicians, the name of Raghavan Narasimhan standing out prominently for his great contributions to complex variable theory. However the output of doctorates in quantity has been too small and the range of interests too narrow to make any impact on the technological and economic development of our country. It was soon realised that there was a need for Institutions for higher research in mathematics in other parts of the country. Some were created within the Universities as centres of advanced research as in Chandigarh and Madras while the Institute of Mathematical Sciences was started in Madras independent of the Universities. An expanding community of professional mathematicians with doctorate degree is emerging from these centres. It was to be seen whether these mathematicians will be needed by industry in India and or whether they will seek opportunities in the more affluent institutions in the United States.

In the realm of statistics, India produced a personality as impressive and pervasive as that of Professor Bhabha. Professor Mahalonobis was the founder of the Indian Statistical Institute in the early 1930s; He was particularly fortunate in his early students - Professor C.R.Rao, R.C.Bose and S.N.Roy who became statisticians of world-wide reputation. While two of them migrated to the United States, C.R.Rao remained in India making fundamental contributions to this day and carrying forward the message and spirit of Mahalonobis. India has been particularly strong in statistics and many a time I have been asked what the favourable factors were for this predilection towards statistics.

Though statistics has been a favourite profession, the study of stochastic processes has been confined to only a few groups in our country. It was my privilege to be associated with the famous British mathematical statisticians Professors Bartlett and Kendall in the 1950s and I was able to train a band of Ph.D. students in Madras following my own work, a summary of which was published in the Handbuch der Physik in 1956. It is gratifying that one of my distinguished colleagues Professor Vasudevan is carrying out a vigorous programme of research with the eminent mathematician

Professor Dick Bellman of California on the application of mathematical methods to biological and medical sciences. Other centres for work on stochastic processes are the Indian Institute of Technology in Madras and the Annamalai University.

In the domain of theoretical physics Bhabha's contributions stand out supreme in India during the past thirty years. There has been no original contribution from an Institution within India comparable with that of Bhabha's work during the past few decades. The period has been the golden age of Physics in America with an uninterrupted flow of Nobel Prize winning ideas from physicists like Feynman and Gellman, Bethe and Schwinger. Institutions within India have produced a broad spectrum of competent middle class physicists who provide effective support to the experimental groups in the country. At Matscience we were able to complete a comprehensive programme on matrix theory inspired by Bhabha's own particular leanings towards the subject.

In applied mathematics the story is about the same. Though there have been active schools under persons like B.R.Seth and P.L.Bhatnagar in the Institute of Technology, there are not many applied mathematicians of world stature. In the realm of astro-physics Chandrasekhar's name shines in unique glory and there seems to be a very little interest in Indian universities in astrophysical problems. A beginning has been made to support the experimental group in radio astronomy with theoreticians and only the future can unfold whether we will have an effective group or not in the astrophysical sciences.

Thus surveying the entire scene in India we must confirm our belief that it is only in the realm of pure mathematics that India made great strides with Harish-Chandra as the leading light of our times. Very recently I had the opportunity to meet him at work in his spacious and comfortable room in the Institute for Advanced Study over looking the luscious lawns and the verdant environment of that famous centre of learning where Einstein found his haven and Oppenheimer propagated his ideas. Today Harish-Chandra is reckoned among the greatest mathematicians of the world like Weil, Selberg, Erdos, Grothendick and Serre. Watching him I felt very optimistic about

India's future role in mathematical sciences. What we need today is just a stimulating atmosphere of competitive research to foster the genius that already exists in our country. A few suggestions would be relevant which if taken seriously would help in creating such an atmosphere.

1. A fraction of the staff in graduate colleges should hold research degrees. Adequate facilities should be provided for research-minded staff to participate in conferences and seminars.

2. Active scientists from outside should be invited to deliver weekly seminars at colleges and universities.

3. Organisation of annual symposia where the work from research institutions should be actively compared and discussed.

4. Provision of adequate funds for research workers to present papers and participate in an International conferences.

5. Travelling fellowships within India to stimulate competition and friendly cooperation.

If out of a vacuum India has produced Ramanujan, Chandrasekhar and Harish-Chandra, can we not foresee the magnitude of the possibilities if a suitable environment is provided for the discovery and encouragement of such talent all over the country?

CAREERS IN MATHEMATICAL SCIENCES*

Alladi Ramakrishnan

Let me congratulate Mr.Oza and the sponsors of the seminar for the imaginative enterprise of bringing together young aspirants to discuss the range and scope of careers in mathematical sciences. I confess that Mr.Oza has anticipated and taken a march over me in organising this conference which I myself have been planning at our Institute for some time. The sponsors could not have chosen a better moment, for our country today is on the threshold of a great intellectual renaissance with the immediate prospect of harnessing the abundant resources of scientific talent for its economic and social regeneration.

The last four decades have seen greater changes in human civilisation than centuries before and these changes are the direct and inevitable results of great discoveries in science and the consequent progress in technology and industry.

The ten years preceding the war witnessed the development of aviation with propeller aircraft and electronics based on the thermionic valve which transformed the transport and communication system in the world. The atomic age was born in 1945 when the first man-made explosion occurred at Almogorodo in the deserts of New Mexico. Aviation and the harnessing of nuclear power were, in magnitude and intensity, greater than anything achieved before and in the view of Winston Churchill man suddenly found himself in possession of the means of his destruction or his salvation. Equally spectacular have been the further advances in aviation through the discovery of jet propulsion and in solid state electronics through transistors, microminiaturised integrated circuits and new types of amplifiers [illegible]

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*Key-note address delivered by Professor Alladi Ramakrishnan in the Seminar on 'Careers in Mathematical Sciences', on 9th February 1976.

like lasers and masers which altered the pace of human activities and the range of communication. Simultaneously was ushered in the computer era laying at the disposal of man an instrument almost as versatile as and less fallible than the human brain. By 1960 the stage was set for space exploration which was achieved during the last few years. Thus we are today living in a world as different from that before the war as the world of the early twentieth century was from that before the industrial revolution.

The most important difference between the technologies of the post-war and pre-war periods is the pre-eminent role of mathematical sciences. It was theoretical physicists like Bohr and Einstein who conceived of the possibility of releasing nuclear energy from fission of it was Fermi who confirmed their predictions in the laboratory. It was Oppenheimer, then a young physicist at Berkeley, who was chosen as the architect of the atomic energy programme. Scientists like Teller and Bethe realised that fusion was a greater source of energy. The billion dollar march in three decades from the mechanical differential analyser at/ Harvard to the IBM 370 of multinational conglomerates has been made possible through efforts initiated by mathematicians like Johann Von Neumann and solid state physicists like Bardeen and Shockley. The role of mathematical sciences in the space age is just too obvious to be stressed when interplanetary travel and space exploration are becoming a reality.

In this complex technological society, statistical studies are essential in industry and economics, agriculture and food production planning and management, population growth and control biology and medicine. The U.N. sponsored organisations are employing statisticians of high competence in increasing numbers. It is no surprise that a Nobel Prize for economics was awarded to I.B.Koopman, a mathematical economist.

The mathematician today has a wide choice of careers in which he can use his hardwon experience. Mathematical science has become a mode of thought, a discipline which one acquires assiduously before applying it to various domains.

Among the mathematicians today who take their Master's or Ph.D. degrees only five per cent may continue to take creative mathematics as a career and seek high university positions. Since their talents become obvious at a very early age the identification of the ten per cent is not difficult. Another twenty per cent can take to teaching in schools, college and technical institutions. The rest should apply their knowledge to practical ends in various fields. Thus the mathematician has an 'eightfold way' open to him on graduation.

1. Creative mathematicians in universities and specialised institutions.
2. Teaching in schools, colleges and technical institutions.
3. Generation distribution and conservation of energy and power from nuclear and other sources.
4. Aerodynamics, Aeronautics and Space Technology
5. Electronics and Communication Sciences
6. Computer Sciences
7. Statistics and application to Life Sciences - Biology and Medicine.
8. Statistics and application to Economics, Planning and Management in Industry and Agriculture.

To make effective use of the steady stream of mathematical talent two major developments are necessary in our country.

1. The educational institutions must attract creative mathematicians of the highest quality, so that the mathematical spirit can permeate arts and sciences. In a recent report from the United States it is stated that the median salary for mathematicians is twenty three thousand dollars per annum. About twenty five per cent get more than thirty while ten per cent get more than forty thousand dollars, taking into account their consulting practice. It is therefore necessary that universities in India should make mathematics an attractive profession.

2. There must be an awakening amongst the sponsors of technology and industry that throught-ful planning, optimisation and prognostication are necessary for economic advancement and therefore mathematicians, scientists and statisticians should be employed in larger numbers along with personal of technical skill and competence. With increased sophistication in technology the distinction between soft and hardware is disappearing, the softest of software being the human brain.

Looking at the scene in India the outlook is promising since our nation has entered, as an effective partner along with the affluent countries, the age of nuclear energy, space exploration and computer science. If we are taking these developments for granted we should remember that these have been the direct result of the ideas and plans which originated in a single mind about thirty years ago - that of Dr.Homi J.Bhabha whose versatility was as legendary as that of Leonardo Da Vinci - mathematician, physicist, engineer, architect, artist, planner, administrator, a brilliant guide and an active worker who never lost his youthful imagination in adult life and was gifted with wisdom and judgment even in this early youth.

The greatest transformation Bhabha has achieved is to throw open the doors of the ivory tower and let the scientist move out to enrich the lives and ensure the well-being of those around him. The optimism which I imbibed from my great teacher Professor Bhabha has been enhanced during my travels during the past thirty years and contacts with scientists in over two hundred institutions of higher learning in the world today.

It is a world enlightened by Einstein and Heisenberg, spanned by Jumbo-jets and Concords, girdled by satellites and skylabs, linked to sister planets through manned and unmanned spacecraft, where almost instantaneous communication is possible across oceans and continents and even interplanetary space. It is Tennyson's vision come true - of heavens filled with commerce, of argosies of magic sails and airy navies grappling in the blue. Bliss is to be alive at this period in human history but to be very young is heaven. So God bless you, the fortunate youth, in your endeavours and aspirations.

NSS/4.12.76

INDIAN CONTRIBUTION TO MATHEMATICAL SCIENCES DURING THE PAST TWENTY FIVE YEARS*

Alladi Ramakrishnan

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This is an attempt at a rapid review of the Indian contribution to mathematical sciences during the past twenty five years, that is, after the birth of India's freedom and the organised sponsorship of science in our Institutes and Universities. In this account, by mathematical sciences I shall mean pure mathematics, theoretical physics and statistics and I shall not refer to applied mathematics, the ramifications of which are too numerous for the present discussion.

After the genius of Ramanujan had burst, blazed forth and vanished there followed a period of three decades when the Indian Mathematical scene was illuminated by similar, isolated but brilliant minds like Vijayaraghavan, Chowla, Vaidyanathaswamy, Ganapathy Iyer and S.S.Pillai in pure mathematics, Satyen Bose and Megnad Saha in theoretical physics. While abundant mathematical talent was available in our schools and colleges there was little or no interest in creative research in our country. Even a brilliant product of an Indian University like Chandrasekhar, after graduation, went to Cambridge and migrated to the United States starting a career which took him to supreme heights of fame and honour as an astrophysicist during his tenure at the Yerkes Observatory and the University of Chicago.

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*Talk delivered at the All India Radio, Madras on 8th January, 1975.

The first major organised effort in the mathematical sciences was initiated by Professor Bhabha who carrived in India in 1940 fresh from his laurels in Cambridge, carrying the great surges of mathematical thought from various centres of learning in Britain and Europe. Harishchandra who became one of the most famous mathematicians in the world started his work as a student of theoretical physics under Professor Bhabha. After making significant contributions to theoretical physics Harishchandra moved to the realm of pure mathematatids when he migrated to the United States. His mathematical contributions relating particularly to Lie Algebra and group representations have brought him international glory. Though he is now settled as a professor at the Institute for Advanced Study at Princeton, his influence is directly felt in India through his contributions.

The greatest revolution which Bhabha achieved was to make mathematical sciences an active and attractive profession. Starting with a one room Cosmic ray research unit at the Indian Institute of Science, Bangalore, he became the creator, sponsor, sustainer and leader of the gigantic atomic energy programme which included in its scope large-scale development of mathematical sciences. At about that time Meenakshisundaram and Chandrasekharan had established themselves as mathematicians of the first magnitude. Of them Chandrsekharan grasped the opportunity offered by Bhabha's predilection for excellence in mathematical sciences, joined the Tata Institute of Fundamental Research in Bombay and initiated a rigorous mathematical discipline in India on 'true Western lines'. His books on Analytical number theory and Arithmetic functions are standard works characterised by clarity, consciseness and completeness.

Under his leadership there was a dramatic period of expansion and achievement, when the Institute drew the best talent from our Universities. The name of Raghavan Narasimhan stands out for his contribution to Complex Analysis. He has settled down as a professor at the University of Chicago in the United Stated, while Chandrasekharan shifted to Zurich, Switzerland. The high traditions of those mathematicians are being continued by active workers at the Tata Institute.

Though Bhabha is famous as the sole architect of the atomic energy programme and the chief sponsor of mathematical sciences, his own scientific contributions are of estimable value in two fields - theoretical Physics and Stochastic theory. In theoretical physics every paper of his was of fundamental significance - meson physics, relativistic wave equations and the Dirac algebra. He 'enlarged the rythm' of the Dirac equation to discribe particles of higher spin. It is a curious fact that further work on the Dirac Algebra came also from a different direction from the group associated with me at Madras. We extended the Dirac structure to higher dimensional matrices leading to the generalization of the Clifford algebra to more parameters and higher powers.

In the realm of stochastic theory Bhabha set in motion a new wave of ideas through his famous paper on cascade theory which won for him the Fellowship of the Royal Society. It is in the appendix to that paper we observe the first gleams of stochastic theory as applied to physical processes. My colleagues and I were inspired by the questions raised by him and in developing stochastic theory we used new analytical methods and new concepts which were summarised in 1956 in my article in the Handbuch der Physik.

In Calcutta in the mid-thirties a young physicst had moved into the domain of statistics and by his personal magnetism, talent for organisation and creative genius, he established the now famous affluent Indian Statistical Institute. Mahalonobis gathered round him some of the brightest men who have made significant contributions to probability and statistics. Among his first students were R.C.Bose S.N.Roy and C.R.Rao. While Bose and Roy moved to the United States and helped to build the department of statistics at North Carolina, C.R.Rao continues to be the leading light of Indian Statistics to this day. There are many eminent Indian Statisticians to-day occupying high academic positions in various universities and centres in the United States. Thus in the field of statistics India can claim a fair share in world leadership.

In presenting the review, I have taken the attitude of a tourist who was asked to count the skyscrapers of New York. I have mentioned only those that strike my vision and the listeners can extrapolate through analogy and comparisons.

Looking at the Indian scene today the outlook seems very bright. Indeed India has and will continue to make major contributions to the worldwide endeavour in mathematical sciences. Though many of our finest mathematicians are in the United States they are really products of the Indian environment for they had their undergraduate education in India and in some sense had discovered themselves before seeking opportunities elsewhere. This implies that the material avialable in our schools and Universities is first rate. With a little imaginative planning on the part of the sponsors and a streak of idealism in the academicians we can retain our talented men within the country while providing them opportunities to propagate their work outside its frontiers. While science is international the resources which sustain mathematical effort are essentially national. Today we have three flourishing institutions of research, the Tata Institute, in Bombay, the Indian Statistical Institute, in Calcutta the Institute of Mathematical Sciences, in Madras, advanced centres within Universities at Chandigarh and Madras and many active departments in other Universities and technological institutions.

We must make a concerted effort to search for creative talent in our schools and colleges. We must enliven the scientific atmosphere by stimulating competition without pernicious rivalry. We must provide a forum for free discussion and dissemination of knowledge and encourage publication of scientific results without compromising standards of excellence. The question of 'relevance is irrelevant' in first rate research - for mathematics is a product of the human mind, the health and excellence of which will ensure beneficial influences from technological and scientific achievements.

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MATSCIENCE - A HAVEN OF FREEDOM*

Alladi Ramakrishnan

The Institute of Mathematical Sciences or MATSCIENCE as it is well-known or the Jewel of Tamil Nad as I called it before the President of India, is the only one of its kind in our country devoted to the pursuit of mathematical sciences in all their ramifications from abstract mathematical logic to the applications of analytical methods to technology and the life sciences. In structure and constitution it is modelled on the famous Institute for Advanced Study at Princeton with accepted emphasis on creative research on international standards of excellence. Its academic staff is divided into three groups, permanent members who are full or associate professors of established reputation in their respective fields, visiting scientists providing stimulus and competition for creative thought and younger members working for their Ph.D. under the guidance of the permanent members. The Ph.D. programme is intended to bring senior scientists into close contact with the younger generation and in this sense it is an additional feature not usually present in centres for advanced learning outside the universities.

The most striking feature of the Institute is the complete freedom given to a scientist during the tenure of his work here. It is accepted as axiomatic that excellence in creative work can be achieved only when a person is able to think and work in 'enlightened leisure' with 'absolute freedom' to publish the results of his research. The relevance of research to economic development and the utilisation of mathematical methods are achieved by bringing scientists in different disciplines together rather than by prescribing, imposing, predetermining or restricting the nature of work of a creative scientist.

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* Talk delivered at the All India Radio, Madras on 23rd August 1974.

To stimulate exchange of ideas, active workers from other centres are frequently invited to give seminars at the Institute on their research work and opportunities are afforded to members of our Institute to participate in scientific meetings at home and abroad.

To estimate its present achievements and understand the future programme we must be aware of the circumstances that led to the creation of the Institute. The stirring story of its creation is part of the annals of Indian science. I take this opportunity to recall the magic moments when the miracle happend. Till the year 1952 there was no research department in physics in theUniversity of Madras. I had the privilege of joining as its first member in June 1952. Frequent travels during the ten years of my tenure at the University convinced me that theoretical physics should be fostered side by side with experimental work and mathematics should form the real basis for theoretical physics. Since opportunities in the university were meagre for theoretical Physics, I gathered a group of young aspirants in my family home Ekamra Nivas where we discussed current problems at informal seminars. This attracted the attention of Professors Bohr and Dirac, Bellman and Lighthill, Salam and Chandrasekhar and through a series of events each improbable as the other, the Institute was created on the 3rd January, 1962 by the Government of Madras with the support of the Prime Minister of India, Jawaharlal Nehru and the finance minister of our State, Mr.C.Subramaniam. The creation of Matscience set in motion an intellectual renaissance, the nature and magnitude of which will be realised in the years to come. We have been fortunate in receiving the continued support of the Government of Madras through the successive Chairman of the Board of Governors, Subramaniam, Venkataraman and now Nedunchezhiyan. We hope the assistance of the Government of India will match the magnificent support of the State Government.

Our initial efforts for the first four years were confined to the theory of stochastic processes and the physics of elementary particles. Professor Bhabha can well be considered the father of research in stochastic theory in India and Matscience as the rightful heir to this legacy and tradition. I was initiated into stochastic theory in the year 1947 when I worked under Professor Bhabha on the famous fluctuation problem of Cosmic Radiation. The work done in association with my colleagues amounts to an extension, expansion, modification development of Bhabha's original ideas and this is the highest tribute I can pay to my most revered teacher and guide. This has naturally resulted in the creation of new techniques and methods which are finding increasing applications. In the year 1971, a summary of this work was presented at the International Conference on Point Processes at I.B.M. Yorktown Heights, New York. It is extensively quoted in text books of A.T.Bharucha-Reid (McGraw Hill), M.S.Bartlett (Cambridge), T.E.Harris (Springer Verlag) and in innumerable papers.

My distinguished colleagues Professors Vasudevan, Ranganathan and Radhakrishnan are carrying on this 'stochastic tradition' with remarkable ingenuity to a wide range of applications in statistical mechanics, solid state physics and even biology and medicine.

After the amazing triumph of Feynman's formalism of quantum electrodynamics in 1949, no one dared to attempt improvements or suggest alterations in the theory. For the first time the division of the propagator was suggested at Matscience, the new concept of Feynman patterns introduced and the mathematical consequences studied in intricate detail. Reference to this has been made by Professor

Weinberg and the most recent work in the Physical Review indicates a surge of interest in these new aspects of Feynman formalism. Detailed announcements were made in a well-attended seminars at Stanford and Berkely as early as 1962, in Rochester in 1963. A summary was presented at the Capital Conference on graph theory in 1973 at Washington, D.C.

Professor Bhabha's predilection towards matrix theory is well known in scientific circles and my own interest in that subject can be traced to my association with him as early as 1974. I need only refer to series of original papers contained in my book 'L-matrix Theory or the Grammar of Dirac Matrices'. All the papers have been reviewed in Mathematical Reviews.

The new approach to matrix theory was presented at the international conference on Numerical Analysis at Dublin this year in an invited one-hour address.

Today, the Dirac equation for the electron is the only valid equation in physics and attempts were made by Bhabha to extend such equation to other elementary particles. There are other possible extensions than that suggested by Professor Bhabha and this is included in my book on 'L-matrix theory'. This led to higher dimensional Dirac matrices, the generalized Clifford algebra and a new approach to internal quantum numbers and a generalization of the Gell-Mann-Nishijima relation. The paper on internal quantum numbers was presented at the Rutherford Centenary Conference in the year 1971 held at Christ Church, New Zealand.

The most active members of our group in high energy and nuclear physics are Professors Santhanam and Srinivasa Rao who have worked on various branches of physics - weak, electromagnetic and strong interactions.

The contribution entitled 'Einstein - A natural completion of Newton' has appeared in the Solomon Bochner issue of the Journal of Mathematical Analysis and Applications (1973). It purports to set at rest all futile speculations regarding the existence of faster than light particles by means of a simple and elegant mathematical approach. This work was presented at the University of Texas at Dallas before accredited experts on gravitation theory.

We have an equal interest in the general theory of relativity and the fundamental principles of quantum mechanics and work in these domains is going under the direction of my eminent colleague Professor K.H.Mariwalla.

As will be seen from the above summaries, our research work is closely connected with the contributions of the eminent Indian scientists, Bhabha and Chandrasekhar, the reputed statisticians Bartlett and Kendall, the world famous Nobel Prizemen Feynman and Gell-Mann and the scientific seers of all time, Einstein and Dirac.

While working in theoretical physics, we were quite conscious of our inadequacies and well aware of the all pervasive nature of the mathematical discipline. The preamble to the constitution of our Institute puts unambiguous emphasis on the development of mathematical sciences in the widest possible range. In January 1966, a significant beginning was made in pure Mathematics in a spirit so well expressed by Professor Marhsall H.Stone the mathematician's attitude to other disciplines such as physics is something like. 'I try to help every one but I have also my own concerns'.

Professor Unni is our leading mathematician and with singleness of purpose he devoted himself to the building of the mathematics group with the initial impetus given to him by Professor Hayman, a visiting professor at Matscience in 1966. Unni's main interest is in functional analysis but he is orienting the future programme in our Institute so that it can play a very important role in the applications of mathematical sciences to economic and social needs retaining its identity as an international centre in functional analysis. The success of the International Conference in January 1973 through the active participation of over sixty mathematicians from over twenty countries is the highest tribute which the worldwide mathematical community has paid to our country in general and Matscience in particular.

The students of Matscience are finding easy access to the great centres of learning after obtaining their Ph.D. degree. Our academic staff is in close contact with about 200 research institutes abroad and with more than 300 scientists of outstanding eminence the world over. It is with justifiable pride that we can look back on the achievements of the Institute for the past twelve years.

We look forward to the future with unfailing faith in the mathematical talents of the rising generation. We cannot promise them affluence or soft comforts or pleasant methods of acquisition of worldly goods. What we can offer are, an open window to let in and out the vital breezes of new ideas, a table and a blackboard for serious work, freedom from interference in contemplative thought, a ready access to a well equipped library and above all, stimulating contact with their compeers all over the world.

These are attractions enough to make the mathematician's career worth pursuing despite modest salaries and meagre benefits. We hope the most gifted minds of our country are lured to this enchanting world of numbers and functions, algebraic or analytic, limits and approximations, rational or irrational !

Welcome to MATSCIENCE - the haven of freedom.

Professor P.M.S.Blackett*

Alladi Ramakrishnan

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The most striking feature of the illustrious career of Professor P.M.S.Blackett is its duality - it is essentially British in mode and style while its significance and impact are international. As one who has watched that career as an eager fellow-scientist, I shall take the liberty of emphasising this dual aspect for it demonstrates that a truly great scientist is essentially human and is influenced by his own national environment on the one hand and impelled and inspired by the universality of science on the other.

Patrick Maynard Stuart Blackett was born in 1897 and true to the British tradition was trained as a regular officer of the Navy. He started his career as a naval cadet taking part in the first world war at the end of which he started his research work at Cambridge in 1921.

The birth of modern physics had occurred at the dawn of this century through the twin discoveries of the quantum theory of matter by Planck and relativity theory by Einstein. By 1921 physics had passed the exuberance of youth and was bursting into the manhood of relativistic quantum mechanics with the impending onset of Dirac's formulation of the famous equation for the electron. Based on this, quantum electrodynamics was built into a complete theoretical structure and awaited confirmation of its predictions through experiment. The time was propitious for such experimentation since Wilson had invented the cloud chamber which could make 'visible' particles normally invisible to the naked eye because of their smallness in size and

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*Talk delivered at the A.I.R. , Madras, on the 19th July 1974.

greatness in velocity. Among the leading speculations were the production of pairs of charged particles by a photon or a quantum of light or the inverse phenomenon of the disappearance of pairs of particles into photons. The fantastic nature of these transmutations excited a passionate French scientist to perceive poetic beauty in natural phenomena.

The characteristic feature of the British attitude to experimentation is the simplicity of the apparatus and the ingenuity in its use. The stoic devotion to science of processors of Oxford and Cambridge is as British as the insular pride of John of Gaunt handed down to Drake and Nelson, Wellington and Churchill. No wonder the simple principle which Wilson established that a fast invisible particle when passing through a cloud chamber leaves a track of visible ions, the characteristics of the track revealing all the qualities of the particle-charge, mass, momentum, energy was taken up by Blackett and perfected into an art of arts. There was no more sophistication in the physics of the cloud chamber then in the ageless wonder of the phenomenon of the golden sun gleaming through the clouds. It was only natural therefore that Blackett should have sought guidance from the grandmaster Sir Ernest Rutherford, the most British of all scientists though he came from the distant outpost of the Commonwealth, Christechurch in New Zealand. The Cavendish Laboratory reared this breed of physicists and those who came into contact with Lord Rutherford became Nobel prizemen or at least fellows of the Royal Society, native or foreign ! Each left a mark on the domain of physics as clear as the tracks of particles observed in the cloud chambers ! It so happened that at a time when the great accelerators were not invented, nature provided these gifted scientists with projectiles faster than any laboratory could have produced with all the ingenuity of man. It was the hey-day of cosmic ray experimentation following the discovery at the beginning of this century that very fast particles were entering this earth from solar, galactic and extragalactiv sources. These provided the experimental material comprising highly energetic particles. The time was right - for theory had reached a maturity to tell the experimentalist what he should look for. The place was right - the Cavendish Laboratory which nurtured brilliant experimenters endowed with ingenuity and imagination. And Blackett was there at the right time and the right place. After gaining additional experience at Gottingen under James Franck he returned to Cambridge to collaborate with Occhealini designed a counter controlled cloud chamber, a brilliant invention by which he managed to make the cosmic rays take their own photographs for which he received the Nobel Prize in 1948. In the spring of 1933 Blackett and Occhealini confirmed Anderson's discovery of the positive electron so brilliantly predicted by Dirac.

In the year 1937 he succeeded Sir Lawrence Bragg at the Manchester University adding to the rich Redbrick tradition the stimulus of the Oxbridge atmosphere he had already imbibed. The dark walls of the Manchester University made darker by grime and smoke, the cold lecture halls and laboratories reveal the trully British attitude to fundamental science that great discoveries can be done under sparten conditions provided there was a will and the spirit so well expressed by Sir Winston Churchill - 'give us the tools we will finish the job'. The/ Wilson's cloud chamber provided the tool and Blackett and his collaborators completed that job which Dirac initiated in quantum electrodynamics. During the world war II Blackett, like all his gifted countrymen, served the national cause by placing his scientific talents at the disposal of the country.

He served in the Royal Aircraft establishment, he served as a Scientific adviser to the coastal command. He was involved in the studies of anti-Uboat war and became Director of the Naval Operational Research at the Admiralty.

At the end of the war, he returned to his first love, the laboratory at Manchester and as fortunate to have as his colleagues Rochester and Butler who discovered the strange high energy particles and thus ushered in a new era in modern physics.

The biblical span of Blackett's life covers three stages of modern physics. From 1900-1928, the growth of relativistic quantum theory, from 1928-1948 the experimental confirmation of the predictions of these theories, from 1948 onwards the era of strange particle and their proliferation. The third phase meant a study of trillion volt particles through billion dollar budgets and Professor Blackett who was used to the Rutherford tradition that the best ideas are not expensive turned to fundamental problems in other domains.

He entered the domain of theoretical physics by speculating on the isotropy of cosmic radiation and the origin of interstellar magnetic fields. This led him to revive interest in the thirty-year-old speculations and on the origin of the magnetic field of the earth. But his ideas are not accepted as valid. Such is the impartial judgment of science which awards a Nobel prize for one contribution and rejects another if it does not meet the unyielding demands of truth.

Let us now discuss the impact of Blackett's personality on Indian science. It is hardly surprising that since his fundamental contributions were in the study of cosmic radiation he became one of the closest friends of Dr.H.J.Bhabha who proposed the famous cascade theory of cosmic ray showers. Again we find here his British character asserting itself for he showed a keen interest in the scientific development in India and watched with perfect equanimity the transition of British India into a free republic. Like a true scientist of the modern era he was sympathetic towards the aspirations of a new republic to develop its own scientific potential. I had the good fortune of meeting Blackett quite often at the Tata Institute of Fundamental Research in Bombay when I was working there as a student under my great teacher Professor Bhabha.

Blackett conformed to the great tradition of creative scientists who continue to think as long as they breathe. When he participated at the Jaipur conference in 1963 he was still one of the leading lights of Cosmic Ray Physics. We had the privilege of receiving him at our Institute, Matscience just a few years ago when in the true style of a British scientist he emphasised the need for close contact with universities and under graduate education. It is my earnest hope that in our country the new generation will be inspired by the noble examples of Blackett and Bhabha, who represented the universality of science but still retained strongly their national character so that their talents and energies not only increased our understanding of nature butwere used for the immediate objectives of national development. They have demonstrated by example and precept that there is no conflict between nationalism and science.

Let us cherish and preserve the Bhabha-Blackett tradition which represents the finest example of Indo-British cooperation in Science and technology.

SATYENDRANATH BOSE - A TRIBUTE*

Alladi Ramakrishnan

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The eminent place of Professor S.N.Bose in the annals of physics can be well described in the following manner.

The material universe is made up of fundamental constituents of matter known as elementary particles which fall into two classes, the Fermions and Bosons, named after the great physicists Enrico Fermi and Satyen Bose. This classification is based on the statistics obeyed by the particles when grouped together and characterised by the distribution in energy. The universe around us is perceived by light and light or equivalently radiation is made up of photons which obey the Bose statistics. What greater claim to immortality can there be for a scientist engaged in understanding the nature of matter!

Satyendranath Bose was a thirty year old reader in theoretical physics in 1924 at the Calcutta University when he wrote the paper on Planck's radiation law or the law of Photon energy distribution which earned for him a permanent place in the world of science. Earlier he had written a joint paper with Meghnad Saha, another luminary in Indian physics, proposing an equation of state known as the Saha-Bose equation in the Philosophical magazine in 1918. With the anxiety of a creative scientist he sent his paper on Planck's law for comments to the greatest man in the field, Albert Einstein in Germany. In a manner characteristic of truly great men Einstein appreciated his contribution, translated it into German and sent it for publication to the Zeitschrift fur Physik.

It was during the period 1925-30 that the quantum mechanical theory of matter originated through the wave-equation of Shrödinger, developed by Heisenberg, interpreted by Born and perfected by Dirac

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*Talk delivered at A.I.R., Madras, on 15th February 1974.

What an amazing achievement that Bose should have explained the radiation law before the growth of quantum theory ! It is possible to describe the meaning of the two types of statistics even to non-scientists with the rigour and precision of modern mathematics as follows.

In physics we are concerned with the distribution of particles in a number of cells, the word cell being used in the most general sense to denote the value of any attribute like energy. It has been found that three possible assumptions can be made regarding the law of distribution.

1. Any number of particle can be found in one cell, with varying probabilities described by what is so well known as a Poisson distribution.
2. There can be zero or one particle only in a cell with specified probabilities.
3. There can be any number in a cell with <u>equal</u> probability.

The first assumption leads to the Maxwell Boltzmann distribution known for the past two centuries since the birth of classical mechanics. The second is the Fermi-Dirac distribution characterising the collection of elementary particles like electrons and protons which are Fermions. The third yields the Bose-Einstein statistics characterising particles like photons which are bosons. The Fermi-Dirac and Bose-Einstein statistics can be understood only within the frame-work of quantum mechanics. The ramifications of these statistics form the basis and content of the theory of statistical mechanics which is an integral part of modern physics.

Since I was acquainted with these statistics even during my collegiate career, the name of Bose was fascinating legend to me in much the same way as that of Ramanujan. I had heard that Bose had worked as a professor at Calcutta and later at Dacca. My own deep interest in probability theory and stochastic processes led me to speculate on the meaning of Bose statistics and in 1956 I incorporated the past described method of understanding these statistics into my article in the Handbuch der Physik published by the Springer Verlag in Germany. Since that time I had a great desire to meet Professor Bose at the earliest opportunity and this came in 1959 when I was invited as one of the participants to the summer school organised at Mussurie under directorship of Satyen Bose. It was then I saw the living legend in action, the impact of his genius and even more his humanity made a great impression on my career. I feel it worthwhile describing in some detail his role in the summer school which revealed the personality of this great man in full measure and also his frank views on the administration of Indian Science. The summer school was the first of its kind organised under the director sponsorship of the Minister of Scientific Research Proressor Humayun Kabir. The response from various universities and research institutions was spontaneous and total. However a question was raised and discussed whether such summer schools, to be more useful, should be topical and emphasise a particular subject. Professor Bose felt this issue was of no consequence. He laid great emphasis on the presentation of original papers. He ignored the suggestion that summer schools should be devoted to particular subjects. He emphatically expressed his opinion that instead of stressing mediocre work in a concentrated form on a particular subject he would prefer creative work on various aspects of physics being presented at the conference ! I was his staunch ally in this view point and therefore I came into very close contact with him. I was deeply impressed by his extraordinary brilliance, his unbending honesty his whole-hearted devotion to truth and natural indifference to power and influence. He directed the conference with exuberant confidence and inspiring optimism. The proceedings of this conference are now available to the scientific community, but unfortunately this type of scientific meeting has never been followed later. When the Institute of Mathematical Sciences was founded I was keen on carrying forward the ideas and objectives emphasised by Satyen Bose. It looked as if I was an Ekalayya while this Dronacharya had many Arjunas as his disciples perhaps in his own province. We are really following the 'Bose principle' at the MATSCIENCE summer schools with accepted emphasis on creative work!

India today can ill afford to lose a savant and scientist like Satyen Bose. At eighty he had the intellectual zest of a lad of eighteen. Youth had never left his imaginative brow as in the case of the great number theorist Mordell who contributed papers to research journals even as an Octogenarian.

Our country has lost all its giants in the field of science - Ramanujan, Saha, Raman , Bhabha and now Satyen Bose. There is a real and present danger that we may be over-taken by brazen mediocrity made more impudent and secure by the absence of genius and idealism. The best way to cherish the memory of Bose is to foster individual initiative, emphasise creative activity and insist on excellence in scientific research.

NSS/13.10.76

TEACHING AND RESEARCH IN MATHEMATICS

Alladi Ramakrishnan

I am happy and grateful to be given an opportunity to talk on the relationship between teaching and research in Mathematics. Teachers have always been revered and respected in soceity, particularly so in our country in which the intellectual traditions can be traced to the dawn of civilisation. Among the intellectual pursuits mathematics holds a pre-eminent place, for mathematics is the basis of all sciences. We are to-day living in a scientific age where the life of man and the environment around him are profoundly influenced by the developments in science.

In spite of the primary role of mathematics, questions are frequently asked: Is mathematics an abstract or applicable science ? Is a mathematian's output an important factor in the economic advancement of the country ? Can a populous democracy like India afford the luxury of an intellectual pursuit like mathematics ? Is it possible to harness mathematical talent for practical purposes ? Time and again these questions are raised, answered incompletely, and discussed inconclusively as controversial issues. To me it looks obvious that the mathematical method is the essence of a civilisation based on the development of science. From this view-point the distinction between pure and applied mathematics seems unnecessary and artificial. It is well-known that the greatest creators of mathematics of all time like Newton, Leibnitz, Laplace, Poincare, Euler, Gauss, Cauchy, Reimann and more recently, Hilbert, Weyl,

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The Review of this talk given at the Mathematics Teachers Conference in the year 1974.

Birkoff and Neumann have equally influenced the growth of physical sciences. Of course in recent years increased knowledge, increased sophistication and specialisation have led to finer divisions of science. But this cannot ignore the inter-relations among various branches of science. Mathematicians have evolved such subjects as algebraic geometry, algebraic topology algebraic number theory and even algebric logic. Therefore I shall adopt the view that there is a unity of thought among various sciences and this unity is particularly apparent if we study the mathematical basis of such Sciences. The mathematical traditions of India are as old as its civilisation. Our country played a part in the development of geometry, astronomy number theory and mathematical reasoning in general. Due to various historical and political circumstances our country did not participate in the great scientific movements from the fifteenth to the nineteenth century. But it is well recognised to-daythat many Indian mathematicians since the time of Ramanujan have contributed and are contributing to the main stream of mathematical thought. If this is to continue and grow, suitable orientation towards mathematics has to given even at school level as is done in the advanced countries. But America and Russia, in spite of their great diversity in ideologies, are placing adequate emphasis on mathematical training and recognising the primary role of mathematics in education.

Teaching and research are inseparable twins and one cannot survive without the other. It may be that a good teacher is not a good researcher or vice-versa but thetwo groups must co-exist. There must be a desire to impart existing knowledge and there must also be the impulse to generate new ideas and extend the frontiers of knowledge. Teaching consolidates existing knowledge and perfects inchoate understanding through critical examination. Research is the dynamic art of keeping the frontiers moving and therefore I consider teaching and research as two facets of the same intellectual discipline.

Being a theoretical physicist, I am closely associated with mathematicians of all shades-pure and applied, and concerned with problems of how how they are discovered, how they are trained, what opportunities have to be offered to them at school, college and post-graduate level, how their expert training can be used not only for the advancement of the subject but for the economic progress of the country. In any discipline excellence is achieved only if the basic training is sound and there likes the primary role of instruction and teaching. The relationship between the teacher and the student has been treated as vital, sacred and fruitful though it has gone through very many phases of evolution with time and environment. It is a relationship for mutual benefit, for the exchange of views, though it starts with one person imparting and the other receiving knowledge. As one who has been closely associated with the educational institutions and by a fortunate circumstances with advanced mathematical institutions of international stature, I shall take the liberty of describing the significance of the mathematical method in the general framework of education. It can also be applied to various fields with profound and beneficial consequences. More than that the mathematical method pervades our life in all aspects. The mathematical method as I understand it can be visualised in five stages.

1. Recognition, 2. formulation, 3. solution
4. interpretation and 6. extension.

The same principle is applicable to every walk of life- in industry in medicine, in economics, in domestic, national and international relations. By recognition I mean the initial realisation of some order or pattern in an agglomeration of facts and observations. The second step is the formulation of the problem arising from such recongnition. This has to be done in precise terms so that the well-known methods of mathematical theory can be applied or new methods evolved to solve the problem. The third is the solution. This requires of course extraordinary talent which is the product of both 'persipiration and inspiration'. The fourth stage is to understand the meaning of the solutions and interpret them suitably. Finally We find that the solutions lead to possible extensions which result in the unfolding of new domains for investigation. Thus the five stage peocess goes on and this is inherently dynamic. The purpose of teaching is to inculcate the spirit of mathematical enquiry and make these five stages a part of our intellectual training.

Let me illustrate this situation with respect to two major developments in mathematics and physics. It is well-known that a few centuries ago, in games of chance certain regularities were observed. Though it may seem an apparent contradiction, the recognition of this regularity in randomness became the starting point of the theory of probability. The problem was formulated precisely by defining the meanings of events and trials and the frequency of successes and failures in a series of trials. The methods for solution were based on concepts of mathematical analysis, of limiting processes and of algebraic manupulations. The solutions to this problem came in the form of distribution functions characterising the outcomes of trials. The interpretation of these results made probability theory one of the most useful of all sciences. Today there is not a single field of human endeavour in which the ideas of probability theory have not found applications. The extensions of these concepts to operations research, systems analysis, information theory, control theory, management sciences, genetics, demography, econometries, planning for economic and social growth in general, are well known.

In the realm of physics this five stage process is even more strikingly apparent. From various experiments condudted over a century it was found that the velocity of light was independent of the frame of reference from which it was measured. The evidence was accumulated from a variety of sources - from direct experiments on the velocity, from phenomena in optics, from logical consistency of the electromagnetic equations. The formulation of the problem was made in terms of coordinate transformations and the solution was ultimately found by Einstein by his famous apace time transformation formulae. The various interpretations led to the equivalence of mass and energy the applications of which are determining the future course of human civilisation.

To-day the world is facing a new challenge, the magnitude of which has been realised only in recent years. Mankind is confronted with a shortage of material resources leading to an energy crisis. But the resources of human ingenuity are without limit and our hope lies in the scientific solution of problems which science has created against itself. This needs expert knowledge which can be cultivated only by scholars, savants and scientists. Their joint endeavour leads a total success.

NSS/25.11.76

THE IMPACT OF SCIENCE ON SOCIETY*

Alladi Ramakrishnan

The impact of science on society is so powerful, so pervasive, so complete that it has become common-place for every one to express opinions thereon with zest and assurance - scientist and layman, wealthy and poor, savant and peasant. This is as it should be, for science affects and in fact determines the very texture of our lives. Let us study this impact from two view points and from two levels. We shall refer to the social and economic consequences on the one hand, the psychological and moral aspects on the other at national and international levels. We start with the well-known fact, which is not dullened by repetition, that the world after the discovery of the scientific method during the last four centuries has been transformed more than in the preceding two thousand years. More changes have been wrought in the last four decades than in the preceding four centuries after the birth of science.

Let us concern ourselves with the changes during these four decades. Advances in two fields of human activity have altered human life as never before - first in transport the second in communication. With the invention of the aeroplane, humming skyways of traffice have bound peoples of the world closer together than the railroads and the ocean routes since the days of the renaissance and the industrial revolution. While the locomotive and the automobile have made each country a single economic unit system. It was in the thirties that the first civil aircraft started flying just before the second world war. Tennyson's dream of 'heavens filled with commerce, argosies of magic sail, pilots of purple twilight and airy navies grappling in the central blue' became a reality. When

*Talk delivered at the All India Radio, Madras, on 3th Septr. 1973.

the war broke out it was air-power that determined ultimately the fate of the combatant nations. Hitler met his doom on the British skies inspite of being the triumphant masterof western Europe. Supremacy in the air ultimately determined the victor. The war quickened the great revolution in aviation and at its end, fleets of large-size transports, first with piston engines and then with the turbo-propellers spanned the skies. By 1960 the jet plane was found safe and comfortable and soon thousands of jetaircraft began transporting millions of people across the oceans and continents. This has resulted in a transmigration of peoples, as the world has never before witnessed and the concept of nationality had to undergo a drastic change.

As spectacular was the developments in the field of transmission of messages and information through new means of communication. First the telegraph and the telephone then the radio and the radar and later the great electronic revolution in communication through satellites. The development of electronic devices reached such perfection and efficiency during the war that all these facilities were soon available for civilian life. Today messages travel with the speed of light. Was it not just two hundred years ago that the tales of two cities were mutually transmitted through horse-back couriers and mail-coaches between Paris and London ?

International commerce has assumed a new significance since technological advancement is universal and its benefits are shared by all. Distances between places do not any longer matter. Inter-relation of currencies and the movement of goods from one part of the world to another have removed the economic frontiers though the political barriers still remain. Europe has now become a single economic community. Within each country parochialism is vanishing as it has already done in the United States. Almost instantaneous phone service, interstate highways and a network of air lanes have united the fifty states of America into one integrated economic and political unit. The scientific developments during the war made it possible to rebuild the ravaged cities and establish normalcy within a few years. Who can now say watching the booming tempo of Berlin's nightlife and the garish gaiety of Tokyo's Ginza that these cities were bombed and blasted during the last world war?

What is more, America itself became economically involved with countries against which it waged a mortal struggle just three decades ago. In 1945 it wiped out Hiroshima and Nagasaki from the face of Japan. Today the affluent American insists on buying Japanese electronic equipment and Japanese cars with brazen preference. Thirty years ago the allied airforce pulverised Stuttgart and Dusseldorf to heaps of rubble. Today English and American tourists pride themselves in possessing German camaras and optical equipment. There was a time when the Western world thought of communism as a morbid repudiation of human values. Today the representatives of the Kremlin are taken in colourful motordades to be received at the White House at star-spangled banquets. It was not too long ago that America poured billions of dollars to sustain tottering governments in Eastern Asia to contain the menacing spectre of communism. Today the United States invites red China as an equal partner in global commerce.

In the field of physiology and medicine great advances have been made in the conquest of disease and this has increased the possibility of leading healthier lives. But this has not increased the longevity of man. Billions of dollars have been spent in building hospitals, training nurses and doctors, providing drugs and nutrition but this has not increased the span of human life. The problems have become complex because more things are achieved, more changes wrought in our environment in a single lifetime the duration of which has remained unaltered since the dawn of mankind. This anomaly has confused human imagination and therein lies the major problem of the impact of science on soceity. The problem has to be traced to the / single anomaly that the biological growth goes on at the same rate while the external world is being transmuted at increasingly faster pace. The seven ages of man have the same duration and human pleasures are centred round the same emotions that stirred the human heart since the birth of man. Even the astronauts who walked on the moon and rambled in space still yearned for simple human pleasures the honeyed-breath of love and the warmth of their children's cheeks.

Inspite of scientific triumphs we have not improved the quality of living and perhaps we are in dange of losing that tender art. The fitful fever of life has over-taken us and all the appurtenances of sciences are used to make things move faster, happen faster, disappear faster and create faster - to what end ? Has this enriched our lives or has this brought peace and grace into ... human relations ?

On the contrary the rapacity of man, his greed and unconcern for the safety and well-being of his fellowmen still persists. Only the methods change. The piracy on the seas has shifted to the skies. Standing armies are replaced by stock piles of hydrogen bombs. Slavery has been abolished but economic exploration of the weak by the strong still goes on made more sinister by the weapons of a perverted science.

Many years ago when I was at school my great father used to draw my attention to the contrast between science and politics. He compared the nationalism of politics with the internationalism of science. While the developments in science have made the world economically a single unit, national jealousies still prevail, pernicious prejudices are still preserved. Tempers still run high in the committees and meetings of the United Nations. But we should not blame science or the scientist for these problems, rather we must cultivate a scientific attitude to life. This does not imply that every one should attempt to study and practise science. In fact the old adage is still true - little knowledge is a dangerous thing. The pursuit of science must be done by those who have a special talent for creative activity. In regards to others, it is the scientific attitude that has to be imbibed rather than scientific information. By a scientific attitude I mean the method of trial and error, the willingness to accept facts even if they defy apparent intuition, the dynamic urge to move, to adopt, to adapt, to change to create, in short to use effectively the gifts of imagination and thought. That is the legacy of Copernicus and Galileo that is the spirit of Newton and Einstein.

We, who are alive today, are grateful to Providence for allowing us to witness the transition to the age of nuclear power and spatial exploration which represents the second renaissance in the history of human civilisation. Man is now invested with the power to make 'this earth a warless world robed in universal harvest pole to pole'. Will he use it so, will be follow light and do the right ?

Years ago in 1938 when the storm was gathering on the darkening skies of Europe, as a school boy I wrote in an essay that the world will be safe only if the philosophy of the Buddha is implanted on the genius of Einstein. The four decades that have rolled by have confirmed this boyhood faith.

ON THE EVOLUTION OF PHYSICAL THEORIES*

Alladi Ramakrishnan

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I am deeply sensible of the pleasant privilege of delivering the Krishnan memorial lecture to this enlightened group of science teachers of India. My own personal regard and affection for Sir K.S.Krishnan were so deep that I wish to pay my tribute by explaining some important ideas I discussed at leisure with this great savant and scientist. I remember clearly talking to him about the success of a very recent physical theory and he immediately replied that we should wait till logical completeness and mature comprehension follow the initial triumph of that theory. This set me thinking and I wish to summarise before you my own thoughts and invite your critical judgment on my own theory of the evolution of physical theories!

Musing on the history of physical science from Archimedes to Einstein, it seems an irresistible conclusion that successful physical theories pass through five stages of evolution.

- First: Systematic observations and collection of data relating to some physical phenomena.
- Second : Discerning a pattern or some order in the agglomeration of facts leasing to the formulation of the problem to explain the pattern.
- Third : Solution of the problem by making new assumptions or hypotheses.
- Fourth : The trimmph and confirmation of the theory.
- Fifth : The theory is unable to explain new facts which demand a new hypothesis

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*Sir K.S.Krishnan memorial lecture. This is the summary of the lecture delivered extempore before the All India Science Teacher's association on the 28th December 1973.

The end of one theory therefore becomes the beginning of another and this regenerative process characterises the nature of all creative work. Let me illustrate this by three examples from the annals of physics - Newtonian mechanics followed by the theory of relativity, classical electromagnetism followed by quantum electrodynamics, the theory of isotopic spin followed by the theory of unitary symmetry.

Mechanics is the primary source of all physics and in the pre-Newtonian era of Copernicus, Galileo and Kepler, observations were made on moving bodies, colliding and disintegrating masses relating to terrestrial and astronomical phenomena. Regularities were observed in the periods of motion of bodies ranging from a simple pendulum to planets in orbits ! The characteristics of such motion could be explained only by Newton's famous postulate that it is acceleration and not velocity that leads to the concept of forces which determines the rate of change of momentum. Thus Newton formulated the famous three laws of motion which dominate human thought to this day and may continue to do so for all time. God said 'Let Newton be and all was light'. Newtonian mechanics successfully explained all observed phenomena in the universe around us. Its logical structure implied the concept of relative velocity which in turn meant the possibility of a rest system for all bodies. But observations during the 19th century revealed that the velocity of light was constant in all frames of reference which also implied that light could have no rest system. The Newtonian approach was in adequate to explain the immutable value of the velocity of light and at the dawn of the twentieth century Einstein put forward the hypothesis of space time continuum and the laws of transformation connecting space and time. He not only resolved the paradox of constancy of light velocity but proved the equivalence of mass and energy, the realisation of which is determining the course of human civilisation.

Electro-magnetic phenomena were studied both through direct experiments on electricity and magnetism and also in optics, realising that light was electro-magnetic in character. The pattern related to the puzzling relationship between the magnetism and electricity and this was solved completely by Maxwell. His theory was so perfect that there is a hyperbolical statement that even if physical knowledge ceases to exist, Maxwell's equations will survive! But these equations could not explain the corpuscular nature of light revealed through the photo-electric effect at the beginning of this century. It could not also explain the energy distribution of radiation from hot bodies. The solution came through Planck's epoch-making hypothesis of the quantum nature of light followed by the development of quantum mechanics by Bohr, Schrodinger and Heisenberg and finally Dirac who achieved the confluence of relativity and quantum mechanics.

Finally we shall refer to the theories relating to internal quantum numbers of elementary particles. After the formulation of quantum mechanics it was believed that the forces among elementary particles were electro-magnetic in nature and depended on their ' 'charges'. However data from nuclear physics revealed that far stronger forces bound the particles together and these were charge - independent. This could only be explained by the Heisenberg's hypothesis of isotopic spin based on the mathematical stucture of a Lie algebra. However in the early 1950's there was such a proliferation of elementary particles from the high energy accelerator which could not be described only through the concepts of charge and isotopic spin. Gell-mann introduced a new quantum number called 'strangeness' and devised a higher symmetry scheme based on the Lie algebra including both the quantum numbers, isotopic spin and strangeness. However new problems seem to arise demanding the inclusion of further quantum numbers. Is the Lie algebra adequate to deal with this demand or do we need other mathematical structures like the Generalised Clifford Algebra ?

Many such problems still challenge the physicist to-day and so the eternal quest goes on as nature reveals its endless secrete to the most remarkable of God's creations - the mind of man.

FUNDAMENTAL SCIENCE AND TECHNOLOGY*

Alladi Ramakrishnan

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It is both impertinent and embarrassing for me to speak to a group of enlightened engineers about the role of fundamental sciences in technology. This is now accepted almost as axiomatic and the study of basic sciences is today an integral part of the curriculum in technology. However, I feel there is a necessity to emphasise three aspects in the inter-relationship of pure and applied sciences with particular reference to advanced education in India.

What is treated as an axiom is that the mathematical sciences are useful and necessary tools, but what may not be equally obvious is that the pursuit of fundamental sciences for its own sake is an endeavour which almost guarantees the growth of technology. I can best express this through the intimatable words of one of the greatest physicists of the world today Professor Julian Schwinger of Harvard.

> 'The scientific level of any period is epitomized by the current attitude toward the fundamental properties of matter. The world view of the physicist sets the style of the technology and the culture of the society, and gives direction to future Progress'[1].

Thus, if the growth of technology depends on the moving frontier of fundamental sciences, this can be achieved not by treating basic sciences as tools, but as the primary aim of those who are devoted to their development. This has been adequately realised in the United States which has sponsored the simultaneous growth of fundamental and applied sciences. In fact, in India, where a desire for economic development has become not only a necessaitybut almost an obsession

*Lecture delivered at the Engineering Summer School (Normal Programme) Southern Region, Guindy, Madras-25, on 28th June, 1965 with the planners and administrators, there is a great danger of treating fundamental sciences as a tool, albeit necessary, yet only an appendage to applied technology. This shortsighted attitude will lead to a stifling of initiative in the creative sciences and may ultimately retard the technological development in the country.

There is a second significant feature in the relationship between pure and applied sciences. In the growth of human knowledge, it is impossible to predict whether theoretical or experimental work precedes the other in any stage of development. There are as many examples of discoveries of experimental work being stimulated by theoretical predictions as there are experimental discoveries leading to new theories. It was Dirac's logical interpretation of negative energy states that preceded Anderson's discovery of the positron. On the other hand, the experimental discovery of strange particle stimulated the Gell-Mann-Nishijima relation which burgeoned into the beautiful SU(3)-symmetry. This has been best expressed by Murray, Gell-Mann of California as follows:

> 'There is the really exciting prospect of total surprises, things completely outside our experience, which our present-day theoretical language is inadequate to describe. For the last few years, theoreticians have been doing pretty well. Fifteen years ago they were in miserable repute after spending ten years describing the muon by a theory of the pion. The experimental discovery of strange particles took them totally by surprise, just like the existence of the muon. I think another reversal of the positions of experimentalists and theorists is about due now. The strain has been accumulating for 15 years, the shock should come fairly soon'[2].

Thus, to the experimenter, the theorist should be a companion and a coworker in the high endeavour of understanding and mastering the forces of nature, and not just a useful assistant providing him with the necessary tools. The Churchillian assertion 'give us the tools, we will finish the job' should be supplemented by an equally valid assertion 'that tools are the creation of human ingenuity to the variety or extent of which no limits can be set'.

The third aspect of this relationship is that it is impossible to foresee the domain of the applicability of any advance in fundamental sciences. A gravitational theorist would be convinced of the validity of the relation $E = Mc^2$ purely through the principles of Lorentz invariance while a nuclear theorist would use it for estimating the energy released in nuclear fission. A theoretical physicist will not be surprised if a new gifted entrant to elementary particle physics, unacquainted with gravitational laws, rediscovers the principle of special relativity purely by the study of hyperfine structure of spectral lines ! The two frontiers in the study of the basic law of natural sciences, that of the very large, (the cosmos) and that of the very small (elementary particles) seem to merge with our increased understanding of such laws. The same situation seems to be true as regards the domains of pure and applied sciences.

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NSS/18.10.1976

PRESENT STATUS OF THEORETICAL PHYSICS IN INDIA

Alladi Ramakrishnan

1. Introduction

The most significant feature of scientific development in the twentieth century has been the simultaneous advance of fundamental research especially of a theoretical nature on the one hand and the applied sciences with special emphasis on their relation to technological progress on the other. Before the birth of modern physics, as it is understood today, the role of mathematics in physical sciences has been essentially that of a tool, albeit valuable for the study and systematisation of observations. When relativistic and quantum mechanical description of matter was forced upon the physical world by the discoveries of Einstein, Planck, Bohr, Heisenberg and Dirac during the first few decades of this century, the deductive and mathematical study of nature assumed an importance, equal to that of experimental investigations. The role of mathematical sciences in general and theoretical physics in particular in the scientific advancement of a country was realised especially by America and Russia. The creation and spectacular rise of great schools of theoretical work in the United States at Harvard, Princeton, Rochester and Berkeley coincided with the corresponding advances in experimental physics.

Unfortunately the situtation in India has been quite different. Little or no emphasis has been laid till now on high standards of mathematical discipline even for post-graduate studies in sciences

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This review was given before the creation of the Institute of Mathematical Sciences in the year 1962.

there has been an indifference and apathy towards fundamental research of a theoretical nature. The direct consequence of such an attitude has been the falling of standards in practically every branch of science. It is common knowledge that our students sent for training abroad found the mathematical discipline in America almost 'oppressive' and this has naturally affected the prestige of Indian education in the eyes of world.

II. The need for centres of mathematical Sciences

If India has to take an honoured and rightful place in mathematical education, there is no other way than through the establishment of centres or institutes of mathematical research in different parts of the country. The time is now propitious for the establishment of such centres or institutes of mathematical sciences in view of the professed policy of the Government to concentrate on higher scientific education under the third five-year plan. Such centres will have much in common with centre like Institute for Advanced Study in Princeton where the main objective is pure research of a very advanced theoretical nature. A few years ago an Institute was started under the leadership of Professor Yukawa for the advancement of theoretical physics, a subject to which the Japanese have made significant contributions in recent years. More recently, the Scandinavian countries have created a new Institute entitled the 'Nordita' on the same lines as the celebrated Bohr Institute for Theoretical Physics at Copenhagen.

The creation of such a comprehensive centre of theoretical physics, applied mathematics and astrophysics will earn the gratitude and admiration of the young scientific community in India which has been hoping and yearning for opportunities which have hitherto been available only outside our country.

Recent developments in Astrophysics show an increasing application of basic ideas of nuclear physics in the understanding of Stellar phenomena. Many cosmological problems like the origin of solar system, stars and galactic nebulae are being solved by means of the knowledge gained in the study of nuclear reactions. In a similar way, a theoretical physicist engaged in the problem of the origin of cosmic rays borrows many ideas from astrophysics. Thus a mutual collaboration between a theoretical physicst and an astrophysicist is necessary. Since the basic training in the mathematical discipline is common for any theoretical physicist and an applied mathematician, collaboration between the two will be of mutual benefit.

These centres may be parts of the university as the Enrico Fermi Institute of Nuclear Studies in the University of Chicago or like the Institute Fluid Dynamics in the University of Maryland. The centre in full strength may consist of the following staff besides research workers:

a) One Professor in theoretical physics,

b) Three Readers, one each in theoretical physics, applied mathematics and astrophysics,

c) Three lecturers, one in each of the above subjects,

d) Visiting Professors and Readers.

A principal stimulus for research work in these subjects is contact with leading workers in other centres of the world. It is a fortunate circumstance that many visits of foreign scientists are arranged by the Science Congress, Government of India and by the Department of Atomic Energy. It will therefore be of great assistance to the research workers in these centres of mathematical sciences, if financial assistance is made available to enable such visitors to spend sometime in such centres, To this end, visiting professorships may be instituted. Eminent theoretical physicists and applied mathematicians can be invited to stay in such centres for periods ranging from a month to a year on a salary of Rs.2000/- per month or an honorarium of Rs.200 per lecture. In order to get the services for short periods of talented workers from one centre to another, visiting readership may be created which carry an honorarium of Rs.75/- per lecture or on a salary of Rs.800/- per month.

III. Factors essential to a successful working of these centres of Mathematical Sciences

The success of such research centres will essentially depend on the feasibility of finding persons to direct and man such centres. I feel quite strongly that the conventional statements that there are not enough persons in India to direct research is without foundation. It is an unhappy tendency in our country to reco-gnize talent only when it is discovered and honoured by foreign societies like the Royal Society of England or the Universities of the United States. If we were to justify the high intellectural tradition to which our ancient country is heir, we would be bold enough to recognise talent in our country. The postulate that there is not enough talent in the country is not borne out by facts. Professor S.Chandrasekhar, the greatest theoretical astrophysicist in the world today, was constrained to start his research career in the Cambridge and has now settled down in Chicago as an American citizen. Professor Harischandra, perhaps the most gifted of our mathematicians, made his great reputation in the mathematical world when he was only a research student under Professor Bhabha. Professor Salam's work was recognised as outstanding in fundamental physics four years before he was invited to the Indian Science Congress on his election to fellowship of the Royal

Society. It is a trajedy too deep for tears that we seem to wait so long before accepting the reputation of an Indian scientist that we are not able to attract them to our institutions after they have settled down as permanent members of the staff of the leading institutions in the world. It is time we shake ourselves out of an attitude of apathy towards indigenous talent. I have not the least doubt that if we have the willingness to start centres of mathematical sciences in various parts of India we can find leaders of competence inspired by the necessary sense of idealism.

With almost no resources at my disposal except my abiding faith in these ideals, I started, on my return from Princeton, a humble experiment just two years ago in our own home city in forming a group of workers in theoretical physics devoted to the pursuit of science in the spirit of their compeers elsewhere in the world. The success of this experiment has gone far beyond my wildest dreams and if today I am able to claim that this group is as active as any in India and bids fair to be the nucleus of an intellectual renaissance, it is because of the abundance of talent available here which is just waiting for opportunities for expression. During the past twelve months our group had the pleasure of personal contact with some of the distinguished physicists who have come to Madras and who have expressed their warmest appreciation of the nature of the effort of this scientific community.

Far from being an intrepid venture, the creation of such centres of mathematical sciences would become an example to be followed in other parts of India. The existence of such centres will not be inconsistent with an expansion of the physics and mathematics departments in the Universities. In Princeton for instance, there flourishes side by side the Institute for Advanced Study and the University of Princeton and their collaborative achievements has become part of the scientific tradition of the United States. At present it is a general feature in our Universities that each subject is pursued only under the direction of only one professor. Since a University is concerned with a large number of departments, the possibility of having many professors in one department may seem remote under the present circumstances.

Only one point perhaps remains to be clarified. I agree that research institutes should not be divorced from teaching. A true scientist must be willing to impart knowledge and it is only through the propagation of ideas from teacher to students that we can ensure a stready stream of fresh talent. The sactity of the relationship between the teacher and student has been handed down to us from the Vedic age and constitutes an integral part of our way of life. Lectures, symposia and seminars can be organised frequently in these specialised centres so that teachers from the various colleges in the neighbourhood and young aspirants to research career can come into close contact with active workers. In the words of Oppenheimer, the teaching of science is at its best when it is most like an appre- nticeship and there can be no better venue of apprenticeship than a centre which provesses to foster such creative work.

NSS/23/11/76

SCIENCE REVIEW*

Alladi Ramakrishnan

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I shall attempt, in this brief talk, to describe the nature and magnitude of the scientific revolution that is taking place in our lives today.

One of the greatest surges in the history of human thought occurred at the dawn of the twentieth century with the birth of quantum theory and relativity. Man's vision of nature was till then confined to classical phenomena. Those observable to the naked eye or through instruments to aid it and the laws of nature were essentially those postulated by Newton and Maxwell. Those laws were found inadequate to explain the phenomena relating to the sub-microscopic world of atoms and nuclei. To speak of the observation of the dynamical motions of such microscopic entities is of course a contradiction in terms, for, were they observable, they would be classical. ~~But they do lead to observable, they would be classical~~. But they do lead to observable effects, heat, light, radiowaves, x-rays, radio-activity, transmutation of elements and many phenomena of atomic and nuclear origin. The physicists were therefore faced with an unprecedented situation - to explain observable phenomena relating to unobservable entities. This was achieved by devising a mathematical scheme, to represent the dynamical behaviour of such microscopic entities, such that the predictions of the scheme relate to observable phenomena. This scheme known as quantum mechanics represented as revolutionary a change in outlook as that brought about by the Copernicus and

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*Talk delivered at A.I.R., Madras on 23rd June, 1961.

was created by the efforts of a few thinkers like De Broglie, Schrodinger, Heisenberg and Dirac. Their ideas were not in any sense derived from previous concepts. They emerged 'out of the blue' as postulates in much the same way as the creation of calculus and classical electro-magnetism, earlier in the history of physics. The immediate incentive for the creation of such a structure was the dual nature of light and matter discovered by Planck and De Broglie, respectively. Quantum mechanics with its probabilistic interpretation solved the paradoxes and was soon enlarged net merely to explain the interaction of light with matter but nuclear phenomena, particularly radio-activity.

During the 'beautiful' years of its growth, it remained mainly the concern of the restless minds of long haired scientists pursuing the work in idyllic tranquillity of university halls and quadrangles. It never occurred even to the forward looking minds that within two decades, their discoveries will affect the course of human destiny. The descriptions of the lives of scientists at Gottingen look to us like pages from a book of fairy stories. It was in such an atmosphere that new discoveries were made which were precursors to that of atomic fission, that marked the birth of new atomic age -- the discovery of neutron by Chadwick, the artificial production of tran-suranic element by Fermi and the construction of machines which could product high energy particles. Even then, it never occurred to the scientist that the harnessing of nuclear energy was a practical possibility. With the discovery of fission by Hahn and Strassman and the possibility of chain reactions it became clear that man was suddenly placed in possession of a source of power more potent than any which hitherto directed the course of human civilisation.

The global war came as a pressing stimulus for the construction of the atomic bomb. This project undertaken by the mightiest and most opulent nation in the world is the greatest example of co-operative endeavour of scientists of all time. When the first atomic bomb successfully exploded with the brightness of a thousand suns, it was clear that man has trenched upon God's domain -- raising in the minds of many, doubts and fears that such intrusion into the supernatural " cannot be ill, cannot be good" . These doubts tormented even the fathers of the bomb and when a few years later, the question of the construction of the hydrogen bomb by nuclear fission was raised, Oppenheimer refrained from co-operation and it was only later that Edward Teller and his associates undertook to complete with the Russian scientists in the race for the " Super",

Meanwhile efforts of a more benignant kind were going on in England for the peaceful uses of atomic energy. Their efforts, in contrast to the nightmare of universal destruction by atomic bombs, raised hopes of a millineum when mankind can be relieved of sickness and poverty and of want and suffering.

As far as the scientists were concerned, the relief from the pressure of war and the necessity to work on defence projects restored to them the opportunities for creative work. Once again the pursuit of pure science became their primary objective and with it came the resurrectionof the 'Beautiful' years. Both America and Russia wrested from Europe the Initiative for work in theoretical and experimental sciences. The technological developments during the war had of course a profound influence on the development of pure sciences. The three major fields which engaged the attention of the most gifted scientists were;

i) Nuclear Physics,

ii) Aerodynamics,

iii) Astrophysics and

iv) Space research and their applications.

In the field of fundamental physics, three notable advances can be mentioned on a par with the great discoveries of science. The outstanding problems of electrodynamics, in the hands of Feynman, Schwinger, Tomonaga and Bethe were completely solved by 1950. It was proved by Lee and Yang, two chinese physicists in America, that the laws of nature need not remain invariant in a space reflected world, a concept hitherto held sacrosanct like the conservation of energy. New fundamental constituents of matter, the strange particles and antiparticles were discovered in various laboratories. Their behaviour has created a situation as challenging as that before the birth of quantum mechanics. As bold a deviation from conventional ideas is necessary today, we are in need of another Heisenberg.

It is not only in the sub-microscopic world that new ideas have been set in motion. The possibility of flight has always held the fascination of man, but only the beginning of this century witnessed the invention of the aeroplane. Under the sterm necessities of the second world war the great advances in aerodynamics and aeronautics were made. The battle of Britain, the finest example of the triumph of the human spirit, was possible because of Britain's supremacy in aviation and aerodynamic sciences. At the conclusion of the war, it was realised that the world had shrunk to a smaller measure, as the skies became the highways of transport to men and material - smaller still as the piston engines of aircrafts were soon replaced by the smoother turbo-props and later by the sonic and supersonic jets.

If the skies just above him have excited his imagination through the ages, man has been fascinated equally by domains for beyond of starry realms without bound, without dimension where length, breadth and height and time and place are lost. Astronomy dealing with the dynamical motion of planets and stars is one of the oldest of sciences which can be traced back to the dawn of the human thought but astrophysics which deals with the stellar structure and evolution is comparatively a very young subject, study of which has been made possible with the introduction of spectroscopy. It was only in the last few years that another discovery widened the horizons still further: Like all famous discoveries, it was made unobtrusively in the private laboratory of a young investigator. The birthday of Radio Astronomy can be attributed to the publication of a paper by Jansky in 1932 announcing the reception of radiation of long wavelengh from the sun. It grew into a full-fledged science with the discovery of 21 CM radiation from hydrogen by the Dutch physicists Van de Hulst in Harvard. It was indeed fortuitous that God had designed the universe such that the parts of it that emit radio waves are not coextensive with those which emit visible radiation. The radio astronomer builds a picture of universe just as real and meaningful as the familiar visible universe. When two pictures differ, they compliment one another.

It must of course be remembered that the radio stars are not the first objects revealed to us by such emissions. Sir Edward Appleton, had shown, years before, the existence of the ionosphere by the reflection of long-wave length radio signals. But for the ionosphere, radio communication across the world is an impossibility. For historical reasons the initiative in the radio astronomy first came from England and Australia. This has created a resurgence of interest in astronomy in the United States and the U.S.S.R.

The study of astrophysics is closely bound with that of cosmology which has raised the most fundamental problem about the origin of the universe. Whether the observed expanding nature of the universe is consistent with an evolutionary or stationary character is one of the outstanding problems of cosmology. Very recently Bondi has put forward the theory that cosmological repulsion can be explained as due to electrostatic forces, despite the equality in numbers of positive and negative charges on the basis of a revolutionary hypothesis that opposite charges are not equal in magnitude.

While man has been fascinated by the study of the universe around him through observation and speculation, he has recently been impelled by a new desire to travel in interplanetary space. With the development of aerodynamics, chemical technology, electronics and radar techniques, this dream has become a reality.

For obvious reasons, space travel and its unpredictable consequences have dominated the hopes and fears of the human race to such an extent that national prestige has recently became the most important factor in its development. There is an international race in progress to explore space with satellites and moon-probes and one hardly need quote the grand Russian successes to illustrate the prestige value of such scientific ventures.

Any discussion on the contemporary revolution in science will be incomplete without a reference to the notable advances in Biology and the healing art of medicine. The conclusion of the first world war marked the beginning of the era of anti-biotics from Pencillin to Darenthin which offer miraculous cures for both infective and organic diseases. Advances in surgery have been euqlly spectacular with new techniques of grafting by suppression of anti-bodies through x-rays.

Hospitals not only have banks for blood but also for kidney grafts, Endocrine glands and bone marrows.

This scientific revolution of our century has been possible by the efforts of enquiring minds of many nations, efforts animated by only one desire to understand and probe the mystery of the universe to which we belong. It is perhaps relevant for us in India to ask the question what part of country has played in this international efforts. With the exception of the Raman effect and the contributions of Ramanujam in Mathematics and Chandrsekhar in Astrophysics, our participation has been very little. The future of course looks very hopeful since we are now with the active assistance of our Government, embarking on a programme of research on a scale and magnitude comparable to those in more advanced nations of the world. But we must remember that creative work is not just a product of organisation and finance. We must be impelled by a sense of sublime idealism and feel the joy of elevated thoughts whose dwelling is in the light of setting suns and in the mind of man. Only then we can hope to be participants in this eternal quest for a happier sunlit world, brightened by the lights of science and natural philosophy.

nss/30.10.1976

THEORETICAL PHYSICS IN THE UNITED STATES OF AMERICA*

Alladi Ramakrishnan

Perhaps the most important feature of scientific effort in the twentieth century is the simultaneous advance in fundamental sciences on the one hand and in technology on the other. This is particularly noticeable in the United States where despite the fact that technology has had such an impact on the amazing prosperity of the United States and scientific man-power is in constant demand by industry, fundamental research still engages the attention of the most gifted minds which emerge from its universities. As a typical example of this trend towards basic sciences, We shall consider the status of and contributions in theoretical physics in America today.

Physics deals with the study of matter and natural phenomena and such study consists of two parts:

(1) The precise measurement of physical quantities.

(2) Interpretation of such measurements and consequent understanding of natural phenomena.

The first part falls within the doman of the experimenter, the second, of the theoretical physicist. Till the advent of quantum mechanics, the connection between experiment and theory was quite direct, since the description of nature was based on classical concepts.

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*This article is based on the impressions of the author during the period of his residence (1957-58) as visiting member at the Institute for Advanced Study, Princeton, U.S.A. He has great pleasure in thanking, Professor J.R.Oppenheimer, the Director of the Institute, for his warm hospitality and acknowledging the travel grant of the Asia Foundation which enabled him to accept the membership.
Reprinted from 'CURRENT SCIENCE', 1958, 27, 469-473.

But for a quantum mechanical description of matter, a complex mathematical formalism was introduced; no longer a 'pictorial' and 'conventional' method possible. Hence the relationship between experimental observation and the theories became more indirect and involved, perhaps even obscure except to those familiar with mathematical theories. On the other hand, the testing of these theories demand such precision in measurement that the experimenter had to devise new and ingenious techniques based on inventive technology and engineering.

The Universities in America realised this distinction quite clearly and soon became centres of fundamental research besides being just 'training grounds' for technical personnel in industry. With the vigour and initiative characteristic of America's growth and expansion, they invited talent from all parts of the world. The unhappy state of Europe during the turbulent period of the World War became a fortuitous circumstance for America's intellectual and scientific advancement--Einstein, Bohr and scores of leaders of scientific thought moved into the new world which was ready to imbibe the spirit and influence of basic research and fundamental science.

By the end of the Second World War, not merely the importance of mathematical sciences as 'tools' for technology, but their significance as an independent discipline necessary for the intellectual vitality and prestige of a nation was well realised. Theoretical physics became 'fashionable' and pure mathematics attained its 'Queenly' pre-eminence. The 'competition' between the theorist and experimenter in suggesting 'leads' to the understanding of nature, led to very important theoretical discoveries and advances in experimental techniques. Laboratories supported by governmental aid and the co-operative effort of the Universities poured forth data on fundamental physical phenomena as 'food for theoretical speculation'.

Thus the theoretical study and interpretation of such phenomena became an active pursuit and profession and ceased to be just the close preserve of the leisured savant and the profound natural philosopher.

In studying the progress of theoretical physics, it is convenient to classify it into three broad divisions:

(1) Formal and deductive approach to quantum mechanics,

(2) Interpretation of high energy phenomena and elementary particle interactions,

(3) Low energy phenomena and study of nuclear 'structure'.

1. DEDUCTIVE APPROACH

The logical approach to quantum mechanics was initiated by Dirac with his formulation of the theory of the electron. While Heisenberg, Schrodinger and other architects of modern physics built up quantum theory by intuition and physical insight, Dirac was one of the first to make a formal deductive and rigorous formulation.

Encouraged by the successful prediction by Dirac of the positron and anti-particles in general, in the early forties theoreticians like Fierz, Pauli and Bhabha seriously attempted to 'deduce' equations on a postulational basis. Though these attempts did not meet the desired success, they helped to inject more logic and rigour into theoretical physics. In the United States, Schwinger is the most famous exponent of the view originally expressed by Einstein that the axiomatic basis of theoretical physics cannot be extracted from experience but must be freely invented.

The deductive and logical approach naturally attracted the attention of pure mathematicians like Neumann and Weyl at the Institute for Advanced Study. The classic works of Neumann on the logical foundations of quantum mechanics and of Weyl on group theoretic methods are considered as part of the necessary equipment of any theoretical physicist today. But somehow, pure mathematicians did not make any substantial contribution to the content of quantum mechanics, presumably, as has been stressed in an interesting review of Hilbert's life, because of the fundamental difference between a mathematician's insight and a physicist's intuition. However, the abstract approach still holds the minds of many theoretical physicists and systematic attempts are being made to formulate field theory in a rigorous and deductive manner. The work of Nishijima and Wightman in the United States, the recent proofs of dispersion relations by Taylor, Oehme and others at the Institute for Advanced Study are examples of such attempts. Very recently, Heisenberg and Pauli have attempted to explain the mass spectrum of elementary particles by means of non-linear spinor equation which has been quantised in a revolutionary way by making use of the indefinite metric originally doe to Dirac. But it has to be conceded that despite the recognition of the necessity of a deductive approach to quantum mechanics, there is considerably widespread scepticism in the United States whether such approach will 'deliver the goods' in the near future. There seems to be more faith in the opinion of MaxBorn that the art of scientific prophecy can be learnt not so much by reliance on abstract reasoning as by deciphering the secret language of nature from nature's documents, the facts of experience.

2. High Energy Physics

The first major American contribution after the second World War was in the field of quantum electrodynamics. By 1948, the application of quantum theory to electrodynamics initiated by Dirac two decades earlier reached a stage when theoreticians were faced with fundamental difficulties which needed essentially new methods and they were provided by the outstanding work of Schwinger at Harvard and Bethe, Feynman and Dyson at Cornell.

The quantum electrodynamics based on the classical concept of point charge gave rise to well-known difficulties such as the infinite self energy of the electron and the 'ultra-violent castastrophe'. Essentially connected with these difficulties are the infinite fluctuations of the charge and current in the case of matter field and the fluctuations of in the field strength in the case of electromagnetic field even in the vacuum state. The existence of such fluctuations of charge and current in the vacuum implies that the vacuum acts like a polarisable medium which causes the phenomena of scattering of light by light or by electrostatic field.

Further progress in the subject came with the experimental discovery of the anomalous magnetic moment of electron by Kusch and the shift in the levels of the hydrogen atoms by Lamb and Rutherford made possible by the war time development of the electronic and microwave techniques. To understand these electrodynamics effects, it was found necessary to introduce the idea of renormalization of mass and charge. Suitable covariant renormalization techniques were developed by Schwinger, using formal field theoretical methods. Quite indepemdetnly without any considerations of field theory, Feynman developed a most unconventional approach based on propagation kernels of single particles which was inherently covariant. His graphical representation of quantum mechanical processes first applied to electrodynamics is now extensively used even in processes involving other elementary particles. The essential equivalence of Feynman's graphical approach and the formalism of Schwinger was established in a fundamental paper by Dyson. 'The evolutionary process by which rel ativistic field theory was escapting from the confusion of its non-relativistic heritage has recently culminated in a new formulation of quantised theory of fields by Schwinger starting from a basic action principle'. This also revealed that the connection between spin and statistics stems from invariance requirments.

By 1952, it was felt that quantum electrodynamics had reached a state of comparative completeness and it was not likely that future development will drastically change the results of electron theory which gave quantum electrodynamics a certain enduring value. 'The real significance of the work of the past decade lies in the recognition of the ultimate problems facing electrodynamics, the problems of conceptual consistence and of physical completeness. No final solution can be anticipated until physical science has met the heroic challgnge to comprehened the structure of the submicroscopic world that nuclear expolaration has revealed'. With the development of high energy machines in the post-war era, many phenomena were observed involving the creation of new and strange particles and high energy physics naturally included the study of these new processes like the production of mesons in nucleon-nucleon collisions and recently in electron-nucleon collisions, and the production of strange particles in high energy interactions.

The vast mass of data from the high energy machines from centres like Brookhaven and Berkeley raised a maze of problems as a challenge to the most gifted of theoreticians. The most famous of them all was the $\theta-\tau$ puzzle- the identity of the masses and life-times of the two types of K-particles with different modes of decay and parity assignments. Dalitz's analysis of this puzzle claimed great attention at the Rochester Conference in 1956 and it is rather exciting to read the discussions after Yang's introductory talk in which Feynman, Yang, Lee Bloch, Gellman and Marshak participated. It was of course given to Yang and Lee to question boldly the invariance of parity under space reflection in weak interactions and suggest the Cobalt experiment which was performed by Wu et. al. and which brilliantly confirmed their predictions. Their remarkable paper reveals the new trend which characterises theoretical physicists today, - the theoretical physist the interest in the universal Fermi int...

During the study of weak interactions/has been received to explain all weak interactions such as β-decay, μ^--capture and hyperon decay. Feynman and Gellman have proposed one such theory by extending the two-component formalism to all Fermi particles while Marshak and Sudarshan have employed the 'chirality' invariance to the same end. For all these theories the exact coupling between Fermi particles is of decisive importance. It looks at present that the vector and axial vector coupling will be preferred rather than the scalar and tensor. Pais and others are investigating the relative parities of the $K^{\pm}$ and K^{0} mesons.

While of course the theory of weak interactions claimed great attention following Lee and Yang's discovery, attempts are also being made to understand the strong interaction of heavy particles. Gell-mann has proposed a global symmetry, i.e., a universal pion-coupling between all heavy particles. He envisages a/degenerate spectrum for the eight baryons in the presence of the pion-coupling. When the K-particle coupling is switched on, the baryons are split into groups as observed, i.e. charge independent multiplets. Of course, the study of strong and weak interactions are included to-gether in the former deductive approach mentioned before.

Meanwhile, there was another important theoretical development in the field of interactions of elementary particles involving strong coupling. In view of the evident breakdown of the perturbation theoretical approach to the study of interactions involving strong coupling, there was a long-felt need for a radically different method to tackle such problems. Goldberger at Chicago first realised the importance of the study of the analytic properties of S-matrix from general considerations and by the use of complex variable theory and in particular Hilbert's theorem he was led to relations connecting the real part of the scattering amplitude to the integral over the imaginary part, the latter being related to the total cross-section. After a number of non-rigorous but intuitive derivations of such relations by Goldberger, Gellman, Salam and others, the dispersion relations for meson scattering by nucleons have been established in a rigorous way by Bogoliubov from U.S.S.R. and Bremmermann and others from U.S.A. The same approach has been employed in the electromagnetic and weak interactions especially by Bogoliubov . Goldberger is currently investigating dispersion relations for π-meson decay. The 'dispersion relation' approach has been utilised to study nucleon-nucleon scattering, the electromagnetic structure of nucleons and similar problems by Goldberger, Chew, Nambu and others.

While high energy physics became fashionable consequent on Lee and Yang's discovery, non-relativistic theories at low energies also demanded considerable attention. Chew and Low's successes in the theory of pion-nucleon interactions exemplify such attempts. They have shown that if one assumes: (1) Pseudo-scalar interaction, (2) Charge independence, (3) Negligible nucleon recoil, and (4) Predominantly P-wave interaction, then the crossing-symmetry, and unitarity of S-matrix are sufficient to establish the remarkable features of nucleon-pion interaction, in particular the resonance. The same method has also been applied for explaining photo-production of pions by utilising the gauge invariance characteristic of electromagnetic interactions.

Drell and others have extended the Chew's theory to include S-wave interaction which is strongly isotopic spin dependent, the nature of which is not fully understood. Chew's theory has also been applied to nucleon-nucleon interaction potential. Assuming only P-wave coupling, Gartenhaus has calculated the nucleon potential upto fourth order in the coupling constant. But this potential is inherently defective in that it does not yield any spin-orbit coupling. Recently, Marshak and Signell have proposed a phenomenological potential which simply consists of Gartenhaus potential plus spin-orbit interactions term obtained from phenomenological considerations.

As has been recognised for a long time, the knowledge of nucleon-anti-nucleon interaction is very essential in explaining the problem of nuclear forces. Attempts have been made to explain the large annihilation cross-section for N-$\bar{N}$. Chew's theory has also been applied to the problem of nuclear forces by Miyazawa from Japan; Klemn and Mcormick from U.S. and Novoshilov from U.S.S.R. who have reduced the problem of two nucleon interaction to that of one nucleon. In recent years, the Compton scattering of protons have been re-examined from the point of view of Chew's theory.

3. Low Energy Physics and Nuclear Structure

While in the field of high energy physics we deal with the nature of elementary particles individually and their interactions the collective properties of nuclear matter and the manybody problem of the nucleus (especially heavy nuclei) depends on data obtained from comparatively low energy phenomena. These theoretical considerations are usually referred to as 'problems of nuclear structure', the aim of which is to derive the nuclear energy levels, nucleon wave functions, imaginary and real potentials associated with the nucleus.

In this, theoreticians have been puzzled for a long time by an apparent contradiction, namely, whatever we know about the nuclear forces indicates that these forces are very strong and have a dependence on position, repulsive cores, exchange character and other 'peculiar' considerations. On the other hand, the properties of the nuclei at low energies both for bound states and for the interactions of nucleons with nuclei show the remarkable validity of the one-body approximation based on a very smooth potential without large magnitude and large variation. This is the basis of many models which work so well, e.g., shell model and the optical model. The apparent contradiction led some people like Teller and Johnson to go to an extreme point of view, viz., to give up any connection between the structure of the nucleus and the nuclear forces as observed in nucleon-nucleon interactions. On the other hand, Brueckner and collaborators attempted rather successfully to resolve this contradiction. The essential merit of the outstanding work of Brueckner lies in that 'it takes the nuclear forces as they are delivered to us and constructs from this a theory of complex nuclei which gives us as good an approximation as possible in the one-body picture'. Further contributions of Goldstein, Tobocman Watson, Reisenfield may be mentioned in this connection. Professor Bethe is more inclined to the programme of Brueckner than the extreme point of view of Teller and Johnson. The experimental work relating to the optical model, the polarisation of neutrons at low energy and nuclear reac-tions involving light and heavy nuclei are being provided from various American laboratories. The emphasis of the theoreticians is still being felt in this field as in high energy physics. The contributions of Professor Lee on the theoretical implication of the parity violation in β-interaction followed by that of C.S.Wu on the experimental evidence of non-conservation of parity in β-decay at the

Rehovoth conference clearly indicate the very close connection between the fields of low energy and high energy physics. The discovery of parity nonconservation in weak interaction which originated in the θ-τ puzzle of the high energy phenomena has become very important in β-interactions.

In a wider sense, the study from a fundamental point of view of problems in different fields of physics has clearly demonstrated the inter-connection between them and the need for frequent exchange of views in conferences like those held annually at Rochester where both the experimenter and the theoreticians are able to discuss the prob problems together. America has taken the lead in the organisation of such conferences, a lead soon followed in Europe, Japan and Russia. The proceedings of such conferences are considered sources as important as publications in scientific journals for future research.

It is the earnest hope of the young scientific community in India that at a time when our country is almost possessed by a desire for technological advancement, enough emphasis should be laid, as has been done in the United States on fundamental sciences as a necessary and independent discipline.

NSS/16.11.76