A. K. Raychaudhuri : Physics Professor Par excellence

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In this article I give my personal impression and estimation of the late Prof. Amal Kumar Raychaudhuri (AKR): a legendary Physics teacher and researcher. There can be no question that he has made the most outstanding contribution from India so far to Einstein's theory of General Relativity (GR). Moreover, he also made his mark as one of the two best Physics teachers who have taught in Presidency College, the other being Acharya Jagadis Chandra Bose.

Life and Career

Born in Barisal in 1923 in an academically inclined family, AKR graduated from Presidency College in 1942 with Physics Honours, obtaining his M. Sc. degree from Calcutta University two years later. Soon afterwards, he joined the Indian Association for the Cultivation of Science (IACS), then located in Bowbazaar. He became a research scholar there, supported by the Council of Scientific and Industrial Research (CSIR) in an experimental project on the study of metal alloys under Prof. Kedareswar Banerjee. Being of a theoretical bent of mind, AKR found the experimental work, assigned to him, rather unattractive. There was not much progress in the project and, after five years, he lost his CSIR scholarship.

Caught in a dire pecuniary situation, AKR was forced to take up a temporary contractual lecturership in Asutosh College where he spent two years. During this period, he began to study GR which is an almost independent discipline in Physics, focusing on the interplay between matter, gravitation and light. He also started learning the related area of cosmology: the science of the origin and the large scale structure of the universe. He initiated these studies under the guidance of Prof. Nikhil Ranjan Sen of the Department of Applied Mathematics of Calcutta University. Soon, however, AKR was doing research quite independently and started publishing original single author research papers in those fields.

In 1952, he was taken back at the IACS which had meanwhile moved to Jadavpur. He was appointed a research officer with the understanding that he would work on the motion of

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electrons in solids under Prof. Debidas Basu. Though AKR did publish some results on the application of a free electron network to metal alloys, he did not find the work of Prof. Basu particularly interesting. Therefore he pursued his own research in GR. It was during this phase of his life that he made his momentous contribution in the form of the Raychaudhuri Equation. That earned him a D.Sc. degree from the University of Calcutta.

Unfortunately, AKR's refusal to collaborate with Prof. Debidas Basu did not go down well with the IACS establishment and his promotion there was blocked. In the light of the international fame that he had acquired by then, the Directorate of Public Instructions, Government of West Bengal, created a special post named "Professor of Theoretical Physics" in Presidency College and appointed him to it. AKR took up this position in 1961 and taught Physics at Presidency College till he retired in 1983. After his retirement, he became an Honorary Professor at the Centre for General Relativity and Cosmology of Jadavpur University and was active there till his demise from cardiac arrest in 2005.

During the two periods, 1961-83 and 1983-2005, AKR published many papers in leading international journals as well as a couple of college level textbooks plus an acclaimed monograph on theoretical cosmology. Another published book, covering GR, astrophysics as well as cosmology, had him as a co-author. Several students obtained their doctoral degrees under his guidance and later became faculty members in various universities. AKR was the recipient of many honours. He became a Fellow of the Indian Academy of Sciences (Bangalore), the Indian National Science Academy (Delhi) and the National Academy of Sciences (Allahabad). He was a Visiting Professor at the University of Maryland for one year. He was first a long term Associate and then an Honorary Fellow of the Inter-University Centre in Astronomy and Astrophysics (Pune). He received doctorates (honoris causa) from Burdwan, Kalyani and Vidyasagar Universities. From 1980 to 1982, he was the President of the Indian Association of General Relativity and Gravitation.

AKR as a Teacher

I shall venture to give a personalized account here. I was priviliged to be in the first batch of students taught by AKR at Presidency College during 1961-62. He lectured to us on properties of liquids–namely surface tension, viscosity, laminar flow and Browninan motion–as well as vibration theory and sound. It will not be out of place here to give a bit of the background. So let me do that first.

Physics in the early nineteen sixties enjoyed unprecedented academic and social prestige. The USSR had just launched the Sputnik satellites and the Lunik moon probe. Moreover, extraordinary discoveries were taking place in Europe and the US on solids, atomic nuclei and the fundamental constituents of matter. The whole field was gripped by ferment and excitement. Most of the star students who topped the list in the 1960 Intermediate Science Examination of Calcutta University opted to take the B.Sc. Physics Honours course in Presidency College.

We were in for a rude shock, though. The instructors, initially assigned to teach us, were poor or at best mediocre. They gave monotonous lessons from ancient-looking notes and fumbled when questioned, often showing an appalling lack of grasp of basic concepts. Several of them were quite scared of the bright students in the class and refused to entertain any questions at all. Once one such professor fled after his lecture from the students seeking to clarify some points and locked himself in the toilet! Of course, the situation changed dramatically for the better when Prof. Hemen Mukherjee, Prof. Shyamal Sengupta and AKR started taking our classes, but that was later.

Given the bleak situation described above, some of us started studying the classic texts on our own. We learnt many theoretical techniques by working through these. That generated a certain amount of self-confidence among us. But it also made us rather conceited, arrogant and contemptuous of our teachers. We started as little monkeys, but soon evolved into big *hanumans* with fat and long tails. It was in this negative atmosphere of cynicism in the class that AKR started his course of lectures to us.

Right from day 1, we were electrified and stunned into boundless admiration. We had never seen, among all the teachers that we had had, such calibre and such class. AKR demonstrated a complete command over whichever topic he taught and treated it extensively and beautifully. He made brilliant use of mathematical techniques and his insightful physical explanations were models of clear exposition. When he was lecturing, there was pin-drop silence among the students. The latter were either mesmerized into listening to him open-mouthed or taking notes furiously. An unseen door had opened in front of us and we were being deftly guided into a treasure house of knowledge and scholarship.

AKR was quite severe in grading our scripts in the college terminal examinations. Whenever we challenged him, he would explain with a disarming smile what our mistakes or inadequacies were. He taught us not to blindly respect what was printed in texts, but to work out all things for ourselves. He frequently showed us simpler and more elegant methods of calcu-

lation than what often appeared in those books. Our arrogant upright stance soon changed into a humble horizontal one aimed at this feet. He became the magical Master and ourselvs his devoted disciples.

We were so impressed by AKR's personality that some of us started stalking him outside college hour—to find out what he did and where he went–so that we could emulate him. In those days AKR used to stay in the Mandeville Gardens area of old Ballygunj. He would generally take a tram from there in the morning, step down at the College Street stop, tuck the *koncha* of his dhoti into the pocket of his punjabi and walk to class. Near the tram stop stood one particular *chanachoorwalla*. One of the stalkers rushed back to us one morning shouting, "I just saw Amalbabu-Sir buying and eating *chanachoor* from that fellow." We had discovered the source of his brilliance! The magic had to be in that particular chanachoor which we all started eating. As Prof. J. Narlikar, in his obituary on AKR, has asked, courtesy Shakespeare: "Upon what doth this our Caesar feed that he has grown so great?" I patronized that vendor till my last day at Presidency College before taking off for further studies at Cambridge University. Whatever infinitesimal amount I have achieved in Physics, I owe it to that vendor.

AKR was not without his sense of humour. One of the students in our class was really fat. We used to call him "*Haati*". While teaching Brownian motion, AKR wanted to emphasize that only fine particles, such as grains of pollen or licopodium powder, would execute such motion when placed in a liquid. "If you put a large object in water," he told us, "it will not perform Brownian motion." Saying this, he stared long and meaningfully at *Haati*.

Nearly forty batches of pupils, including both B.Sc. Honours and M.Sc. students, were taught and trained at Presidency College by AKR during his tenure there. Many of them later achieved national and international fame and distinction: a Fellow of the Royal Society (UK), a number of awardees of the prestigious Bhatnagar Prize, the current director of an international institute at Daresbury (UK), an ex-director of the Tata Institute of Fundamental Research, the current director of the Saha Institute of Nuclear Physics, the current director of the S. N. Bose National Centre for Basic Sciences, the current director of the Harish-Chandra Research Institute, a senior professor at the University of California (Los Angeles), a holder of a named chair at the University of Maryland, a professor at Brandeis University, a senior scientist at a premier laboratory at Grenoble, France, umpteen faculty members in national research institutes and universities. I can go on and on, but deem it sufficient to assert that there exists today a galaxy of national and international stars in Physics, all of whom learnt the basics of their subject at AKR's feet under his inspiration. I bet they all ate *chanachoor* from the same vendor!

AKR as a Researcher

To quote Prof. Narlikar again, AKR was the "doyen of Indian general relativists".

He and Prof. P. C. Vaidya of Ahmedabad undoubtedly put India on the world map of GR research. A substantial body of scholarly work, bearing AKR's name, comprises theories with a variable gravitational 'constant' and cosmological models of a universe without any singular spacetime point where the gravitational energy density would blow up. Indeed, AKR and Prof N. Dadhich of Pune showed, following the earlier work of Prof. J. Senovilla of Cape Town, that such a universe is unphysical, i.e. not realizable in practice, since its average matter density must vanish. This fits in well with the other result, described below, that such singularities are inevitable in a physical universe.

Another important aspect of AKR's research concerned black holes–mysterious "pointlike" configurations swallowing everything nearby–that come about as end products of really massive stars collapsing under their own gravitational pull. There was a wrong impression earlier among many cosmologists, following the classic work of Schwazrchild, about the surface (called the 'horizon') that is defined by the distance from the black hole centre where the swallowing starts. It was thought that this is a genuinely singular surface, i.e. physical quantities blow up there. However, AKR showed that the 'singularity' was an artifact of the coordinate systems chosen. He found a coordinate system without any infinity at the horizon. Physical quantities were shown to be well-behaved there.

The crowning glory, however, of AKR's research in GR was the derivation of the Raychaudhuri Equation in the early nineteen fifties (done in '53, but published in '55). This is a very deep and fundamental result in GR with immense consequences in astrophysics and cosmology. Indeed, it played a crucial role in the revolution that swept the cosmological community off their feet ten years later. I try to give below a nontechnical account of the essential aspect and import of this equation.

According to Einstein, the four dimensional spacetime in which we live gets curved by the presence of matter which automatically generates gravitational pull. This is the basic link between gravity and geometry which is a foundation of GR. This link is quantitatively expressed in terms of set of equations called Einstein's equations. In the curved spacetime, light rays and moving material particles follow optimally shortest paths called geodesics. It was common among earlier cosmologists to assume that the large scale structure of the universe is

homogenous (i.e. with equal locally averaged density at every point) and isotropic (i.e. looking the same in every direction). AKR gave up these assumptions. He considered a general inhomogenous and anisotropic universe with both rotation and shear and without any other assumed symmtery constraint. He then derived his equation which gives a most general description of the convergence or divergence of a pencil of neighbouring paths including geodesics.

The Raychaudhuri Equation is highly significant on several counts. First and foremost, it is a geometric statement on the congruence of the above mentioned paths. It describes how they behave during the course of their dynamical evolution, i.e. how they expand, reconverge, get distorted under the shearing effects of the gravitational pull exerted by massive bodies and how they rotate under the influence of the matter density and the energy density present. Because of these features, the equation has found application not only in cosmology but also in hydrodynamics, the science of fluid flow. More importantly, the equation implies the existence of some paths which inevitably focus into singularities, either in the past or in the future. These singularities are spacetime points where physically measurable quantities, such as curvature and energy density, blow up by tending to infinity.

A decade after AKR wrote down his landmark eqution, the last mentioned result was given a complete and rigorous mathematical generalization in terms of a set of precisely stated singularity theorems proved in GR by S. Hawking, R. Penrose and R. Geroch. These mean that spacetime singularities are unavoidable in GR. Thus the explosive big bang singularity, which is now known from observational data to have created our universe some thirteen billion years ago, is consistent with GR. The same goes for black holes. Indeed, very massive black holes are now known from astronomical data to reside at the centres of spiral galaxies, such as ours, acting as engines that power them.

The above developments shook the field and caused a revolution in the mindset of cosmologists who were forced to accept the real existence of spacetime singularities, at least within the framework of GR, instead of fruitlessly trying to build models of the universe without them. The importance of the Raychaudhuri Equation in this revolution is clear from the thirteen references to it in the classic Cambridge monograph: "The large scale structure of spacetimc by S. Hawking and G. Ellis".

Postscript: a Personal Note

I would like to end with an account of my last encounter with AKR. In 2003, Jadavpur University arranged a symposium to celebrate the 80th birthday of AKR. I had the honour to

deliver the keynote address. I talked about supersymmetry which is a proposed invariance of transformations between fermionic and bosonic matter.

An important prediction of this idea, as applied to particle physics, is the occurrence of new kinds of signals at the Large Hadron Collider (LHC). The latter is a gigantic mega-acclerator under construction in Geneva, Switzerland. Now scheduled to start running in mid-2009, it promises to recreate in the laboratory conditions that existed in the early universe about one trillionth of a second after the big bang.

During the tea-break after my talk, AKR confronted me. "Probir", he said, "you people who work on supersymmetry are like President George W. Bush of the U.S." I was completely taken aback, failing to see any connection between Dubya and supersymmetry. When asked to clarify, AKR quipped, "If the U.N. inspectors find weapons of mass destruction in Iraq, fine. Even if they don't, Bush will attack Iraq anyway. Similarly, if LHC finds supersymmetry, fine. But even if it doesn't, you will continue to work on supersymmetry anyway." For once, I respectfully begged to differ. "Sir", I replied, "if the LHC does not see supersymmetry, most people, including myself, will stop working on it."

AKR passed away two years later. Prof. Dadhich wrote in his obituary: "A lighthouse falls!" It has indeed fallen, but the light continues to burn in our hearts. The IACS has tried to make amends for its once unjust treatment of AKR by naming a brand new lecture hall after him. I do hope that Prseidency College will take a similar step to enshrine the memory of this great and wonderful professor of Physics.

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