The physics in our future

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Physics in India is a century-old tradition, shaped by many heroic figures and strengthened by hundreds of dedicated practitioners. The subject itself is in a state of rapid expansion at its major frontiers, namely the complex, the large and the small. How are we placed in this scene? Are our strengths and investments optimal? If not, what needs to be done? Increasingly, technology is based on and drives science. In physics, what are the most-promising areas of overlap for us? These are some of the questions I try to explore here.

Physics today

I first sketch briefly the areas of growth in physics. As mentioned above, there seem to be three principal ones, namely the small, the large and the complex. The first is the subnuclear domain of elementary material constituents, basic forces and their possible unification. The second is the cosmic realm of stars and galaxies. The complex refers to systems with a large number of interacting constituents, which may be atoms or electrons or neurons; loosely, this is the physics of condensed matter and of other complex systems. These three concerns are connected in many deep ways with each other and with other vigorously active large areas such as plasma physics, optical physics and nuclear physics which I will touch upon only briefly; physics is a seamless web.

The small (or high energy physics)

The journey into the small, made possible by accelerating particles to high energies and letting them collide, was marked by spectacular milestones till the late seventies and early eighties. These took us to the relatively symmetrical world as it is at about 10^{-17} cm where electromagnetic and weak nuclear forces are seen to be aspects of the same basic force. A major step further would be the superconducting supercollider (SSC), proposed to be completed by 1999 at a cost of about ten billion dollars (if funded). This will push the energy scale to 40 TeV (40×10^{12} eV) and the length scale of phenomena within our reach to 10^{-19} or 10^{-20} cm. Our understanding of the 'standard model' of electroweak and strong interactions will be tested in new ways, and unexpected phenomena may show up. At about 10^{-33} cm, because of strong quantum fluctuations in the fabric of spacetime, all basic forces including gravitation 'need' to be unified. A number of theoretical scenarios inspired by this goal have been actively explored in the last decade.

The large (astronomy and astrophysics)

Observational astronomy, the study of the large, has been revolutionized in virtually every region of the electromagnetic spectrum by new ideas as well as technical advances. We can 'see' much further and more selectively than ever before. The universe is much stranger than imagined. Most of its mass ($\simeq 90\%$) is invisible; it is bathed in primeval 3 K radiation with miniscule (parts per million) but telling temperature ripples; galaxies are strewn in space, not at random, but correlated as far as the 'eye' can see; peculiar objects such as pulsars, quasars, black holes and cosmic strings abound. Even the familiar Sun, looked at closely, has many truly unusual features. Coming to grips with these realities, and others emerging, is a great challenge. How does all this structure arise from perfect symmetry?

The complex (condensed matter, complex systems,...)

The above two frontiers are easy to spot; indeed traditionally the omnipresent is described succinctly as अणोरणीयान्, महतो महीयान् (smaller than the smallest, larger than the largest). The third, at an intermediate level of scale but often a higher level of complexity, is beginning to reveal its scientific richness. When things are put together, often new properties emerge that do not even make sense for the constituents! Yttrium, barium, copper and oxygen in the right proportion ($YBa_2Cu_3O_7$) and proximity make an unusual metal that loses all electrical resistance when cooled to liquid nitrogen temperatures. Since the variety of systems naturally existing, man made, and to be made is infinite, this is a subject without end. Further, emergent behaviour implies that qualitatively new organizing principles are needed at different levels of complexity; the basic principles are not of much help. The last twenty years or so have seen a remarkable outpouring of new phenomena, systems and ideas in this area. As a very small sample I mention new quantum states of matter such as fractionally quantized Hall effect

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systems, and the cuprate metal; novel assemblies such as neural networks, spongy membranes, sandpiles or fullerene solids; new ideas such as reptation, fractals or self-organized criticality. Building on this growth, a movement has started up the hierarchy of complexity, towards sciences such as developmental biology, computer science, or even economics. Finally, this is the physics base of semiconductor electronics, optoelectronics, superconductor applications, materials technology, etc. Partly because of these three reasons, namely deep variety, upward range, and technological applicability, world-wide activity in condensed matter physics is greater than that in all other parts of physics put together. This is at present the major enterprise of physics and its major growth area as well.

Other areas

Optical physics. The unique ability to control light that the laser has given us, is being used in a number of novel and beautiful ways. New quantum states such as 'squeezed' light have been produced and explored. Many new directions owe to analogies with complex systems, e.g. chaos, photon bandgap and light localization, diffusing wave spectroscopy, optical matter. As photonics, this field is a large part of future information technology.

Plasma physics. The ionized state (with its magnetic field effects, collective excitations, instabilities, etc.) is rich in phenomena and is also the route for controlled thermonuclear fusion (tantalizingly close).

Nuclear physics. Recent research in this field has concentrated on unusual bits of nuclear matter, found in energetic heavy ion collisions.

The Indian scene

Within the broad outlines of the growth of physics described above, where are we? In this section, I attempt to answer this question, and also briefly indicate the investments recently made or being made in various areas. We shall compare the two patterns in the next section, and will find that in several areas strengths and investments need to be greatly increased for the health of our science.

High energy and particle physics

In the area of the small, a number of Indian groups (in TIFR and some universities) have participated in major accelerator experiments abroad, a recent example being that on the Z^0 meson decay width. The most recent major commitment here is to the SSC project in the USA, in terms of detection equipment, magnets, etc., to be made by the participating groups. The projected cost is about Rs 50 crores, while the dollar value (as indicated by the SSC coordinators) is 50 million. This will enable Indian groups to be a part of the SSC programme.

India has a long and distinguished tradition of nonaccelerator particle and radiation physics, starting with the pioneering work on cosmic rays in the early fifties. One well known recent example of this activity is the deep underground Kolar Gold Field experiment searching for proton decay, which after nearly fifteen eventful years is being discontinued for nonscientific reasons. Another is the search for possible, hitherto undetected, basic forces using an extremely sensitive torsion balance at Gauribidanur in Karnataka. Many different activities in this field which straddles high energy physics and astrophysics are being pursued, for example high energy hadron production in extensive air showers, and gamma ray astronomy using a specially designed setup (Ooty).

The theoretical study of elementary particles/fields has been the largest activity in theoretical physics in India, with large to sizeable groups in about half a dozen research institutes and a smaller number of universities/IITs. There has been a significant activity in phenomena-related theory, e.g. the quark gluon plasma, and top quark search. There has also been wide ranging and internationally recognized work on model field theories, such as string field theory and topological field theories.

Astronomy and astrophysics

Dedicated efforts over the last three decades have led to the establishment of major facilities in virtually every area of observational astronomy, with significant results in several fields. For example, the radio telescope at Ooty has been scientifically very productive, a well-known result being the relation established between angular size and energy flux density of distant galaxies; this argues in favour of an evolutionary cosmology. Other radioastronomy facilities include the Gauribidanur radio observatory and the 10-m radiotelescope for mm wave astronomy at the Raman Research Institute. Infra-red astronomy has been pursued by balloon-borne instruments, a thirty-year-old tradition. A 1.2-m infra-red telescope at Mount Abu (Gurusikhar) operated by PRL Ahmedabad is expected to be in use soon. The 2.4-m Vainu Bappu Optical Telescope (VBT) at Kavalur has been functioning since 1985; recent investigations include surface photometry of galaxies and active galactic nuclei. Solar astronomy is nearly a century old in Kodaikanal. X-ray astronomy has been pursued by balloon and satellite-borne instruments. In gamma-ray astronomy, rare ultra high energy events from identified sources have been detected at KGF and Ooty extensive air shower detector arrays, and there are similar radiation detector facilities at Pachmarhi and Gulmarg.

Theoretical work in astronomy and astrophysics has a distinguished history, examples being the work of M. N. Saha on thermal ionization and stellar spectra, and that of P. C. Vaidya and A. K. Raychaudhuri on general relativity/cosmology. This tradition of broad interest continues at several centres and designated institutions, such as TIFR, IIA, IUCAA, RRI, PRL, IISc and a small number of universities including Osmania and Delhi.

Building on the breadth and depth of the expertise in this field briefly indicated above, a comprehensive growth path has been charted by the astronomy astrophysics community for the immediate five-year period. The most spectacular single facility envisaged is the giant metre wave radio telescope, whose prime mover is G. Swarup. This will be an instrument unique in its size (30 fully steerable parabolic dishes, each with a diameter of 50 m, spread over about 25 km) and frequency range (40–1500 MHz). The instrument will take advantage of the low man made noise in India in this frequency region. It will search for strongly redshifted 21 cm lines, thus directly reaching into the early epoch of galaxy formation, search for extra terrestrial intelligence, and will also function as a general world class telescope. Other facilities proposed are augmentation of the VBT, new solar telescopes, and preliminary work on a large (4 m) optical telescope. The total equipment investment, including institutional allocation for this purpose (to TIFR, IIA, RRI, PRL Ahmedabad, UP State Observatory), is projected to be about Rs 150 crores or so over the period 1992–97.

The UGC has set up a new centre, the Interuniversity Centre for Astronomy and Astrophysics (IUCAA) at Pune. Its mandate is to take up challenging research problems in the field, with essential participation of the university community. The capital investment in this institution is in the range of Rs 30 crores.

Condensed matter physics

Modern condensed matter physics in India can perhaps be traced back to the pioneering work by Raman and his school on light scattering from solids and liquids. In the last twenty years or so, the field has flourished in a number of directions. For example, the sustained exploration of the many phases of liquid crystals by the RRI group has been marked by the discovery of the discotic liquid crystal, a new mesophase. Significant and in some cases pioneering work has been done on mixed valent and heavy fermion systems, glassy semiconductors, superconductivity, physics of dense colloidal systems, quasicrystals, metal insulator transitions, etc. Several application-oriented developments are also noteworthy, e.g. semiconductor grade silicon, various kinds of thin films, and special alloys. In some areas of materials science/technology related to defence or atomic energy where self-sufficiency is essential, major facilities have been set-up. Examples are SSPL New Delhi, BARC Bombay, IGCAR Kalpakkam and DMRL Hyderabad.

The activity in condensed matter physics is spread over a number of institutions centered around individuals or small groups. The support in most cases is in the project mode, with funding from agencies such as the DST, UGC, DNES and CSIR, and with no long term goal or commitment. There are no institutions or major centres exclusively devoted to condensed matter physics research or to any of its subfields. The total support to condensed matter research (except high-temperature superconductivity or HTSC) is in the range of about Rs 5 crores per year, more than half (~ Rs 2.7 crores) being from the DST.

An area in which national coordination was promoted (prior to HTSC) is metallic glasses. One unwitting but welcome fallout of this programme was the state of preparedness when quasicrystals were discovered. In consequence, Indian groups made several significant early discoveries in this field.

Soon after HTSC was found in the cuprates, a programme of supporting basic and applied research and equipping laboratories in this area was initiated. A considerable amount of important work has been done in synthesizing new systems, determining their structure, properties, etc. The effect of dopants, anomalous thermopower, tunnelling spectroscopy, and nonresonant microwave absorption are some of the significant experimental contributions. A number of laboratories can now make good thin films; SQUIDs have also been made. Internationally, the activity in physics almost exclusively uses high quality thin films or increasingly larger single crystals. The latter has not happened here on a serious scale. The total investment in this five-year programme, now coming to an end, is about Rs 25 crores.

In condensed matter theory, significant contributions have been made in a wide variety of area, such as exactly soluble quantum and classical statistical models, liquid–solid transition, classical and quantum disordered systems, mesoscopic systems, phase transitions and critical behaviour, spin glasses, self-organized criticality, complex fluids such as microemulsions and colloids, fluctuating membranes, nonequilibrium phenomena, classical and quantum fluids, high T_c superconductivity, etc. The contributions have, in many cases, made a crucial difference to the growth of various subfields. The work is being done in a number of institutions; there are perhaps two groups with six or so physicists, and a few others with a smaller number.

The only major condensed matter-related investment in process is the synchrotron facility under construction at Indore. The 485-MeV source, a competitive machine in its spectral range (far ultraviolet/soft X-ray) will be commissioned in a few years, at a cost of about Rs 7–10 crores. An X-ray source (INDUS-II) is also planned.

Other areas

In optical physics, there has been work in the areas of holography and fibre optics. In theoretical optics, there are a few active and distinguished individuals with major contributions. The investment in this area, aside from that by BARC, is very small, less than Rs 2 crores per year.

In plasma physics, the major development in the last several years has been the DST-funded Institute of Plasma Research at Ahmedabad. A tokamak plasma device (ADITYA) has been operational here since 1989, and plasma breakdown as well as convective loss studies have been made with it. There is also an active theoretical plasma physics group here; there are active individuals at a few other places. Another institution with major experimental plasma physics activity is BARC. The investment in the Institute of Plasma Research is about Rs 30–40 crores.

Starting from the fifties, and partly because of the nuclear energy programme, there has been considerable nuclear physics activity. Several DAE institutions such BARC, VECC (Calcutta) and aided institutions such as TIFR, SINP (Calcutta), IOP (Bhubaneswar) are substantially in this field. The UGC has recently established an Interuniversity Centre for Nuclear Research (IUCNR) located at JNU, New Delhi. Many of these institutions have, or operate, or plan to have heavy ion accelerators for nuclear reaction and solid state implantation studies. There is also a long tradition of work on nuclear fission, mainly at BARC, and theoretical activity in many institutions. The total equipment investment recently made or planned is in the range of Rs 60 crores or more.

Assessment and new initiatives

The above picture of the Indian physics scene invites a few conclusions. I mention some here and suggest on their basis some initiatives that are urgently needed.

Breadth

It is clear that physics research in India is being done over a broad distribution of areas. Some of it is comparable to the best in the world. The breadth and occasional depth are due to the dedication of scientists often working under dispiriting conditions, as also to the steady public support for science. Unfortunately, as is apparent, even basic research is not mostly being done where it is done best, namely in universities.

Human resources

The number of people with the right abilities, motivations and training entering almost every area of physics research in India is becoming a smaller and smaller fraction of our real needs. This is our most serious long term limitation. Solutions have to be sought and found at several levels; provision of undergraduate science education that is attractive and of high quality, integrated PhD programmes for post BSc students to be taken up by many institutions which have the resources, and finally the return of frontline research to universities in the form of appropriately supported small units (individuals, small groups) in a mode that ensures survival as well as organic growth. This serious problem needs much constructive attention.

Pattern of support

Support for some areas in physics is commensurate with scientific promise and/or local strength. Overall, this seems to be the case in astronomy and astrophysics, high energy physics, plasma physics and nuclear physics. The investments are tailored to what is possible. The total support is indeed sizeable on the Indian scale; but this kind of science is expensive. One cannot build a big radio telescope for little.

In condensed matter physics and optical physics, the investment seems to be too low by a factor of five to ten. The scientific depth and breadth, applicability, and availability of Indian talent (local and nonlocal) require, I believe, a qualitative change in the scale of support. The fact of marginal support is obvious in several ways. The equipment funding available in these two areas together is about Rs 6 to 7 crores per year, spread thinly over many groups (e.g. DST supported last year 26 projects at a total of Rs 3.7 crores). There are hardly any identified research institutions or stably supported groups/centres. Several major areas of great promise (a list follows later) are not being pursued, or not at an appropriate level. There are some major facilities such as the neutron spectrometers at BARC and the synchrotron being built at Indore, and there is also a programme in superconductivity. However, the main strength of the 'small science' areas is the variety and depth of experimental activity. This requires many high quality groups active at the frontier, with the infrastructure to make it possible. This has not happened in condensed matter or optical physics except in a very few cases.

Some reasons for serious support to these areas have been mentioned earlier; briefly, they are: scientific depth, variety and applicability. Further, because of the relatively small size and cost of laboratories and the variety of subfields, a very large amount of creative science can be done, many students trained in a number of fields both for science and technology, occasional failures tolerated with the likelihood that at least a few will do very well. Much work can be done in universities provided other conditions are right. Finally, condensed matter is an area where continuous and creative interaction between theory and experiment is possible locally. This is almost more essential for good theoretical physics!

With all these advantages, why isn't everyone beating at the door! One reason is perhaps the lack of effective and sustained advocacy. Another is that paradoxically, very large projects are easier to fund! There is also a mindset (naive 'fundamental'ism, reductionism), dating back to the fifties, which has been manifestly unsustainable for a generation now. There is also often the feeling that while the subject may even be interesting, not much financial support is needed. This is a dangerous myth, since facilites for preparation, characterization, measurement and low temperature work are all needed. A good lab may cost anywhere from Rs 1 to 10 crores to set up, depending on the area and the infrastructure and at least 10% of the cost per year to maintain. Indeed there have been several areas where we had a head start, but could not go beyond a certain point because of limited facilities (in addition to limitations of scientific ability or flair).

Condensed matter materials science initiative

I suggest a condensed matter/materials science initiative, with the goal of world class research (basic/applicable/applied) in several areas of condensed matter and optical physics. DST could be the conduit for such a programme. Because of the many-sided nature of the field, many laboratories, say of the order of fifteen, need to get going. Some of these may simply be in the form of a long-term commitment to existing groups with a record of success. In some other areas, there may be people in the country, who are not being supported at the right level, nor in the areas of special interest to such an initiative. In many other cases, one may have to look for people outside the country. If it is clear that there is a long term, serious commitment on the part of the funding agencies and the Indian scientific community, and we make the effort, I believe we will be able to attract several excellent people specially under the present international conditions.

Areas of growth

What are some of the areas that should be effectively supported? The following is a short, partial list.

Molecular electronics/organic solid state. A whole zoo of new kinds of systems such as conducting and semiconducting polymers; totally organic transistors, magnets, electrooptic materials, superconductors; molecules for energy storage and conversion, as well Langmuir Blodgett films have been made. They involve new chemistry and new solid state physics, are in an early stage of development, and in a sense are a medium tech route to new technology.

Optoelectronics/photonics. This field, making use of modern microfabrication techniques, semiconductors and optical fibres to produce an optimal hybrid technology marrying photonics with microelectronics, is in a state of rapid expansion. In spite of much spadework and lip service, and its 'manifest destiny', there are no international level facilities or groups in this field.

Optical physics. In this land of Raman, there is not much new light! The field itself is in a state of explosive growth, limited only by the physicist's imagination. The last few years have seen lithographed periodic solids with optical band gaps (candidates for novel microlasers and photon localization), optical matter, optical solitons, chaos in nonlinear optical systems, photon squeezing, and various other novelties!

Amorphous silicon. Japan has embarked on a solar energy programme to reduce costs by a factor of ten by the year 2000, and to make a:Si a commercial reality. An enormous amount of sustained basic and applied science is needed in this field.

Soft condensed matter. These systems have unusual properties because major configurational changes cost only thermal energy, or can be easily induced externally, examples being membranes, microemulsions, electrorheological fluids, ferrofluids, polymers and colloids. They are just beginning to be probed and tickled by sophisticated means. Many of them are obviously useful.

Oxides. The work required to unravel the intrinsic physical properties of cuprate superconductors shows that we are just beginning our exploration of this electronically fascinating world of systems.

Condensed matter/complex systems theory. As indicated earlier, there is an expanding effort to make nontrivial physical models for complex systems. The field abounds in unexpected phenomena. There is considerable strength in India in this field, and pioneering science is possible with investment mainly in people and some computing power!

There is no major effort in most of these areas, though in many cases their value is realized. Lack of long-term commitment, lack of faith in ourselves and interagency confusions, are some contributory factors. It is no secret that we are falling behind, or have not started in many of these fields; nor are we running a different race. Unless action is taken early, making full use of the scientific infrastructure that has been built up over the last four decades and augmenting it pragmatically, we will become mere spectators in science and clients in technology.

Conclusion

I believe that there is every kind of interesting physics in our future, because of the continuing strength of the Indian tradition in this field and in spite of our slow responses. Some suggestions on how to make it happen are given above.

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Engineering science in India: Some issues and challenges

R. A. Mashelkar

INDIA is a nation in transition today. The new Industrial Policy announced in July 1991 has opened up the Indian industry to foreign investment and technology collaboration. With a move towards the market-driven economy and integration with the global economy, it has become imperative that the Indian processes and products become competitive in the international context, both in terms of quality and cost. In product and process development the future emphasis will have to be on competitive export. The path from 'discovery to delivery' or 'concept to commercialization' will, therefore, have to be traversed with a sense of urgency and daring. The innovativeness of our R&D will play a crucial role in India gaining a technological supremacy in at least some select areas. This implies a major responsibility on the engineers of tomorrow. Not only will we need hard core practising engineers but we will also need new generation engineering scientists, who would interface effectively with science on one hand and technology on the other.

What is the status of engineering science in India today? It is sad to see that barring a few isolated islands of excellence, our performance in engineering science has not been up to the mark. What is the reason for this sad state of affairs? Unfortunately, the interface between science and engineering research as well as that between engineering research and engineering industry has been rather poor. Among Indian engineers, there is an erroneous impression that engineering research consists only of design, development and aspects relating to production. The fact that a close symbiotic relationship exists between science and technology and therefore, new concepts and new knowledge make a direct impact on engineering has been, by and large, missed. It is obvious that in order to produce world-class technologies not only do we require high class science, but also the level of originality and innovation in engineering needs to be comparable to that in the frontline scientific research, on which the original inventions are based. Our engineering graduates, by and large, have not been attracted towards engineering science. The reason is that there has been no demand on engineering scientists in Indian industry.

It is well known that the R&D capabilities in the Indian industry generally are poor and manufacturing in Indian industry, based on its own R&D, has been rather limited. The major emphasis so far has been on reverse engineering and import substitution. Therefore, well trained engineering scientists armed with modern tools and analytical skills, who can establish an intelligent relationship between the advanced level of research on one hand and the traditional industry on the other, have not been in demand. This state of affairs cannot simply continue any more. The new context of international competitiveness itself will put serious demands on everyone. One therefore hopes that engineering science will flourish in years to come.

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