this argument, the slow-folding type is likely to require the assistance of chaperonin proteins for their proper folding. The trapping method developed by Horwich's group will be invaluable in classifying proteins into these two groups. This can be achieved by determining the relative amount of time a protein spends on a chaperonin molecule before completion of chaperonin-mediated folding. For this, different proteins can be tested for their ability to fold *in vitro* in the presence of groEL. After the folding reaction is initiated with wild-type groEL, groES and Mg-ATP, the mutant groEL can be added to the reaction mixture after different periods of time and the relative amount of substrate protein that is trapped by the mutant groEL determined. A protein which goes through less number of iterative cycles of binding and release before reaching its native structure will be inefficiently trapped by the mutant groEL in contrast to proteins which complete fold through many such iterative cycles. The former can be classified as fast-folding and the latter as slow-folding types. A comparison of the sequences of these two classes of proteins is likely to reveal sequence motifs that are important in limiting the interaction of any protein with the chaperonin.

In conclusion, the detailed working of a chaperonin machine is depicted in Figure 2 with the help of a cartoon diagram.

1. Hemmingsen, S. M. *et al.*, *Nature*, 1988, **333**, 330–334
2. Hemmingsen, S M. *et al.*, *Nature*, 1992, **357**, 650.
3. Ellis, R. J., *Phil Trans. R. Soc. Lond. B*, 1993, **339**, 257–261.
4. Gergopolous, C. P. *et al.*, *J. Mol. Biol*, 1973, **76**, 45–60.
5. Sternberg, N, *J Mol. Biol*, 1973, **76**, 29–43.
6. Fayet, O. *et al.*, *J. Bacteriol.*, 1989, **171**, 1379–1385.
7. Neidhardt, F. C. *et al.*, *Annu. Rev. Genet*, 1984, **18**, 295–329.
8. Horwich, A L. *et al.*, *Cell*, 1993, **74**, 907–917.
9. Goloubinoff, P. *et al*, *Nature*, 1989, **342**, 884–889.
10. Vittanen, P. V. *et al*, *Protein Sci.*, 1992, **1**, 363–369.
11. Hendrix, R. W., *J. Mol. Biol.*, 1979, **129**, 375–392.
12. Carazo, J. M. *et al.*, *J. Struc. Biol.*, 1991, **106**, 211–220.
13. Saibil, H. R. *et al*, *Curr. Biol*, 1993, **3**, 265–273.
14. Braig, K. *et al*, *Proc. Natl. Acad. Sci. USA*, 1993, **90**, 3978–3983.
15. Chen, S. *et al*, *Nature*, 1994, **371**, 261–264.
16. Martin, J. *et al.*, 1991, *Nature*, 1991, **352**, 36–42.
17. Hendrick, J. P. and Hartl, F. U, *Annu. Rev. Biochem.*, 1993, **62**, 349–384.
18. Braig, K. *et al.*, *Nature*, 1994, **371**, 578–586.
19. Hartl, F. U., *Nature*, 1994, **371**, 557–559.
20. Fenton, W. A. *et al.*, *Nature*, 1994, **371**, 614–619.
21. Anfinsen, C. B, *Science*, 1973, **181**, 223–230.
22. Zahn, R. *et al.*, *Nature*, 1994, **368**, 40–45
23. Bochkareva, E S *et al*, *Nature*, 1988, **336**, 254–257.
24. Horwich, A. L. and Willson, K R., *Phil. Trans. R. Soc. Lond B*, 1993, **339**, 313–326
25. Mendoza, J. A, *J. Biol Chem*, 1991, **266**, 13044–13049.
26. Vittanen, P. V. *et al*, *Biochemistry*, 1991, **30**, 9716–9723.
27. Zahn, R. and Plukthun, A, *Biochemistry*, 1992, **31**, 3249–3255.
28. Weissman, J. S. *et al.*, *Cell*, 1994, **78**, 693–702.
29. Freedman, R. B., *Cell*, 1989, **57**, 1069–1072.
30. Fischer, G and Schimd, F. X., *Biochemistry*, 1990, **29**, 2205–2212.
31. Kandror, O. *et al.*, *J. Biol. Chem.*, 1994, **269**, 23575–23852.

ACKNOWLEDGEMENT. I thank Drs Kakoli Mukherjee and Anindya Sinha for sharing their views on the manuscript and helping me in drawing the cartoon diagram.

Amitabha Chaudhuri is in the Institute of Microbial Technology, P.B. No. 1304, Sector 39-A, Chandigarh 160 014, India.

COMMENTARY

Importance of basic research in the context of global change*

R. Chidambaram

This is a time of transition for Indian science. There is economic liberalization at home and there is the end of the cold war – at least in its earlier avatar – abroad. And there is a demand for environmentally benign and eco-friendly sustainable development. How should the Indian science and technology system react to these changes?

Any activity – political, military, economic, scientific or cultural – must have only one objective in view, namely, how to improve the quality of life of our citizens while ensuring the security of the country. We should quickly put India on to the fast track of national development and keep it there, without sacrificing the values for which the country has always stood for. We have the unfortunate tendency, as Indians, to denigrate ourselves too much. I do not think we have done too badly in any sphere since independence, though our talents and our resources could have made higher levels of achievements possible.

The attack on the Indian university system explicit in the proposal for the National Science University – discussed so well in recent issues of *Current Science* – is a case in point. The arrogance of that proposal is matched only by its absurdity. How can one ignore the excellent work done by a very large number of Indian scientists who have spent all the time of their professional careers in this country and imagine that a group of NRI scientists, working part-time and starting from scratch, will transform the scientific education scenario in the country? Have these people heard of

---

*Based on the lecture given at the Symposium on S & T Policy and Economic Reforms, organized by Dr P. S. Lokanathan Memorial Society, Bangalore, on 15 March 1995.

the green revolution and the oil exploration effort which led to the discovery and exploitation of Bombay High? Are they aware of the impact that some national laboratories like the NCL and some university departments like the UDCT of Bombay University have had on the Indian chemical industry? How have Indian scientists and technologists been able to build nuclear reactors, launch satellites or build sophisticated missile systems, using young men trained indigenously?

And these achievements have been possible in spite of technology control regimes that are operating now in strategic areas of high technology, which deny India some kinds of equipment and technologies in the name of non-proliferation and missile technology control. They also serve the interests of rich and developed countries by preventing diffusion of technologies needed for development by other countries. As long as Indian industry in non-strategic areas tends to generally use yesterday's technology, it will not be affected much by these technology control regimes. But as India becomes globally more competitive, Indian industry will find such regimes becoming operational for commercial reasons also and outside sources of technology will dry up. That is when the Indian industry will begin to feel more and more the need for indigenous R & D support.

What we are talking about above is applied research (where the motivation is to gather new knowledge with utilitarian objectives) and technology development (where the motivation is to create a product or a process). The reasons to support basic research (where the motivation is to gather new knowledge to satisfy curiosity) have to be sought elsewhere.

Support to science

The spurt in support to science, both basic and applied, in USA and in erstwhile USSR, was driven by the exigencies of the Second World War and then by the Cold War. There is perceptible change now in their approach to science – perhaps temporary – which seems to be caused by systemic boredom, accompanied by personal disinterest, with only a few young native Americans and Russians opting for a career in scientific research. In USA there seems to be a feeling 'What more can Science deliver?'. In Russia, whose economy has collapsed for the present in spite of their outstanding achievements in science and technology, the tendency could be to blame the latter for their present difficulties. The situation in India is very different.

We should not lose sight of our long-term perspective while pursuing short-term goals. In pursuing short-term and essential objectives, we should also not forget that India is *not* a small country. I am convinced that there is no frontier area of science and no area related to any high technology to which India should not commit itself – the extent of the commitment should depend on how far in the future such areas are likely to have an impact on India. To take a few examples, we should take measures to eliminate vitamin A deficiency in children and pursue other aspects of preventive health care but also participate in the global search for cures for AIDS and cancer. There is also no conflict between delivering economical non-conventional energy systems to rural areas and doing research on fast breeder reactors. India's relatively higher thrust must, of course, be in areas related to critical and strategic technologies and to agriculture, biotechnology, information technology and materials technology. But other areas must not be neglected.

Basic and applied research

The distinction between basic research and applied research is often blurred. The study of the origin of life or of the origin of the universe are fascinating fields but are clearly examples of basic research. But there are many situations where motivations for both kinds of research coexist. One of my colleagues is studying the structure of the HIV protease enzyme using the X-ray crystallography technique, which is an interesting basic research problem in itself. But his other purpose is to design an inhibitor for this enzyme which is the one which opens the protein coat of the AIDS virus and makes it infectious. My own studies on the equation of state and phase transformations at high pressures have had both a basic research motivation and an earlier applied research one related to peaceful nuclear explosion phenomenology. Similarly other studies in BARC on fission phenomena have had both basic research interest and an applied one related to the design of better and safer nuclear reactors.

Why support basic research?

The primary motivation for government or industry support to research is to help technology development for peaceful or defence purposes. But government support to basic research should have other motivations, which should be analysed in a national perspective. There is, of course, the duty of the state in any civilized country to allow intellectuals the opportunity to let their curiosity wander in trying to understand natural phenomena or ask and to answer questions of all kinds. Imagine the possible achievements of Srinivasa Ramanujan – 'the magical genius' as Kak once called him – if he had been supported by the government.

After a lecture by Michael Faraday (1791–1867) in the Royal Society, on the newly discovered phenomenon of electricity, a politician asked him: 'That was very interesting, but will it ever be used for anything?'. Faraday replied: 'Sir, one day you will tax it'. Some results of basic research do get converted into products and processes producing a great deal of wealth. But the support to basic research in India cannot be based on such possibilities.

Basic research is needed in Indian Universities to improve the quality of teaching. A teacher who is also doing research is much more in touch with the latest developments in his subject. Basic research is needed in national laboratories to support applied research and technology development and to attract the best intellects. In both the Manhattan Project and the Pokharan PNE Experiment Project, there was need for basic research scientists. The gaps in advanced applied research and technology development efforts can often be filled only by the expertise and knowledge available with basic research scientists.

International interactions and flow of information

Success in basic research at the international level is a matter of national pride. Applied research scientists and technology developers, though they create national wealth, are unfortunately less visible.

The national psyche needs eminent scientists like C. V. Raman, Srinivasa Ramanujan, M. N. Saha, S. N. Bose, Hargobind Khorana and S. Chandrasekhar to make us feel proud. But these are basic research scientists So was H. J. Bhabha, who transformed himself from a basic research scientist to a science manager.

There is another important aspect of basic research which is very relevant to Indian interests. The flow of information is free in the international basic research community and this is the knowledge that could form the basis for future technology development. Information flow gets restricted when you come to applied research and is totally blocked, unless you pay for intellectual property rights, once technology development is complete. In the field of crystallography, for example, with which I am familiar, a great deal of information on drug design is freely available in the basic research community and could be profitably used by the Indian pharmaceutical industry for its own technology development.

It may appear a contradiction of sorts but it is a fact that the latest technologies are needed for basic research and are, therefore, often first developed in large basic research laboratories. It is in India's interest to participate in international mega-projects in science.

Conclusion

Basic research is, of course, the fountainhead of ideas for technology development. The applied research edifice in India today is weak, except in mission-oriented agencies. Its growth in the future will be sustained by building a strong basic research foundation *now*. Otherwise, we run the risk of stifling our future S & T agenda. Of course, the S & T community must have a commitment to indigenous technology development. And the nation and its political system must have faith in the scientists. As Frederick Seitz once said: 'The advance of science requires money given with appreciation and wisdom.'

R. Chidambaram is in Anushakti Bhavan, Chhatrapati Shivaji Marg, Bombay 400 039, India.

Census of India's biodiversity: Tasks ahead

T. N. Khoshoo

There are varying and often conflicting estimates floating around nationally and internationally regarding India's biodiversity, particularly the number of animal species. Thanks to A. K. Ghosh (Director, ZSI), reliable information has been collated on animal species. Based on the current knowledge as summarized by Ghosh[1], Khoshoo[2] and Singh[3], the total number of living species identified in India so far is 126,188 (Table 1). With the publication of this table, speculations about the extent and nature of species richness in India should be set to rest till such time a formal census is undertaken.

According to the World Conservation Monitoring Centre (WCMC)[4], the total number of species described at the global level so far is 1,604,000. However, this Centre estimates that at the global level there are likely to be 17,980,000 species. i.e. about 11 times more than the presently known species. The increase is likely to be primarily from the tropics and subtropics. However, a more realistic and a working figure for species[4] at the global level is around 12,250,000.

Out of the 126,188 species described from India (Table 1), Monera (bacteria) are 850 species (0.67%), Protista (Protozoa only: minus their multicellular descendants) 2577 species (2.04%), Fungi 23,000 species (18.23%), Animalia 74,875 species (59.27%) and Plantae 24,886 species (19.79%). Nearly 72% of India's biowealth is constituted by fungi (18.23%), insects (40%) and angiosperms (13.50%). This tallies generally with the overall trend seen in tropics and subtropics. Although India has only 2.4% of the land area of the world as a whole, according to the present estimates, India's contribution to the global biodiversity is around 8% species. While India stands seventh as far as the number of species contributed to agriculture (including animal husbandry) is concerned, qualita-

Table 1. Number of biota in India[1–3]

Taxon	Number of species	Percentage
Bacteria	850	0.67
Algae	2500	2.00
Fungi	23,000	18.23
Lichens	1600	1.30
Bryophyta	2700	2.14
Pteridophyta	1022	0.80
Gymnosperms	64	0.05
Angiosperms	17,000	13.50
Protozoa	2577	2.04
Mollusca	5042	4.00
Crustacea	2970	2.35
Insecta	50,717	40.00
Other invertebrates including hemichordata	11,252	9.00
Protochordata	116	0.10
Pisces	2546	2.02
Amphibia	204	0.16
Reptilia	428	0.34
Aves	1228	1.00
Mammalia	372	0.30
Total	126,188	100.00