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Status of physics research in India: An analysis of research output during 1993–2001

B. M. GUPTA,[a] S. M. DHAWAN[b]

[a] *National Institute of Science, Technology & Development Studies,*
Dr K. S. Krishnan Marg, New Delhi – 11012, India
[b] *National Physical Laboratory, New Delhi – 110012, India*

The paper reviews the present status of Indian physics research, in particular its nature of research system, nature of institutions involved, type of education offered and outturn at postgraduate and Ph.D level, the extent to which extra-mural funding support is available from various governmental R&D agencies, and the nature of professional organizations involved. The study is based on analysis of Indian physics output, as indexed in Expanded Science Citation Index (Web of Science) during 1993–2001. The study also discusses various features of Indian physics research such as its growth in terms of research papers, institutional publication productivity, nature of collaboration, and the quality and impact of its research output.

Introduction

The physics research in India is largely a state sponsored activity, organized at institutional level with funding coming mainly from the state. The framework for physics research is a part of the general framework for science and technology research in the country, well structured and organized by sectors, such as Mission oriented R&D sector, Universities & Colleges sector, Institutes of National Importance, Industry sector and others.

Over the last several decades, the country had witnessed growth and development of scientific enterprise, comprising various types of institutions involved in scientific research, at three levels. Firstly, a number of research laboratories were established

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Address for correspondence:
B. M. GUPTA
E-mail: bmgupta1@yahoo.com, bmgupta@nistads.res.in

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under the newly established scientific departments/agencies like the Department of Atomic Energy (1954), Defense Research & Development Organization (1958), Department of Electronics (1970), Department of Science & Technology (1970), Department of Space (1972), Council of Scientific & Industrial Research (1942), Indian Council of Medical Research, Indian Council of Agricultural Research, etc. Their primary aim was to carry out basic and applied research, besides making direct contributions to the technological needs of the country in the chosen areas, such as atomic energy, space, engineering, agriculture, medicine, etc. The R&D agencies/departments provide funds to research institutes under their jurisdiction. Besides, they provide funding to other research institutes as well through their extramural funding schemes (Table 1).

Table 1. Extra-mural funding support from R&D agencies/departments in physical sciences

R&D Agency	1991–1992		1997–1998		2002–2003	
	Allocations (Rs in million)	No of projects	Allocations (Rs in million)	No of projects	Allocations (Rs in million)	No of projects
Council of Scientific Industrial Research (CSIR)	6.038	17	21.068	36	39.75	52
Department of Atomic Energy (DAE)	3.003	6	4.584	9	35.906	24
Department of Ocean Development (DOD)	2.593	2	0		14.904	1
Defense R & Development Organization (DRDO)	0.671	1	18.862	18	59.775	32
Department of Science & Technology (DST)	88.559	87	84.35	67	113.842	89
Department of Space (DOS)	1.182	2	3.74	7	12.519	12
University Grant Commission (UGC)			16.67	40	15.094	37

Source: Directory of extra-mural research and development projects approved for funding by selected central government agencies/departments. DST: New Delhi

Governmental R&D agencies/departments in India offer financial support to such other research institutions that are not under their administrative jurisdiction. Such extra-mural funding to physical sciences by R&D agencies/departments had remained stagnant during the period from 1993–1994 to 2002–2003. Though their extra-mural budget for all sciences had shown consistent rise, their share for extra-mural support to physical sciences has not shown any corresponding increase (Table 2, Figure 1). Such a trend indicates that the physical sciences have been losing its importance as a priority area in S&T research.

Table 2.Extra-mural research & development projects approved by major government R&D funding agencies/departments, 1993–1994 to 2002–2003

Year	Physical sciences projects		All sciences projects	
	No	Total approved costs (Rs. in million)	No	Total approved costs (Rs. In million)
1993–1994	129	211.90 (8.95%)	1440	1271.60
1994–1995	143	118.80 (9.10%)	1557	1313.30
1995–1996	136	143.30 (7.92%)	1716	1619.80
1996–1997	152	308.20 (8.46%)	1795	1864.80
1997–1998	179	312.20 (10.05%)	1780	2185.60
1998–1999	199	660.10 (9.70%)	2050	3498.40
1999–2000	128	663.90 (7.13%)	1793	4249.20
2000–2001	219	29.25 (10.90%)	2009	286.71
2001–2002	216	44.32 (9.37%)	2304	444.95
2002–2003	250	29.77 (9.19%)	2718	448.69

Source: Directory of Extra-mural Research and Development Projects Approved for Funding by Selected Central Government Agencies/Departments. DST: New Delhi

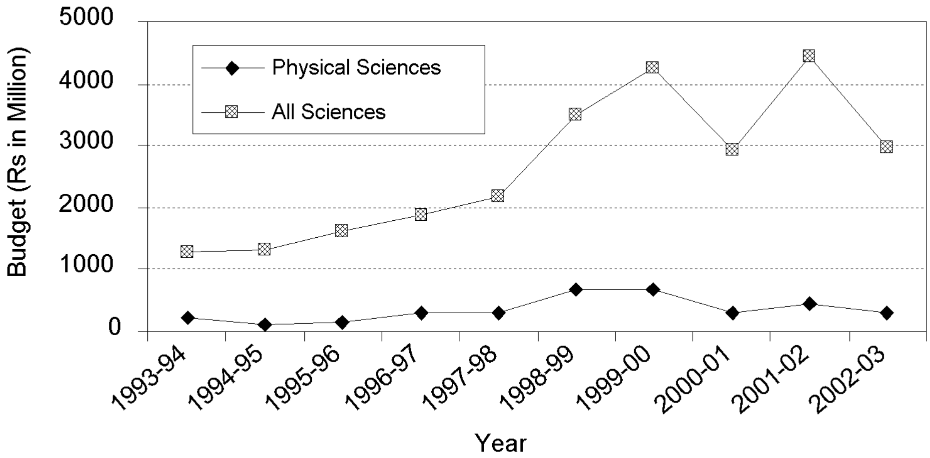

Figure 1. Shift in R&D budget allocation in India: Physical sc vs all sciences: 1993–1994 to 2002–2003

Secondly, India has established a few institutes of national importance while some others were given the similar status. These included institutions such as Indian Institute of Technology at Delhi, Mumbai, Kanpur, Chennai, Kharagpur and Guwahati; Indian Institute of Science, Bangalore; and Indian Statistical Institute, Calcutta. They are the leading centers of postgraduate education and research in engineering and technology, chemistry, physics, and in other disciplines. Many of these institutes offer graduate &

postgraduate degrees programs. Some of these institutes have also established advanced centers of research in nuclear physics, laser technology, display technologies, electronics systems, and materials science.

Thirdly, India has more than 250 universities, deemed universities and inter-university centers, funded by central and state governments, have been established in the country till today and they have been offering graduate & postgraduate courses in physics, besides offering facilities for doctoral research. Under various research programs of UGC and DST, the universities have developed expertise, laboratory and infrastructural facilities in different fields of physics. Some of them have been identified for advanced centers of research in high priority national identified research areas. In addition, they have also been conducting research with the extra-mural funding support of the major government R&D agencies/departments of the Government of India.

Most of the universities offer two-year master's degree in physics and also in related areas, such as applied physics (Guru Nanak Dev Univ), astronomy & astrophysics (Osmania & Punjabi), applied geophysics (Guru Nanak Dev), electronics (Jadavpur, Andhra, Gorakhpur, Delhi, etc), and radiation physics (Calicut Univ). In addition, few universities also offer M.Sc (Applied Science) or MSc Tech degrees of two to three years duration in various sub-fields of physics, such as geophysics (Banaras), lasers science (Devi Ahila, and Anna Univ), atmospheric sciences (Cochin), electronics (Delhi), materials sciences, biophysics, and medical physics (Anna Univ). The universities also offer postgraduate diplomas of one-year duration in radio electronics (Calcutta), space sciences (Andhra and Gujarat), and spectroscopy (Annamalai). Doctoral courses are offered by most of the universities.

The UGC has set up autonomous inter-university centers within the university system to create world-class research facilities in subjects not adequately covered in the university departments & colleges and to facilitate the formulation of common research programs of research & development in collaboration with universities, Indian Institutes of Technology (IITs) and other research institutions. The first in the series was the Nuclear Science Centre in New Delhi at the Campus of Jawaharlal Nehru University. This center has established a pellet Ron for aceltron-based research as a common facility for the entire universities & colleges system. The next in line was the setting up of an Inter-University Centre for Astronomy & Astrophysics in Pune. It has established an internationally competitive environment by making use of the Giant Meter Wavelength Radio Telescope Facility set up at Tata Institute of Fundamental Research in Pune. Next in line was the establishment of Inter-University Consortium by UGC through a Memorandum of understanding with the Department of Atomic Energy in 1989. The main objectives of the consortium were to provide an institutional framework to enable the maximum utilization of research facilities of the Department of Atomic Energy by the universities. The consortium has three centers, one at Indore for Synchrotron Radiation Source, the second at Bombay for Dhruva and the third at

Calcutta for Variable Energy Cyclotron. In addition the UGC had also established the following three national facilities for the wider use of the academic research community: (i) Western Regional Instrumentation Centre, Mumbai; M.S.T.Radar Facilities at Sri Venkateswar University, Tirupati and Crystal Growth Centre at Anna University, Chennai.

The annual outturn of the postgraduate students in physics from educational institutions in the country had shown consistent rise over the years in contrast to the Ph.D. degrees awarded during 1966 to 1989 (Table 2). The Ph.D. outturn has shown sharp rise from 127 in 1966 to 389 in 1984. However, in the subsequent period from 1985 to 1997, PhDs outturn started fluctuating between 342 and 455.

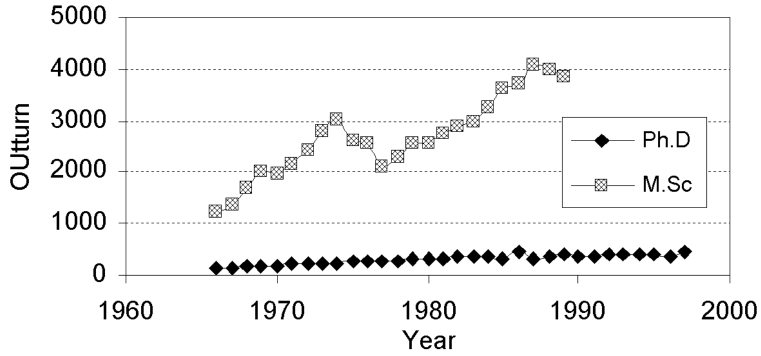

Figure 2. Annual outturn at masters and doctoral level in physics: 1966–1896

Table 3. Masters degree outturn in physics from Indian universities: 1996–1989

Year	Outturn	Year	Outturn	Year	Outturn
1966	1254	1974	3005	1982	2883
1967	1364	1975	2594	1983	2963
1968	1706	1976	2579	1984	3279
1969	2026	1977	2091	1985	3605
1970	1993	1978	2302	1986	3730
1971	2156	1979	2582	1987	4077
1972	2411	1980	2558	1988	4004
1973	2784	1981	2768	1989	3862

Source: RAJAGOPAL, N. R, SEHGAL, Y. P., AHUJA, I. M. L.: *Journal of Scientific & Industrial Research*, February 56, 1997, pp. 73–85.

Table 4. Annual output of Ph.Ds in physical sciences

Year	Total	Year	Total
1966	127	1982	369
1967	155	1983	382
1968	174	1984	389
1969	202	1985	342
1970	199	1986	440
1971	215	1987	341
1972	223	1988	389
1973	242	1989	420
1974	214	1990	363
1975	275	1991	386
1976	279	1992	390
1977	287	1993	399
1978	289	1994	423
1979	320	1995	430
1980	342	1996	388
1981	328	1997	455

Source: RAJAGOPAL, N. R, SEHGAL, Y. P., AHUJA, I. M. L.: *Journal of Scientific & Industrial Research*, February 56, 1997, pp. 73–85.

India has established national academies in S&T such as Indian Academy of the Sciences (Bangalore), Indian National Science Academy (Delhi), and National Academy of Sciences (Allahabad). Besides, India witnessed the emergence of several professional associations and societies. These include Indian Physics Association, Indian Physical Society, Indian Association of Physics Teachers, Optical Society of India, Indian Laser Association, Plasma Science Society of India, Indian Nuclear Society, Particle Accelerator Society of India, Indian Society for Atomic & Molecular Physics, Indian Society of Surface Science & Technology, Astronomical Society of India, Indian Vacuum Society, Ultrasonic Society of India, Acoustical Society of India, Meteorology Society of India, Photonics Society of India, Solar Energy Society of India, Association of Medical Physicists of India, Semiconductor Society of India, Indian Society for Radiation Physics, Indian, Nuclear Society, Indian Carbon Society, and Materials Research Society of India. Their role in catalyzing and promoting physics research in the country has been significant. They organize seminars & conferences, discussions and disseminate information through newsletters & research journals. At present India publishes nearly 50 national journals in physics & related areas, most of which are published by professional, research institutions and private publishers in the country.

It must be recognized that physics research base in India has since expanded significantly and diversified across various fields and sectors, and a strong professional community of workers has been slowly built. India at present has more than 450 research institutions having strong infrastructure in physics research. These institutions, mainly belonging to both Universities & Colleges sector and Mission oriented R&D

sector, have been undertaking research in basic and applied areas of physics and also for developing physics-based technologies. However, after independence, the focus of research in physics shifted from universities to national research institutes and institutes of national importance. Over the years, the country has been able to establish and enrich its research institutions, supporting them with larger funding, latest infrastructure & research facilities, and improved computing & network facilities. The country has evolved a strong teaching and research community, and built strong network linkages at national & international levels. A few scholars have also reviewed the state of research in physics in India [11–14].

The Department of Science & Technology has been actively promoting research in frontier and emerging areas of physics through its Science & Engineering Research Council (SERC), which is guided by a Program Advisory Committee (PAC) consisting of eminent scientists. The SERC with the help of PAC had also prepared a document *Vision for R&D in Physical Sciences*, which identified thrust and challenging areas to be pursued in the country and given priority under funding by central government R&D agencies/departments.

Objectives

The main objective of this study is to examine the current status of Indian physics, as reflected in the country research output during 1993–2001, its growth, its strong and weak subject areas of research, its collaborative profile, quality of S&T output, and institutional productivity and quality.

Methodology, data source and literature review

The basic publication data used in this paper is derived from the Expanded Version of Science Citation Index (SCIE) database, available in Web of Science. The raw publications data along with their citations has been downloaded from the Web of Science in February 2004. For determining metrics on publications data on India we searched all records having 'India' in the author affiliation field and pertaining to a select publication 'year'. The data so retrieved were downloaded and later imported into a database management system for data cleaning and coding. In data cleaning, all duplicate records as well records pertaining to publication years not under the purview of our study, were eliminated. In addition, a lot of value addition to this database was carried out in terms of coding of institutional, city and state names, nature of research organization and its affiliation to parent funding bodies and to broad sector, nature & type of collaboration involved, and affiliation of participating countries to their sub-region and continent, impact factor of the journal, classification of each record in terms of ISI journal classification, etc. The entire database was finally customized for carrying out large-scale computation of publication and citations data for comparative analysis of research performance by sectors, regions, and institutions across various subject fields of Indian S&T output.

For defining research output by subject, publications were classified by subject content of the journal publishing such articles. For this purpose, we made use of the classification scheme in use by the Thomson-ISI for defining the main subject fields and sub-fields in the Web of Science database. This hierarchical classification system of Thompson-ISI uses two layers: 12 broad scientific fields, and 178 sub-fields

The study used absolute bibliometric indicators such as journal-based publication and citation counts for data analysis. The count of scientific papers published in peer-reviewed international journals provides an estimate of the volume of research activity and related knowledge production. The citations to these papers provide an idea about the transfer and utilization of this knowledge. In citations analysis, the basic assumption is that a frequently cited paper has greater probability to influence subsequent research activities than a paper with no citations or few citations. Thus, a set of papers with different citations can be compared in terms of visibility and impact on the scientific community.

A few important studies have been carried out in the country based on the physics and related publications output. Raina and Gupta [1, 2] undertook a study on institutionalization of physics research in India (1990–1950), using publications output as a base. They identified major fields of research in pre-independence period and contribution of important scientists. Modeling the growth of world and Indian publications data using INSPEC database from 1907 to 1994 has been carried out by Gupta & al. [3–5]. A few studies have been undertaken by scholars focusing on analysis of cross country output, research priorities and nature of collaboration in various sub-fields of physics. [6–8] Gupta and Dhawan [9] also undertook a study on the analysis of collaborative research between India and Russia and reported that 70% of the total collaborative publications were in physics field alone. Broad characteristics of physics research and publications output in different period blocks have been carried out by Dhawan and Gupta, etc. [10–15] from time to time. Comparative studies on publications output by India and China have been carried out by Dhawan and Garg, etc. [16, 17]. Publications output by India and from other countries in various sub-fields of physics such as high energy physics, lasers, liquid crystals, superconductivity, and holography have also been studied from various angles by various scholars. [18–25]. Quality of Indian physics research has been studied by Dhawan and Gupta [26] using journal impact factor and citations received per paper data in the Indian context.

Analysis and results

Publication size

India is one of the top ten countries in the world well known for its leadership and rich contributions to physics research. It has been publishing its research output in mainstream journals published world over. Publications data from the *Web of Science* database reveal that India had published a total of 27018 research papers in national and international mainstream journals in physics during 1993–2001. Its annual publications output rose from 2768 papers in 1993 to 3336 papers in 2001, showing an annual average publications growth rate of 2.5% for these 9 years (Figure 3, Table 5). The growth trend in the publications output as shown by India was linear in character, and typical of any well-stabilized and well-established subject field.

Table 5. Annual publications output in physics: 1993–2001

Year	Papers
1993	2768
1994	2760
1995	2744
1996	2972
1997	2993
1998	3065
1999	3223
2000	3157
2001	3336
Total	27018

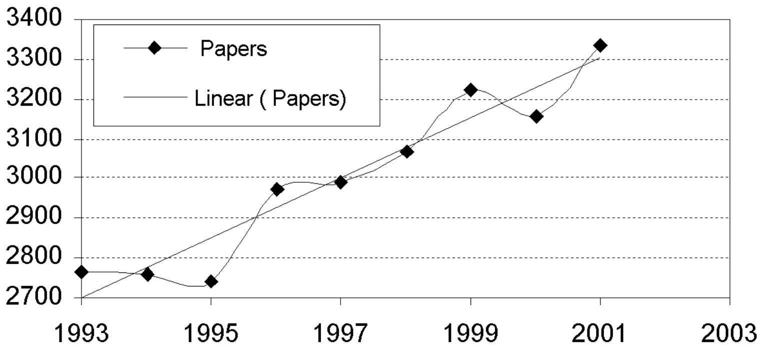

Figure 3. Annual growth in physics research: 1993–2001

The triennial publications output in physics showed that India published 8272 papers in 1993–1995, 9030 in 1996–1998, and 9716 in 1999–2001. Its publications growth was 9.1% for the triennial period, 1993–1995 to 1996–1998, which declined to 7.6% during 1996–1998 to 1999–2001 (Figure 4, Table 6). Evidently, India been contributing to physics output at a much higher rate in the early nineties than in the late nineties.

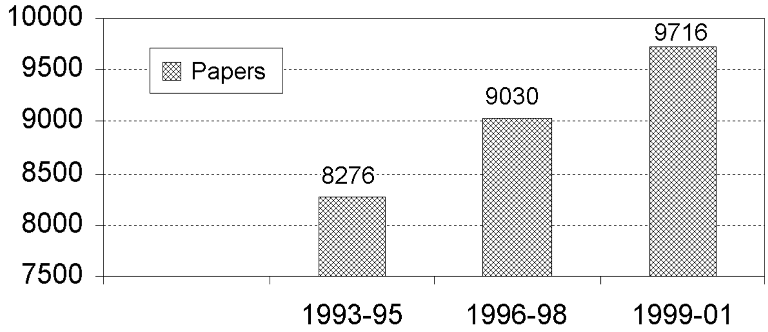

Figure 4. Triennial growth in physics research output

Table 6. Triennial publications output in physics 1993–2001

Year	Papers	Triennial growth rate, %
1993–1995	8276	
1996–1998	9030	9.11
1999–2001	9716	7.60
Total	27018	

Institutional publications productivity pattern

In all, 1307 research institutions across the country participated in physics research during 1993–2001. The institutional participation showed a rising trend from 604 institutions in 1993–1995 to 707 in 1996–1998 and to 843 in 1999–2001. The institutional participation was the highest from the Universities & Colleges sector (71.92%), followed by Mission oriented R&D sector (15.84%), industry sector (5.20%) and Institutes of National Importance (0.77%) (Table 7).

Table 7. Institutional participation in physics research by sector: 1993–2001

Sector	Number of institutions				Share of institutions, %			
	93–95	96–98	99–01	93–01	93–95	96–98	99–01	93–01
Univ. & Coll.	425	595	622	940	70.36	84.16	73.78	71.92
Mission oriented R&D	120	132	141	207	19.87	18.67	16.73	15.84
Institutes of national importance	10	10	10	10	1.66	1.41	1.19	0.77
Industry	23	34	32	68	3.81	4.81	3.80	5.20
Others	26	36	38	82	4.30	5.09	4.51	6.27
Total	604	707	843	1307	100	100	100	100

Physics research activity was confined mainly to select few institutions in the country despite wider institutional participation during 1993–2001. Bulk of the contributions (97.5%) came from few select institutions (i.e. 197 institutions) and the remaining 2.5% share from 1110 institutions. The publications productivity pattern in physics did not change significantly during the 9 long years as seen from institutional productivity curves drawn for the three triennial publications periods 1993–1995, 1996–1998, and 1999–2001. These three curves overlap with the institutional productivity curve for the period 1993–2001 (Figure 3). In other words, the institutions that had been leading the country in physics research during 1993–1995 continued to lead it till 1999–2001.

The top 25 institutions account for 60% share to the country output in physics. Of these, 12 institutions are from the Mission oriented R&D sector, 6 from Institutes of National Importance, and 7 from Universities & Colleges sector (Table 7A)

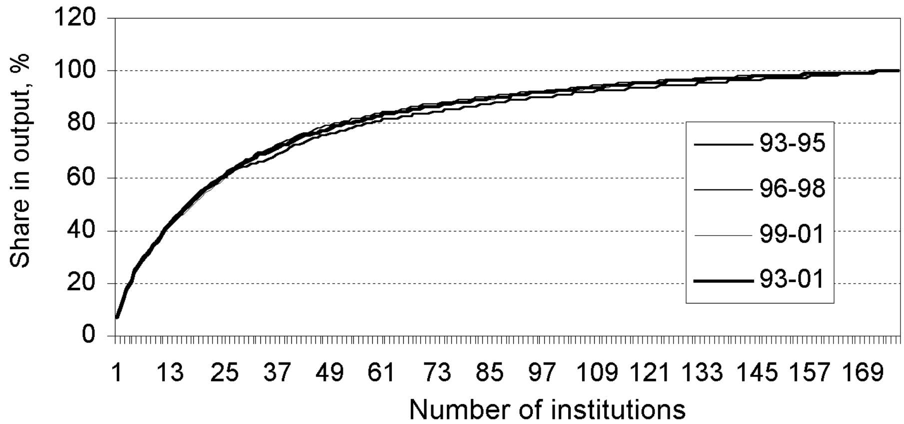

Figure 5. Productivity curve of research institutions in physics

Table 7A. Top 25 institutions in physics ranked by productivity

Rank	Name of the institution	Inst. code	Number of papers			
			1993–1995	1996–1998	1999–2001	1993–2001
1	Tata Institute of Fundamental Research, Mumbai	TIFR	597	638	773	2008
2	Indian Institute of Science, Bangalore	IIS-BANG	472	564	685	1721
3	Bhabha Atomic Research Centre, Mumbai	BARC	432	443	562	1437
4	Indian Association for Cultivation of Science, Kolkata	IACS	273	354	369	997
5	Indian Institute of Technology, Chennai	IIT-MADR	281	307	264	852
6	Saha Institute of Nuclear Physics, Kolkata	SINP	154	323	351	828
7	Indian Institute of Technology, Kanpur	IIT-KANP	198	259	276	733
8	Jadavpur University, Kolkata	JADAUC	211	221	262	694
9	Indian Institute of Technology, Delhi	IIT-DELH	232	253	205	690
10	Indian Institute of Technology, Kharagpur	IIT-KHAR	182	201	262	645
11	Indian Institute of Technology, Mumbai	IIT-BOMB	181	195	222	598
12	University of Delhi, Delhi	DELHUD	165	194	237	596
13	Institute of Physics, Bhubaneshwar	IOP	178	217	172	567
14	Physical Research Laboratory, Ahmedabad	PRL	124	197	239	560
15	Hyderabad University, Hyderabad	HYDEUH	191	183	164	538
16	National Physical Laboratory, Delhi	NPL	184	166	166	516
17	Indian Institute of Astronomy, Bangalore	IIA	130	138	201	469
18	Banaras Hindu University, Varanasi	BANAUV	142	158	143	443
19	Inter University Centre for Astronomy & Astrophysics, Pune	IUCAA	76	155	190	421
20	Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore	JNSCASR	95	146	178	419
21	Panjab University, Chandigarh	PANJUC	112	121	172	405
22	Calcutta University, Kolkata	CALCUC	121	124	133	378
23	Centre for Advanced Technology, Indore	CAT	94	124	144	362
24	Institute of Mathematical Sciences, Chennai	IMS	88	102	166	356
25	Indira Gandhi Centre for Atomic Research, Kalpakkam	IGCAR	77	126	150	353

Collaboration in physics research

Co-authorship in research papers has been interpreted as an index of collaboration in research. Publications data for 1993–2001 reveal that India had collaboration in physics research with as many as 60 countries in the world, from almost all regions including North America, South America, East Asia, South East Asia, Middle East, Africa, and

Europe. However, its publications output from such collaborative efforts differed from region to region and country to country. The collaborative research activities were pursued both at bilateral level and multilateral level. At national level, India had collaboration at intra-state level and inter-state level.

Table 8. Distribution of collaborative research papers in physics by nature of collaboration

Year	TP	TCP	TNCP			TICP		
			Total	INTRS	INTS	Total	BILAT	MULTI
93–95	8272	1730 (20.91)	642 (37.1)	409	272	1174 (67.86)	932	242
96–98	9030	3028 (33.53)	1550 (51.2	1056	645	1747 (57.69)	1356	391
99–01	9716	4929 (50.73)	2797 (56.7)	1841	1229	2704 (54.86)	2015	689
Total	27018	9687 (35.85)	4989 (51.5)	3306	2146	5625 (58.07)	4303	1322

TP = Total Papers; TCP = Total Collaborative Papers; TNCP = Total National Collaborative Papers; TICP = Total International Collaborative Papers; INTRS = Intra-State Collaborative Papers; INTS = Inter-State Collaborative Papers

The collaborative share of the country output in physics showed substantial rise from 20.9% to 50.7% during 1993–1995 to 1999–2001. At national level, it rose from 37% to 56.7% share. In contrast, its collaborative share international level declined from 67.9% to 54.9% during the corresponding period (Table 8).

The collaborative research by India was bilateral as well as multilateral in nature, but the country emphasis was more on bilateral research. The bilateral share of papers in the collaborative output by the country at international level was 76.5% and its multilateral share of papers was 23.5% (Table 9).

Table 9. International collaboration in physics research

Year	TP	TCP	Total international collaborative papers		
			Total	Bilateral	Multilateral
1993–1995	8272	1730	1174(67.86)	932(79.39)	242(20.61)
1996–1998	9030	3028	1747(57.69)	1356(77.62)	391(22.38)
1999–2001	9716	4929	2704(54.86)	2015(74.52)	689(25.48)
Total	27018	9687	5625(58.07)	4303(76.50)	1322(23.50)

TP = Total Papers and TCP = Total Collaborative Papers

Table 10. National collaboration in physics research

Year	TP	TCP	Total national collaborative papers		
			Total	Intra-State	Inter-State
1993–1995	8272	1730	642(37.11)	409(63.71)	272(42.37)
1996–1998	9030	3028	1550(51.19	1056(68.13)	645(41.61)
1999–2001	9716	4929	2797(56.75)	1841(65.82)	1229(43.94)
Total	27018	9687	4989(51.50)	3306(66.27)	2146(43.01

TP = Total Papers and TCP = Total Collaborative Papers

The collaborative research at national level in physics was greater at intra-state level than at the inter-state level. The intra-state share in the collaboration at national level was 66.2% and for at intra-state level it was 43% (Table 10).

India had collaborative partnership with 60 countries for physics research during 1993–2001. Of these, the USA, Germany, France, England, and Japan were its major collaborative partners, as they account for 80% of internationally collaborated papers. India had partnership with other countries as well, but the publication share from such collaborations had been small.

Impact of physics research output

The impact of the publications output by India in physics research has been studied on two indicators: (i) average impact factor per paper, which is based on the impact factor of journals publishing research output, and (ii) average citations per paper, which is computed on cumulative citations received by research papers upon publication in journals till Feb 2004.

It is generally believed that research papers from developed countries reach their citations peak in 3 to 4 years of their publication in journals. However, in the case of India, research papers were found to reach their citations peak in 9 to 10 years of their publication in journals. For example, the papers published in 1993, 1994 or 1995 accumulated nearly 6 citations per paper, the highest in 9 to 11 years of their publication (Table 11).

The average IF per paper for the overall publications output by the country was 1.34. Comparing the IF per paper on annual basis, it varied between 1.25 and 1.36 during the eight years period from 1993 to 2000, but it suddenly jumped to 1.5 in 2001. It implies that of recent, India has started publishing its research output in physics in relatively higher impact factor journals (Table 11).

Table 11. Impact of India's physics research output: 1993–2001

Year	Total papers	Average IF per paper	Av. citations per paper	Citations window in years
1993	2768	1.35	6.86	11
1994	2760	1.36	6.30	10
1995	2744	1.32	6.23	9
1996	2972	1.31	5.60	8
1997	2993	1.25	5.05	7
1998	3065	1.31	5.04	6
1999	3223	1.32	4.42	5
2000	3157	1.36	4.26	4
2001	3336	1.50	2.92	3
Total	27018	1.34	5.11	–

Citations window is the time period during which citations received by a paper upon its publication are measured.

Bulk of the country output (63%) was published in low impact journals (IF between 0.001 and 1.999), 21% in medium impact journals (IF between 2.0–3.999), and 3% in high impact journals (IF 4.0 and above). Besides, 13% output was published in zero impact journals.[1]

The country share in low impact journals declined from 66% to 59% during 1993–1995 to 1999–2001. It also declined in medium impact journals from 24% to 20% during the same period. In contrast, its share in high impact journals showed rise from 1% to 6% during the same period. It shows an upward trend in the quality of research in physics during 1993–2001 (Table 12).

Table 12. India's physics research output by journal impact factor

	Publications count				Share of output in journals, %			
JL. IF range	93–95	96–98	99–01	93–01	93–95	96–98	99–01	93–01
0.00–0.00	755	1177	1466	3398	9	13	15	13
0.01–1.99	5429	5812	5752	16993	66	64	59	63
2.00–3.99	1968	1880	1924	5772	24	21	20	21
4 & More	120	161	574	855	1	2	6	3

Table 13. India's physics research output by citations per paper

	Publications count				Share of papers in the citation range, %			
Citat. per paper	93–95	96–98	99–01	93–01	93–95	96–98	99–01	93–01
Zero	1729	2250	2940	6919	21	25	30	26
Between 1 & 4	3384	3850	4349	11583	41	43	45	43
Between 5 & 19	2592	2505	2145	7242	31	28	22	27
More and 20	567	425	282	1274	7	5	3	5
Total	8272	9030	9716	27018	100	101	100	101

The citations window for papers published during 1999–2001 varies from 3 to 5 years and is still enough for citations to reach their peak. Hence this data were not considered for comparative analysis but listed in the table merely for description purposes only.

Nearly 5% papers received high citations (20 or more citations per paper). Nearly 27% papers received medium rate citations (5 to 19 citations per paper), and 43% received low citations (1 to 4 citations per paper). Besides, 26% papers received no citations since their publication during 1993–2001. This citations data for the country output published during 1993–2001 was taken from the *Web of Science* on Feb 2004 (Table 13).

[1] Zero impact journals are, though, JCR indexed journals but whenever they fail to get citation in a particular year their impact factor is rated as zero. These journals should not be construed even by mistake as non-JCR indexed journals.

Table 14. Journal impact factor vs. output by range of citations range (1993–1995)

IF range	Citations range: 0 citations per paper	1–4 citations per paper	5–19 citations per paper	20 and more citations per paper	Total papers (TP)	TP in %
0.000–0.0000	167	344	204	40	755	0.09
0.001–1.999	1396	2433	1441	159	5429	0.66
2.000–3.999	162	590	900	316	1968	0.24
4 and more	4	17	47	52	120	0.01
Total papers	1729	3384	2592	567	8272	1.00
TP in %	0.21	0.41	0.31	0.07	1.00	0.00

Table 15. Journal impact factor vs. output by range of citations range (1996–1998)

IF range	Citations range: 0 citations per paper	1–4 citations per paper	5–19 citations per paper	20 and more citations per paper	Total papers (TP)	TP in %
0.000–0.0000	337	535	258	47	1177	0.13
0.001–1.999	1711	2626	1369	106	5812	0.64
2.000–3.999	196	665	803	216	1880	0.21
4 and more	6	24	75	56	161	0.02
Total papers	2250	3850	2505	425	9030	1.00
TP in %	0.25	0.43	0.28	0.05	1.00	0.00

Table 16. Journal impact factor vs. output by range of citations range (1999–2001)

IF range	Citations range: 0 citations per paper	1–4 citations per paper	5–19 citations per paper	20 and more citations per paper	Total papers (TP)	TP in %
0.000–0.0000	508	654	267	37	1466	0.15
0.001–1.999	2114	2689	905	44	5752	0.59
2.000–3.999	261	825	718	120	1924	0.20
4 and more	57	181	255	81	574	0.06
Total papers	2940	4349	2145	282	9716	1.00
TP in %	0.30	0.45	0.22	0.03	1.00	0.00

Furthermore, it was seen that the country share of highly-cited papers declined from 7% in 1993–1995 to 3% in 1999–2001. Secondly, 21% to 25% of the country output published during three different periods of study failed to win even a single citation since their publication (Table 14). A more detailed picture about distribution of papers by citations won per paper and by journal impact factor per paper is shown in Tables 14, 15, and 16.

The Mission oriented R&D sector received the highest citations (8.54 citations per paper in 1993–1995 and 6.62 citations per paper in 1996–1998). The decline in the citations won per paper may be attributed to differences in the citations windows of the two data sets being compared. For papers published during 1993–1995 the total citations window was between 9 to 11 years, and for papers published in 1996–1998 it was between 6 to 8 years.

Publications productivity by subject

Publications output by India during 1993–2001 was the highest in condensed matter physics (20.3%), followed by atomic, molecular & chemical physics (9.87%), applied physics (8.63%), crystallography (7.43%), astronomy & astrophysics (6.88%), nuclear physics (6.69%), optics (4.88%), fluids & plasmas physics (4.43%), particles & fields physics (3.49%), spectroscopy (2.57%), thermodynamics (2.48%) and acoustics (2.10%) (Table 17).

Table 17. Research output by physics sub-fields

Physics sub-fields	Publications output				% Share to the national output in physics				% Growth 1993–1995 1999–2001
	93–95	96–98	99–01	93–01	93–95	96–98	99–01	93–01	
Acoustics	209	203	156	568	2.53	2.25	1.61	2.10	–25.36
Applied Physics	1122	1282	1328	2331	13.56	14.20	13.67	8.63	18.36
Astron.& Astr	563	593	704	1860	6.81	6.57	7.25	6.88	25.04
Crystallography	621	659	728	2008	7.51	7.30	7.49	7.43	17.23
Nuclear Physics	644	705	789	1808	7.79	7.81	8.12	6.69	22.52
Optics	605	641	732	1318	7.31	7.10	7.53	4.88	20.99
Phys – At., Mol. & Ch.	780	848	1040	2668	9.43	9.39	10.70	9.87	33.33
Phys – Fluids & Plasma	307	414	476	1197	3.71	4.58	4.90	4.43	55.05
Phys – Part. & Fields	524	603	765	943	6.33	6.68	7.87	3.49	45.99
Phys Cond. Matter	1834	1947	1818	5492	22.17	21.56	18.71	20.33	–0.87
Spectroscopy	255	269	335	695	3.08	2.98	3.45	2.57	31.37
Thermodynamics	264	328	318	669	3.19	3.63	3.27	2.48	20.45
Physics – Misc	1677	1836	1659	5461	20.27	20.33	17.07	20.21	–1.07
Total	8272	9030	9716	27018	100.00	100.00	100.00	100.00	17.46

Condensed matter physics, atomic, molecular and chemical physics and applied physics are considered high productivity sub-fields as their output has been very above the country average in physics (7.7%). Astronomy & astrophysics, nuclear physics, optics, fluids & plasmas physics, particles & fields physics, spectroscopy, thermodynamics and acoustics have shown productivity below the country average in physics. Crystallography showed productivity at country average (Table 17).

Fluids & plasmas physics had been the fastest growing area during 1993–1995 to 1996–2001 (55%). This is followed by particles & fields physics (45.9%), atomic, molecular & chemical physics (33.3), spectroscopy (31.3%), astronomy & astrophysics (25%), nuclear physics (22.5%), optics (20.9%), thermodynamics (20.4%), applied physics (18.3%), and crystallography (17.2%). Condensed matter physics and acoustics had shown negative growth rate (Table 17).

Table 18. Distribution of publications output & participating institutions by physics sub-fields

Subject	1993–1995		1996–1998		1999–2001		1993–2001	
	Papers	Inst.	Papers	Ins.	Papers	Inst.	Papers	Inst.
Acoustics	209	64	203	73	156	63	568	130
Astron.& Astr	563	98	593	102	704	111	1860	190
Crystallography	621	134	659	127	728	150	2008	237
Optics	361	82	452	104	505	135	1318	203
Appl Physics	771	143	742	146	818	180	2331	289
Atomic, Mol. & Chem Phys.	780	104	848	158	1040	203	2668	208
Cond. Matter Physics	1795	228	1919	271	1778	281	5492	449
Fluids % Plasmas Physics	307	80	414	91	476	106	1197	158
Nucl Physics	567	115	612	126	629	136	1808	214
Particles & Fields Phys	259	71	288	66	396	74	943	115
Spectroscopy	203	89	221	92	271	134	695	200
Thermodyn.	162	64	246	73	261	104	669	152
Physics – Misc	1674	281	1833	298	1954	366	5461	562
Average	636.31		694.62		747.38		2078.31	
Physics total	8272	604	9030	707	9716	843	27018	1307

During 1993–2001, the institutional participation was the highest in condensed matter physics (449 institutions), followed by applied physics (289), crystallography (237), nuclear physics (214), atomic, molecular & chemical physics (208), optics (203), spectroscopy (200), astronomy & astrophysics (190), fluids & plasmas physics (158), thermodynamics (152), acoustics (130), and particles & fields physics (115) (Table 18).

Findings and suggestions

Findings

If extra mural funding is any indicator for judging country's priorities in science and technology, then certainly physics has been losing its importance in the country over time.

Ph.D. outturn in physics has slowed down during 1985 to 1997, compared to its past performance during 1966 to 1984.

India's annualized growth in physics research, measured in terms of publications output, has been very small, 2.5% for the last 9 years. Universities & Colleges sector has shown the largest institutional participation in physics research (72.6% of total institutions in physics), followed by Mission-oriented R&D sector (11.1%), and the Industry sector (5.20%)

Excellence in physics is still confined to select few institutions in the country despite wider institutional participation in research. Hardly 15% of the institutions (197 out of 1307) account for as much as 97.5% of the country output in physics. This trend had been persisting for the last 9 years.

India's publications share through collaborative research has been rising, e.g. it rose from 20.9% to 50.7% during in 1993–1995 to 1999–2001. India's partnership with countries such as USA, Germany, France, England, and Japan accounts for 80% of collaborative research at international level.

The quality of physics research output by India has been still low as is evident from its low average impact factor, 1.34. Mission-oriented R&D sector has shown average IF (1.68) above the country average (1.34), followed by Universities & Colleges sector (1.16), Industry sector (0.90), and others sector (0.68).

The quality of physics research output by India has been low as is also evident from low share of highly-cited papers in the country output. Hardly 4.8% received high citations (20 or more citations per paper). Nearly 27% received medium rate citations (5 to 19 citations per paper), and 43% received low citations (1 to 4 citations per paper). Besides, 26% received no citations.

Of the 4.8% highly-cited papers**,** 9.7% (124 papers) were published in zero impact journals,[2] 24.2% (261 papers) in low impact journals (IF between 0.001 and 1.999), 51.3% (652 papers) in medium impact journals (IF between 2.0 and 3.999), and 14.8% (189 papers) in high impact journals (IF 4.0 and above). This finding is significant since it reveals that even the papers published in low impact journals do have the potential to win high citations provided the quality of research reported in such papers is of merit and significance.

Publishing in high impact journals is not always to be assumed as an index of quality since not all such papers eventually receive high citations. For example, only 1% of highly-cited papers (1274) account for 90% of the total citations received by such papers, and the remaining 99% papers for 10% citations only.

International collaboration contributes to the quality of research more than collaboration at national level. Of the highly-cited papers (53.8%), international collaboration accounted for the larger share.

Condensed matter physics is the most preferred area of research accounting for 20.7% of the country output in physics during 1993–2001. Applied physics ranks second with 13.8% share, followed by atomic, molecular & chemical physics (9.8%), nuclear physics (7.9%), crystallography (7.4%), optics (7.3%), particles & fields physics (7%), astronomy & astrophysics (6.8%), fluids & plasmas physics (4.4%), thermodynamics (3.3%), spectroscopy (3.1%), and acoustics (2.1%).

There is disparity in quantity and quality of publications output by leading institutions. Indian Institute of Technology, Madras ranked at the top on the basis of its publications productivity but ranked 6th in terms of quality of its output measured on composite quality index. The same observation applies to top institutions such as Indian

[2] Zero impact journals are JCR indexed journals failing to get citation in a particular year; thereby their impact factor is rated as zero. These journals should not be construed even by mistake as non-JCR indexed journals.

Institute of Technology, Kanpur, Indian Institute of Science, Bangalore, University of Poona, Pune, Tata Institute of Fundamental Research, Mumbai, Raman Research Institute, Bangalore, etc.

Suggestions

The centers of excellence in physics are very few, particularly in the Universities & Colleges sector. There is a strong need to come up with a national plan, wherein low publication productivity institutions could integrate with bigger institutions within their own geographical regions, and thereby get the opportunities to learn from the expertise in bigger institutions, besides using their experiences, equipment and facilities available with them in specific fields.

For enhancing quantity and quality of research output, there is a need to develop goal-oriented and need-based programs at the national and institutional level. There is also need to change the methods of deciding priorities for allocation of funds, particularly in the extra-mural funding given by research agencies, and also change the system of awarding research contracts.

There is a need to draw out plans for encouraging collaboration in physics especially international collaboration. At the national level, inter-institutional participation for collaboration should be mandatory particularly for larger funded projects under extra-mural programs of research agencies.

Efforts must be made to encourage institutions to publish in relatively higher impact factor journals.

To ensure that India publishes highly-cited papers and in greater number, the following suggestions may be considered for implementation:

- Ensure focused funding in weak areas as well as in high tech areas.
- Make quantum jump in the student's fellowship for doctoral and post doctoral work in areas of national importance.
- Ensure greater accountability & monitoring in funded research projects by insisting on publishing in high quality journals.
- Quality publishing should be mandatory for Ph.D. awards.
- Enhance opportunities for international collaboration in research.
- Encourage younger talent to go for post-doctoral research in advance countries by providing them fellowships abroad.
- Increase accessibility to electronic resources in physics and related sciences institutions.
- Improve research infrastructure through modern equipments.
- Put in place a system for rewarding creative people at younger and early age, such as increasing the number of awards for younger scientists.

- Improve research environment in research institutions by introducing better award system, encouragement of creative work, goal oriented research and flexile organizational system.
- Set up more centres of excellence on the lines of inter-university centres or on the lines of institutes of national importance to attract good talent and ensure quality in research.
- Universities & College sector collaborative linkages with R&D sector should be enhanced in a big way. Senior scientists with good academic credentials from R&D institutions should be allowed to act as PhD guides, and also get an opportunity to teach specialized courses. This will help the PhD students to get better research guidance in new and frontier areas and also modern research infrastructure and facilities.
- Promote formal linkages between universities and national science institutes through joint research projects and projects, as well encouraging collaboration with industries and user organization of technologies.
- Ensure support to select research centers on long terms basis in selected areas to help them become internationally competitive.
- Infuse young blood with good academic track record for teaching in universities.
- Upgrade science laboratories, improve internet connectivity, information access, course contents and quality of teaching with a view to improve the quality and quality of research in universities and colleges.
- Improve linkages with industry to make physics research industry-oriented.

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