Jointly published by Elsevier Science Ltd, Oxford and Akadémiai Kiadó, Budapest

Scientometrics, Vol. 42, No. 1 (1998) 17–40

FOUR ASPECTS OF THE INSTITUTIONALIZATION OF PHYSICS RESEARCH IN INDIA (1900–1950): SUBSTANTIATING THE CLAIMS OF HISTORICAL SOCIOLOGY THROUGH BIBLIOMETRICS

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(Received December 8, 1997)

This paper examines the process of the institutionalization of research in physics in India. In order to do so, it employs bibliometric data such as research publications in physics research journals between 1900 and 1950. This data is then analyzed to obtain certain indicators that are pointers of the aspects of the institutionalization of research in physics in India. The four aspects of institutionalization studied here are important for the researches of those adopting sociological approaches in the study of the history of sciences. Thus the bibliometric techniques employed complements the efforts of historians of science studying the professionalization of physics research in India, and in this case those dealing with disciplines like physics. Further, the bibliometric data helps substantiate the claims of historians of science that the years 1905 to 1935 were particularly important for the history of physics in India. The conclusions of historians are based on success stories of a few leading physicists of the time. Within an institutional framework, this paper argues that there was a larger ground swell indicative of the emergence of a physics research community in India.

Introduction

This paper examines the institutionalization of physics in early twentieth century India through the integration of a sociologically informed historical perspective with bibliometric data. We employ the term *historical bibliometrics* to refer to *approaches that seek to ferret out historical insights into a discipline, that could later enable or confirm problematizations of historians of science, by employing bibliometric data, such as publications in research journals.* In this particular case, we shall obtain some bibliometric indicators in order to explore the aspects of the institutionalization of physics research in India.

0138–9130/98/US $ 15.00

This requires that we specify the aspects of institutionalization we seek to investigate, as well as the bibliometrically obtainable indicators that could be seen as measures of the degree of institutionalization. There are four distinct aspects to the institutionalization of a discipline or sub-discipline. The first has to do with the creation of consensus through the adoption of what *Shapin* and *Schaffer* refer to as 'literary technique' (*Shapin* et al., 1989) which in this case refers to the agreed upon structure of presenting research results and having them wetted by peers associated with research journals. The fact that within the community of physics, researchers increasingly recognize that the principal form of communicating research results is the research paper appearing in a refereed journal, with the results presented in a pre-defined format, is itself an indicator of the acceptance of a routinized practice, that is an element of institutionalization (for convenience let us refer to this as I_1). And one of the measures of the gaining credibility of this practice can be probed through the increased number of publications as well as the growing number of publications per author. In fact, to put it in Joseph Ben David's words, these indicators may be considered measures of the institutionalization of the scientific role, and in this special case that of physics. The second aspect, has to do with the globalization of research traditions. In the emerging global civilization, if we are to accept Ben David's account, even with reservations, the newly acquired knowledge was to be widely disseminated as the 'collective good of humanity' (*Schott*, 1993, p. 198). On this count it would be interesting to explore the time lag between the institutionalization of a discipline at the metropolises of science and the periphery. A decreasing time lag is itself a measure of how rapidly a community of scholars was forming in India, and its stability is indicated by the manner in which researchers at the periphery keep abreast with current research problems at the centre (I_2). The third aspect has to do with the emergence of institutions of research, either situated within university departments or in contemporary parlance at research institutions, whose effect in quantitative terms may be seen in enhanced productivity in sub-disciplines which these research institutes are investigating (I_3). Finally, there is the self-propagating aspect of any institutionalized activity, whose existence can be assessed through the appearance of local publications, and the extent of collaboration between researchers constituting the community. This can be inferred from the collaboration coefficients employed to study disciplines and sub-disciplines (I_4).

As pointed out in *Raina* et al. (1996), *the rate of growth of physics publications in India manifests close to doubling behaviour between 1905 and 1935*, after which one of the saturation plateaus so characteristic of the growth of disciplines begins to appear (see Table 1). Further studies would possibly reveal that there is another explosive growth following the emergence of Big Science in India (*Raina* et al., 1997), a

phenomenon that marks the post 1950s era, falling outside the scope of our study. In any case the ground for this explosive growth was being prepared during the last decade of the period under study.

As the table indicates, the number of papers published almost doubles every five years. However, a plateau appears after 1940. This may be ascribed to the decline in scientific communications with the onset of the war years. But more importantly, *the decades 1910 to 1930 are very crucial for physics in India on more than one count.*

Table 1
Number of papers published from India between 1901 and 1950 in India

Years	Total papers	Single-author	Collab. coeff.
1901–1905	29	29	0.0
1906–1910	59	59	0.0
1911–1915	85	72	0.078
1916–1920	155	120	0.113
1921–1925	356	267	0.128
1926–1930	626	431	0.163
1931–1935	1224	820	0.174
1936–1940	1239	827	0.173
1941–1945	1034	727	0.156
1946–1950	1144	789	0.165

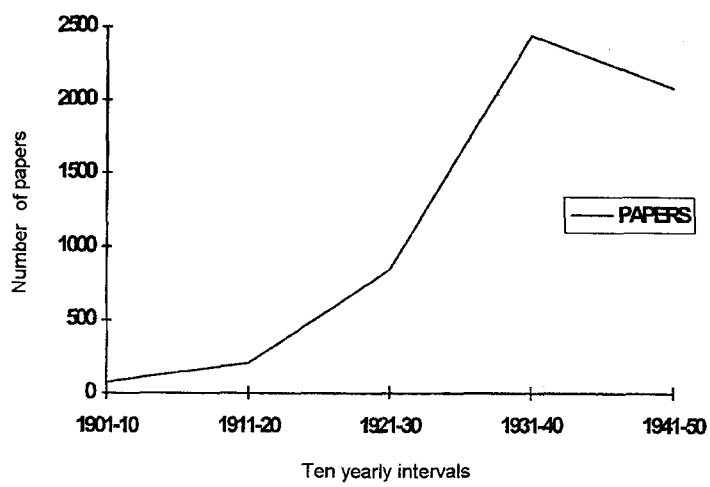

Fig. 1. Ten yearly publications from India in physics in the decades between 1900 and 1950

Figure 1 indicates *a rapid rise in the number of publications during the decade 1910–20*. The sharp rise in gradient is such that it produces a whole order of magnitude increase in publications within the next three decades. There is another change in gradient at the end of the 1930s – a linear extrapolation from this point would result in 3800 papers at the end of 1950. The shortfall is of the order of 1300. *The first steep rise has to do with the acceptance of the University Charter of Research introduced in 1904* (*A Century*, 1976), C. V. Raman's attempts to upgrade the *Proceedings of the Indian Association of the Cultivation of Sciences* into the *Indian Journal of Physics*, the formations of a number of research teams around Indian physicists who had made an impact on the frontiers of the physics in the early decades of this century. We can see this to be a consequence of the interplay between three factors. Though the Indian Association for the Cultivation of Sciences was founded in 1876, the number of research publications coming out of the Association was not significant till thirty years later. This has to do with the Society's focus during these years with science teaching at the collegiate level (*Sen*, 1994, p. 45–46). Once the University Charter of Research was enacted, Asutosh Mukherjee, the Vice Chancellor of Calcutta University insisted that the objective of the University would be satisfied when it offered students facilities to undertake research. This required educational endowments, and establishing and equipping laboratories and libraries (*Sen*, 1992, p. 381). Mukherjee was responsible for revising the courses for the Master's degree, which in turn generated much enthusiasm and raised the aspirations of students pursuing post-graduate education (*Sen*, 1994, p. 46). And finally, it was Raman who realized the importance of scientific publications alongside laboratory research. Further he maintained that results of research carried out in India and considered important should be published in India (*Sen*, 1992, p. 386).

In addition, institutionalization is reflected in the growing collaboration between scientists. In terms of the publication practices of physicists, there is an increase in collaboration coefficient during these decades, that itself is an additional marker of the formation of a community of physicists. We had in an earlier paper (*Raina* et al., 1996) merely parametrized the collaboration practices of four Indian physicists, viz. Raman, Saha, Bhabha and Krishnan. In this paper, we examine author productivity for the community of physicists spread over half a century, 1900–1950, as well as the nature of collaboration in a number of fields that have acquired currency over this century: these being astronomy and astrophysics (AA), acoustics (AC), atomic and molecular structure (AMS), radioactivity, nuclear physics and cosmic ray physics (RNC), X-ray physics (XP) and spectroscopy (SP).

Productivity in physics and its sub-disciplines: 1900–1950

Historical studies recognize the period 1890 to 1935 as crucial for the emergence of Indian physics, for these decades are punctuated by the notable contributions of J. C. Bose, C. V. Raman, M. N. Saha and S. N. Bose. In terms of the number of publications the contributions of five physicists was dominant. The bibliometric data further suggests the emergence of a community of physicists in India as well as the institutionalization of physics research. In particular, *it could be emphasized that the decades 1910 to 1930 constitute the major landmark in the institutionalization of physics research. Thus the eventful researches of these front running physicists is symptomatic of a much broader process of the institutionalization of physics research in the country.* To illustrate the point from a different perspective, let us look at the increase in the number of physicists publishing research papers and the evolution of the author productivity. Table 2 provides ten yearly cumulations of papers and the author productivity. Figure 2 plots the average number of publications per year and the average number of publications per physicist against time.

Table 2
Ten yearly cumulations in author productivity

Years	Number of authors (A)	Number of papers (P)	Mean papers per author (P/A)	Gini coeff.
1901–10	29	86	2.96	0.3641
1911–20	76	276	3.63	0.4955
1921–30	336	1269	3.77	0.4924
1931–40	884	3222	3.64	0.4729
1941–50	913	2919	3.197	0.4091

The figures in the table indicate that *between the end of 1920 and the end of 1930 there is more than a four hundred per cent increase in the number of authors, and almost a two hundred and fifty per cent increase between 1930 and 1940. The period 1910 to 1930 is then the period of most rapid growth of the community. However, the mean number of papers per author begins to stabilize by the end of the 1920s*, as we see the figures for three consecutive decades is 3.63, 3.77 and 3.64. The Gini coefficient in like manner over the same period remains more or less constant. There is a dip in all the numbers for the period 1941–1950 – this could be called the War time dip. It may be conjectured that the figures are likely to grow exponentially after the 1950s when there was a renewal in infrastructure and support for physics.

Fig. 2. Number of physicists from India publishing cumulated over ten years, and the average number of papers published per year

Figure 2 very clearly indicates the period during which the institutionalization of physics research in India commences. *Both the number of physicists publishing and the number of papers published per physicist increase together during the decade 1911–20, and increase till the end of the 1940s. The growth of the two together suggests that (1) publications had become an important form of communication for physicists, and (2) collaboration had become a current practice amongst physics researchers.* The imperatives of the commencement of the Second World War are telling on physics research during the decade 1940–50.

Productivity in six sub-disciplines of physics

Having discussed the overall development of the discipline, we come to the sub-discipline publication profiles and the author productivity of six sub-disciplines: these being acoustics; astronomy and astrophysics; atomic and molecular physics, radioactivity, nuclear physics and cosmic ray physics; spectroscopy; and X-ray physics. The evolution of productivity in these disciplines is determined by their currency within the metropolises of science. In brackets are the dates corresponding to the emergence of these as sub-disciplines in their own right: acoustics (1850); astronomy (?) and astrophysics (>1870); atomic and molecular physics (>1880); radioactivity (>1900), nuclear physics (>1920) and cosmic ray physics (>1930); spectroscopy (>1880);

X-ray physics (>1900). These particular sub-disciplines have been chosen to gain some insight into the institutionalization of more recent sub-disciplines of modern physics in India. Acoustics, an older sub-discipline by far, provides an interesting counterpoint; while astronomy and astrophysics occupies a middle ground between the two. Table 3 gives the total number of papers published in these sub-disciplines and the number of authors who have contributed to these sub-disciplines from India.

Table 3
Number of authors and publications in some core sub-disciplines of modern physics

Sub-disciplines	Number of authors	Number of papers	Papers per author
Acoustics	105	307	2.92
Astron. & Astrop.	172	585	3.4
Rad. Nucl. & Cosm.	189	545	2.88
Spectroscopy	330	1334	4.04
Atomic & Mol. Phys.	93	142	1.53
X-ray	121	338	2.79

Over this fifty year period *the bulk of the publications are in three areas, viz. that of spectroscopy, astronomy and astrophysics and radioactivity, nuclear and cosmic ray physics.* Prior to 1900 there were schools of research, institutes and observatories that were doing research on spectroscopy, astronomy and astrophysics. The contributions of astronomers like Jansen, Lockyer, Naegamvala and Evershed have been well documented by astronomers, and historians of astronomy (*Kochhar* et al., 1993). However, it is also important to recognize the connection between spectroscopy as an independent domain of investigation, and the fact that spectroscopy was employed as a technique for studies on the spectra of sun and the stars. In which case, physicists would have been mobile across a range of sub-disciplines. In like manner, those employing techniques of spectroscopy would simultaneously have been contributing to the study of atomic and molecular physics. Furthermore, Table 3 indicates that the number of papers per author is greater than 2.5 for those disciplines where experimental techniques are preponderantly employed: acoustics, astronomy and astrophysics, spectroscopy and X-ray physics. In addition, it is interesting to observe that *during this period there is a reduction in the time lag between the commencement of research in a sub-discipline in the metropolises of science and their institutionalization in India. During the last few decades of the nineteenth century this lag was of the order of about twenty years: e.g. from the first experiments on radioactivity undertaken by Becquerel and the Curies, to the appearance of the first papers from India. By the 1930s this lag is reduced to less than half a decade, e.g. Bhabha was amongst the initiators of cosmic*

ray physics, albeit as a theoretical physicist. As soon as he comes to India he gets together a team of theoreticians and experimentalists to undertake work on cosmic ray physics. On the other hand, this is not true for theoretical physics. Physicists like Saha and Bose, actively participated, in the constitution of theoretical astrophysics and the finalization of quantum theory. *Hence by the early decades of the present century, the formation of research networks, and the institutionalization of physics research closed the temporal distance separating metropolis from province.*

Concentration within sub-disciplines as an indicator of institutionalization

Figure 3 indicates the ten yearly cumulations of the papers published tend to cluster during the first two decades of the present century. The main area of activity was astronomy and astrophysics, and C. V. Raman had initiated some work on acoustics. *After 1920 research activity begins to pick up very rapidly in terms of the number of areas of research. While astronomy and astrophysics exhibit the most rapid growth, a discipline that already had a history of over a century in the country, spectroscopy, through the efforts of Raman appears to be catching up fairly rapidly. By the 1930s, both the number of publications and researchers are distributed across a range of sub-disciplines. Consequentially, the contributions in other disciplines grows rapidly, while that of astronomy and astrophysics reaches a plateau by 1950. Spectroscopy, radioactivity, nuclear and cosmic ray physics and X-ray physics display remarkable growth rates, while there is a decline in the number of publications in the area of acoustics. A larger number of researchers were moving to newer areas.*

In Table 2, the Gini coefficient for the total publications in physics indicates that *the concentration of publications increases during the early decades of this century, evens out around 1940, and diminishes in the decade commencing 1940.* This could possibly indicate that *the publishing base had begun to widen.* Let us now examine the degree of concentration across the sub-disciplines we have been discussing. Most of the sub-disciplines chosen include contributions from physicists working in India, who had made an international mark in their domains of investigation: e.g. Evershed, Raman, Krishnan, the two Boses', Saha, the senior Narlikar, Raychaudhuri. An important concern for an institutional account is to address the issue *whether the bulk of research in these sub-discipline's was the product of the effort of a few gifted individuals, or were these efforts the most renowned contributions of a broader community coming to grips with the newly emerging front of knowledge.*

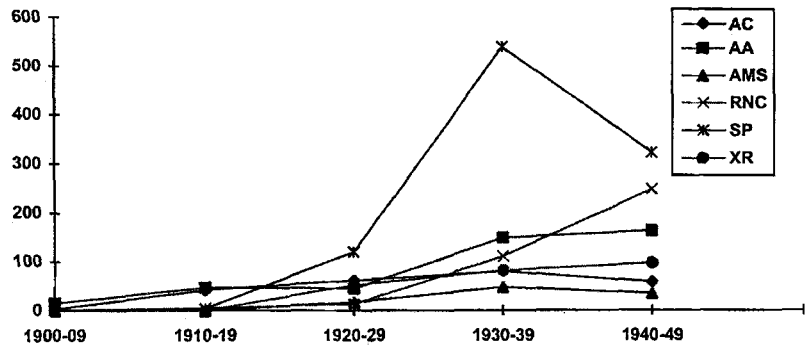

Fig. 3. Ten yearly cumulations of papers published from India in the areas of acoustics (AC), astronomy and astrophysics (AA), atomic and molecular structure (AMS), radioactivity nuclear physics and cosmic rays (RNC), spectroscopy (SP), X-rays (XR)

Table 4
Degree of concentration of physics sub-disciplines

Sub-disciplines	Percentage of physicists contributing 25% of papers	Percentage of physicists contributing 50% of papers	Percentage of physicists contributing 75% of papers
Acoustics	1.90	8.57	33.33
Astron. & Astrop.	1.74	6.97	26.16
Rad. Nucl. & Cosm.	4.23	14.28	37.03
Spectroscopy	3.63	11.51	30.00
Atomic & Mol. Phys.	7.52	25.80	61.29
X-ray	4.95	14.87	42.14

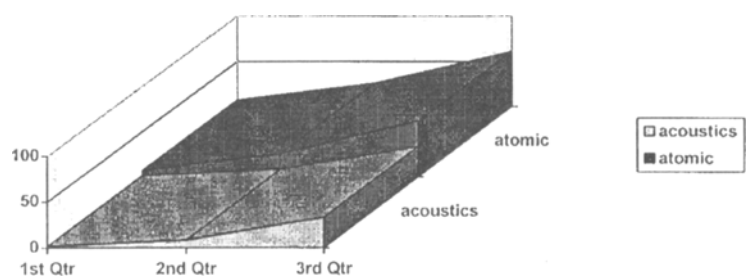

Fig. 4. Publication base in two sub-disciplines, acoustics and atomic and molecular physics

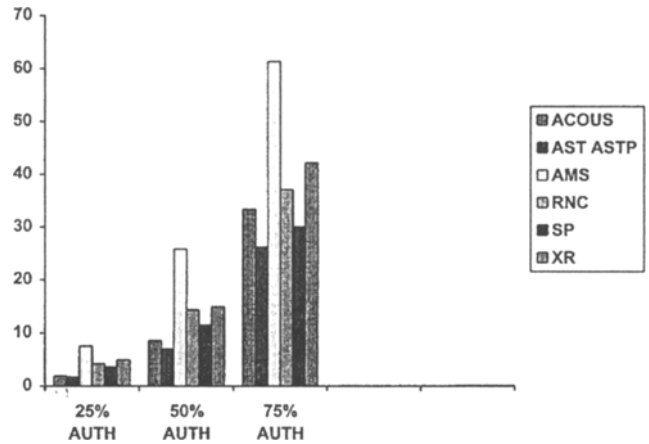

Fig. 5. Percentage contributions of physicists to six sub-disciplines

It is evident from table 4 that *in the newer areas of physics* such as atomic and molecular physics (7.52%), radioactivity, nuclear and cosmic ray physics (4.23%) and X-ray physics (4.95%) *a greater percentage of physicists contribute to the discipline.* In fact the base of the pyramids of these disciplines is broader and the peaks flatter; while in the older disciplines the base – percentage of physicists contributing 75% of the papers – is narrower and the peak – percentage of physicists contributing 25% of the papers – more pointed (see Fig. 4).

The figure illustrates the point made above for six-sub-disciplines: namely that *in the older disciplines the contributions were highly dependent on the researches undertaken by a few individuals and their teams of researchers, or the researches undertaken at a few observatories, such as those established by the British. A larger number of physicists were possibly groomed in the newer disciplines that in turn aided the dispersal of these disciplines through universities and other research institutions.* This reading provides scope for a historiographic comment regarding the *two modalities of the transmission of scientific knowledge in the former colonies. In the older disciplines we observe the slow transmission, almost percolation, of the practices of scientific research systems through imperial institutions of science.* On the other hand, *with the introduction of the University Charter of 1904, Indian researchers adapt their educational system to the globalized community of practices instituted through the*

metropolises of science, and register their contributions through publications, both nationally and internationally.

Furthermore, if we could examine the number of authors in terms of which a lasting community of researchers was constituted, it would be interesting to examine the above table in the light of the next one.

Table 5
Number of authors with more than 25, 50 and 75 papers during the period 1900–1950

Number of papers	Number of authors
>100	4
>75	7
>50	17
>25	32

During this period, the number of authors with more than 100 papers is 4, and the figure doubles subsequently, for 75, 50 and 25 papers. Amongst the first eight, one naturally finds the list being headed by Raman, and at number eight we have Bhabha, whose career extends beyond the period under consideration. However, while the number of publications is no indicator of the impact of the work of physicists, since S. N. Bose does not appear in this table, these *32 physicists may be considered to constitute the core community of physicists during this decade, preparing the ground for the next decade.* Furthermore, closer scrutiny reveals that with the sole exception of Raman, his student K. S. Krishnan, and M. N. Saha, the other *thirty physicists contributed about 50% of their papers in one sub-discipline of physics.* This itself could be *a reflection of the acute professionalization that physics was undergoing during these decades.* However, all these physicists published in more than one sub-discipline of physics. While *those contributing more than fifty papers had papers distributed over more sub-disciplines than those with less than fifty papers.* Thus it may be suggested that physicists contributing more papers tend to research a larger number of sub-disciplines as well.

The globalization of physics research in India

The extent of globalization may be examined by looking into the avenues of publications of research papers appearing from India during the period 1900–1950, and then examine their proportion when compared with the total publications appearing all over the world. We begin by looking at the physics publications in Indian and foreign journals. This will indicate the extent of networking of physicists in India with the cluster of research problems current amongst their colleagues in the metropolises of science, and that of the schools of physics and the community of physicists in India reflected through physics journals and periodicals. Figure 6 gives the number of papers published in Indian and foreign periodicals.

Period	Number of publications in Indian journals		Number of publications in foreign journals	
1901–05	14	(48.2%)	15	(58.7%)
1906–10	33	(55.93%)	26	(44.07%)
1911–15	57	(67.05%)	28	(32.95%)
1916–20	79	(50.96%)	79	(49.04%)
1921–25	134	(37.64%)	226	(62.36%)
1926–30	234	(39.32%)	361	(60.68%)
1931–35	691	(57.43%)	512	(42.57%)
1936–40	815	(65.77%)	424	(34.33%)
1941–45	848	(82.33%)	182	(17.77%)
1946–50	830	(74.5%)	284	(35.50%)

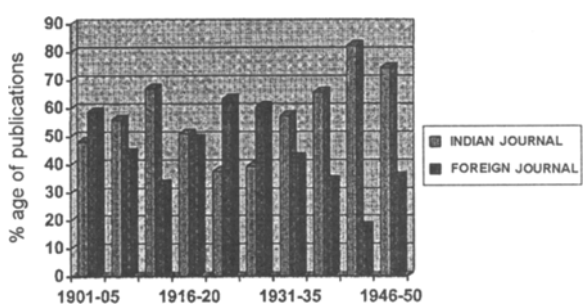

Fig. 6. Physics publications from India appearing in Indian and foreign journals

A cursory examination of Fig. 6 reveals that *after 1925 there is a consistent increase in the number of publications of Indian physicists in Indian journals as opposed to foreign journals.* These percentages have been obtained from a count of 48 Indian periodicals and 116 foreign journals. *The period 1916 to 1930, as has been proposed, is the period of institutionalization of physics in India, a process one of whose dimensions is globalization.* We see the number of publications going up from 79 to 361. After 1931 there is a dip in the number of publications in international journals. This may be ascribed to two sets of factors. In the post 1938 years, this may be attributed to the diminution of communications during the years of Second World War.* *In the 1930s some of the peer leaders of Indian physics consciously switched their publications to Indian journals in order to promote the development of physics research in India*, both in terms of the quality of research, and as a marker of professionalization of research, the institutionalization of the practice of communicating results of physics research.

In order to discuss the publishing avenues of physicists working in India, it is essential to examine the number of physics journals published in the metropolises of science, and take cognizance of the shifting centres of physics. However, immediately after the end of the Second World War, the centre of physics research had shifted to the United States of America, but prior to that the leading journals publishing papers in physics were published from United Kingdom, France and Germany. Table 6 gives the ratio of the number of journals where Indians published papers in physics abroad to the total number of journals in that country publishing papers on physics.

Table 6
Country-wise distribution of journals where physics papers from India appeared to the total number of journals published from that country

Years	United States	United Kingdom	Continental Europe
Upto 1900	(2/2)	(7/30)	
1901–10	(2/4)	(6/31)	(5/5)
1911–20	(6/21)	(7/60)	(5/11)
1921–30	(14/67)	(13/400)	(15/143)
1931–40	(14/62)	(13/623)	(27/231)
1941–50	(19/144)	(16/268)	(4/9)

* Since the number of publications in physics from India during the first two decades of this century was fairly small, it would be difficult to correct for the diminution in the number of publications, if any, during the First World War.

It is evident from Table 6 that during the period under discussion, most of the journals publishing research papers on physics were published from Great Britain and the continent. The fact that journals that commenced publication from United States in the 1920s and 30s, predisposed Indian physicists to send papers there for publication, in addition to the papers sent to England: English was the language of instruction for physicists in India. *While a great deal of the new work in physics was published in German journals, language was an important factor in deciding where Indians published.* However, between the 1920s and the end of the 1930s, Indian physicists published in 15 and 27 journals in continental Europe – *in the hyperactive 1930s, Indians published in as many as 17 German journals*, when the total number of journals from the continent in which physics from India appeared was 27. If not in terms of the proportion of the journals covered, it is in absolute terms of journals published there appears to be a parity between papers published in British and American journals.

This is the macro-characterization of the publication practices of physicists. We now examine where physicists working on various sub-disciplines published. As was the case previously, we shall look at six sub-disciplines. Table 7 gives the number of physics publications in India to the number of those appearing abroad for six sub-disciplines of physics.

Table 7
Physics publications in six sub-disciplines from India in Indian and foreign journals

Years	Acoustics	Astron. & Astrophys.	Rad, Nucl. & Cosm. Phys.	Spectr.	Atomic & Molec. Phys.	X-Ray Phys.
1901–05		(2/2)				
1906–10	(2/3)	(6/12)		(1/0)		
1911–15	(10/7)	(13/3)		(3/0)		
1916–20	(13/21)	(7/15)		(2/3)		
1921–25	(11/19)	(9/11)	(1/6)	(6/23)	(1/6)	(2/6)
1926–30	(7/20)	(8/12)	(1/11)	(61/94)	(1/11)	(31/31)
1931–35	(19/8)	(23/60)	(17/6)	(166/124)	(17/6)	(20/11)
1936–40	(41/11)	(28/52)	(19/9)	(155/45)	(19/9)	(41/8)
1941–45	(23/4)	(53/42)	(15/1)	(132/17)	(15/1)	(50/4)
1946–50	(25/14)	(26/32)	(11/2)	(156/32)	(11/2)	(26/6)

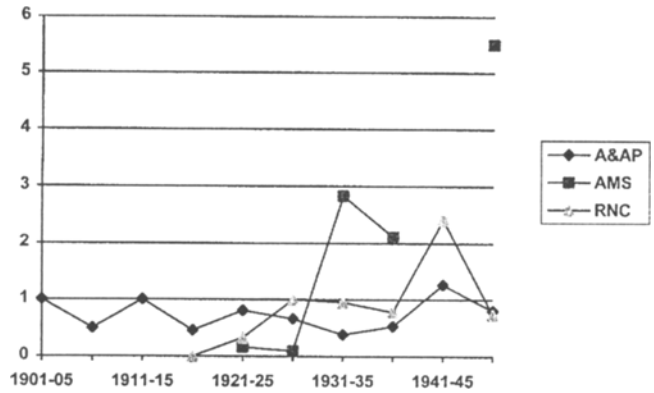

Fig. 7. Ratio of publications in astronomy and astrophysics, atomic and molecular physics and radioactivity, nuclear and cosmic ray physics from India appearing in Indian journals to those appearing in foreign journals

For the disciplines of astronomy and astrophysics, atomic and molecular physics, radioactivity, nuclear and cosmic ray physics, we plot the ratio of the number of physics publications in Indian journals to the number of physics publications from India in foreign journals in Fig. 7. When this ratio is less than 1, the number of publications abroad is greater – the peers of the sub-discipline reside abroad; when the ratio equals 1, then the number of publications is the same – a few peers in India on the other hand if the ratio is greater than 1, then the number of physics publications in Indian journals is greater – probably indicates that there is a critical community of researchers working in that sub-discipline. We have taken the ratio above for three sub-disciplines, these being astronomy and astrophysics; atomic and molecular physics; and radioactivity, nuclear and cosmic ray physics. *In the case astronomy and astrophysics*, a sub-discipline which was grounded in India for a much longer time, while the absolute number of publications keeps increasing, the ratio is close to 1, and never exceeds it until 1940, after which point it climbs marginally over 1. Which probably means that *(1) this community primarily had its publications abroad, (2) and that a significant number of journals did not emerge in the sub-discipline – there is a direct relationship between the number of researchers and the number of publications.* While *studies in radioactivity* date back to the last decade of the nineteenth century, the discipline *alongside nuclear physics picks up in 1925, and the ratio crosses 1 by 1930.* This also has to do with contingency, since as pointed out elsewhere, the number of journals and *the number of physicists published and publishing from India begin to*

reach out to a community from 1925 onwards. We witness a similar behaviour with *atomic and molecular physics; wherein the ratio crosses 1 by 1930.* Thus with the younger disciplines the ratio crosses one within a shorter time span, also because there is already a core set of journals available being published from India and accessible to researchers in India, in addition to those available internationally.

Relative growth rate of physics research papers from India

We cannot discuss the growth of physics research in India independently of the rate of growth of physics research on a global scale. A reasonable indicator that would enable a comparison between these two growth rates is the relative growth rate defined as

$$R_a = \frac{\log W_2 - \log W_1}{T_2 - T_1} \tag{1}$$

where W_2 is the number of publications during the interval T_2, and W_1 during T_1.

Figure 8 is a plot of the mean relative growth rates for world physics publications (WMR(A)) as well as the mean relative growth rates for publications in physics appearing from India (IMR(A)). Since the discipline commences later in India, as well as the fact that the absolute numbers are small the mean relative growth rates for India are greater than the international rates. It is important to note that *the mean relative growth rates internationally (WMR(A)) appear to flatten out during the period 1911–1930.* During this very period *there is a dip in mean relative growth rates for India as well (IMR(A)). In the Indian case, IMR(A) begins to flatten out after 1940.* However, it is not possible to say anything about this flattening out. This has to do with the eventuality that *there is a new lease of life with the second stage of institutionalization of science in India after the 1950s, in which case the curve will go through another growth-saturation cycle.* This argument may as well be true for growth rates in world physics publications as well. Another feature worth noticing is that *WMR(A) reaches saturation more slowly than does IMR(A)*, which is the case with a substantial corpus of publications. This means that, as has been pointed earlier, that *the first few decades of the present century (1910–1930) were the decades of most rapid growth in physics publications from India.* Since we are looking at relative growth rates on a log scale, the subsequent growth rates exhibit flattening out.

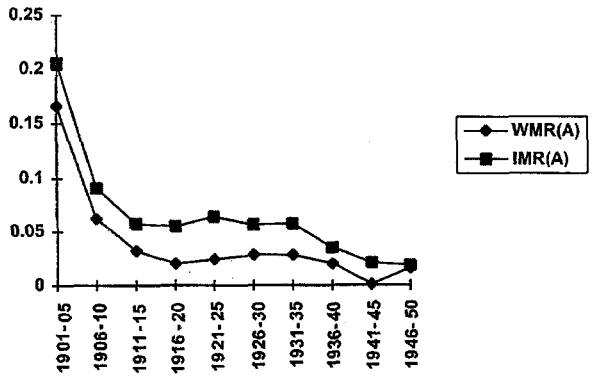

Fig. 8. The relative growth rates of physics publications, both globally (WMR(A)) and in India (IMR(A))

Activity Index for six sub-disciplines

Now, let $x_i(\Delta t_i)$ be the output of a sub-discipline during an interval say 1920–1930, and the total publications in the sub-discipline over the period 1900–1950 be given by $w_i = \Sigma x_i(\Delta t_i)$. Further, $X_i(\Delta t_i)$ be the total number of publications in a time interval Δt_i, and $W = \Sigma X_i(\Delta t_i)$, be the total number of physics publications from India during the period 1900–1950. A modified form of the activity index with normalized values, for each of the sub-disciplines, A_s, may be given as

$$A_s = [x_i(\Delta t_i)/w_i]/[X_i/W] \qquad (2)$$

This modified activity index will correspond to the sub-discipline for the given time interval. In the above formula, the quotient essentially normalizes the values of the activity indices computed for the various sub-disciplines. Table 8 gives the activity index so computed.

For each time interval and for each sub-discipline the percentage contribution of each sub-discipline is then plotted graphically in Fig. 9a.

Table 8
Normalized activity indices for six sub-disciplines

Years	Acoustics	Astron. & Astrophys.	Atomic & Molec. Phys.	Rad. Nucl. & Cosm. Phys.	Spectr.	X-Ray Phys.
1941–1950	73.62	88.54	93.63	183.64	96.55	106.49
1931–1940	76.83	82.24	126.16	81.61	122.40	86.37
1921–1930	42.46	50.10	116.69	24.74	114.12	187.64
1911–1920	504.89	246.53		31.70	20.34	
1901–1910	134.99	308.16			6.93	
1851–1900	0	245.36				
1801–1850	36.83	353.55				

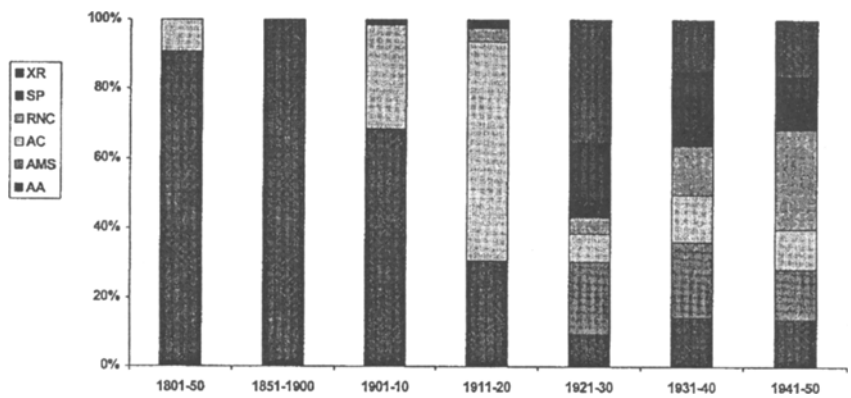

Fig. 9a. Plot of activity indices as percentages for six sub-disciplines of physics

Figure 9a shows that *the principal area of activity until 1910 in India is astronomy and astrophysics.* This does not mean that there was no research undertaken in other areas, but that when the values are normalized this was the most conspicuous area of activity. By the decade 1901–10, acoustics and to a small extent spectroscopy is edging astronomy and astrophysics. By then end of the next decade activity in radioactivity, nuclear and cosmic ray physics has registered its presence. *With each passing decade after 1910 another sub-discipline makes its presence on the activity map of physics in India.* With this distribution of activity, the activity index for astronomy and astrophysics shrinks. *Between 1920 and 1940 the bulk of activity of these six sub-*

disciplines is in the area of X-ray physics, spectroscopy and acoustics. By 1940, radioactivity, nuclear physics and cosmic ray physics come to occupy a sizable activity index. This has to do with the institutionalization of the discipline in India. During the decade 1920–30 all six areas have notable activity indexes – that further substantiates our point of the importance of this decade for the history of physics in India.

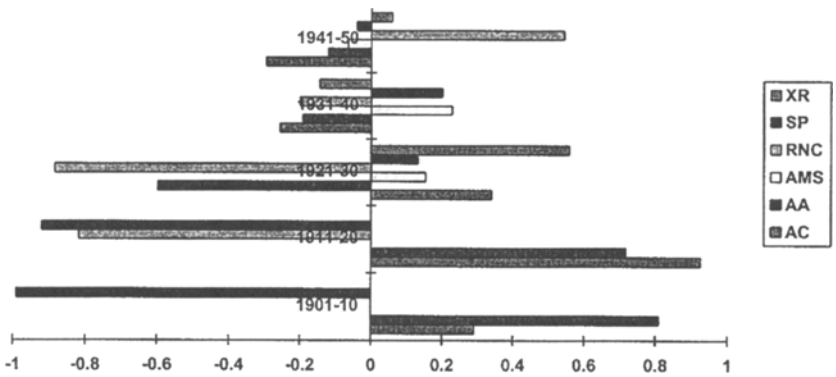

Fig. 9b. Sine projections of the values of the activity index for the very same six sub-disciplines

If we take the sinθ projections (Fig. 9b) of the above values of the modified activity indices we obtain a graph that illustrates those sub-disciplines with rising and declining activity indices. Thus astronomy and astrophysics which was the most important until 1920, displays a negative value after 1920, or declines vis-à-vis the emergence of other disciplines. Other than astronomy and astrophysics, acoustics is the other sub-discipline where there was ample activity, and even with acoustics we notice that it shares the same fate as astronomy and astrophysics after a decade. X-ray physics has a positive value during the decade 1920–30 when compared to other disciplines. *Radioactivity, nuclear and cosmic ray physics actually shows positive values when compared with other disciplines after 1940 – and this as indicated elsewhere has to do with the emergence of at least three schools of research in nuclear physics and a very important school of research in cosmic ray physics founded by Bhabha.*

Discussion of results

Three sets of factors may be said to have contributed to the growth of organized scientific research in the first decades of the present century: these being infrastructural, communicational and economic. Among the infrastructural factors we may include the establishment of laboratories and libraries, paid research supervisors and researchers. The communicative research practices include the organization of conventions and congresses and serial scientific publications. And the last included adequate financial support for infrastructure development and scientific communication (*Sen*, 1992, p. 386). In this paper we have examined how the discipline of physics was institutionalized and the nature of institutionalization is reflected in the evolution of publications in physics journals.

Institutionalization: reporting practices and literary techniques (I_1)

The rate of growth of physics publications from India manifests close to doubling behaviour between the years 1905 and 1935. Both the number of physicists publishing and the number of papers published per physicist increased together during the decade 1911–20, and this trend continued till the end of the 1940s. The growth of the two together suggests that publications had become an important form of communication for physicists.

Institutionalization: globalization and transmission (I_2)

1. The majority of physics publications appear in three of the six sub-disciplines studied, viz. that of spectroscopy, astronomy and astrophysics and radioactivity, nuclear and cosmic ray physics.
2. The most noteworthy feature is that during this period there is a reduction in the time lag between the commencement of research in a sub-discipline in the metropolises of science and their institutionalization in India. During the last few decades of the nineteenth century this lag was of the order of about twenty years; by the 1930s this lag is reduced to less than half a decade. Hence by the early decades of the present century, the formation of research networks, and the institutionalization of physics research closed the temporal distance separating metropolis from province.

3. After 1920 research activity picked up very rapidly in a number of areas of research. Astronomy and astrophysics exhibited the most rapid growth, spectroscopy, through the efforts of Raman appears to be catching up fairly rapidly.
4. However, by the 1920s a greater percentage of physicists contributed to the discipline in the newer areas of physics. In fact the base of the pyramids of these new sub-disciplines is broader and the peaks flatter; while in the older disciplines the base – percentage of physicists contributing 75% of the papers – is narrower and the peak – percentage of physicists contributing 25% of the papers – more pointed. This also informs the nature of communities emerging.

   The above findings feed back into theories of history of science in the former colonies, in particular regarding the two modalities of the transmission of scientific knowledge in the former colonies. The older disciplines are characterized by the slow transmission of the practices of scientific research systems through imperial institutions of science. On the other hand, the introduction of the University Charter of 1904, facilitates the adoption of the newer sub-disciplines, as distinct from geomagnetism, geology and meteorology, when Indian researchers adapt their educational system to the globalized community of practices instituted through the metropolises of science.
5. Of the core group of 32 physicists who had authored more than 25 papers during the period under consideration, it was found that 50% of their papers addressed more than one sub-discipline of physics – a reflection of the professionalization in physics.
6. Finally, after 1925 there was an increase in the number of publications of Indian physicists in Indian journals as opposed to foreign journals. Language was an important factor in deciding where Indians published – in the hyperactive 1930s, Indians published in as many as 17 German journals. The period 1916 to 1930 is the period of globalization of Indian physics. Internationally the mean relative growth rates (WMR(A)) of physics publications flattened out during the period 1911–1930. In the Indian case, this occurs after 1940. The first few decades of the present century (1910–1930) were the decades of most rapid growth in physics publications from India.

Institutionalization: appearance of research institutes and schools (I_3)

1. The decades 1910 to 1930 were very crucial for physics research in India on more than one count. The rapid rise in the number of publications during the decade 1910–20 could in addition be imputed to the acceptance of the University Charter of

1904 that empowered universities to undertake postgraduate teaching and research. As a result by the 1930s, the number of publications and researchers were distributed across a range of sub-disciplines. Furthermore, as a consequence of globalization a larger number of researchers were moving to newer areas of research.

2. During the early decades bulk of research in these sub-discipline's was the product of the effort of a few gifted individuals, around whom schools gradually emerged. These efforts were the most renowned contributions of a broader community coming to grips with the newly emerging front of knowledge. The older disciplines were highly dependent on the researches undertaken by a few individuals and their teams of researchers. The case was otherwise with the newer disciplines. This aided the rapid dispersal of these disciplines through universities and other research institutions.
3. Furthermore, in the 1930s the peer leaders of Indian physics switched their publications to Indian journals in order to promote the development of physics research in India. The community of astronomers and astrophysicists primarily published abroad, which meant that the community had strong links with the global community, and that the community was not large enough in the country – there is a direct relationship between the number of researchers and the number of publications.
4. The principal area of activity until 1910 in India is astronomy and astrophysics. Between 1920 and 1940 the bulk of activity of these six sub-disciplines is in the area of X-ray physics, spectroscopy and acoustics. By 1940, radioactivity, nuclear physics and cosmic ray physics register significant activity indices. This had to do with the institutionalization of the discipline in India. During the decade 1920–30 all six areas had notable activity indices – that further substantiates our point of the importance of this decade for the history of physics in India. Radioactivity, nuclear and cosmic ray physics became important when compared with other disciplines after 1940 – this had to do with the emergence of at least three schools of research in nuclear physics and a very important school of research in cosmic ray physics founded by Bhabha.

Institutionalization: the sense of community (I_4)

The first three decades constitute a major landmark in the institutionalization of physics research in India, wherein eventful researches of front running physicists was symptomatic of a much broader process. Between the end of 1920 and the end of 1930

there was a four hundred per cent increase in the number of authors, and almost a two hundred and fifty per cent increase between 1930 and 1940. A substantial community of researchers was beginning to appear. As seen earlier the number of physicists publishing and the number of papers published per physicist increase together during the decade 1911–20, and this trend continues till the end of the 1940s. This suggests that collaboration had become a current practice amongst physics researchers. While, the period 1910 to 1930 is the period of most rapid growth of the community, the mean number of papers per author begins to stabilize by the end of the 1920s.

By the 1930s, the number of publications and researchers were distributed across a range of sub-disciplines. The Gini coefficient for the total publications in physics indicates that the concentration of publications increased during the early decades of this century, implying that the publishing base had begun to widen.

As discussed above in the newer areas of physics a greater percentage of physicists contributed to the discipline. While the older disciplines were dependent on the researches undertaken by a few individuals and their teams of researchers. About 32 physicists constituted the core community of physicists during this half century, and all published in more than one sub-discipline of physics. The appearance of Indian journals and the practice initiated by the leaders of Indian physics to publish in Indian journals promoted the development of physics research in India.

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