Table 1. Distribution of 902 papers by citation frequency and journal IF

Citation count per paper	Number of papers in IF range				
	1 to < 2	2 to < 3	3 to < 6.14	Total count	Total%
0	61	30	28	119	13.2
1–7	262	158	100	520	57.6
8–15	53	54	59	166	18.4
16–30	22	21	29	72	8.0
31–157	6	10	9	25	2.8
Total	404 (44.8%)	273 (30.3%)	225 (24.9%)	902	100

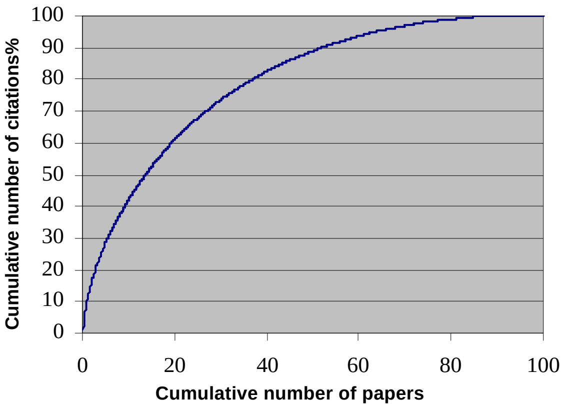

Figure 1. Distribution of citations to Indian papers published in physics during 1997.

in physics had received low citations, between 0 and 7 per paper.

These facts only seek to highlight the point that citations to a paper do not depend upon journal IF, although journal IF does depend upon citations. Certainly, journal IF cannot be taken as the only indicator for measuring the quality of a research paper. It is more so because acts of citation only seek to underscore the theoretical and practical significance of a paper, or its intrinsic value for future research[4]. Citation count probably sounds a more accurate and objective indicator of research quality. Statistically also, the Pearson correlation coefficient between journal IF and citation count computed on 902 records was low (0.21).

The pockets of excellence in research seem to be confined to a select few papers and not to any larger set of papers. For example, only 10% papers accounted for 42% citations, 20% for 61% citations, 30% for 73% citations, and 50% for 89% citations (Figure 1). This observation further confirms the prevalence of a wide gap in research evaluation based on journal IF and citation frequency.

The study finds that there is wide disparity in the evaluation of research measured on journal IF and citation count. As expected, research papers published in high impact journals failed to receive proportionately high citation, in six years since their publication in 1997. This trend was applicable to the bulk of Indian physics output considered in this study. Majority of such papers had their citation frequency below the average citation count for the whole sample. Nearly 13% papers did not receive even a single citation in six years since their publication.

The disparity is because citations do not depend upon journal IF, although journal impact does depend upon citations. Citations depend mainly on the theoretical and practical significance of the research reported in the paper. Citation count seems a more reliable indicator of a paper's worth than the journal IF. Evaluation based on journal IF can be sometimes misleading and hence not objective.

These finding are based on a study of 902 papers published in 1997 by Indian authors in 29 high IF physics journals. Though specific to the field of physics, these findings have serious implications on current research evaluation practices followed in the country. Besides judging the quality dimension of research output, citation count is also a useful indicator for identifying pockets of excellence in research. For example, in this study it is found that barely 10% of Indian physics papers had accounted for very high per cent of citations (42%). This has implications for rewarding merit.

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S. M. Dhawan[1,*]
B. M. Gupta[2]

[1]*National Physical Laboratory, Dr K.S. Krishnan Marg, New Delhi 110 012, India*
[2]*National Institute of Science, Technology and Development Studies, Dr K.S. Krishnan Marg, New Delhi 110 012, India*
**For correspondence*
e-mail: smdhawan@yahoo.com

Science in India

According to an analysis by Arunachalam[1], India's rank in world output of scientific papers covered in the Science Citation Index (*SCI*) slid down from 8th in 1980 to 15th in 2000, with the number of papers indexed in *SCI* falling from 14,987 in 1980 to 12,127 in 2000. On the other hand, China and South Korea have shown considerable increase (e.g. 924 to 22,061 papers from 1980 to 2000 by China). Therefore, he concluded that scientific output, as reflected by number of papers covered in *SCI*, has gone down or at the most stagnated. Some other authors[2–4] have contested this view and have pointed out that the number of papers published alone cannot be used to measure the state of health of science. The cita-

Table 1. Number of papers and citations per paper during 1991–2000

Branch	Country	No. of papers (1991–2000)	Citations per paper (1991–2000)
fNanotechnology	USA	9993	9.22
	Japan	4251	6.18
	China	3168	2.42
	South Korea	579	2.15
	India	636	3.15
Neutrinos	USA	3421	18.62
	Japan	794	21.77
	China	239	6.74
	South Korea	196	20.35
	India	486	18.26
Photonics	USA	1111	11.53
	Japan	599	5.63
	China	183	3.94
	South Korea	70	4.13
	India	23	9.17
Conducting polymers	USA	1388	15.47
	Japan	702	10.45
	China	278	2.87
	South Korea	229	3.87
	India	105	5.27
Quantum dots	USA	2584	14.64
	Japan	1686	7.3
	China	677	2.92
	South Korea	255	2.59
	India	117	4.79
Magnesium boride	USA	132	9.65
	Japan	67	8.67
	China	66	1.44
	South Korea	32	3.16
	India	11	0.64
Quantum cryptography	USA	570	3.52
	Japan	181	1.31
	China	62	0.85
	South Korea	29	1.14
	India	19	1.95
Molecular self-assembly	USA	2300	26.56
	Japan	728	11.14
	China	287	4.18
	South Korea	104	7.65
	India	104	6.7
Opto electronics	USA	19670	5.86
	Japan	5696	3.9
	China	2621	1.57
	South Korea	720	1.82
	India	1279	2.36
Fuel cells	USA	713	6.2
	Japan	434	4.18
	China	93	1.27
	South Korea	126	2.48
	India	77	2.84

Source: ISI, *Web of Science*, Thomson, ISI.

tions received by papers may also be taken into account.

Recently, ISI, '*Web of Science*'[5] has carried out such an analysis in some subfields of science with respect to papers indexed during 1991–2000. We reproduce these in Table 1 in case of USA, Japan, South Korea, China and India. It may be seen from this table that though the publications from India are smaller in number compared to those from China and South Korea, the impact factor measured by citation per paper is mostly higher. This is also supplemented by a recent analysis on Indian scientific contribution from 1992 to 2002 by *Web of Science*[6]. According to this, citations per paper have gone up from 1.15 in 1992 to 1.6 in 2002.

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R. P. GUPTA

Office of the Principal Scientific Adviser to the Government of India,
326, Vigyan Bhawan Annexe,
Maulana Azad Road,
New Delhi 110 011, India
e-mail: rpgpsa@hub.nic.in

Arunachalam replies:

About two years ago, in a short paper in this journal, I had shown that as reflected by the number of papers indexed in the CD-ROM version of *Science Citation Index*, science in India was stagnating whereas science in China, South Korea and Brazil was marching ahead rapidly[1]. This paper attracted the attention of some scientists[2,3] and the Parliament. A few others[4–6] wrote to this journal as well and their comments prompted Balaram[7] to point out that 'scientometrics in India is a field in the grip of practitioners, who are largely devoid of the insights that are necessary for scholarly and thoughtful analysis'. The general thrust of these papers, as humorously put by Balaram, was one demanding execution of those who brought bad news! I tried my best to provide clarifications to the points raised by each one of them[8–10].

Now Gupta[11] suggests that it is better to use citations per paper in addition to the number of papers published by a country while evaluating the state of health of science in different countries. There is nothing new; Thomson–ISI have been providing such data for many years in at least three of their products, viz. *Essential Science Indicators*, *National Science Indicators* and *ScienceWatch*. A simple web search on Google or Vivisimo for 'citations per paper' throws up many examples. Sylvan Katz[12] has concluded that 'relative citation index that is based on citations per paper may be an inappropriate metric for international bibliometric comparisons'. Gupta contends that although the number of papers published by China and South Korea is increasing rapidly, 'the impact factor measured by citation per paper is mostly higher' for India. To substantiate this point, Gupta has chosen ten physics- and chemistry-related research fronts – such as nanotechnology, photonics, conducting polymers, quantum dots, quantum cryptography, optoelectronics and fuel cells – in most of which India has recorded higher citations per paper than South Korea and China over the ten-year period 1991–2000 (as claimed by Gupta). While in virtually every field USA and Japan have recorded higher citations per paper than India, China and South Korea, in quantum cryptography India has a better citation rate than Japan. South Korea has a better citation rate than India in molecular self-assembly, magnesium diboride superconductors and neutrinos, and China has a better citation rate than India in magnesium diboride superconductors.

Surely there are bound to be sub-fields and research fronts where India will have a better citation rate than China and South Korea and vice versa. In the field of global warming, China, Brazil and South Africa have larger number of citations per paper than India, in the period 1991–August 2001 [www.esi-topics.com/gwarm/nations/d1c.html]. But why should one look at only a few selected research fronts? Why should not one look at the citations to all papers from these countries?

Let us look at citations per paper for all papers published by these countries over the period January 1993–31 August 2003 (Table 1). If we consider all papers published, both Brazil and South Korea are ahead of India in citations per paper.

I deliberately included Guinea Bissau, Bermuda, Senegambia and Rwanda in the Table to emphasize that we should use these numbers carefully. The top 20 countries in terms of citations per paper also include Panama, Gambia, the Congo Democratic Republic, Seychelles and the Netherlands Antilles. USA, which is the world's leader in both the number of papers published and in the total number of citations, ranks sixth in the average number of citations per paper, and Japan does not find a place in the top 20.

Incidentally, it would be difficult for anyone to verify the numbers given by Gupta as he has not given the correct bibliographic references. His references 5 and 6 are incomplete. The data given in table 1 of his paper are found in the Special Topics section of *Essential Science*

Table 1. Number of papers published and citations per paper for selected countries over the period January 1993 to 31 August 2003

Country	Papers	Citations	Citations per paper	Rank
Guinea Bissau	135	2477	18.35	1
Bermuda	207	3387	16.36	2
Senegambia	205	3004	14.65	3
Rwanda	161	2297	14.27	4
Switzerland	137,661	1,769,220	12.85	5
USA	2,705,352	33,089,756	12.23	6
Japan	713,542	5,098,499	7.15	+
South Korea	111,406	420,349	3.77	+
India	177,687	538,739	3.03	+
China	236,996	658,355	2.78	+
Brazil*	82,096	330,231	4.02	92

*Data for Brazil is for the period January 1992–31 October 2002. [http://in-cites.com/countries/brazil.html]
+, Not in the first 20 ranks.
Source: http://in-cites.com/countries/2003allfields.html

Indicators [www.esi-topics.com], and Gupta has not mentioned the years right. According to Gupta, all the data on number of papers and average citations per paper pertain to the period 1991–2000. In reality though only three sets of data (nanotechnology, quantum cryptography and conducting polymers) pertain to this period; the data for optoelectronics pertain to 1991–99; the data for neutrinos, photonics, quantum dots and magnesium diboride pertain to 1992–2002; the data for molecular self-assembly pertain to 1991–2001, and the data for fuel cells pertain to 1993–2003. Also, Gupta uses the term 'impact factor' for the nation as a whole although the term is used only for journals. Gupta says that for Indian papers citations per paper have gone up from 1.15 in 1992 to 1.6 in 2002, but does not say citations in how many years. Unfortunately, such casual use of numbers without a good understanding of what they mean or refer to is increasingly becoming common in India. But I would expect someone assisting the Principal Scientific Adviser to the Cabinet to report data accurately, use technical terms (such as impact factor) with care, and provide bibliographic references correctly.

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SUBBIAH ARUNACHALAM

M.S. Swaminathan Research Foundation, Chennai 600 113, India
e-mail: arun@mssrf.res.in

COMMENTARY

Marine gas hydrates: their economic and environmental importance

Anil K. Gupta

With increasing energy demand and depleting energy resources, gas hydrates may serve as a potentially important resource of future energy requirements. The conditions suitable for the occurrence of gas hydrate exist in a few hundred metres of the rapidly accumulating continental margin organic-rich sediments[1]. Methane is formed from the microbiological decay of organic matter in the absence of oxygen and can also be of thermogenic origin. The gas hydrate study was started in 1778 (by Priestly), whereas the chemistry of gas hydrates was discovered in the early 19th century, when in 1810, Humphrey Davy found that ice-like crystals were formed when the aqueous solution was cooled[2]. The interest in gas hydrate research has increased steadily since 1965, when gas hydrate deposits were first reported in the Soviet Union[3]. The intensive exploration activity undertaken by the oceanographers and petroleum geologists during the last decade, facilitated widespread occurrence of gas hydrates in the continental margin areas.

Importance of gas hydrates

It has become increasingly evident that naturally occurring gas hydrates are important components of the shallow geosphere and are of societal concern in at least three major ways: resource, hazard and climate[1]. Two reasons make gas hydrates attractive as a potential resource. First is the enormous amount of methane that is apparently sequestered within clathrate structures at shallow sediment depths within 2000 m of the earth's surface. Second is the wide geographical distribution of the gas hydrates. It was mentioned that the energy potential of methane hydrates is considerably greater than that of the other unconventional sources of gas, such as coal beds, tight sands, black shales, deep aquifers and conventional natural gas[4]. The resource potential of marine gas hydrate is yet to be ascertained, but considering the possibility of enormous gas reservoirs, gas hydrates will continue to attract attention until their development potential is measured.

Role in continental margin sediment instability

If large volumes of methane are stored in marine reservoirs, they may significantly influence the sedimentary environment in which they occur. The formation and subsequent decomposition of gas hydrates within the sediments affect the physical properties of the sediment as well. Changes in pressure and temperature will decompose solid gas hydrates to gas and water, which may lead to sediment instability and failure.

Environmental impact

It is assumed that the release of methane from marine hydrates during climatic maxima and minima has played a significant role in climate change. The earth has witnessed several intervals of climate change, typified by lowering and rise in sea level due to rapid cooling and warming. Because several of these time intervals are characterized by major inputs of