

**HOMI JEHANGIR BHABHA: HIS COLLABORATORS, CITATION IDENTITY, AND HIS CITATION IMAGE MAKERS**

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**Abstract**

In this paper, we studied synchronous references (references in the same papers) and diachronous citations (citations to the papers) of the renowned theoretical physicist, Homi Jehangir Bhabha. We utilized the Science Citation Index (SCI) on CD from 1982 – 2006. We identified his coauthors, his most cited works, citation identity (authors whom he had cited) and citation image makers (authors citing him). Bhabha published his first paper in 1933 at the age of 24 and the last paper in 1966, the year of his demise. His 66 papers could be categorized into nine fields: Cosmic ray physics (18 papers); Elementary particle physics, and Field theory (14 papers each); Quantum electrodynamics (6 papers); Nuclear physics (4 papers); General, and Interaction of radiation with matter (3 papers each); and Mathematical physics and General physics (2 papers each). He collaborated with 18 authors in 18 papers; the remaining 48 papers were single-authored. His citation identity consisted of 212 different authors, of whom six were Nobel laureates. He received 328 citations to his works, his overall citation rate being 10.6 per cited paper and the highest citation rate was 21.2 to his papers in the field of Elementary particle physics. His most often cited paper was in Quantum electrodynamics with 54 citations. His image makers comprised 537 different authors. Bhabha has the distinction of being cited by at least two Nobel laureates, P.M.S. Blackett and H. Yukawa in their respective Nobel lectures.

Keywords: Scientometrics; Bibliometrics; Ego-centric citation analysis; Authorship patterns; H.J.Bhabha

**INTRODUCTION**

In this study we analyzed the references of the works of Homi Jehangir Bhabha (H.J.Bhabha), a renowned theoretical physicist, and also citations to his works during much later years in 1982 to 2006 in the Science Citation Index (SCI). Such analyses of synchronous and diachronous references can be used to map the intellectual and social networks of the researcher. This paper is based on the concept of ego-centric analysis first introduced by Howard White (White 2000; White 2001; White & McCain 1998) which includes:

- (a) coauthors (authors who published with the specific author)

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- (b) citation identity (authors who are cited by the specific author)
- (c) citation image makers (authors who cite the works of the specific author).

Bar-Ilan (2006) carried out an ego-centric citation analysis of the works of the mathematician and computer scientist, Michael O. Rabin using three databases: the Web of Science, Google Scholar and Citeseer. Cronin and Shaw (2002) studied identity-creators and image-makers of three information scientists: Blaise Cronin, Stephen Harter and Rob King.

H.J. Bhabha was a world renowned theoretical physicist. He was born in Bombay (presently Mumbai), India, on 30th October 1909. After completion of his secondary education in Bombay at the age of 17, he proceeded to Gonville and Caius College at Cambridge. His initial pioneering research was in the areas of Cosmic Radiation, Elementary-particle Theory and Quantum Theory. He obtained his doctoral degree at Cambridge in 1934. In 1941, at a young age of 31, Bhabha was elected as a fellow of the Royal Society of Edinburgh on the recommendation of the Nobel laureate Dr. C. V. Raman. The Indians being elected by the Royal Society is indicative of the elected fellows' high quality work. This is evident from the fact that out of the six physicists (H.J. Bhabha, J.C. Bose, Subramanyam Chandrasekhar, K.S. Krishnan, C.V. Raman and M.N. Saha) who were elected in the first half of the twentieth century, four were nominated for Nobel Prize for Physics. H. J. Bhabha was nominated in the second half of the twentieth century by J. Hadamard, a mathematician from the Institut de France (Singh 2007). Bhabha was an outstanding student and secured highly coveted scholarships in England in the thirties. He worked with several eminent nuclear physicists such as Lord Rutherford, Wolfgang Pauli, Enrico Fermi, and Niels Bohr. Bhabha was on a short holiday to India from England when the Second World War broke out. Most of the scientists in England were engaged in war activities, and since basic research was no longer possible there, Bhabha decided to stay back in India. He joined the Indian Institute of Science at Bangalore where he was made a professor in 1944 and led research on cosmic rays.

In March 1944, Bhabha submitted a proposal to Sir Dorab J. Tata to set up an institute for fundamental research. The then Government of Bombay favoured the proposal by becoming the joint founder of the proposed institute, and the Tata Institute of Fundamental Research was established in 1945. Bhabha decided to build a new laboratory entirely devoted for the atomic energy technology development programme, and this led to the existence of the Atomic Energy Establishment in 1954.

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The Indian Science Congress elected Bhabha as its president in 1951. In 1957 he was made an honorary fellow of both Gonville and Caius College, Cambridge, and the Royal Society of Edinburgh. Bhabha was associated with scientific and honorary societies of many countries. He was made an honorary life member of the New York Academy of Sciences in 1963. He was a fellow of the American Academy of Arts and Sciences, a foreign associate of the US National Academy of Sciences, and a member of the Scientific Advisory Committee of both the United Nations and the International Atomic Energy Agency. He chaired the First International Conference on the Peaceful Uses of Atomic Energy, the Indian National Committee for the International Council of Scientific Unions and the Scientific Advisory Committee to the Cabinet, Government of India. Bhabha was awarded the Padma Bhushan by the Government of India in 1954. Nobel laureate S. Chandrasekhar in his response on whom he considered as the great scientist in India, during an interview with the Deccan Herald, indicated that “...(Homi) Bhabha has contributed more than anyone else to science in India” (Vedantam 1997).

Bhabha met with an untimely death in an air-crash near Mont Blanc peak of the Alps on 24, January 1966, while he was on his way to Vienna to attend a meeting of the Scientific Advisory Committee of the International Atomic Energy Agency.

#### **OBJECTIVES**

The main objective of this paper is to study the influence and the on-going interest in the works of H.J. Bhabha. In this context we have studied his:

- Publication profile
- Coauthors
- Citation profile (i.e. the most-cited publications)
  - citation identity (authors cited by Bhabha)
  - citation image makers (authors citing Bhabha)
- h-index (a scientist has index  $h$  if  $h$  of his/her papers have at least  $h$  citations each and the other papers have no more than  $h$  citations each.

#### **MATERIALS AND METHODS**

A listing of 63 publications of Bhabha considered for all the analysis in this study were taken from ‘Homi Jehangir Bhabha: Collected Scientific Papers’ (Sreekantan et. al 1985). Three papers were traced in SCI which were not included in this source, and these were added to the list. A total of 66 papers

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were included in the study (Appendix 1). References to all these 66 papers were listed; all the authors indicated in the references were recorded.

Data collected from SCI had to undergo some kind of editing and data cleansing. On looking up the index of each year in the SCI field 'cited author/reference' for all the likely variations of 'Bhabha', we found the following variations: 'bhabha', 'babha', 'bhabba', 'bhabdha', and 'bhagha'. We made a search for all these variations, and scrutinized each record to weed out those not citing the works of H.J. Bhabha. This could be done very precisely, because all the original publications of H.J. Bhabha were available.

The following definitions are used in this study:

Citation identity: Authors cited by the specific author

Citation image makers: Authors citing the specific author

Citation rate: Citations per cited paper

## **RESULTS AND DISCUSSION**

### **Publication profile of H.J. Bhabha**

Bhabha published his first paper in 1933 at the age of 24 under the guidance of W. Pauli, which was published in the *Zeitschrift fur Physik* and for which he won the Isaac Newton Studentship in 1934. He subsequently published 65 papers; his last paper was published in 1966.

Bhabha published 18 (28.6%) papers in the domain Cosmic ray physics and 14 papers each were in Elementary particle physics and Field theory. These three domains comprised 73% of his papers (Table 1). The striking feature of his papers is that he is a single author in 48 (80%) of his papers and he is the first author in all his co-authored papers except one (Taylor et al 1950).

### **(a) Coauthors**

H.J. Bhabha had 18 coauthors in 18 of his 66 publications. Thus, the majority of his publications are singly authored. Table 2 gives the authorship pattern in the papers by Bhabha. Table 3 displays the 18 authors who coauthored papers with H.J. Bhabha.

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Table 1: Yearwise publications in the different domains by H.J. Bhabha during 1933 - 1966

Year	Domains									Total	Cumulation	Productivity Age	Age of Bhabha	
	A	B	C	D	E	F	G	H	I					
1933	1										1	1	1	24
1934	1	1									2	3	2	25
1935		2									2	5	3	26
1936	1	1	1								3	8	4	27
1937				2	1						3	11	5	28
1938				1				2			3	14	6	29
1939				1	3	1					5	19	7	30
1940					1	2					3	22	8	31
1941				1	4	1					6	28	9	32
1942		2		1							3	31	10	33
1943				1	1						2	33	11	34
1944				1	1	1					3	36	12	35
1945				2	1	2					5	41	13	36
1946			1	1		1					3	44	14	37
1947						1					1	45	15	38
1948				1	1						2	47	16	39
1949					1	1					2	49	17	40
1950				3				2			5	54	18	41
1951						2		1			3	57	19	42
1952						1					1	58	20	43
1953						1					1	59	21	44
1954				3				1			4	63	22	45
1955										1	1	64	23	46
1958										1	1	65	26	49
1966										1	1	66	34	56
Total	3	6	2	18	14	14	2	4	3		66			
%	4.8	9.5	3.2	28.6	22.2	22.2	3.2	6.3			100			

(A=Interaction of radiation with matter; B=Quantum electrodynamics; C=Mathematical physics; D=Cosmic ray physics; E=Elementary particle physics; F=Field theory; G=General physics; H=Nuclear physics; I=General)

Table 2: Authorship pattern in papers of H.J.Bhabha

Authorship	No. of papers
Single author	47
two-authored	14
three-authored	1
four-authored	3
six-authored	1
Total	66

Table 3: Co-authors of H.J. Bhabha

Authors	Frequency	Authors	Frequency
Bhabha, H.J.	66	Shrikantia, G.S.	1
Harish-Chandra	3	Ramakrishnan, A.	1
Saxena, R.C.	2	Madhava Rao, B.S.	1
Hoteko, H.E.	2	Hulme, H.R.	1
Heitler, W.	2	Heeramaneck, J.R.	1
Daniel, R.R.	2	Corben, H.C.	1
Chandrashekhar Aiya, S.V.	2	Chou, C.N.	1
Chakrabarty, S.K.	2	Carmichael, H.	1
Taylor, H.J.	1	Prasad, N.B.	1
Swami, M.S.	1		

**(b) Citation profile**

***Most cited publications***

Of the 15587 references in the papers citing H. J. Bhabha, 331 citations (2.1%) were to his works. Total synchronous references in a paper ranged from 3 to 1334, and citations to the papers of Bhabha ranged from 1 to 5 in each paper. Bhabha received 331 citations from 1982 to 2006 to 31 papers. On an average he received 10.7 citations per cited paper (citation rate) and 5 citations per publication (cited and uncited). According to Gusman (2003) citation rate gives measure of productivity or relative importance for the cited papers, especially within the concerned field. One citation to his collected papers has not been considered because reference to the exact paper is not known and two other references were incorrect. Hence 328 citations have been considered for this segment of citation analysis. Considering reference being made to his eponyms

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without actually giving him due credit in the Reference Sections, he had lost more than 402 citations during 1982 – 2002 as observed in our previous study (Swarna et al 2004). Figure 1 indicates yearwise distribution of citations to the papers of H.J. Bhabha.

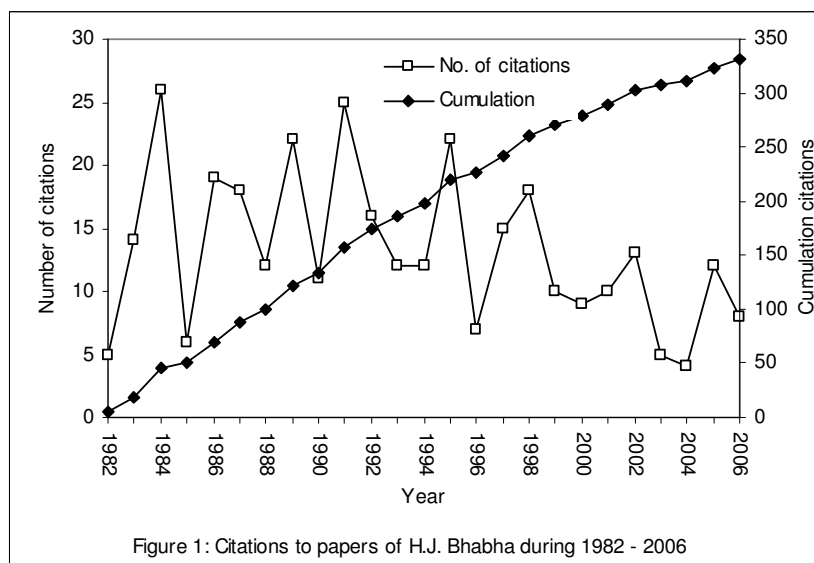


Figure 1: Citations to papers of H.J.Bhabha 1982 – 2006

Marx and Cardona (2004) explain since 1974 in SCI only about 0.5% of the references in papers in all fields of science have been to papers published before 1900, whereas about 4% have been to papers that were published before 1950. The age of papers cited tend to peak 3 years after their publication. According to them, papers can still have an impact several decades after they are originally published. In any discipline, it is expected to find a small number of papers that are frequently cited and a large number that are cited only once or may not be cited at all. According to Garfield (1970) such uncited papers should not be considered insignificant as they can be excellent untapped sources for further research for masters or doctoral theses.

Table 4 indicates citations to his papers as per subject of his papers. He received maximum (106) citations to only 5 of his 14 papers published in Elementary particle physics.

Table 4: Citations to the papers of H.J. Bhabha classified according to subject

Subject	No. of papers published	No. of papers cited	No. of citations	Citation rate
A-Interaction of radiation with matter	3	0	0	0.0
B-Quantum electrodynamics	6	4	84	21.0
C-Mathematical physics	2	2	17	8.5
D-Cosmic ray physics	18	6	58	9.7
E-Elementary particle physics	14	5	106	21.2
F-Field theory	14	8	40	5.0
G-General physics	2	0	0	0.0
H-Nuclear physics	4	3	10	3.3
I-General	3	3	13	4.3
Total	66	31	328	10.6

Of the nine fields in which Bhabha had published, the maximum citation rate was 21.2% to his works in Elementary particle physics and 21.0% to his works in Quantum electrodynamics, indicating that papers in these fields have greater impact today than his other fields of research.

The five most cited papers of H. J. Bhabha during 1982 to 2006 are documented in Table 5. Considering the time which has lapsed since Bhabha published his papers, the direct influence and on-going interest in his work is quite extraordinary. Cakewell and Garfield have done citation analysis of Einstein's works during 1970 – 1974 to study the impact (Cakewell & Garfield 1980). In the words of Cardona "In our field of physics a paper cited over the years more than 50 times has had considerable impact. If cited over 100 times it becomes an important paper" (Cardona 2003). Since we are considering citations to his papers from 1982 onwards, its possible he would have received many more citations earlier to this period and an appreciable numbers of papers would have been in the categories as mentioned by Cardona.

Bhabha's most cited paper (see Table 5) according to Virendra Singh (Singh 1985) is considered the crowning achievement, because this paper earned him the eponym 'bhabha scattering'. In our paper "Eponymous citations to Homi Jehangir Bhabha" (Swarna et al 2004), we found maximum (290) eponymous citations were made to 'bhabha scattering'.



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The fourth paper in Table 5 which was cited 31 times, earned him another eponym ‘bhabha equations’. This work at the age of 27 earned him a permanent place in the textbooks on cosmic ray physics (Deshmukh 2003)

Table 5: Five most cited papers of H.J.Bhabha during 1982 – 2006

Subject	Cited works	Times cited
Quantum electrodynamics	‘The scattering of positrons by electrons with exchange on Dirac’s theory of the positron’ Proc. Royal Soc. A, V.154, 1936: pp. 195-206	54
Elementary particle physics	‘Relativistic wave equations for the elementary particles’, Rev. Mod. Phys., V.17, 1945:pp. 200-216	38
Elementary particle physics	‘General classical theory of spinning particles in a Maxwell field’ Proc. Royal Soc. A, V.178, 1941: pp. 273-314	32
Cosmic ray physics	‘The passage of fast electrons and the theory of cosmic showers’, Proc. Royal Soc. A, V.159, 1937: pp. 432-458	31
Quantum electrodynamics	The creation of electron pairs by fast charged particles’, Proc. Royal Soc. A, V.152, 1935: pp. 559-586	23

**Citation identity**

The citation identity of an author is the list of authors cited by him/her. Synchronous references in the papers of H.J. Bhabha were taken into consideration for preparing his citation identity. Bhabha’s citation identity comprised 212 authors, based on 635 references to 842 authors (authors counted with multiplicity). He cited himself 133 times. The overall synchronous self-citation rate is 20.9% (Lawani 1982).

Synchronous self-citation rate indicates self-consistence of an author in his work. According to Kragh (1990) scientists who follow an independent research program outside the mainstream of a research field will tend to cite themselves frequently. Study of his synchronous self-citations as a knowledge generating system was made by Swarna et al (2006). Of the 212 different authors cited, 96 (45.3%) were recitations, and 116 uncitations. Table 6 indicates names of authors who have been referenced at least 10 times by H.J. Bhabha in his papers. Of the 12 authors six are Nobel laureates. There are other Nobel laureates whom he has cited but have not been included here: H. Yukawa and R.A. Millikan.

Table 6: The most frequently occurring names in Bhabha's citation identity

Author	No. of times referenced
Heitler, W.	48
*Dirac, P.A.M.	29
*Pauli, W.	22
*Heisenberg, W.	22
Kemmer, N.	21
*Rossi, B.	20
*Blackett, P.M.S.	17
*Bethe, H.A.	13
Wilson, A.H.	12
Fierz, M.	12
Harish-Chandra	10
Auger, P.	10

\*Nobel Prize winners

### Citation image makers

The set of authors who refer to an author are termed citation image-makers. Altogether 537 different citing authors to the papers of Bhabha were identified in SCI from 1982 to 2006. Table 7 indicates all the top image makers according to SCI, except those who have cited him only once.

Table 7: The citation image makers according to SCI

Citing author	Frequency	Citing author	Frequency
Salesi-G	7	Walser-MW	2
Smirnov-YF	5	Varshney-VP	2
Petrukhin-AA	5	Vanginneken-A	2
Nikitin-AG	5	Tsertos-H	2
Moshinsky-M	5	Sustersic-L	2
Lynn-KG	5	Strakhovenko-VM	2
Lopezbonilla-JL	5	Spradley-JL	2
Kokoulin-RP	5	Simpson-PJ	2
Chibani-O	5	Simon-JZ	2
Akhiezer-AI	5	Shulga-NF	2
Sharma-A	4	Schreckenbach-K	2
Schultz-PJ	4	Scheurich-H	2
Recami-E	4	Saavedra-O	2
Morales-J	4	Rosenblum-A	2
Massoumi-GR	4	Rivas-M	2
Lennard-WN	4	Ribaric-M	2
Labonte-G	4	Rekalo-AP	2

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Corben-HC	4	Radjabov-MR	2
Barut-AO	4	Pal-PB	2
Wu-XY	3	Ovando-G	2
Takahashi-T	3	Nix-JR	2
Suda-T	3	Nii-N	2
Shibata-H	3	Nash-PL	2
Scheid-W	3	Nadzhafov-IM	2
Salvat-F	3	Nadjafov-IM	2
Saar-R	3	Mukunda-N	2
Rowe-EGP	3	Mirantsev-LV	2
Rosales-MA	3	Merenkov-NP	2
Reynaud-S	3	Mckeown-M	2
Palathingal-JC	3	Logan-LR	2
Ozaki-S	3	Kurths-J	2
Ots-I	3	Krusche-B	2
Okada-A	3	Kozhuharov-C	2
Ohashi-Y	3	Kleiss-R	2
Nakamura-I	3	Kienle-P	2
Muraki-Y	3	Keitel-CH	2
Molina-A	3	Katkov-VM	2
Mitsui-K	3	Jauregui-R	2
Minorikawa-Y	3	Hernandez-A	2
Mikamo-S	3	Havas-P	2
Matsuno-S	3	Hassan-MK	2
Lozada-A	3	Gupta-DK	2
Loide-RK	3	Grun-N	2
Llosa-J	3	Gould-H	2
Koutroulos-CG	3	FernandezVarea-JM	2
Kobayakawa-K	3	Eby-PB	2
Kitamura-T	3	Drechsler-W	2
Kirina-TM	3	Dekker-H	2
Kawashima-Y	3	Debergh-N	2
Kamiya-Y	3	Castagnoli-C	2
Jaen-X	3	Cant-A	2
Jaekel-MT	3	Bush-BW	2
Higashi-S	3	Bracken-AJ	2
Herdegen-A	3	Boyer-TH	2
Ghosh-VJ	3	Blanchot-G	2
Brown-LM	3	Bertulani-CA	2
Asokakumar-P	3	Berends-FA	2
Aguirregabiria-JM	3	Beckers-J	2
Wu-TT	2	Baier-VN	2
Wu-SL	2	Armbruster-P	2
Welch-DO	2	Aers-GC	2

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400 authors cited his works only once

Only one author was common as a coauthor, citation identity and as citation image maker: H. J. Corben.

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According to Sen (1969) scientists whose works are cited by Nobel laureates can be considered as the 'richest' members of the scientific community. In this sense Bhabha has the distinction of being cited by P.M.S. Blackett (1948) and H. Yukawa (1949) in their respective Nobel lectures (Fragmyr 1998), even though both the cited papers (Bhabha 1938a; 1938b) received only 6 and 2 citations respectively in SCI.

#### ***h-index***

According to Hirsch the cumulative impact and relevance of an individual's scientific research output can be quantified by h-index. He has defined h-index as the number of papers with citation number  $\geq h$  (Hirsch 2005). On this basis h-index of Bhabha is 10, considering SCI (on CD ROM) from 1982 to 2006.

#### **CONCLUSION**

In this study we have characterized H.J. Bhabha's publication profile, his coauthors, his most cited works, his citation identity, and citation image makers. Considering the time which has lapsed since Bhabha has published his papers, the on-going interest in his work is quite extraordinary. In his publishing span of 25 year he published 66 papers, which could be categorized into nine fields: Cosmic ray physics (18 papers); Elementary particle physics, and Field theory (14 papers each); Quantum electrodynamics (6 papers); Nuclear physics (4 papers); General, and Interaction of radiation with matter (3 papers each); and Mathematical physics, and General physics (2 papers each). He collaborated with 18 authors in 18 papers, the remaining 48 papers being single-authored. His citation identity comprised of 212 authors. Of the top ten of them, six were Nobel laureates. He received 328 citations to his works, his overall citation rate being 10.6 per cited paper and the highest citation rate was 21.2% to his papers in the field of Elementary particle physics. His most often cited paper was in Quantum electrodynamics with 54 citations. His image makers comprised of 537 different authors. He has the distinction of being cited by at least two Nobel laureates, P.M.S. Blackett and H. Yukawa in their respective Nobel lectures.

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**APPENDIX 1**

**Chronological personal bibliography of Research Publishing Career  
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