# Classic-Author Synchronous Self-References: The Knowledge-generating-system at an Individual Scientist Level

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**ABSTRACT:** Quantitative analysis of the events of synchronous references in the research papers followed throughout the publishing career of an individual scientist revealed interesting highlights on the knowledge-generating-system. In the case study of H. J. Bhabha first quinquennium and fifth quinquennium of his research career had low self-references; third quinquennium and fourth quinquennium had moderate self-references; whereas second quinquennium had highest self-references. The two major clusters of self-references occurring during the second and third quinquennium were indicators of active periods of knowledge-generating and faster communications.

**Keywords**: Author self-citations; Author self-references; Classic-author; Classic-Author Synchronous Self-References; Classic paper; H. J. Bhabha; Publication productivity; Recency; Synchronous self-citations; Temporal profile of self-references; Time-lag

## 1. Introduction

Self-references form a significant portion of the reference network. Self-references are indicative of continuity of pursuing one's own research. While self-references enrich personal intellectual growth, references to others amounts to import of intellectual experiences from other contemporary researchers. Studies show that the rate of self-references vary between 10 per cent to 20 per cent, depending on the field and development of research in that field. Author self-references pattern has been studied across one or more disciplines (Snyder & Bonzi, 1998; Tagliacozzo, 1977). One of the reasons to self-cite is that reference needs to be made to previous works on which the present work builds (Borgman & Furner, 2002). The reasons for authors to refer to their own works and works by others are very similar (Bonzi & Snyder, 1991). Lawani (1982) has classified references into four species of which Species I is where the first author of the citing paper is also the first author of the cited paper, and it is called as ***classic-author self-citation***. Also, in a more restricted version publications having identical first author in the citing paper and the cited paper are included as author self-references (Garfield, 1979a).

Individual scientist is considered as a unit of generating knowledge. An author who includes particular reference is

announcing to readers the relevance of these references to the citing paper at some point while conducting the research or during the writing process (Harter, 1992). Referencing behaviour may be specific characteristic, like any other behaviour specific to an individual. Garfield (1994) and Aksnes (2003) had felt the need for systematic studies considering self-references. Till date we have not come across any comprehensive study of self-referencing behaviour of an individual scientist, hence, the present case study was undertaken.

## 2. Objectives

Knowledge organization system in the contents of a research paper and the ideas investigated are reflected in the references. Present paper attempts to explore synchronous references in the life-time publications of an individual scientist with the objectives to:

- Know dynamic association pattern of self-references and references to others;
- Correlate collaborative levels with synchronous references;
- Quantify recency in synchronous references;
- Identify connectivity networks of citing and cited documents; and
- Differentiate high publication production period from moderate and low productivity periods, and establish its relationship with self-references

## 3. Materials and methods

Present paper is a unique case of the 'Classic-Author Synchronous Self-References (C-ASS-R)' because Homi Jehangir Bhabha was either solo author or was the first author in all collaborations, except one of his papers (Taylor et al., 1950). Objective of the study was exploratory basic research into the process of generating knowledge at an individual scientist level.

The source used for this study was *Homi Jehangir Bhabha: Collected Scientific Papers* (Sreekantan et al., 1985). The year of publication was taken into consideration while arranging the papers sequentially.

Data collection technique involved quantitative content analysis on all references (purposive) referred to (in text, as footnotes, and at the end of the text) in each of the papers of H. J. Bhabha. It was categorized into:

- the C-ASS-R as recommended by Aksnes (2003) by considering only the first-author in self-references, and
- the references to others (i.e. all references except the C-ASS-R).

An author, while referring to his own works also refers to the works of others. Synchronous Self-Reference Rate (SSRR) is the ratio in percentage of self-references by the author in an article to the total number of references in the same article. According to Lawani (1982) SSRR of 100 per cent is very rare. For example, P. A. M. Dirac had referred only to himself in many of his papers (Kragh, 1990).

Synchronous Self-Reference Rate (SSRR) varies from individual to individual as a unique behavior of each individual. Same researcher may have changes in SSRR from time to time when shifts occur in working from one domain to other domain in the lifetime. SSRR may change as per the channel of communications preferred over a period of time. Synchronous Self-Reference Rate (SSRR) for S. Chandrasekhar (Kademani et al., 1996a) in various domains were: Plasma physics (20.4%); Stochastic, statistical hydromagnetic problem in physics and astronomy (19.6%); Mathematical theory of black holes and colliding waves (19.4%); Stellar structure and stellar atmosphere (17.8%); Radiative transfer and negative ion of hydrogen (14.9%); Tensor-virial theorem (14.3%); Relativistic astrophysics (12.6%); and Hydromagnetic and hydrodynamic stability (10.5%); SSRR for C. V. Raman (Kademani et al., 1994) in various domains were: Floral colours and visual perception (26.9%); Physics of crystals (26.4%); Optics (19.7%); Optics of minerals and diamonds (19.6%); Acoustics (11.7%); and Scattering of light (5.6%). SSRR for K. S. Krishnan (Kademani et al., 1996b) for various domains were: Thermionics (19.0%); Magnetism (14.8%); and Spectroscopy (9.8%). SSRR for R. K. Mitra (Kalyane et al., 2001) calculated domain-wise were: Methodology (16.7%); Biochemical genetics (14.8%); Molecular biology (11.6%); Bioenergetics (9.7%); Plant biochemistry (4.2%); and Biotechnology (0.0%). Mean SSRR for C. R. Bhatia was 0.5 per cent (KALYANE and SEN, 1998). Overall SSRR for following scientists were: Vikram Sarabhai - for Cosmic rays, 16.5% (Kademani et al., 2000); R. Chidambaram - for highly cited and/or most significant publications, 12.2% (Kademani & Kalyane, 1996); and R. G. Rastogi – for Geomagnetism, 25.1% (Munnolli & Kalyane, 2003). For the papers of Tibor Braun published in the core journals preferred by him to channelise his publications, SSRR was found to vary from 19 to 70 per cent (Kalyane & Sen, 2003) as follows: *Journal of Radioanalytical and Nuclear Chemistry Letters* (70%); *Trends*

*in Analytical Chemistry* (30%); *Scientometrics* (28%); *Analytica Chimica Acta* (22%); and *Fresenius Zeitschrift fur Analytische Chemie*, renamed as *Fresenius Journal of Analytical Chemistry* (19%). Scientometric analysis of synchronous references (Upadhye et al., 2004) in the nine Physics Nobel lectures by Nicolaas Bloembergen (1981), Arthur L. Schawlow (1981), Kai M. Siegbahn (1981), Kenneth G. Wilson (1982), Subrahmanyan Chandrasekhar (1983), William A. Fowler (1983), Carlo Rubbia (1984), Simon van der Meer (1984), and Klaus von Klitzing (1985) indicated high variations: No. of Synchronous References ranged from 24 (Meer) to 283 (Siegbahn); Synchronous Self-References ranged from 5 (Rubbia) to 88 (Siegbahn); synchronous references to others ranged from 10 (Chandrasekhar) to 255 (Wilson); Synchronous Self-Reference Rates ranged from 6.66 % (Rubbia) to 65.51 % (Chandrasekhar); Single-Authored References ranged from 15 (Klitzing) to 160 (Wilson); Multi-Authored References ranged from 4 (Chandrasekhar) to 194 (Siegbahn); Collaboration Coefficient in the synchronous references ranged from 0.14 (Chandrasekhar) to 0.75 (Klitzing); and Recency (age of 50 % of the latest references) ranged from 2 years (Klitzing) to 18 years (Chandrasekhar).

The difference between the publication year of the referring paper and the publication year of the referred paper ($\Delta t$) may throw light on interdependence of research programmes of individual scientist. References are generally backward in time. If referring and referred papers are published in the same year, the age of the reference is zero. The average age of references within a particular referring paper or series of papers reflects how modern the paper is or how integrated it is in the evolving research forefront. In rapidly evolving 'hot' areas, age of the references will be small and in many cases zero. If the average age of references is large, it usually indicates that the paper or series of papers belong to a stagnating research area or is out of contact with the mainstream research (Kragh, 1990).

Present paper attempts to visualise temporally (Price, 1986) the self-references profile by linking the citing papers by H. J. Bhabha with the cited papers by H. J. Bhabha.

## 4. Results and discussion

### 4.1 *Pattern of synchronous self-references and references to others*

Sixty-three papers by H. J. Bhabha had a total of 589 references of which 131 were self-references and 458 references to others. Overall Classic-Author Synchronous Self-References (C-ASS-R) rate for H. J. Bhabha was 22.2 per cent.

Five papers did not have any references and one paper (Bhabha, 1950) had only one reference and that too, self-reference. The C-ASS-R were in his 48 (76.2%) papers. Snyder and Bonzi (1998) reported the rate of self-references in physical sciences as (15%), social sciences (6%), and humanities (6%).

Self-references and references to others in each of the 63 papers (see Appendix) of H. J. Bhabha are chronologically profiled in Figure 1. His paper 'The theory of the elementary particles' (Bhabha, 1946) had maximum eight C-ASS-R. The maximum number of references to others was 42 in his paper titled 'On the penetrating component of cosmic radiation' (Bhabha, 1938a).

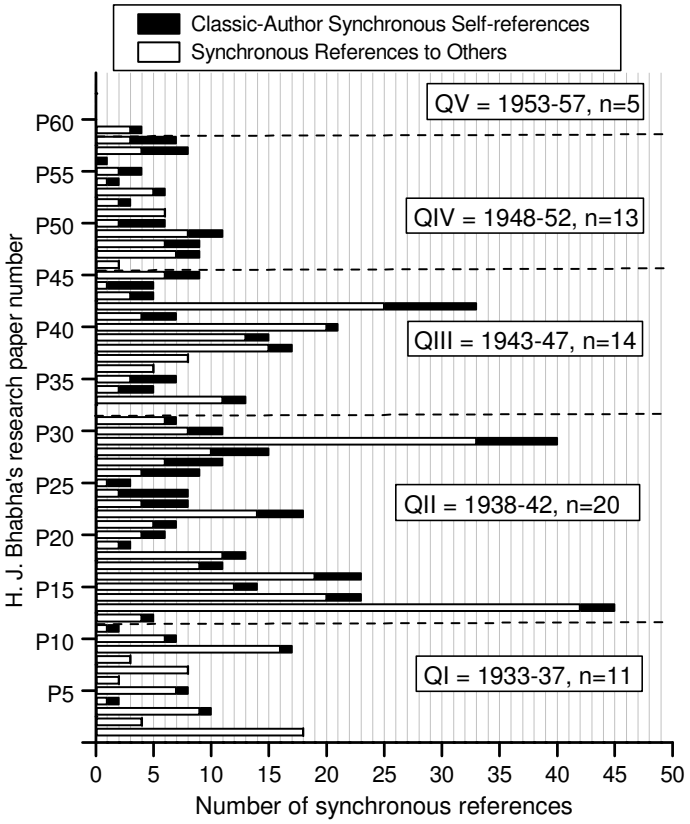


Figure 1. Number of synchronous references in the papers by H. J. Bhabha

Self-references ranged from 0 – 8, mean being 2.1, mode 1, median 2, and SD 1.9. These values for references to others were: range (0 – 42), mean (7.3), mode (2), median (5), and SD (6.3). Data reveals positively skewed curves for C-ASS-R, references to others, and total references. For C-ASS-R rate the range was 0–100 per cent. High rate of synchronous self-referencing indicates the extent of self-consistency in the research of the author during that period. This also indicates that the focus of the researcher was in a micro-domain that had proportionately few scientists working at global level and very few were associated with him. Moreover, confidentiality of the research endeavour had prime consideration at that time.

Publishing career quinquenniumwise (QI = 1933 – 37, QII = 1938 – 42, QIII = 1943 – 47, QIV = 1948 – 52, and QV = 1953 – 57) data for papers were sorted, and mean and standard deviation were calculated for plotting Figure 2. QII had high productivity of 20 papers with 64 self-references and 216 references to others.

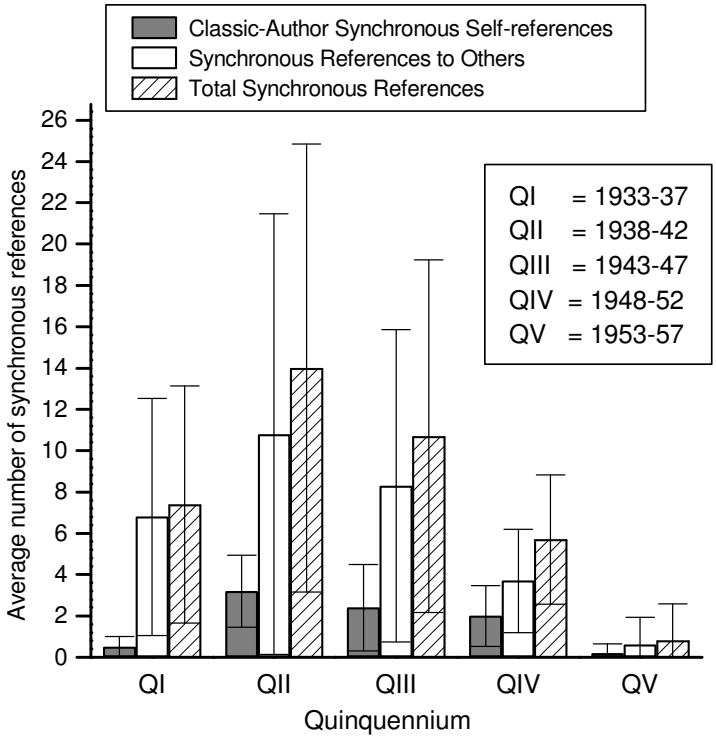


Figure 2. Research publishing career, quinquenniumwise statistics for the synchronous references (averages ± standard deviations), in the papers by H. J. Bhabha

Categorised data for the number of papers having C-ASS-R, references to others, and total references are provided in Table 1.

There were no C-ASS-R in 14 papers. Only one C-ASS-R was present in another 15 papers. Two C-ASS-R were in 12 papers. Three and four C-ASS-R were in eight papers each. There were five C-ASS-R in three papers. Six, seven, and eight C-ASS-R were found in one paper each.

Table 1: Synchronous references profile in the papers by H. J. Bhabha

| No. of ynchronous references class (c) | No. of papers considering the: | | | Total no. of references | | |
|---|---|---|---|---|---|---|
| | Classic-Author Self-References in each paper (s) | references to others in each paper (o) | total references in each paper (t) | self (c x s) | others (c x o) | Total (c x t) |
| 0 | 14 | 6 | 5 | 0 | 0 | 0 |
| 1 | 15 | 5 | 1 | 15 | 5 | 1 |
| 2 | 12 | 8 | 5 | 24 | 16 | 10 |
| 3 | 8 | 5 | 4 | 24 | 15 | 12 |
| 4 | 8 | 7 | 3 | 32 | 28 | 12 |
| 5 | 3 | 3 | 5 | 15 | 15 | 25 |
| 6 | 1 | 6 | 4 | 6 | 36 | 24 |
| 7 | 1 | 2 | 6 | 7 | 14 | 42 |
| 8 | 1 | 4 | 6 | 8 | 32 | 48 |
| 9 | 0 | 2 | 4 | 0 | 18 | 36 |
| 10 | 0 | 1 | 1 | 0 | 10 | 10 |
| 11 | 0 | 2 | 4 | 0 | 22 | 44 |
| 12 | 0 | 1 | 0 | 0 | 12 | 0 |
| 13 | 0 | 1 | 2 | 0 | 13 | 26 |
| 14 | 0 | 1 | 1 | 0 | 14 | 14 |
| 15 | 0 | 1 | 2 | 0 | 15 | 30 |
| 16 | 0 | 1 | 0 | 0 | 16 | 0 |
| 17 | 0 | 0 | 2 | 0 | 0 | 34 |
| 18 | 0 | 1 | 2 | 0 | 18 | 36 |
| 19 | 0 | 1 | 0 | 0 | 19 | 0 |
| 20 | 0 | 2 | 0 | 0 | 40 | 0 |
| 21 | 0 | 0 | 1 | 0 | 0 | 21 |
| 23 | 0 | 0 | 2 | 0 | 0 | 46 |
| 25 | 0 | 1 | 0 | 0 | 25 | 0 |
| 33 | 0 | 1 | 1 | 0 | 33 | 33 |
| 40 | 0 | 0 | 1 | 0 | 0 | 40 |
| 42 | 0 | 1 | 0 | 0 | 42 | 0 |
| 45 | 0 | 0 | 1 | 0 | 0 | 45 |
| Total | 63 | 63 | 63 | 131 | 458 | 589 |

Correlation between C-ASS-R and references to others is very low ($r = 0.27$) and reveals independence of each statistical data (Figure 3), as the occurrence of one event does not influence the probability of occurrence of the other event.

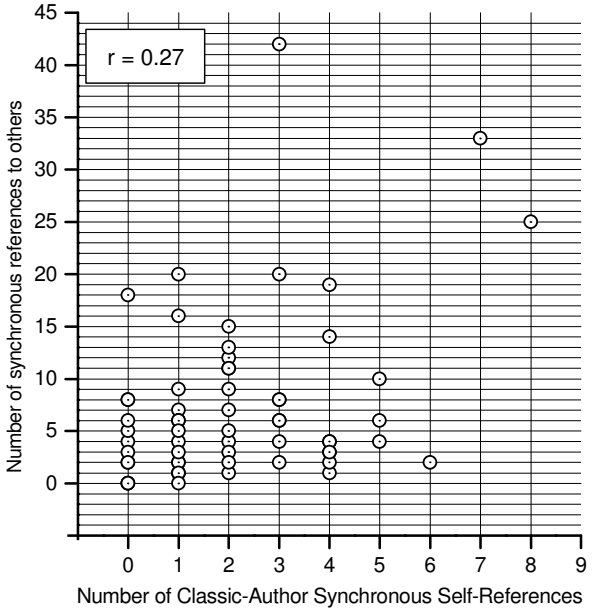


Figure 3. Scattergram for number of Classic-Author Synchronous Self-References in each paper and corresponding number of references to others in the papers by H. J. Bhabha

4.2 *Collaborative level and synchronous references*

The collaborative level i.e. by considering the number of author(s) in the byline of the publications (host papers of H. J. Bhabha) and correspondingly sorting data for number of C-ASS-R per paper, number of references to others per paper, and total number of references per paper, the data were plotted in Figure 4. Correlations are presented in Table 2. The number of C-ASS-R and synchronous references to others per paper and total number of synchronous references per paper continued to increase with the rise in the number of authors (two to four portion of the data) per host paper, hence, high positive correlation was observed for this portion of data.

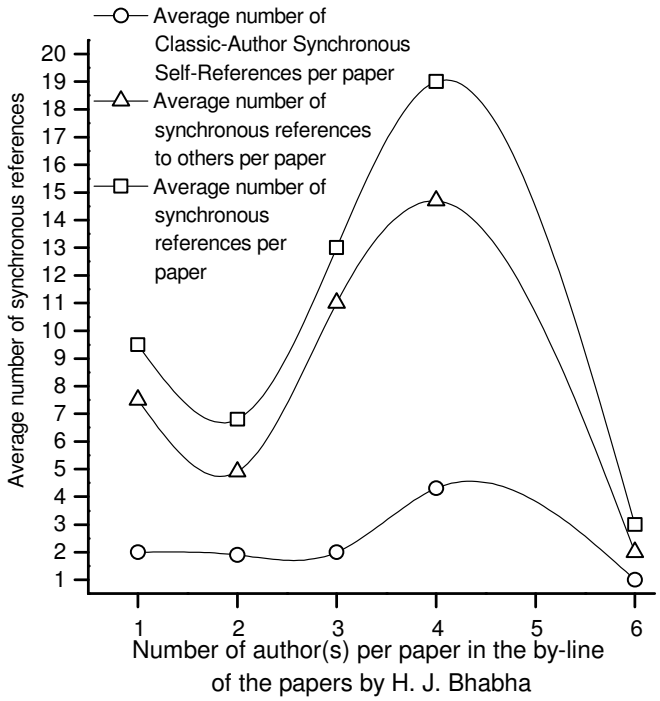


Figure 4. Average number of Classic-Author Synchronous Self-References, synchronous references to others, and number of synchronous references per paper, as a function of number of authors per paper as per the by-line of the publications by H. J. Bhabha

Table 2: Number of Classic-Author Synchronous Self-References, number of synchronous references to others, and number of synchronous references per paper, as a function of number of authors per paper as per the by-line of the publications by H. J. Bhabha

| Collaborative level i.e. no. of authors per host paper | Average no. of Classic- Author Synchronous Self-References per paper | Average no. of references to others per paper | Average no. of references per paper |
|---|---|---|---|
| 1 | 2.0 | 7.5 | 9.5 |
| 2 | 1.9 | 4.9 | 6.8 |
| 3 | 2.0 | 11.0 | 13.0 |
| 4 | 4.3 | 14.7 | 19.0 |
| 6 | 1.0 | 2.0 | 3.0 |
| Correlations with various considerations of the data: | | | |
| 1 to 6 authors | -0.089 | -0.188 | -0.172 |
| 1 to 4 authors | 0.774 | 0.839 | 0.850 |
| 2 to 4 authors | 0.884 | 0.990 | 1.000 |
| 2 to 6 authors | -0.208 | -0.293 | -0.282 |

When only run-of-the-mill papers were considered, Tagliacozzo (1977) did not find any relationship. However, when the diachronous self-citations of a random sample and two quality samples of cancer research papers were studied (Lawani, 1980), statistically significant positive correlations between mean self-citations and collaborative levels were obtained for each of the quality samples.

More cumulativeness at the level of individual researcher, are likely to cause more self-references. Here, explanation, and thus building on earlier work are important (Aksnes, 2003). At micro-domain levels one would find that scientists working in narrow specialities have the highest self-references counts (Garfield, 1979b). Self-referencing is natural and inevitable when a researcher is involved in in-depth research in a micro-domain (Pichappan, 2002).

In some way Garfield is also responsible for triggering the trend of citing each other (just for increasing citations), and citing one-self at the least relevant situations and is also self-motivated due to the forces (publish or perish syndrome) of evaluating for promotions based on citations to the credit of the individual, particularly in some universities and R & D institutions or while making decisions to select awardees. This situation did not exist during the period of H. J. Bhabha. Hence, Bhabha was not motivated by any other criteria but the thought contents of the documents cited, irrespective of whether the source belonged to himself or to others. Hence, his bias towards self-references is ruled out.

### 4.3 *Recency in referencing*

Age ($\Delta t$) of each reference (588) cited by H. J. Bhabha in his papers (Table 3) was calculated. One reference to others whose year of publication could not be ascertained was omitted. The age of the references ranged from zero years to 27 years for references to others, and from 14 years to +1 year (+ indicates reference forward in time i.e. one cited paper was published one year following the citing paper) for self-references. Proportion of C-ASS-R is more recent than references to others. About 50 per cent of the latest C-ASS-R were just one year old, whereas 50 per cent of references to others were three years old.

The recency in self-references is expected since authors are aware of their own publications. Having considered C-ASS-R of only one researcher, self-references are under the constraint of the researcher's age, which is explained by Aksnes (2003) as the author has no relevant former works within the micro-

domain, C-ASS-R at the beginning of the researcher's initial career were naturally more recent and fewer than references to others.

Table 3: Recency of synchronous references in the papers by H. J. Bhabha

| Recency | Age* (Δt) | Self-references | | | References to others | | |
|---|---|---|---|---|---|---|---|
| | | Freq. | % | Cumulative % | Freq. | % | Cumulative % |
| Very recent | +1 | 1 | 0.8 | 0.8 | 0 | 0.0 | 0.0 |
| | 0 | 25 | 19.1 | 19.9 | 50 | 10.9 | 11.1 |
| | -1 | 39 | 29.8 | 49.7 | 110 | 24.0 | 35.1 |
| | -2 | 24 | 18.3 | 68.0 | 60 | 13.1 | 48.1 |
| | -3 | 10 | 7.6 | 75.6 | 48 | 10.5 | 58.6 |
| Less recent | -4 | 11 | 8.4 | 84.0 | 35 | 7.6 | 66.2 |
| | -5 | 5 | 3.8 | 87.8 | 25 | 5.4 | 71.7 |
| | -6 | 5 | 3.8 | 91.6 | 37 | 8.1 | 79.7 |
| | -7 | 5 | 3.8 | 95.5 | 23 | 5.0 | 84.7 |
| | -8 | 2 | 1.5 | 97.0 | 25 | 5.4 | 90.2 |
| Old | -9 | 2 | 1.5 | 98.5 | 10 | 2.2 | 92.4 |
| | -10 | 0 | 0.0 | 98.5 | 12 | 2.6 | 95.0 |
| | -11 | 1 | 0.8 | 99.3 | 4 | 0.9 | 95.8 |
| | -12 | 0 | 0.0 | 99.3 | 4 | 0.9 | 96.7 |
| | -13 | 0 | 0.0 | 99.3 | 4 | 0.9 | 97.6 |
| | -14 | 1 | 0.8 | 100.0 | 4 | 0.9 | 98.5 |
| | -15 | 0 | 0.0 | 100.0 | 2 | 0.4 | 98.9 |
| | -16 | 0 | 0.0 | 100.0 | 1 | 0.2 | 99.1 |
| | -25 | 0 | 0.0 | 100.0 | 1 | 0.2 | 99.3 |
| | -26 | 0 | 0.0 | 100.0 | 1 | 0.2 | 99.6 |
| | -27 | 0 | 0.0 | 100.0 | 1 | 0.2 | 99.8 |
| | Total | 131 | 100.0 | | 457 | 99.6 | |

( *Age = The number of years the cited paper antedated or preceded the citing paper, + Age = Forward or in-press or antenatal reference, 0 Age = current reference i.e. having same publication year for citing and cited paper, − Age = Backward in time or publication of cited paper antedated the citing paper)

Three papers had exceptionally high time-lags for references to others of 25 years (Bhabha, 1941), which refers to Lorentz transformation (Lorentz, 1916); 26 years and 27 years (Bhabha, 1936) which refers to the invariance in the Maxwell equations, as was proved by a direct transformation by Cunningham (1909) and Bateman (1910).

The proportions of C-ASS-R and references to others (Figure 5) clearly illustrate the age of references with reference to the publication year of the citing paper.

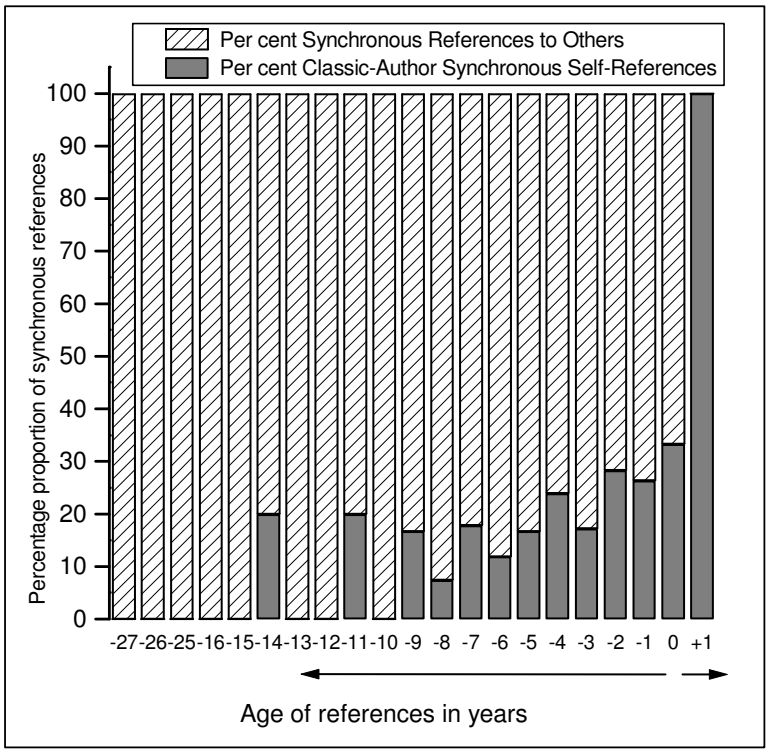


Figure 5. Agewise proportion of references to others and Classic-Author Synchronous Self-References depicted temporally in backward and forward (in-press) directions in the papers by H. J. Bhabha

4.4. *Temporal Profile of Classic-Author Synchronous Self-References*

Usually references given by authors run backwards in time, whether C-ASS-R or references to others. Bhabha has also cited his works that were in-press at the time of publishing his citing paper. These linked citing-cited network of documents are indicated (Figure 6), by rings (for the published papers) and by bullets (for the in-press papers) linking the events of occurrence of the C-ASS-R to the cited papers by H. J. Bhabha. Five of these in - press papers were published in the same year as the citing paper, but while arranging the papers in chronological order such papers were arranged after the respective citing paper.

The publication productivity in Quinquennium I shows only a few cross-linked papers, which is expected, at the beginning of a researcher's career. The density of cross-linked papers

increased in the QII and QIII and then decreased in the QIV and QV.

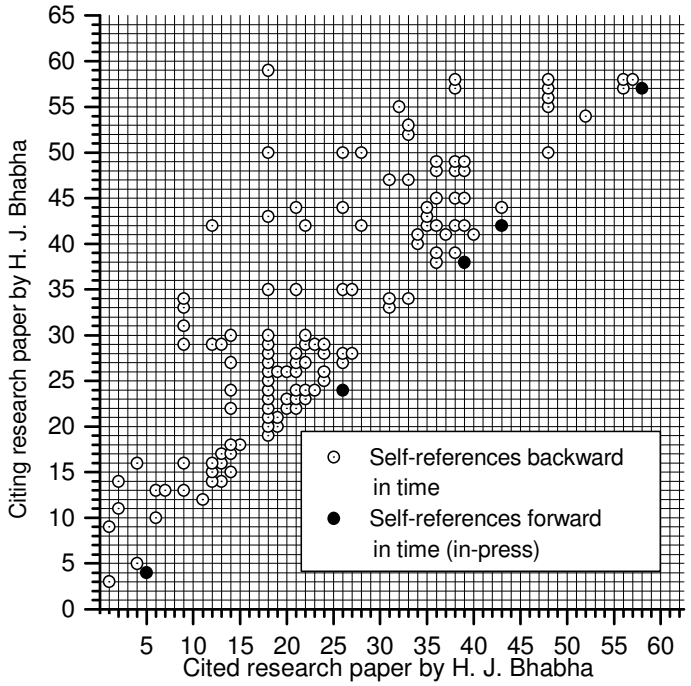


Figure 6. Temporal profile of Classic-Author Synchronous Self-References linkages in the citing and the cited papers by H. J. Bhabha

Two major clusters of self-references in 11 papers with 46 self-references and 12 papers with 33 self-references were indicators of focus in research activity where high C-ASS-R were found in association with one in-press and two in-press papers respectively. Pichappan (2002) has stated that one of the reasons to self-cite is to alert researchers of their forthcoming work (i.e. in-press). Such references have been termed as 'forward citations' (Baird and Oppenheim, 1994).

Another small cluster of C-ASS-R was in seven papers having 12 self-references, of which one was in-press. Hence, in-press self-references can be taken as indicators of highly active period(s) of the researcher with focus in the nuclear science micro-domain.

H. J. Bhabha had referred to his paper 'Classical theory of mesons' (Bhabha, 1939a) maximum 16 number of times. So it is considered as classic paper (price, 1986). First self-reference to this classic paper was in the same year (Bhabha, 1939b). Subsequently he continued to refer to this paper in his 11 consecutive papers (Bhabha, 1940a; Bhabha, 1940b; Bhabha, 1940c; Bhabha, 1941a; Bhabha and Madhava Rao, 1941;

Bhabha, 1941b; Bhabha and Corben, 1941; Bhabha, 1941c; Bhabha, 1941-42; Bhabha and Basu, 1942; and Bhabha, 1942) followed by four other papers (Bhabha and Harish-Chandra, 1944; Bhabha and Harish-Chandra, 1946; Bhabha, 1950; and Bhabha, 1953), which were published within a span of 15 years during 1939 to 1953. This shows his consistency in pursuing research in the domain of mesons. The nomenclature 'meson' itself is due to Bhabha, Kemmer and Pryce as stated in the preface (Sreekantan, et al., 1985). Dieks and Slooten (1986) commented that when an article can be regarded as a pioneering work in a certain discipline, the citation scores are determined more by the dynamics of the relevant scientific disciplines than by the aging of the articles.

After India's independence in 1947, Pandit Jawaharlal Nehru became the first Prime Minister of India and entrusted H. J. Bhabha with the responsibilities of building R & D facilities in atomic research for peaceful purposes. This involved Bhabha more in administrative activities. Hence, he had very few publications and self-references after 1947.

The vast literature on citation aging covers items such as research front specialities, information life-expectancy, obliteration, delayed recognition, longevity and life-time citation, and also citation induced differences by discipline, type and quality of the publication, and socio - historical aspects of the community stratification (Vlachý, 1985).

### 4.5 *Quinquennial publication productivity in relation to self-references*

Quinquennial publication productivity of H. J. Bhabha was correlated with his corresponding quinquennial Classic-Author Synchronous Self-References (Figure 7), which revealed high positive correlation ($r = 0.94$).

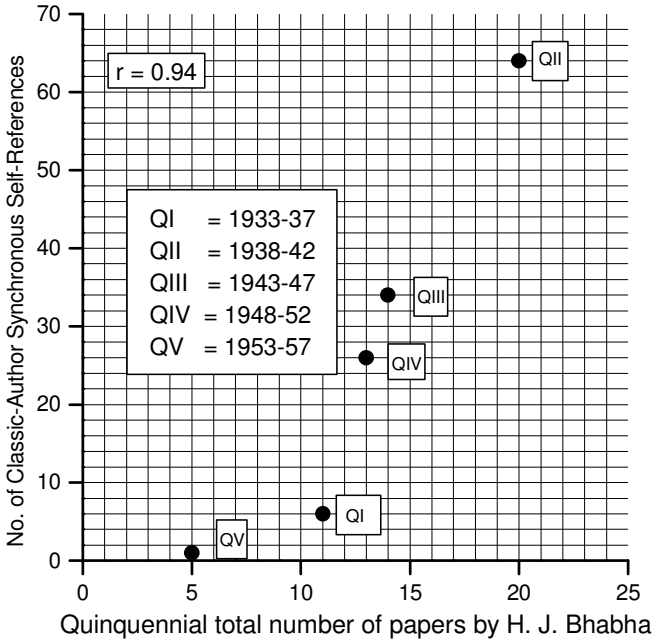


Figure 7. Correlation of quinquennial publication productivity of H. J. Bhabha with his Classic-Author Synchronous Self-References

Only high publication productive authors can have expertise and high self-references. So publication productivity is independent variable and self-references are dependent variable on publication productivity. Expertise is directly related to self-references. Publication productivity reference curve (Kalyane et al., 2001) of a role model researcher may be parallel and followed by synchronous self-references as an indication of continuity of the research, which needs to be explored.

## 5. Conclusions

A scientist continues progress in his research activity by building on ones own previous research and research by his contemporaries. H. J. Bhabha focused his research activity in nuclear science.

Self-references are an indication of expertise in the field. In the present context Classic-Author Synchronous Self-References (C-ASS-R) should be viewed as building-blocks in the recurrent and cumulative process of self-learning and in the mechanism of generating new knowledge. C-ASS-R rate of H. J. Bhabha was 22.2%. There was positive but low correlation (r = 0.27) between C-ASS-R and references to others. Positive correlation was obtained as the number of authors per paper increased from two to four for: average Classic Author

Synchronous Self-References; average synchronous references to others; and average references per paper.

Recency (50 % of the latest references) in references is an indicator of mainstream and frontier leadership in the domain. Recency in the papers of H. J. Bhabha was one year for C-ASS-R and three years for references to others. Temporal self-references network depicts the thought content connectedness of the documents. High positive correlation ($r = 0.94$) was observed for quinquennial publication productivity vs corresponding quinquennial C-ASS-R.

The two clusters of 12 papers each had concentration of C-ASS-R (46 and 33) associated with the in-press self-references were indicators of the periods of high focus and creativity (during 1939–1942 and 1945–1949) in generating new scientific knowledge at faster rate than before-and-after the episodes at an individual scientist micro-level. On a temporal scale, scientific discoveries often occur in a relatively short period of time since an important breakthrough in an idea or an appropriate new facility makes new advancements possible. This period where research career of an individual scientist seems to be the most productive for knowledge-generating activity, needs attention for human resource harnessing and further research.

Hence, administrators of science should identify such scientists and institutions at the Nurturing Phase (Mabe and Amin, 2002) for providing appropriate facilities required for their advancements.

This paper is dedicated to the reminiscences of Homi Jehangir Bhabha during Golden Jubilee of the Department of Atomic Energy (India).

**References**

Aksnes D. W. (2003), A macro study of self-citation, *Scientometrics*, 56 (2), 235-246.

Baird Laura M., Oppenheim Charles (1994), Do citations matter?, *Journal of Information Science*, 20 (1), 2-15.

Bateman H. (1910), *Proc. Lond. Math. Soc.*, 2 (8), 223.

Bhabha H. J. (1936), The wave equation in conformal space, *Proceedings of the Cambridge Philosophical Society*, 32, 622-631.

Bhabha H. J. (1938a), On the penetrating component of cosmic radiation*, Proceedings of the Royal Society of London*, 164A, 257-294. (Communicated by R. H. Fowler)

Bhabha H. J. (1938b), Nuclear forces, heavy electrons and the β decay, *Nature*, 141 Jan 15, 117-118.

Bhabha H. J. (1938c), On the theory of heavy electrons and nuclear forces, *Proceedings of the Royal Society of London*, 166A, 501-528.

Bhabha H. J. (1939a), Classical theory of mesons, *Proceedings of the Royal Society of London*, 172A, 384-409.
(Communicated by P. A. M. Dirac)

Bhabha H. J. (1941), Radiation reaction in relation to scattering phenomena, *Business Matters of the National Academy of Sciences, India*, 33-46. Reprinted in *Proceedings of National Academy of Science*, 12A (1942).

Bhabha H. J. (1946), The theory of the elementary particles, *Reports on Progress in Physics*, 10, 253-271.

Bhabha H. J. (1950), Some new results on relativistic wave equations, *Report of International Conference, 'Elementary particles'*, Bombay, (1951), 81.

Blackett P. M. S. (1948), Cloud chamber researches in nuclear physics and cosmic radiation, Nobel lecture, (13 December, 1948) In: Frangsmyr T., Ed., *Nobel Lectures Including Presentation Speeches and Laureates Biographies: Physics* (*1942–1962*), Singapore: World Scientific, (1998) 97-119.

Bonzi S., & Snyder H .W. (1991), Motivations for citations: A comparison of self-citations and citation to others, *Scientometrics*, 21 (2), 245 – 254.

Borgman C. L. & Furner J. (2002), Scholarly communication and bibliometrics, In: B. Cronin, ed. *Annual Review of Information Science and Technology*, 36. New Jersey: Information Today, Inc.: 3-72. Also available at: http://skipper.gseis.ucla.edu/faculty/jfurner/HTML/arist02.pdf

Cunningham E. (1910), *Proc. Lond. Math. Soc.*, 2 (8), 77.

Dieks D. & Slooten W. J. (1986), Historic papers in Physics – The case of Hugo Martin Tetrode, 1985-1931, *Czechoslovak Journal of Physics*, B36 (1), 39-42.

Garfield E. (1979a), Is citation analysis a legitimate evaluation tool? *Scientometrics* 1 (4), 359-375.

Garfield E. (1979b), *Citation Indexing - Its Theory and Application in Science, Technology and Humanities*. John Wiley and Sons, New York, p245.

Garfield E. (1994), The relationship between citing and cited publications: A question of relatedness, *Current Contents*, (13 April, 1994) 15. Also available at: http://www.isinet.com/isi/hot/essays/useofcitationdatabases/5.html

Harter S. P. (1992), Psychological relevance and information science, *Journal of American Society for Information Science*, 43 (9), 600-615.

Kademani B. S. & Kalyane V. L. (1996), Outstandingly cited and most significant publications of R. Chidambaram, a nuclear physicist, *Malaysian Journal of Library and Information Science*, 1 (1), 21-36.

Kademani B. S., Kalyane V. L. & Kademani A. B. (1994), Scientometric portrait of Nobel laureate Dr. C. V. Raman, *Indian Journal of Information, Library and Society*, 7 (3-4), 215-249.

Kademani B. S., Kalyane V. L. & Kademani A. B. (1996 a), Scientometric portrait of Nobel laureate S. Chandrasekhar, *JISSI: The International Journal of Scientometrics and Informetrics*, 2 (2-3), 119-135.

Kademani B. S., Kalyane V. L. & Kademani A. B. (1996 b), Scientometric portrait of Sir K. S. Krishnan. *Indian Journal of Information, Library and Society*, 9, (1-2): 125-150.

Kademani B. S., Kalyane V. L. & Vijai Kumar. (2000), Scientometric portrait of Vikram Ambalal Sarabhai: A citation analysis, *SRELS Journal of Information Management*, 37 (2), 107-132.

Kalyane V. L. & Sen B. K. (1998), Scientomentric portrait of C.R.Bhatia – An Indian geneticist and plant breeder, *Malaysian Journal of Library and Information Science*, 3 (1), 25-42.

Kalyane V. L. & Sen B. K. (2003), Research productivity of Tibor Braun: An analytical chemist-cum-scientometrician, *Annals of Library and Information Studies*, 50 (2), 47-61.

Kalyane V. L., Madan V. K. & Vijai Kumar (2001), Reference curve for Indian role model scientist, *Malaysian Journal of Library and Information Science*, 6 (1), 57-70.

Kalyane V. L., Prakasan E. R. & Vijai Kumar (2001), Scientometric portrait of Ranjit Kumar Mitra, *ILA Bulletin*, 37 (2), 39-53.

Kragh H. (1990), Dirac bibliometrics. In: *Dirac: A Scientific Biography.* Cambridge: Cambridge University, 293-314.

Lawani, S. M. (1980), Quality, collaboration and citations in cancer research: A bibliometric study, PhD Dissertation, Florida State University.

Lawani S. M. (1982), On the heterogeneity and classification of author self - citations, *Journal of the American Society for Information Science*, 33 (5), 281-284.

Lorentz (1916). The Theory of Electrons, Leipzig: B. G. Teubner

Mabe M. A. & Amin Mayur (2002), Dr Jekyll and Dr Hyde: Author-reader asymmetries in scholarly publishing, *Aslib Proceedings: New Information Persceptives*, 54 (3), 149-157.

Munnolli S. S. & Kalyane V. L. (2003), Scientometric portrait of Ram Gopal Rastogi. *Annals of Library and Information Studies*, 50 (1), 1-17.

Pichappan P. & Sarasvady, S. (2002), The other side of the coin: The intricacies of author self-citations. *Scientometrics*, 54 (2), 285-290.

Price D. J. (1986), *Little Science Big Science…and Beyond*, Columbia: Columbia University Press, 168. In: Belew, Richard K. (2000) *Finding Out About: A cognitive perspective on search engine technology and the WWW.* Cambridge: Cambridge University Press, 188.

Sen B. K. (1969), Indian contributions in Nobel lectures, *Annals of Library Science and Documentation*, 16 (1), 35-36.

Snyder H. & Bonzi S. (1998), Patterns of self-citation across disciplines (1980-1989). *Journal of Information Science*, 24 (6), 431-435.

Sreekantan B. V., Singh V. & Udgaonkar B. M. (eds). (1985). *Homi Jehangir Bhabha: Collected Scientific Papers*. Mumbai: Tata Institute of Fundamental Research: 1-1023.

Swarna T., Kalyane V. L. & Vijai Kumar. (2004), Eponymous citations to Homi Jehangir Bhabha. *Malaysian Journal of Library and Information Science*, 9 (1), (in-press).

Tagliacozzo R. (1977), Self-citations in scientific literature, *The Journal of Documentation*, 33 (4), 251-265.

Upadhye, Rekha P., Kalyane, V. L., Vijai Kumar & Prakasan, E. R. (2004), Scientometric Analysis of Synchronous References in the Physics Nobel Lectures, 1981-1985: A Pilot Study, *Scientometrics* (in-press).

Vlachy J. (1985), Citation histories of scientific publications, the data sources, *Scientometrics*, 7 (3-6), 505-528.

Yukawa H. (1949), Meson theory in its developments, Nobel lecture, (12 December,1949). In: FRANGSMYR T., Ed., *Nobel Lectures Including Presentation Speeches and Laureates Biographies : Physics* (*1942 – 1962*), Singapore: World Scientific, (1998) 128-134.

**APPENDIX**

Chronological personal bibliography of Research Publishing Career (1933–1954) of Homi Jehangir Bhabha

P1 Bhabha, H.J. 1933. Zur Absorption der Höhenstrahlung. *Zeits. für Physik.*, Vol. 86: pp. 120-130.

P2 Bhabha, H.J. 1934. Passage of Very Fast Protons through Matter. *Nature*, Vol. 134: p. 934.

P3 Bhabha, H.J. and Hulme, H.R. 1934. The Annihilation of Fast Positrons by Electrons in the K-Shell. *Proc. Royal Soc.*, Vol. 146 A: pp. 723-736. (Communicated by R.H. Fowler)

P4 Bhabha, H.J. 1935. On the Calculation of Pair Creation by Fast Charged Particles and the Effect of Screening. *Proc. Camb. Phil. Soc.*, Vol. 31: pp. 394-406.

P5 Bhabha, H.J. 1935. The Creation of Electron Pairs by Fast Charged Particles. *Proc. Royal Soc. A*, Vol. 152: pp. 559-586. (Communicated by R.H. Fowler)

P6 Bhabha, H.J. and Heitler, W. 1936. Passage of Fast Electrons through Matter. *Nature*, Vol. 138: p. 401.

P7 Bhabha, H.J. 1936. The Scattering of Positrons by Electrons with Exchange on Dirac's Theory of the Positron. *Proc. Royal Soc.* A, Vol. 154: pp. 195-206. (Communicated by R.H. Fowler)

P8 Bhabha, H.J. 1936. The Wave Equation in Conformal Space. *Proc. Camb. Phil. Soc.*, Vol. 32: pp. 622-631.

P9 Bhabha, H.J. and Heitler, W. 1937. The Passage of Fast Electrons and the Theory of Cosmic Showers. *Proc. Royal Soc. A*, Vol. 159: pp. 432-458. (Communicated by N.F. Mott)

P10 Bhabha, H.J. 1937. Negative Protons in Cosmic Radiations. *Nature*, 139: p. 415.

P11 Bhabha, H.J. 1937. Experimental Test of the Proton-Neutron Exchange Interaction. *Nature*, Vol. 139: p. 1021 and Continuation note on p. 1103.

P12 Bhabha, H.J. 1938. Nuclear Forces, Heavy Electrons and the β-Decay. *Nature*, Vol. 141: pp. 117-118.

P13 Bhabha, H.J. 1938. On the Penetrating Component of Cosmic Radiation. *Proc. Royal Soc. A*, Vol. 164: pp. 257-294. (Communicated by R.H. Fowler)

P14 Bhabha, H.J. 1938. On the Theory of Heavy Electrons and Nuclear Forces. *Proc. Royal Soc. A*, Vol. 166: pp. 501-528. (Communicated by R.H. Fowler)

P15 Bhabha, H.J. 1939. The Fundamental Length Introduced by the Theory of the Mesotron (Meson). *Nature*, Vol. 143: pp. 276-277.

P16 Bhabha, H.J. 1939. Cosmic Radiation. *J. Univ. Bombay*, Vol. 8, Pt. 3: pp. 3-16.

P17 Bhabha, H.J., Carmichael, H. and Chou, C.N. 1939. Production of Bursts and the Spin of the Meson. *The Proc. Indian Acad. Sci. A*, Vol. 10, no. 4: pp. 221-223. (Communicated by Sir C.V. Raman)

P18 Bhabha, H.J. 1939. Classical Theory of Mesons. *The Proc. Royal Soc. A*, Vol. 172, no. 5: pp. 384-409. (Communicated by P. A. M. Dirac)

P19 Bhabha, H.J. 1939. Classical Theory of Electrons. *The Proc. Indian Acad. Sci. A*, Vol. 10, no. 5: pp. 324-332. (Communicated by Sir C.V. Raman)

P20 Bhabha, H.J. 1940. Classical Theory of Point Dipoles. *Nature*, Vol. 145: pp. 819-820.

P21 Bhabha, H.J. 1940. Classical Theory of Spinning Particles. *The Proc. Indian Acad. Sci. A*, Vol. 11, no. 4: pp. 247-267 and Errata on p. 467. (Communicated by Sir C.V. Raman)

P22 Bhabha, H.J. 1940. On Elementary Heavy Particles with any Integral Charge. *The Proc. Indian Acad. Sci. A*, Vol. 11, no. 4: pp. 347-368 and Errata on p. 468. (Communicated by Sir C.V. Raman)

P23 Bhabha, H.J. 1941. Protons of Double Charge and the Scattering of Mesons. *Phys. Rev.*, Vol. 59: pp. 100-101.

P24 Bhabha, H.J. and Madhava Rao, B.S. 1941. The Scattering of Charged Mesons. *The Proc. Indian Acad. Sci. A*, Vol. 13, no. 1: pp. 9-24.

P25 Bhabha, H.J. 1941. Note on the Correspondence between the Classical and Quantum Theories of Neutral Mesons. *The Proc. Indian Acad. Sci. A*, Vol. 13, no. 4: pp. 249-254.

P26 Bhabha, H.J. and Corben, H.C. 1941. General Classical Theory of Spinning Particles in a Maxwell Field. *Proc. Royal Soc. A*, Vol. 178: pp. 273-314. (Communicated by P. A. M. Dirac)

P27 Bhabha, H.J. 1941. General Classical Theory of Spinning Particles in a Meson Field. *Proc. Royal Soc. A*, Vol. 178: pp. 314-350. (Communicated by P. A. M. Dirac)

P28 Bhabha, H.J. 1941. Radiation Reaction in relation to Scattering Phenomena. *Business Matters of the National Academy of Sciences:* pp.33-46. Reprinted in *Proc. Nat. Acad. Sci. A*, Vol. 12: pp. 33-46.

P29 Bhabha, H.J. 1941-42. Cosmic Radiation Summary of Ten Lectures Delivered at Calcutta University, December 1940. *Sci. Cult.*, Vol. 7: pp. 470-476 and pp. 520-527.

P30 Bhabha, H.J. and Basu, D. 1942. The Theory of Particles of Spin Half and the Compton Effect. *The Proc. Indian Acad. Sci. A*, Vol. 15, no. 2: pp. 105-117 and Erratum on pp. 461-463.

P31 Bhabha, H.J. and Chakrabarty, S.K. 1942. Calculations on the Cascade Theory with Collision Loss. *The Proc. Indian Acad. Sci. A*, Vol. 15, no.6: pp. 464-476.

P32 Bhabha, H.J. 1943. Recent Advances in the Theory of Fundamental Particles. Presidential Address, Section of Physics, 30th Indian Science Congress, Calcutta, 3. *Proc. Indian Sci. Congress*, Vol. 30: pp. 33-49.

P33 Bhabha, H.J. and Chakrabarty, S.K. 1943. The Cascade Theory with Collision Loss. *Proc. Royal Soc. A*, Vol. 181: pp. 267-303.

P34 Bhabha, H.J. 1944. Note on the Separation of the Electronic and Non-Electronic Components of Cosmic Radiation. *The Proc. Indian Acad. Sci. A*, Vol. 19, no. 1: pp. 23-36.

P35 Bhabha, H.J. and Harish-Chandra. 1944. On the Theory of Point Particles. *Proc. Royal Soc. A*, Vol. 183: pp. 134-141.
P36 Bhabha, H.J. 1945. Relativistic Equations for Particles of Arbitrary Spin. *Curr. Sci.*, Vol. 14: pp. 89-90.
P37 Bhabha, H.J., Chandrashekhar Aiya, S.V., Hoteko, H.E. and Saxena, R.C. 1945. Latitude Effect for Mesons. *Curr. Sci.*, Vol. 14: pp. 98-99.
P38 Bhabha, H.J. 1945. Relativistic Wave Equations for the Elementary Particles. *Rev. Mod. Phys.*, Vol. 17: pp. 200-216.
P39 Bhabha, H.J. 1945. Relativistic Wave Equations for the Proton. *Proc. Indian Acad. Sci. A*, Vol. 21: pp. 241-264.
P40 Bhabha, H.J., Chandrashekhar Aiya, S.V., Hoteko, H.E. and Saxena, R.C. 1945. Meson Intensity in the Substratosphere. *The Phys. Rev.*, Vol. 68, no. 7-8: pp. 147-152.
P41 Bhabha, H.J., Chandrashekhar Aiya, S.V., Hoteko, H.E. and Saxena, R.C. 1946. Meson Intensity in the Substratosphere II. *Proc. Nat. Inst. Sci. India*, Vol. 12, no. 4: pp. 219-226.
P42 Bhabha, H.J. 1946. The Theory of the Elementary Particles. *Rep. Progr. Phys.*, Vol. 10: pp. 253-271.
P43 Bhabha, H.J. and Harish-Chandra. 1946. On the Fields and Equations of Motion of Point-Particles. *Proc. Royal Soc. A*, Vol. 185: pp. 250-268.
P44 Bhabha, H.J. 1946. On the Expansibility of Solutions in Powers of the Interaction Constants. *The Phys. Rev.*, Vol. 70, no. 9-10: pp. 759-760.
P45 Bhabha, H.J. 1947. Relativistic Wave Equations for the Elementary Particles, Physical Society Cambridge Conf. Rep. Internat. Conf. "Fundamental Particles", 1946. *Phys. Soc. Camb.*, Vol. 1: pp. 22-36.
P46 Bhabha, H.J. and Daniel, R.R. 1948. Meson Scattering with Nuclear Excitation. *Nature*, Vol. 161: pp. 883-885.
P47 Bhabha, H.J. and Chakrabarty, S.K. 1948. Further Calculations on the Cascade Theory. *The Phys. Rev.*, Vol. 74, no. 10: pp. 1352-1363.
P48 Bhabha, H.J. 1949. On the Postulational Basis of the Theory of Elementary Particles. *Rev. Mod. Phys.*, Vol. 21, no. 3: pp. 451-462.
P49 Bhabha, H.J. 1949. Theory of Elementary Particles-Fields. Lectures Delivered at *2nd Summer Seminar Canadian Math. Congress*: pp.1-103, held at University of British Columbia, Aug-1949.
P50 Bhabha, H.J. 1950. On a New Theory of Nuclear Forces. *The Phys. Rev.*, Vol. 77, no. 5: pp. 665-668.
P51 Taylor, H.J., Bhabha, H.J., Daniel, R.R., Heeramaneck, J.R., Swami, M.S. and Shrikantia, G.S. 1950. Stars and Single Tracks in Nuclear Plates. *The Proc. Indian Acad. Sci. A*, Vol. 31, no. 2: pp. 130-139.
P52 Bhabha, H.J. 1950. On the Stochastic Theory of Continuous Parametric Systems and its Application to Electron Cascades. *Proc. Royal Soc. A*, Vol. 202: pp. 301-322.
P53 Bhabha, H.J. and Ramakrishnan, A. 1950. The Mean Square Deviation of the Number of Electrons and Quanta in the Cascade Theory. *The Proc. Indian Acad. Sci. A*, Vol. 32, no.3: pp. 141-153.
P54 Bhabha, H.J. 1950. Note on the Complete Stochastic Treatment of Electron Cascades. *The Proc. Indian Acad. Sci. A*, Vol. 32, no.3: pp.154-161.
P55 Bhabha, H.J. 1951. The Present Concept of the Physical World, Presidential Address, 38th Indian Science Congress, Bangalore, 1951. *Proc. Indian Sci. Congress*, Vol. 38: pp. 1-11.
P56 Bhabha, H.J. 1951. Some New Results on Relativistic Wave Equations. *Rep. Internat. Conf. "Elementary Particles", Session VI, Relativistic Wave Equations* (Chairman: G. Wintzel). Bombay 1950 T.I.F.R., Bombay: pp. 81-93.
P57 Bhabha, H.J. 1951. On a Class of Relativistic Wave-Equations of Spin 3/2. *The Proc. Indian Acad. Sci. A*, Vol. 34, no.6: pp. 335-354.
P58 Bhabha, H.J. 1952. An Equation for a Particle with Two Mass States and Positive Charge Density. *Phil. Mag. Ser. VII*, Vol. 43: pp. 33-47.
P50 Bhabha, H.J. 1953. Production of Mesons and the Localization of Field

Energy. *Proc. Royal Soc. A*, Vol. 219: pp. 293-303.
P60 Bhabha, H.J. 1954. High-Altitude Measurements of Intensity of Cosmic Radiation. *Proc. Internat. Conf. "Theoretical Physics"*, Tokyo, 1953 Science Council of Japan: pp. 95-97.
P61 Bhabha, H.J. 1954. Investigation of Heavy Mesons by Means of a Solid Emulsion Block. *Proc. Internat. Conf. "Theoretical Physics"*, Tokyo, 1953 Science Council of Japan: pp. 98-103.
P62 Bhabha, H.J. 1954. Summary of the Bagneres de Bigorre Conference Report. *Proc. Internat. Conf. "Theoretical Physics"*, Tokyo, 1953 Science Council of Japan: pp. 131-136.
P63 Bhabha, H.J. 1954. On Multiple Meson Production. *Proc. Internat. Conf. "Theoretical Physics"*, Tokyo, 1953 Science Council of Japan: pp. 143-148.

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