

## Bhabha Scattering: A Scientometric View

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### ABSTRACT

This paper attempts to highlight quantitatively the growth and development of world literature on Bhabha Scattering in terms of publication output as per International Nuclear Information System (INIS) (1970-2008), *Science Citation Index* (1982-2008), and INSPEC (1969-2008) databases. During 1969-2008 a total of 1305 papers were published by the scientists in the field Bhabha Scattering. The average number of papers published per year was 32.62. The highest numbers of papers 66, were published in 1988 and 1997, respectively. There were 47 countries involved in the research in this field. Germany is the top producing country with 421 papers followed by USA with 420 papers, Italy with 293 papers, and Switzerland with 263 papers. Authorship and collaboration trends were towards multi-authored papers. There were 888 (68.05 per cent) collaborative papers. Istituto Nazionale di Fisica Nucleare (INFN), Italy, topped the list with 256 papers followed by European Organisation for Nuclear Research (CERN), Switzerland, with 243 papers. The most preferred journals by the scientists were: *Physics Letters-B* with 188 papers, *Nuclear Physics-B* with 91 papers, and *Physical Review-D* with 90 papers. The high frequency keywords were: Bhabha scattering (731), radiative corrections (215), annihilation (214), electrons (208), positrons (205), and pair production (202).

**Keywords:** Bhabha scattering, electron-positron scattering, scientometrics, bibliometrics, Homi Jehangir Bhabha, publication productivity.

### 1. INTRODUCTION

Homi Jehangir Bhabha, the architect of Indian Nuclear Science and Technology was born on 30<sup>th</sup> October 1909 in Mumbai. He had his early education at Cathedral and John Connon Schools, Elphinston College and Institute of Science, Mumbai. Bhabha joined Caius College, Cambridge, in 1927 and was a scholar of the college during 1929-1930. Bhabha obtained Mechanical Sciences Tripos in First Class in June 1930 and thereafter went on to work as a research student in theoretical physics. When the Second World War broke out in 1939, Bhabha came to India on holidays and remained in India thereafter. He spent nearly five years at Indian Institute of Science, Bangalore, where he came in contact with the Nobel Laureate Sir C.V. Raman.

Dr Bhabha established Tata Institute of Fundamental Research (TIFR) and Bhabha Atomic Research Centre (BARC) (formerly Atomic Energy Establishment Trombay), and other DAE establishments in India. He held many positions in different capacities and received many awards/honours including Padma Bhushan in

recognition of his outstanding contribution in the field of Nuclear Science and Technology. Bhabha was also an institution builder, painter, musician, educationist and administrator. He died in a tragic air crash in Mont Blanc on 24<sup>th</sup> January 1966<sup>1-5</sup>.

Bhabha was a distinguished theoretical physicist. He worked in the field of elementary particles, high-energy physics for a period of about two decades (1933-1954), and made many significant contributions. His name, in this field, is associated with Bhabha Scattering, Bhabha-Heitler Cascade theory of Cosmic-Ray Showers, Bhabha-Corben theory of Relativistic Spinning Point Particles, Relativistic Bhabha Equations, etc. Bhabha was the first person to calculate the cross-section for electron-positron scattering known as Bhabha Scattering<sup>6</sup>. There are two leading-order Feynman diagrams contributing to this interaction—an annihilation process and a scattering process. The Bhabha Scattering rate is used as a luminosity monitor in electron-positron colliders. This paper is a tribute to Homi Jehangir Bhabha on his birth centenary year (30 October 2008-30 October 2009) to highlight the research activities carried out so far by other

researchers across the globe in the field Bhabha Scattering. Research papers are one of the quantitative measures for the basic research activity in a country. It must be added, however, that what excites the common man, as well as the scientific community, are the peaks of scientific and technological achievement, not just the statistics on papers. There are also other kinds of research and technology developments—mission-oriented, industry-oriented, country-specific, etc. Progress in these cannot be obviously measured by counting only the number of papers<sup>7</sup>. Many scientometric studies have appeared in the literature to focus on the performance of nuclear science in various domains<sup>8-10</sup>.

## 2. OBJECTIVES

The main objective of the study is to present the growth of world literature on Bhabha Scattering and make the quantitative assessment of the research in terms of year-wise research output, geographical distribution of research output, nature of collaboration, highly productive researchers in the field, characteristics of highly productive institutions, channels of communications used by the scientists, and the high frequency keywords appeared in the keywords field in the databases.

## 3. MATERIALS AND METHODS

Data was collected from the INIS (1970-2008), SC/ (1982-2008), and INSPEC (1969-2008) databases. The search string Bhabha Scattering in title, abstract and keywords field was used to download the records on the subject. Duplicate records from these three databases were removed. About 1305 records were analysed using the spreadsheet application.

## 4. RESULTS AND DISCUSSIONS

### 4.1 Year-wise Growth of Papers and Authorship Pattern

During 1969-2008, about 1305 papers were published on Bhabha Scattering by various countries. The average number of papers produced per year was 32.62. The highest numbers of papers (66) were published in the years 1988 and 1997, respectively. Figure 1 gives year-wise papers published, and authorship trend on Bhabha Scattering. Figure 1 shows that growth of the literature was low during 1969-1972 but peaked in 1988 and 1997. It can also be seen from Fig. 1 that collaboration pattern is towards multi-authored papers.

### 4.2 Geographical Distribution of Research Output

There were as many as 47 countries where research is being carried out in the field of Bhabha Scattering. Table 1 lists these countries with their share of research output. Germany and USA are the top research paper producing countries with 421 and 420 papers, respectively. Italy with 293 papers, Switzerland with 263 papers, France with 178 papers, England with 155 papers, and Russia with 150 papers are the other countries doing significant research in the field.

### 4.3 Co-authorship Index

Co-authorship Index (CAI) has been elaborated by Schubert and Brown<sup>11</sup> and is obtained by calculating proportionally the papers by single-, two-, multi- and mega-authored papers for different five year blocks. This

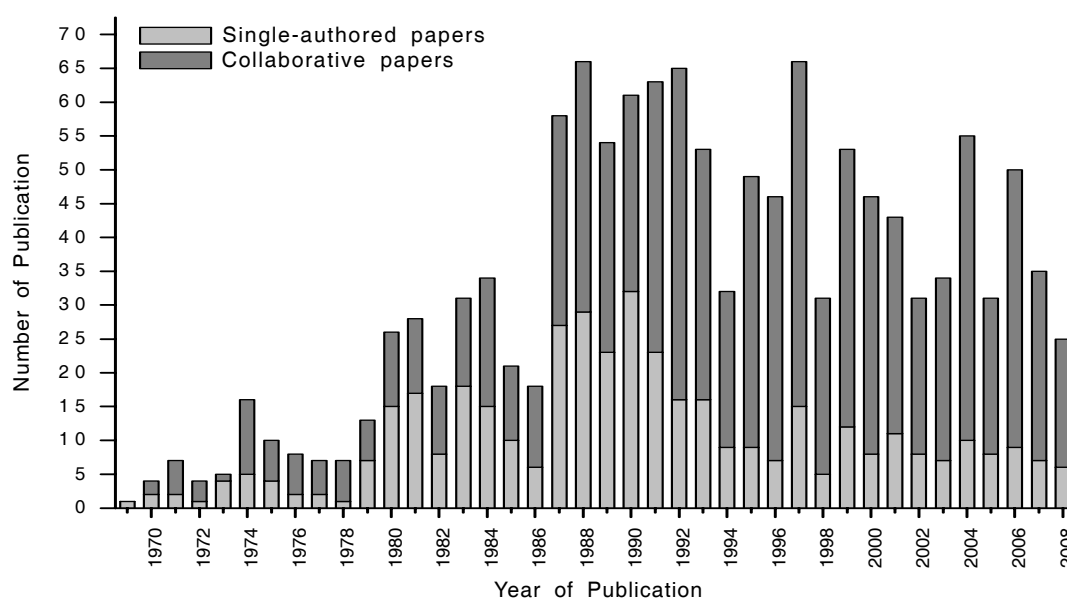


Figure 1. Year-wise publication productivity on Bhabha scattering.

**Table 1. Country-wise distribution of papers on Bhabha scattering**

| Sl. No. | Country         | No. of Papers | S. No. | Country      | No. of papers |
|---------|-----------------|---------------|--------|--------------|---------------|
| 1       | Germany         | 421           | 25     | Scotland     | 41            |
| 2       | USA             | 420           | 26     | Taiwan       | 41            |
| 3       | Italy           | 293           | 27     | Sweden       | 38            |
| 4       | Switzerland     | 263           | 28     | Belgium      | 35            |
| 5       | France          | 178           | 29     | Denmark      | 33            |
| 6       | England         | 155           | 30     | Ukraine      | 27            |
| 7       | Russia          | 150           | 31     | Brazil       | 26            |
| 8       | Poland          | 141           | 32     | Portugal     | 26            |
| 9       | Japan           | 132           | 33     | Czech-Rep    | 25            |
| 10      | Netherlands     | 127           | 34     | Slovenia     | 24            |
| 11      | Spain           | 116           | 35     | Slovakia     | 17            |
| 12      | Peoples-R-China | 109           | 36     | Ireland      | 14            |
| 13      | Hungary         | 93            | 37     | Byelarus     | 13            |
| 14      | Canada          | 90            | 38     | Mexico       | 4             |
| 15      | India           | 82            | 39     | Estonia      | 2             |
| 16      | Israel          | 71            | 40     | Kazakhstan   | 2             |
| 17      | South-Korea     | 58            | 41     | South-Africa | 2             |
| 18      | Finland         | 57            | 42     | Australia    | 1             |
| 19      | Norway          | 53            | 43     | Madrid       | 1             |
| 20      | Bulgaria        | 50            | 44     | Morocco      | 1             |
| 21      | Greece          | 50            | 45     | Rep-Georgia  | 1             |
| 22      | Cyprus          | 47            | 46     | Rep-Korea    | 1             |
| 23      | Romania         | 47            | 47     | Turkey       | 1             |
| 24      | Austria         | 43            |        |              |               |

method is similar to the Activity Index suggested by Frame<sup>12</sup>. To find out CAI, papers were divided into four categories according to the number of authors. These are: single-authored, two-authored, multi-authored papers (with three to four authors), and mega-authored papers with five and more authors.

The CAI was calculated for different five year blocks (Table 2) for the study. It was found that single-authored

papers were more during 1969-1973, 1979-1983, 1984-1988, and 1989-1993; two- authored papers during 1969-1973, 1974-1978, 1979-1983, 1994-1998, and 2004-2008; multi-authored papers during 1989-1993, 1994-1998, 1999-2003, and 2004-2008; and mega-authored papers during 1994-1998, 1999-2003, and 2004-2008. This indicates that solo research activity prevailed during 1969-1993, whereas the group (five or more authors) collaborative research activity was high during 1994-2008.

**Table 2. Co-authorship index for the papers in different five year blocks in Bhabha scattering research**

| Years' block               | Co-authorship Index    |                     |                       |                      | Total no. of papers |
|----------------------------|------------------------|---------------------|-----------------------|----------------------|---------------------|
|                            | Single-authored papers | Two-authored papers | Multi-authored papers | Mega-authored papers |                     |
| 1969-1973                  | 10 (1.49)              | 03 (1.11)           | 2 (0.44)              | 06 (0.86)            | 21                  |
| 1974-1978                  | 14 (0.91)              | 16 (2.59)           | 7 (0.67)              | 11 (0.69)            | 48                  |
| 1979-1983                  | 65 (1.75)              | 15 (1.00)           | 5 (0.20)              | 31 (0.80)            | 116                 |
| 1984-1988                  | 87 (1.38)              | 22 (0.87)           | 34 (0.79)             | 54 (0.82)            | 197                 |
| 1989-1993                  | 110 (1.16)             | 30 (0.79)           | 70 (1.08)             | 86 (0.87)            | 296                 |
| 1994-1998                  | 45 (0.63)              | 34 (1.18)           | 56 (1.14)             | 89 (1.19)            | 224                 |
| 1999-2003                  | 46 (0.70)              | 16 (0.6)            | 55 (1.22)             | 90 (1.3)             | 207                 |
| 2004-2008                  | 40 (0.64)              | 32 (1.27)           | 56 (1.31)             | 68 (1.04)            | 196                 |
| <b>Total no. of papers</b> | <b>417</b>             | <b>168</b>          | <b>285</b>            | <b>435</b>           | <b>1305</b>         |

#### 4.4 Most Prolific Authors

In all, there were 6655 authors who contributed to this field. The most prolific authors were Martin, J.P. with 90 papers followed by Alexander, G.; Gary, G.W. and Hawkes, C.M. with 67 papers each; Becker, U. with 64 papers; Dittmar, M. with 63 papers; and Branson, J.G. with 61 papers. Prolific authors who contributed 50 or more papers are listed in Table 3.

#### 4.5 Organisation-wise Distribution of Papers

In all, there were 655 organisations involved in the research activity in the field of Bhabha Scattering. Table 4 shows the organisations that have contributed 50 or more papers during 1969-2008. INFN, Italy, topped the list with 256 papers followed by CERN, Switzerland, with 243 papers; University of Bologna, Italy, with 144 papers; DESY, Germany, with 138 papers; University of Hamburg,

Table 3. List of authors with  $\geq 50$  papers in Bhabha scattering research

| Author name     | No. of papers |
|-----------------|---------------|
| Martin, J.P.    | 90            |
| Alexander, G.   | 67            |
| Gary, J.W.      | 67            |
| Hawkes, C.M.    | 67            |
| Becker, U.      | 64            |
| Dittmar, M.     | 63            |
| Branson, J.G.   | 61            |
| Allison, J.     | 60            |
| Kawamoto, T.    | 60            |
| Lloyd, S.L.     | 60            |
| Mikenberg, G.   | 60            |
| Bella, G.       | 59            |
| Karlen, D.      | 59            |
| Barlow, R.J.    | 58            |
| Bell, K.W.      | 58            |
| Bethke, S.      | 58            |
| Chang, C.Y.     | 58            |
| Duchovni, E.    | 58            |
| Kellogg, R.G.   | 58            |
| Kobayashi, T.   | 58            |
| Loebinger, F.K. | 58            |
| Chen, A.        | 57            |
| Komamiya, S.    | 57            |
| Orito, S.       | 57            |
| Ward, B.F.L.    | 57            |
| Heuer, R.D.     | 56            |
| Mattig, P.      | 56            |
| Miller, D.J.    | 56            |
| Carter, A.A.    | 55            |
| Charlton, D.G.  | 55            |
| Chen, H.S.      | 55            |
| Clare, R.       | 55            |
| Duerdoth, I.P.  | 55            |
| Mori, T.        | 55            |
| Biebel, O.      | 54            |
| Bourilkov, D.   | 54            |
| Burger, J.D.    | 54            |
| Carter, J.R.    | 54            |
| Chiefari, G.    | 54            |
| Field, J.H.     | 54            |
| Hauschild, M.   | 54            |
| Hemingway, R.J. | 54            |
| Herten, G.      | 54            |
| Hill, J.C.      | 54            |
| Jovanovic, P.   | 54            |
| Lellouch, D.    | 54            |
| Martin, A.J.    | 54            |
| Meijers, F.     | 54            |
| Oreglia, M.J.   | 54            |
| Roney, J.M.     | 54            |
| Adriani, O.     | 53            |
| Aloisio, A.     | 53            |
| Arcelli, S.     | 53            |

| Name            | No. of papers |
|-----------------|---------------|
| Axen, D.        | 53            |
| Banerjee, S.    | 53            |
| Behnke, T.      | 53            |
| Bock, P.        | 53            |
| Burckhart, H.J. | 53            |
| Cuffiani, M.    | 53            |
| Dado, S.        | 53            |
| Duckeck, G.     | 53            |
| Engler, A.      | 53            |
| Fabbri, F.      | 53            |
| Giacomelli, G.  | 53            |
| Goldberg, J.    | 53            |
| Hanson, G.G.    | 53            |
| Keeler, R.K.    | 53            |
| Kraemer, R.W.   | 53            |
| Lafferty, G.D.  | 53            |
| Layter, J.G.    | 53            |
| Ludwig, J.      | 53            |
| Marcellini, S.  | 53            |
| Mckenna, J.     | 53            |
| Merritt, F.S.   | 53            |
| Mes, H.         | 53            |
| Michelini, A.   | 53            |
| Mohr, W.        | 53            |
| Oneale, S.W.    | 53            |
| Pilcher, J.E.   | 53            |
| Plane, D.E.     | 53            |
| Runge, K.       | 53            |
| Vonkrogh, J.    | 53            |
| Anderson, K.J.  | 52            |
| Bobbink, G.J.   | 52            |
| Bohm, A.        | 52            |
| Brown, R.M.     | 52            |
| Capell, M.      | 52            |
| Carnegie, R.K.  | 52            |
| Chen, G.M.      | 52            |
| Coignet, G.     | 52            |
| Geichgimbel, C. | 52            |
| Gentile, S.     | 52            |
| Igokemenes, P.  | 52            |
| Jeremie, H.     | 52            |
| Kawagoe, K.     | 52            |
| Kennedy, B.W.   | 52            |
| LeCoultr, P.    | 52            |
| Levinson, L.    | 52            |
| Mashimo, T.     | 52            |
| Anderhub, H.    | 51            |
| Azmoon, T.      | 51            |
| Azuelos, G.     | 51            |
| Bay, A.         | 51            |
| Berdugo, J.     | 51            |
| Borgia, B.      | 51            |
| Cerrada, M.     | 51            |

| Name             | No. of papers |
|------------------|---------------|
| Fregusan, T.     | 51            |
| Fesefeldt, F.    | 51            |
| Filthaut, F.     | 51            |
| Ganguli, S.N.    | 51            |
| Gurtu, A.        | 51            |
| Hofer, H.        | 51            |
| Hou, S.R.        | 51            |
| Jadach, S.       | 51            |
| Landi, G.        | 51            |
| Letts, J.        | 51            |
| Alcaraz, J.      | 50            |
| Alvigi, M.G.     | 50            |
| Andreev, V.P.    | 50            |
| Arefiev, A.      | 50            |
| Bagnaia, P.      | 50            |
| Battiston, R.    | 50            |
| Berges, P.       | 50            |
| Bertucci, B.     | 50            |
| Betev, B.L.      | 50            |
| Biland, A.       | 50            |
| Chemarin, M.     | 50            |
| Chen, H.F.       | 50            |
| Clare, I.        | 50            |
| Colino, N.       | 50            |
| Deiters, K.      | 50            |
| Denes, P.        | 50            |
| Diemoz, M.       | 50            |
| Dionisi, C.      | 50            |
| Doria, A.        | 50            |
| Duchesneau, D.   | 50            |
| Eppling, F.J.    | 50            |
| Extermann, P.    | 50            |
| Falciano, S.     | 50            |
| Fay, J.          | 50            |
| Fisher, P.H.     | 50            |
| Forconi, G.      | 50            |
| Freudenreich, K. | 50            |
| Gutay, L.J.      | 50            |
| Hebbeker, T.     | 50            |
| Herve, A.        | 50            |
| Jin, B.N.        | 50            |
| Jones, L.W.      | 50            |
| Kaur, M.         | 50            |
| Kittel, W.       | 50            |
| Konig, A.C.      | 50            |
| Kunin, A.        | 50            |
| Lebrun, P.       | 50            |
| Lecoq, P.        | 50            |
| Leiste, R.       | 50            |
| Linde, F.L.      | 50            |
| Lohmann, W.      | 50            |

**Table 4. Distribution of institutes as per number of papers in Bhabha scattering research**

| Sl. No. | Institute                                                                       | Country         | No. of papers |
|---------|---------------------------------------------------------------------------------|-----------------|---------------|
| 1       | Istituto Nazionale di Fisica Nucleare (INFN)                                    | Italy           | 256           |
| 2       | European Organisation for Nuclear Research (CERN)                               | Switzerland     | 243           |
| 3       | University of Bologna                                                           | Italy           | 144           |
| 4       | Deutsches Elektronen Synchrotron (DESY)                                         | Germany         | 138           |
| 5       | University of Hamburg                                                           | Germany         | 124           |
| 6       | Rutherford Appleton Laboratory                                                  | England         | 116           |
| 7       | University of Heidelberg                                                        | Germany         | 89            |
| 8       | University of California Riverside                                              | USA             | 84            |
| 9       | Rhein Westfal Th Aachen                                                         | Germany         | 82            |
| 10      | Massachusetts Institute of Technology                                           | USA             | 79            |
| 11      | University of Lyon 1                                                            | France          | 77            |
| 12      | University of Roma La Sapienza                                                  | Italy           | 77            |
| 13      | Stanford University                                                             | USA             | 76            |
| 14      | University of Maryland                                                          | USA             | 75            |
| 15      | University of Birmingham                                                        | England         | 71            |
| 16      | University of Manchester                                                        | England         | 71            |
| 17      | University of Florence                                                          | Italy           | 68            |
| 18      | University of Montreal                                                          | Canada          | 68            |
| 19      | University of Oregon                                                            | USA             | 68            |
| 20      | Institute of High Energy Physics                                                | Peoples-R-China | 67            |
| 21      | Princeton University                                                            | USA             | 67            |
| 22      | Joint Institute of Nuclear Research                                             | Russia          | 66            |
| 23      | University of British Columbia                                                  | Canada          | 66            |
| 24      | University of Tokyo                                                             | Japan           | 66            |
| 25      | Institute of Nuclear Physics                                                    | Poland          | 65            |
| 26      | California Institute of Technology (CALTECH)                                    | USA             | 64            |
| 27      | Tel Aviv University                                                             | Israel          | 64            |
| 28      | University of Turin                                                             | Italy           | 64            |
| 29      | University of California                                                        | USA             | 63            |
| 30      | University of Freiburg                                                          | Germany         | 63            |
| 31      | University of Perugia                                                           | Italy           | 63            |
| 32      | University of Victoria                                                          | Canada          | 63            |
| 33      | University of Michigan                                                          | USA             | 62            |
| 34      | University of Trieste                                                           | Italy           | 62            |
| 35      | Indiana University                                                              | USA             | 61            |
| 36      | University of Chicago                                                           | USA             | 60            |
| 37      | Carleton University                                                             | Canada          | 59            |
| 38      | Max Planck Institute Physics and Astrophysics                                   | Germany         | 59            |
| 39      | University of Bonn                                                              | Germany         | 59            |
| 40      | University of Tennessee                                                         | USA             | 59            |
| 41      | Weizmann Institute Science                                                      | Israel          | 59            |
| 42      | Purdue University                                                               | USA             | 58            |
| 43      | University of Karlsruhe                                                         | Germany         | 58            |
| 44      | Kobe University                                                                 | Japan           | 56            |
| 45      | Carnegie Mellon University                                                      | USA             | 55            |
| 46      | University of Paris 11                                                          | France          | 55            |
| 47      | National Institute Nuclear and High Energy Physics                              | Netherlands     | 54            |
| 48      | Tata Institute Fundamental Research                                             | India           | 54            |
| 49      | Technion Israel Institute of Technology                                         | Israel          | 54            |
| 50      | University of Alberta                                                           | Canada          | 54            |
| 51      | Commissariat à l'Énergie Atomique (CEA)                                         | France          | 53            |
| 52      | Nationaal Instituut Voor Subatomaire Fysica (NIKHEF)                            | Netherlands     | 53            |
| 53      | Paul Scherrer Institute                                                         | Switzerland     | 53            |
| 54      | University of Geneva                                                            | Switzerland     | 53            |
| 55      | University of Milan                                                             | Italy           | 53            |
| 56      | Hungarian Academy of Science                                                    | Hungary         | 52            |
| 57      | Institute of Theoretical & Experimental Physics                                 | Russia          | 51            |
| 58      | Louisiana State University                                                      | USA             | 51            |
| 59      | University of Naples                                                            | Italy           | 51            |
| 60      | Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT) | Spain           | 50            |
| 61      | Northeastern University                                                         | USA             | 50            |

Germany, with 124 papers; and Rutherford Appleton Laboratory, England, with 116 papers. In India Tata Institute of Fundamental Research is the most productive institute with 54 papers.

#### 4.6 Preference of Channels of Communication by Scientists

Scientists communicated their papers through variety of communications channels. Table 5 depicts the percentage of literature published in different document types. Journal articles constituted 66.44 per cent of the total papers followed by reports (18.47 per cent), conference papers (5.67 per cent), and books (5.52 per cent).

**Table 5. Distribution of papers in various channels of communication**

| Document type     | No. of papers | Percentage |
|-------------------|---------------|------------|
| Journal articles  | 867           | 66.44      |
| Reports           | 241           | 18.47      |
| Conference papers | 74            | 5.67       |
| Books             | 72            | 5.52       |
| Miscellaneous     | 28            | 2.15       |
| Reviews           | 16            | 1.23       |
| Letters           | 4             | 0.31       |
| Notes             | 2             | 0.15       |
| Dissertation      | 1             | 0.08       |

#### 4.7 Preference of Journals for Communication by Scientists

The distribution of papers were spread over 106 journals. The leading journals preferred by the scientists were *Physics Letters-B* with 188 papers followed by *Nuclear Physics-B* with 91 papers, and *Physical Review-D* with 90 papers. Table 6 shows journal-wise publishing of papers. Out of 910 articles published in various journals, about 82 per cent were published in the journals with impact factors ranging from 0.17 to 38.40. This indicates the publication behaviour of scientists; they preferred to publish their papers in high impact journals. Remaining 18 per cent of the papers were published in the journals not covered by *SCI* database.

**Table 6. Journals preferred by scientists for publishing articles in Bhabha scattering research**

| Sl. No. | Journal                                                        | No. of papers | IF (2007) |
|---------|----------------------------------------------------------------|---------------|-----------|
| 1       | <i>Physics Letters-B</i>                                       | 188           | 4.189     |
| 2       | <i>Nuclear Physics-B</i>                                       | 91            | 4.645     |
| 3       | <i>Physical Review-D</i>                                       | 90            | 4.696     |
| 4       | <i>European Physical Journal-C</i>                             | 61            | 3.255     |
| 5       | <i>Nuclear Instruments and Methods in Physics Research-A</i>   | 54            | 1.114     |
| 6       | <i>Zeitschrift fur Physik-C</i>                                | 45            | -         |
| 7       | <i>Physical Review Letters</i>                                 | 38            | 6.944     |
| 8       | <i>Acta Physica Polonica-B</i>                                 | 32            | 0.664     |
| 9       | <i>Verhandlungen der Deutschen Physikalischen Gesellschaft</i> | 30            | -         |
| 10      | <i>Computer Physics Communications</i>                         | 24            | 1.842     |
| 11      | <i>AIP Conference Proceedings</i>                              | 18            | -         |
| 12      | <i>High Energy Physics and Nuclear Physics</i>                 | 13            | 0.171     |
| 13      | <i>Zeitschrift fur Physik-A</i>                                | 11            | -         |
| 14      | <i>International Journal of Modern Physics-A</i>               | 9             | 0.764     |
| 15      | <i>Nuclear Instruments and Methods in Physics Research</i>     | 9             | -         |
| 16      | <i>Physical Review-C</i>                                       | 9             | 3.302     |
| 17      | <i>Physics Reports</i>                                         | 9             | 20.263    |
| 18      | <i>Progress of Theoretical Physics</i>                         | 8             | 1.936     |
| 19      | <i>Journal of High Energy Physics</i>                          | 7             | 5.659     |
| 20      | <i>Pramana Journal of Physics</i>                              | 7             | 0.383     |
| 21      | <i>Journal of Physics-A</i>                                    | 6             | 1.68      |
| 22      | <i>Physics of Atomic Nuclei</i>                                | 6             | 0.515     |
| 23      | <i>Journal of Experimental and Theoretical Physics</i>         | 5             | 1.075     |
| 24      | <i>Nuovo Cimento-A</i>                                         | 5             | -         |
| 25      | <i>IEEE Transactions on Nuclear Science</i>                    | 4             | 1.107     |
| 26      | <i>JETP Letters</i>                                            | 4             | 1.378     |
| 27      | <i>Modern Physics Letters-A</i>                                | 4             | 1.455     |
| 28      | <i>Nuclear Electronics and Detection Technology</i>            | 4             | -         |
| 29      | <i>Physics of Particles and Nuclei</i>                         | 4             | 0.561     |
| 30      | <i>Chinese Physics Letters</i>                                 | 3             | 0.812     |
| 31      | <i>Fizika</i>                                                  | 3             | -         |
| 32      | <i>Journal of Physics</i>                                      | 3             | -         |

| S. No. | Jouranal                                                            | No. of papers | IF (2007) |
|--------|---------------------------------------------------------------------|---------------|-----------|
| 33     | <i>Journal of Physics-G</i>                                         | 3             | 3.485     |
| 34     | <i>Lettere al Nuovo Cimento</i>                                     | 3             | -         |
| 35     | <i>Nonlinear Phenomena in Complex Systems</i>                       | 3             | -         |
| 36     | <i>Nuclear Instruments and Methods in Physics Research-B</i>        | 3             | 0.997     |
| 37     | <i>Nuclear Physics-A</i>                                            | 3             | 3.096     |
| 38     | <i>Physical Review-A</i>                                            | 3             | 2.893     |
| 39     | <i>Pis' Ma V Zhurnal Eksperimental' Noj I Teoreticheskoy Fiziki</i> | 3             | -         |
| 40     | <i>Yadernaya Fizika</i>                                             | 3             | -         |
| 41     | <i>Zhurnal Eksperimentalnoi</i>                                     | 3             | -         |
| 42     | <i>American Journal of Physics</i>                                  | 2             | 0.889     |
| 43     | <i>Annals of Physics</i>                                            | 2             | 1.485     |
| 44     | <i>Annual Review of Nuclear and Particle Science</i>                | 2             | 12.885    |
| 45     | <i>Chinese Physics-C</i>                                            | 2             | -         |
| 46     | <i>Europhysics Letters</i>                                          | 2             | -         |
| 47     | <i>Indian Journal of Physics</i>                                    | 2             | 0.265     |
| 48     | <i>Journal of Chemical Physics</i>                                  | 2             | 3.044     |
| 49     | <i>Journal of Mathematical Physics</i>                              | 2             | 1.137     |
| 50     | <i>Journal of Nuclear Materials</i>                                 | 2             | 1.643     |
| 51     | <i>Journal of Physical Chemistry-A</i>                              | 2             | 2.918     |
| 52     | <i>Physica Scripta</i>                                              | 2             | 0.946     |
| 53     | <i>Reports on Progress in Physics</i>                               | 2             | 11.366    |
| 54     | <i>Rivista del Nuovo Cimento</i>                                    | 2             | 1         |
| 55     | <i>Theoretical and Mathematical Physics</i>                         | 2             | 0.622     |
| 56     | <i>Acta Physica Slovaca</i>                                         | 1             | 0.625     |
| 57     | <i>Archive for History of Exact Sciences</i>                        | 1             | 0.536     |
| 58     | <i>Astronomy and Astrophysics</i>                                   | 1             | 4.259     |
| 59     | <i>Astrophysical Journal</i>                                        | 1             | 6.405     |
| 60     | <i>Canadian Journal of Physics</i>                                  | 1             | 0.886     |
| 61     | <i>CERN Courier</i>                                                 | 1             | -         |
| 62     | <i>Czechoslovak Journal of Physics</i>                              | 1             | 0.423     |
| 63     | <i>Fortschritte der Physik</i>                                      | 1             | 1.413     |
| 64     | <i>Health Physics</i>                                               | 1             | 0.87      |
| 65     | <i>Helvetica Physica Acta</i>                                       | 1             | -         |
| 66     | <i>Indian Journal of Physics-A</i>                                  | 1             | -         |
| 67     | <i>Indian Journal of Pure and Applied Physics</i>                   | 1             | 0.34      |
| 68     | <i>Institute of Physics Conference Series</i>                       | 1             | -         |
| 69     | <i>International Journal of Modern Physics-C</i>                    | 1             | 0.841     |
| 70     | <i>International Journal of Modern Physics-D</i>                    | 1             | 1.87      |
| 71     | <i>International Journal of Theoretical Physics</i>                 | 1             | 0.489     |
| 72     | <i>Japanese Journal of Applied Physics-1</i>                        | 1             | 1.247     |
| 73     | <i>Journal of Instrumentation</i>                                   | 1             | -         |
| 74     | <i>Journal of Molecular Structure: Theochem</i>                     | 1             | 1.112     |
| 75     | <i>Journal of Radioanalytical and Nuclear Chemistry</i>             | 1             | 0.499     |
| 76     | <i>Journal of the Australian Mathematical Society-B</i>             | 1             | 0.418     |
| 77     | <i>Journal of the Faculty of Engineering, Ibaraki University</i>    | 1             | -         |
| 78     | <i>Journal of the Korean Physical Society</i>                       | 1             | 1.204     |
| 79     | <i>Journal of Vacuum Science and Technology-A</i>                   | 1             | 1.278     |
| 80     | <i>Laser Physics</i>                                                | 1             | 0.696     |
| 81     | <i>Malaysian Journal of Library and Information Science</i>         | 1             | -         |
| 82     | <i>Materials Science Forum</i>                                      | 1             | -         |
| 83     | <i>Medical Physics</i>                                              | 1             | 3.198     |
| 84     | <i>Nature</i>                                                       | 1             | 28.751    |
| 85     | <i>Nederlands Tijdschrift Voor Natuurkunde</i>                      | 1             | -         |
| 86     | <i>Nuclear Technology</i>                                           | 1             | 0.534     |
| 87     | <i>Nukleonika Poland</i>                                            | 1             | 0.175     |
| 88     | <i>Physica</i>                                                      | 1             | -         |
| 89     | <i>Physica-A</i>                                                    | 1             | 1.43      |
| 90     | <i>Physica Norvegica</i>                                            | 1             | -         |
| 91     | <i>Physica Status Solidi-B</i>                                      | 1             | 1.071     |
| 92     | <i>Physical Review</i>                                              | 1             | -         |
| 93     | <i>Physical Review-B</i>                                            | 1             | 3.172     |
| 94     | <i>Physics Letters-A</i>                                            | 1             | 1.711     |
| 95     | <i>Postepy Fizyki Poland</i>                                        | 1             | -         |
| 96     | <i>Progress in Particle and Nuclear Physics</i>                     | 1             | 4.101     |
| 97     | <i>Radiation Protection Dosimetry</i>                               | 1             | 0.528     |
| 98     | <i>Review of Scientific Instruments</i>                             | 1             | 1.384     |

| S. No. | Journal                                          | No. of papers | IF (2007) |
|--------|--------------------------------------------------|---------------|-----------|
| 99     | <i>Reviews of Modern Physics</i>                 | 1             | 38.403    |
| 100    | <i>Revue Roumaine de Physique</i>                | 1             | -         |
| 101    | <i>Soviet Journal of Nuclear Physics USSR</i>    | 1             | -         |
| 102    | <i>Teoreticheskaya i Matematicheskaya Fizika</i> | 1             | -         |
| 103    | <i>Uchusen Kenkyu</i>                            | 1             | -         |
| 104    | <i>Ukrayins'kyi Fizychnyi Zhurnal</i>            | 1             | -         |
| 105    | <i>Zeitschrift fur Metallkunde</i>               | 1             | 0.857     |
| 106    | <i>Zeitschrift fur Naturforschung-A</i>          | 1             | 0.691     |

#### 4.8 Distribution of Keywords

Keywords are one of the best scientometric indicators to understand and grasp instantaneously the thought content of the papers and to find out the growth in the subject field. Analyses of the keywords, appeared either in the title or assigned by the indexer or the author himself, help in knowing in which direction the knowledge is growing. The high frequency keywords enable us to understand the various aspects that have been studied. In the current study the high frequency keywords were: Bhabha Scattering (731), Radiative Corrections (215), Annihilation (214), Electrons (208), Positrons (205), and Pair Production (202). Table 7 lists the keywords appeared in the keywords field of the databases.

#### 5. CONCLUSION

Bhabha communicated his paper to *Proceedings of the Royal Society of London* on 20<sup>th</sup> October 1935, which was subsequently published in 1936 to calculate cross-section for electron-positron scattering, which later became an eponym as 'Bhabha Scattering'. This theory (still being used by many scientists across the world) shows the relevance of Bhabha's theory even after 75 years of his work. The highest numbers of papers (66) were published in 1988 and 1997, respectively. The average numbers of papers published per year were 32.62. There were 47 countries involved in the research in this field. Germany and USA were the top countries which produced 421 and 420 papers, respectively. Authorship

**Table 7. Keywords with  $\geq 20$  frequencies appeared in Bhabha scattering research**

| Keyword                        | Frequency |
|--------------------------------|-----------|
| Bhabha Scattering              | 731       |
| Radiative Corrections          | 215       |
| Annihilation                   | 214       |
| Electrons                      | 208       |
| Positrons                      | 205       |
| Pair Production                | 202       |
| Electron Positron Interactions | 189       |
| Gev Range 10-100               | 178       |
| Monte Carlo Method             | 175       |
| Quantum Electrodynamics (QED)  | 164       |
| Differential Cross Sections    | 123       |
| Cross Sections                 | 117       |
| Photons                        | 114       |
| Experimental Data              | 105       |
| High Energies                  | 100       |
| Standard Model                 | 100       |
| Angular Distribution           | 98        |
| Muons Minus                    | 86        |
| Muons Plus                     | 86        |
| Coupling Constants             | 74        |
| Tau Particles                  | 74        |
| E+E Annihilation               | 72        |
| LEP                            | 72        |
| Feynman Diagram                | 70        |
| Leptonic Decay                 | 65        |
| Quarks                         | 65        |
| Beam Luminosity                | 61        |
| Weinberg Lepton Model          | 61        |
| Energy Dependence              | 60        |
| Rest Mass                      | 60        |
| Energies                       | 59        |
| Particle Production            | 58        |
| Angle Bhabha Scattering        | 57        |
| Photon Corrections             | 57        |
| Asymmetry                      | 56        |

| Keyword                      | Frequency |
|------------------------------|-----------|
| Neutral Current Interactions | 55        |
| Limiting Values              | 54        |
| Electron Positron Scattering | 53        |
| Branching Ratio              | 52        |
| Showers                      | 50        |
| Quantum Chromodynamics (QCD) | 49        |
| QED Corrections              | 48        |
| Hadrons                      | 47        |
| Muon Pairs                   | 46        |
| Gev Range 01-10              | 45        |
| Physics                      | 44        |
| Detector                     | 43        |
| Particle Widths              | 43        |
| Reviews                      | 43        |
| Supersymmetry                | 43        |
| E+E Collisions               | 40        |
| Luminosity                   | 40        |
| Calorimeters                 | 38        |
| Excitation Functions         | 38        |
| Mass                         | 38        |
| Bremsstrahlung               | 37        |
| L3 Experiment                | 37        |
| Monte Carlo Program          | 37        |
| Colliding Beams              | 36        |
| Integral Cross Sections      | 36        |
| Total Cross Sections         | 35        |
| Z-Neutral Bosons             | 35        |
| Resonance                    | 34        |
| Decay                        | 33        |
| Higgs Bosons                 | 33        |
| Linear Colliders             | 32        |
| Positron Beams               | 32        |
| Collisions                   | 31        |
| Electron Beams               | 30        |
| Fermion Pair Production      | 30        |

| Keyword                      | Frequency |
|------------------------------|-----------|
| Electron Positron Collisions | 28        |
| LEP Storage Rings            | 28        |
| Muons                        | 28        |
| Polarized Beams              | 28        |
| Weak Neutral Currents        | 28        |
| Drift Chambers               | 27        |
| Electromagnetic Interactions | 27        |
| Energy Spectra               | 27        |
| Mass Spectra                 | 26        |
| Monte Carlo Simulation       | 26        |
| Multiple Production          | 26        |
| Perturbation Theory          | 26        |
| Bosons                       | 25        |
| Intermediate Vector Bosons   | 25        |
| Jet Model                    | 25        |
| Mev Range 01-10              | 25        |
| Calibration                  | 24        |
| Corrections                  | 24        |
| Cross Section                | 24        |
| Energy Resolution            | 24        |

| Keyword                     | Frequency |
|-----------------------------|-----------|
| Low Angles                  | 24        |
| Particle Decay              | 24        |
| Petra Storage Ring          | 24        |
| Radiative Decay             | 24        |
| Weinberg Angle              | 24        |
| Computerized Simulation     | 23        |
| Final States                | 23        |
| Pep Storage Rings           | 23        |
| Lifetime                    | 22        |
| Mixing Ratio                | 22        |
| Weak Interactions           | 22        |
| Z Peak                      | 22        |
| Carlo Event Generator       | 21        |
| Electromagnetic Corrections | 21        |
| Event Generator             | 21        |
| Gev Range 100-1000          | 21        |
| Inclusive Interactions      | 21        |
| Symmetry Breaking           | 21        |
| Inelastic Scattering        | 20        |
| Storage Rings               | 20        |

and collaboration trends were towards multi-authored papers. There were 888 (68.05 per cent) collaborative papers. Solo research activity was predominant during 1969-1993, whereas the group collaborative research activity was high during 1994-2008. The most preferred journals by the scientists were: *Physics Letters-B* with 188 papers, *Nuclear Physics-B* with 91 papers and *Physical Review-D* with 90 papers. It will be quite interesting if one attempts to carryout citation analysis on this subject.

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