Annals of Library and Information Studies
Vol. 56, December 2009, pp. 273-290

An analytical model for investigation of some characteristics of the keywords of the subject fermi liquid: a case study

Bidyarthi Dutta[1], Krishnapada Majumder[2] and B.K.Sen[3]
[1]Librarian, St. Xavier's College, 30, Park Street, Kolkata 700016, Email: bidyarthi.bhaswati@gmail.com

[2]Professor, Department of Library & information Science, Jadavpur University, Kolkata 700032
30, Shivalik Apartments, Alaknanda, New Delhi 110019

Modes of occurrence of keywords devoted to the subject Fermi Liquid, which is a specific domain under the broad area of condensed matter physics was studied. Eight quantitative indicators have been defined and developed on the basis of some parameters associated with keywords and keyword clusters. At least three keywords with a common phrase have been defined as a keyword cluster in this study. The numerical values of the indicators have been calculated for 2562 keyword-clusters, 916 keyword-couples and 4329 single keywords in all, though only top 20 keywords/keyword clusters are selected in decreasing order of numerical values of each indicator for presenting in this paper. The keywords were extracted from titles and abstracts of 6371 research articles devoted to the subject Fermi Liquid, which were collected from the bibliographic database of INSPEC and COMPENDEX, over the time span of twenty years (1985-2004). In total, 67 keywords/keyword clusters are presented here, which appeared 160 times within top 20 ranks (8*20=160) against eight indicators. A keyword cluster consists of at least three keywords and 665 keywords as studied here. The keyword-couples consist of two keywords only. There is no question of forming any cluster by the single keywords. The variations of numerical values of all indicators with the rank of keyword/keyword clusters are shown graphically. The mathematical functions followed by each variational pattern are also discussed.

Introduction

The "Keyword" is an indissoluble part of our daily life. We are always using keywords, consciously, or unconsciously. Looking for anything absolutely begins with recalling a "Keyword" in our memory. The term "Keyword" bears many interpretations. According to Wiktionary, the "Keyword" may be defined as:

1. Any word used as the key to a code.
2. Any word used in a reference work to link to other words or other information; or, A word that describes the subject of an article or book; or, The name of a category of data in an information storage and retrieval system. (In the context of Information Science)
3. A reserved word used to identify a specific command, function etc. (In the context of Programming)
4. Any word that occurs in a text more often than normal. (In the context of Linguistics)

A keyword captures the essence of the topic of a document. In most full-text or bibliographic databases, users can search either within free text, or with keywords. Keywords retrieve documents in an information system. A popular form of keywords on the web is tags, which are directly visible and can be assigned by layman also. A keyword usually consists of a word, phrase or alphanumerical term. They are created by analyzing the document either manually with subject indexing or automatically with automatic indexing or more sophisticated methods of keyword extraction. The keywords generally come from a controlled vocabulary or are freely assigned. Keywords collected from controlled vocabulary, however allow improved retrieval precision of documents on a selected topic. The selection of keywords is thus a vital measure of an information system. The indexers generally read a literature or text to locate the best terms in a thesaurus, and then assign the terms that best describe the document content. The keywords collected in this way are stored in a search index. The function of indexing actually depends on human analysis of a topic or subject. Different indexers may assign different keywords to represent same topic or subject[1]. Common words like articles (a, an, the), prepositions (by, with, for, to etc.) and conjunctions (and, or, but) are not treated as keywords because they can't reflect any essence of the document. Almost every English-language document or site has the article "the", and so it makes no sense to search for it. The most popular search engine, Google removes stop words such as "the" and "a" from its indexes. Sometimes, nascent themes or concepts may lack appropriate keyword to be described compatibly. Suraud et al.[2] observed the non-existence of well-defined keywords in newly-emerging fields, which makes bibliographic searches difficult. The keywords are also known as "Subject descriptors", the term, which was coined by Calvin Mooers in 1948.

There are generally three keyword-based methods of searching information in electronic documents:

1. Keyword matching
2. Browsing though a collection arranged in alphabetical order
3. Browsing through a collection arranged in any subject classification scheme

Traditional general classification schemes provide users with both intellectual and physical access via shelving of documents with call numbers corresponding to subject headings. The physical location of the document and the subject classification are linked together. The standard subject access tools like list of subject headings (Sear's list or Library of Congress) or classification schedules (DDC or CC) are based on controlled vocabulary rather than on the users' terminology. Studies of controlled vocabularies have indicated that they work well when there is an accepted common terminology describing concepts in the concerned subject area and when users are familiar with the terminology[3]. Solomon[4] stated that, "Classification schemes fail too often because they are not grounded in the language and knowledge of users or in the task or situation of use." Hurt[5] suggested that it is necessary to renew and expand indexing and classification systems. Soergel et al.[6] pointed out that existing classification schemes and thesauri lack well-defined semantics and structural consistency. With the advent of electronic information and the internet, the physical location of the material is of much less importance. This has elicited a re-scrutinization of classification schemes with a greater emphasis placed on intellectual access. Bates et al.[7] proposed development in the structures of thesauri and in the design of online information systems. If the classification schemes be freed from the requirement of shelving of one document in one location, then the subject hierarchies can be made more flexible. There is also a greater possibility of customizing classification schemes to fit specific groups of users with particular needs. In traditional library systems, users need document-title and author's name primarily for starting any search, whereas, in electronic environment the foremost need is centered on keywords for doing so. The users from different subject areas use different keywords, and large numbers of keywords form different clusters. The cluster analysis of keywords is an effective method for examining the user's view of information space with the goal of producing flexible and customizable classification scheme. This is based on statistical analysis of different characteristics of keywords. Cluster analysis is used in a wide range of applications in all major disciplines of science and social sciences and it, particularly document-based cluster analysis, paves the way towards automatic classification[8].

Traditional library classification, cataloging and indexing have been centered only on the information sources like books and articles. Online catalogs and search engines allow keyword searching to extend beyond the subject headings, titles, and author fields for searching, but are still centered on the document with the user having to try to fit their search needs, often poorly formulated, to the vocabulary of the author and cataloger or indexer. Programming advances now allow us to collect actual user terminology. Cluster analysis is a technique that enables the researcher to create a picture of the collective users' view of the information space belonging to a specific subject area[9].

The most vibrant source of primary information of a subject is constituted by the articles published in research journals. There are few crux keywords in a research article, which reflect the central theme of the research topic. Such keywords navigate the users towards accurate bit of information. It's also users' common tendency to memorize catchy keywords for mental recall at any instant. Their think-tank is an approximation of a thesaurus or glossary, where a series of semantically related keywords are mapped in a sequence. A user-friendliness of a library or information system thus actually means a keyword-based retrieval system with an optimum recall and precision value that results from information professional's awareness about the keyword need of the information clientele. A keyword-based retrieval system needs a keyword-based, user-centric and dynamic classification scheme, which would be able to develop an effective search tool for users. The existing hierarchical and faceted classification schemes are mostly based on traditional subjects, where scopes of insertion of new-born subject areas are very limited. As new research results are continuously sprouting, new subjects are simultaneously coming and new searches are accumulated by the ongoing users to generate new keywords to be added to the database. In the present environment of mushrooming of new subjects, the classification schemes should be more flexible to accommodate new arrivals.

The existing information processing systems are quite inadequate to provide an effective information retrieval. One of the major shortcomings of the existing systems is that they are silent about the behavioral aspects of the keywords, i.e. the modes of occurrences of the keywords in a database. Also, no system ever described the properties of keywords in quantitative form. However, one of the strengths of the model studied in this paper is its interpretation of the behavioral aspects of the keywords in quantitative form. Keyword clusters have been generated here through indexing of keywords. The indicators defined in this model describe quantitative aspects of the keyword clusters. In all, eight quantitative indicators of trend-analysis have been defined here.

Scope and methodology

This study has been executed over the broad subject physics. The classification scheme followed in *Physics Abstracts* divides the subject physics in ten major areas, of which one subject area is Condensed Matter: Structure, Thermal and Mechanical Properties. The scope of the present study includes the specific subject Fermi Liquid, under this subject area. The published research articles devoted to the area under Fermi Liquid covering a period of twenty years (1985-2004) as appeared in the bibliographic databases of inspec and compendex have been considered for this study. The keywords have been culled out from the published literature collected from the bibliographic databases inspec and compendex on this area for the said time span. The number of research papers devoted to this area appearing in several journals for the said time span as obtained from INSPEC and COMPENDEX is 6371. The keywords have been selected from the titles and abstracts of all these articles. Only research articles have been taken for study out of the entirely available published literatures. The other forms of outcomes like conference proceedings, short communications, reviews, letters, reports, etc. have been excluded from the concerned domain of the present study as the largest contribution to the full set of published literature comes only from the research articles. The identified keywords when organized reveal some interesting features. The large number of keywords occurs in several groups, where each group represents a particular keyword cluster. A keyword cluster is thus a keyword-set consisting of alike keywords. All members of the set of similar keywords contain at least one common term, which is the indicator of the actual subject expressed by that keyword-set. (Example: The keywords 'Singular Fermi Liquid', 'Relativistic Fermi Liquid', 'Renormalised Fermi Liquid' and 'Self-consistent Fermi Liquid" form a keyword cluster. The common term contained by these keywords is 'Fermi Liquid' and this common term also indicates the subject area dealt therein by the keyword cluster). Hence each keyword cluster represents a particular subject domain, which is allied with the main subject. The number of keywords of a cluster and their total frequencies of occurrences are indicators of the volume of a keyword cluster, which again indicates the degree of correlation of the domain with the main subject. Hence, the larger the volume of a keyword cluster, the larger is its degree of correlation with the main subject. The remaining keywords occur as single, as they don't form any cluster. It is to be noted that the single keywords are 'isolated' only with respect to the subject concerned. As they don't form any cluster with a number of identically-termed keywords, therefore they are isolated. In one subject they don't form any cluster, but they may form clusters in other subjects.

The following steps have been followed while selecting keywords from titles, abstracts and lists of keywords and uncontrolled terms of the research articles as available from the bibliographic databases:

1. Reading the title of the research paper carefully to note down insistent and significant terms.
2. Reading the abstract thoroughly and carefully to note down significant terms, which reflect central theme of research, discussed therein.
3. Reading the list of keywords and list of uncontrolled terms of the concerned research article thoroughly.
4. Drawing a comparative layout between the list of keywords as given in the database and the keywords as selected from the title and abstract.

5. Excluding those terms and keywords which are not matching the scope and purpose of the present study. (Those categories of keywords which are not taken under consideration for the present study are given later)
6. The keywords are indexed at the specific terms; the general terms are kept at last; for instance the keyword Relativistic Fermi Liquid has been indexed as Fermi Liquid, Relativistic. The indexed keywords are arranged alphabetically to group in different clusters.
7. The proper nouns are excluded from the list, (name of some eminent persons, scholars or scientists, name of place, name of country etc.) except some special cases, i.e. where any theory, method, process or device are named by the proper noun (e.g. Fermi liquid, Kondo effect, Luttinger liquid, etc.)
8. The keywords are indexed in singular number, but not in plural. Essential articles, prepositions and conjunctions are given in parenthesis at last.

One sample entry from INSPEC to outline the methodologies involved in selection of keywords is presented:

Sample Entry

TY	-	JOUR
A1	-	Coleman, P.
AD	-	Center for Mater. Theor., Rutgers Univ., Piscataway, NJ, USA;
A1	-	Pepin, C.
M1	-	Copyright 2004, IEE
PY	-	2003/12/01
N2	-	Using the Schwinger boson spin representation, we reveal a new aspect to the physics of a partially screened magnetic moment in a metal, as described by the spin-S Kondo model. We show that the residual ferromagnetic interaction between a partially screened spin and the electron sea destabilizes the Landau Fermi liquid, forming a singular Fermi liquid behaviour with a 1/[T ln/sup 4/(T/sub K//T)] divergence in the low-temperature specific heat coefficient C/sub V//T. A magnetic field B tunes this system back into Landau Fermi liquid with a Fermi temperature proportional to B ln/sup 2/(T/sub K//B). We discuss a possible link with field-tuned quantum criticality in heavy-electron materials
JO	-	Physical Review B (Condensed Matter and Materials Physics)
T3	-	Phys. Rev., B, Condens, Matter Mater. Phys. (USA)
T1	-	Singular Fermi liquid behavior in the underscreened Kondo model
KW	-	antiferromagnetism
KW	-	Fermi liquid
KW	-	heavy Fermion systems
KW	-	Kondo effect
KW	-	local moments
KW	-	specific heat
U2	-	singular Fermi liquid behavior
U2	-	underscreened Kondo model
U2	-	Schwinger boson spin representation
U2	-	partially screened magnetic moment
U2	-	metal
U2	-	spin-S Kondo model
U2	-	residual ferromagnetic interaction
U2	-	electron sea
U2	-	Landau Fermi liquid
U2	-	low-temperature specific heat coefficient
U2	-	magnetic field tuning
U2	-	Fermi temperature
U2	-	field-tuned quantum criticality
U2	-	heavy-electron materials
U2	-	ordered moment antiferromagnetism

Explanation of the abbreviations used for field names

TY – Type of publication;
A1 – Author;
AD – Author Affiliation;
M1 – Copyright year;
PY – Year of publication;
N2 – Abstract;
JO – Journal name;
T3 – Abbreviation used for the journal-name;
T1 – Title of the article;

KW – Keyword
U2 – Uncontrolled term

In the sample entry eleven fields are given, out of which only four fields, viz. N2 (Abstract), T1 (Title), KW (Keyword) and U2 (Uncontrolled term) have been considered for this study. The Title and Abstract were scanned meticulously first to have a broad understanding of the subject coverage for marking those keywords which are quite persevering to reflect the core central and peripheral allied theme of the subject concerned. The selected keywords from Title and Abstract have been noted down, and then a comparative layout was drawn between 'Selected' keywords and keywords which are already given in the database to make final selection. The list of keywords finally selected was be taken under consideration to carry out the present study.

The keywords, which are selected from the Title and Abstract, are listed in column A of Table 1. The keywords already given in the database are listed in column B of Table 1.

The keywords belonging to following eight categories are excluded from the scope of this study:

1. Too lengthy keyword (e.g. Low-temperature specific heat coefficient C/sub V//T, this keyword is selected after cutting off the last part)
2. Too common keyword (e.g. Physics)
3. Acronym (e.g. MFT) (Acronym is considered after expansion; e.g. Magnetic Field Tuning for MFT)
4. Too specific jargon (e.g. 1/[T ln/sup 4/ (T/sub K//T)] divergence)
5. Keywords not directly related with central or allied theme of the subject concerned as manifested by the abstract (e.g. Local moments)
6. Symbol (Not occurred here)
7. Formula (e.g. B ln/sup 2/(T/sub K//B))
8. Numerical figure (Not occurred here)

The number of keywords listed in column-A and column-B are 13 and 15 respectively. A comparison between two columns reveals total number of distinct keywords, which is 19, and also avoids missing of any persistent keyword, otherwise the scope of the study will be narrow and the statistics will be poor and biased to hamper the main objectives. Maximum keywords occur in both columns, whereas some keywords are in column B but not in column A, i.e. they are not in title or abstract, but in the given list of keywords (assigned by the author and/or editor). All those keywords have also been considered, as they reflect light from peripheral allied theme of the research paper. The distinct keywords selected after comparison between two columns are listed in the Table 2.

Objectives of the study

- To assist researchers in finding out their relevant subject topic through keyword analysis,
- To develop some specific steps in the search engine optimization process,
- To analyze notable trends in characteristic behavioral process of a subject,
- To identify some basic parameters associated with changing trend of a subject,
- To define some indicators on the basis of these parameters involved, and
- To develop a predictive model for identifying most frequently used keywords and keyphrases present in the document associated with a subject

Keyword Cluster Analysis (KCA)

The total number of keywords analyzed for this study is 17945 over the time span of twenty years (1985-2004). The analysis of these keywords result in finding out 2562 keyword-clusters, 916 keyword-couples and 4329 single keywords in all. The keyword-couples consist of twin keywords and form no cluster. There is also no question of forming any cluster by the single keywords. The clustered keywords are forming keyword-clusters. All clusters are not identical in size. The number of taking keywords part in forming a cluster range from 3 to 665 in this study. Since the size of the clusters widely varies, therefore it is also obvious that different keywords have different abilities to form a cluster.

A keyword cluster from the subject 'Fermi Liquid' is presented as a sample. The common term contained by all keywords of this cluster is 'Hubbard-model'; hence this cluster has been named as 'Hubbard-model'. The frequencies of occurrences of all keywords over 20 years (1985-2004) are also shown.

Variables associated with a keyword cluster

The following variables of a keyword cluster have been taken under consideration for this study. The corresponding representative symbols are given in the adjacent parenthesis.

Table 1 — Comparison between selected keywords

Keywords finally selected from Column A	Keywords finally selected from Column B
Electron sea	Antiferromagnetism
Fermi liquid	Electron sea
Fermi temperature	Fermi liquid
Field-tuned quantum criticality	Fermi temperature
Heavy-electron materials	Field-tuned quantum criticality
Landau Fermi liquid	Heavy Fermion systems
Low-temperature specific heat coefficient	Heavy-electron materials
Partially screened magnetic moment	Kondo effect
Partially screened spin	Landau Fermi liquid
Residual ferromagnetic interaction	
Schwinger boson spin representation	Low-temperature specific heat coefficient
Singular Fermi liquid behavior	Magnetic field tuning (MFT)
Spin-S Kondo model	Metal
	Ordered moment antiferromagnetism
	Partially screened magnetic moment
	Residual ferromagnetic interaction

Table 2 — Distinct keywords after comparison

Antiferromagnetism
Electron sea
Fermi liquid
Fermi temperature
Field-tuned quantum criticality
Heavy Fermion systems
Heavy-electron materials
Kondo effect
Landau Fermi liquid
Low-temperature specific heat coefficient
Magnetic field tuning (MFT)
Metal
Ordered moment antiferromagnetism
Partially screened magnetic moment
Partially screened spin
Residual ferromagnetic interaction
Schwinger boson spin representation
Singular Fermi liquid behavior
Spin-S Kondo model

1. Total number of keywords in an arbitrary cluster k_r is "N_r", say
2. Frequency of Occurrence of all keywords belonging to the same cluster k_r during the entire span 'l' is $\Sigma f_{rj} = F_r$, where $1 \le j \le (l+1)$
3. Occupancy of the said cluster during the time span "l" is "A_r"
4. Highest possible Occupancy of the same cluster is "A_{Max}"
5. Concerned Time span of occurrence of keywords is "l"
6. Number of journal articles contained the entire volume of keywords is "J"

It is to be noted that, the first four variables are cluster variables, i.e. they depend on a particular keyword cluster, while the last two variables are constant for a particular subject taking numerical values 20 and 6371 respectively in the present study, i.e. for the subject 'Fermi-liquid'. The highest possible occupancy (A_{Max}) of a cluster is equal to span of occurrence of keywords (l) multiplied by total number of keywords (N_r) in that cluster.

$$\text{i.e. } A_{Max} = l * N_r$$

Let us take an example from Table 3 for its second keyword, i.e. 'Hubbard-model, 1d'. The frequency of occurrence of this keyword is 21, as it appeared in 21 different journal articles; while its occupancy is 12, as it appeared 12 times only in between 1985 and 2004. Again, if the whole cluster 'Hubbard-model' is considered, then the frequency of occurrence and occupancy will be equal to 700 and 149 respectively. The numerical values of the above variables for the cluster 'Hubbard-model' is given in Table 4.

A keyword occurs with certain frequency in any year. It may occur with a very high frequency but within a narrow time span; on the other hand, it can also come with trifle frequency but over a large time span. The phenomena of occurrence over certain time span has been termed here as 'Occupancy'. Hence, *frequency of occurrence*

Table 3 — The cluster 'Hubbard-model' and its member keywords over 20 years (1985-2004)

	Year																				
Keyword	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	2000	2001	2002	2003	2004	Total
Hubbard-Model		3	8	4	15	21	24	40	28	35	37	27	12	31	54	44	41	28	15	26	493
Hubbard-Model, 1d						1	1		1	4	4		1	1	2	1	1	1	3		21
Hubbard-Model, 2-Band								1							1	5					7
Hubbard-Model, 2-Chain														1							1
Hubbard-Model, 2-Orbital																		1			1
Hubbard-Model, 2d					2	2	4	3	4	2	3	5	5	9	1	5	5	3	1	2	56
Hubbard-Model, 2d-3-Band																1		1			2
Hubbard-Model, 2d Attractive								1			1				1						3
Hubbard-Model, 2d Disordered															1						1
Hubbard-Model, 2d Half-Filled																		1			1
Hubbard-Model, 2d One-Band											1						1				2
Hubbard-Model, 2d Simplified										1											1
Hubbard-Model, 2d T-T'																	1	2		1	4
Hubbard-Model, 2-Fold-Orbital Degenerate																				1	1
Hubbard-Model, 3-Band														1	2						3
Hubbard-Model, 3-Chain Extended															1						1
Hubbard-Model, 3d								1													1
Hubbard-Model, Attractive												1	1	2	3		2	3			12
Hubbard-Model, Disordered												1									1
Hubbard-Model, Electronic										1	1										2
Hubbard-Model, Extended					1			1	3		1	1	1						1		9
Hubbard-Model, Extended 3-Band												1									1
Hubbard-Model, Extended Single-Band																		1			1
Hubbard-Model, Finite-U								1													1
Hubbard-Model, Frustrated																1				1	2
Hubbard-Model, Fully-2d																			1		1
Hubbard-Model, Gas-Phase															1						1
Hubbard-Model, General Multiband																			1		1
Hubbard-Model, Generalized				1																	1
Hubbard-Model, Generalized 2d					1																1
Hubbard-Model,														1							1

Geometrically-Frustrated																
Hubbard-Model, Half-Filled				1		2	1			1	1		1			7
Hubbard-Model, Infinite-Dimensional				1	2	3			1			2				9
Hubbard-Model, Infinite-U						1										1
Hubbard-Model, Infinite-U 3-Band						1										1
Hubbard-Model, Inhomogeneous										1						1
Hubbard-Model, Multiband		1				1					1			1		4
Hubbard-Model, Multiorbital															1	1
Hubbard-Model, Nearly-Half-Filled												1				1
Hubbard-Model, Negative-U				1						2						3
Hubbard-Model, One-Band	1			1			1		3	1		1	1	2		11
Hubbard-Model, Pure												1				1
Hubbard-Model, Pyrochlore												1				1
Hubbard-Model, Quasi-1d											1					1
Hubbard-Model, Repulsive			1	1						1						3
Hubbard-Model, Simple Effective										1						1
Hubbard-Model, Single-Band							1	1		4	2	2				10
Hubbard-Model, Single-Band 2d													1			1
Hubbard-Model, Strong-Coupling	1															1
Hubbard-Model, Strongly Correlated 2d		1														1
Hubbard-Model, SU(N) Symmetric										1						1
Hubbard-Model, T-T’										1				1		2
Hubbard-Model, U = Infinity					1											1
Hubbard-Model, Weakly-2d														1		1
Hubbard-Model, Weakly- Disordered												1				1
Hubbard-Model, Weakly- Repulsive														1		1

and *occupancy* are two vital variables associated with a keyword or keyword cluster, as presented in the Figure 1.

These two variables indicate two fundamental dimensions of a keyword/keyword cluster. High ‘Occupancy’ indicates higher stability over certain time span or higher temporal stability, whereas high ‘Frequency of Occurrence’ is an indicator of greater coverage of a keyword cluster over journal articles. The journal-articles may be looked as the intellectual space, where the keywords exist. A higher value of ‘Frequency of Occurrence’ thus points out higher spatial stability.

Another important variable is number of keywords in a cluster, represented by N_r, which says the strength of a

Table 4 — Numerical values of some variables for the cluster 'Hubbard-model'

Variable	Representative Notation	Numerical Value
Total number of keywords	N_r	56
Frequency of Occurrence	F_r	700
Occupancy	A_r	149
Highest possible Occupancy	A_{Max}	$l^* N_r = 20*56 = 1120$

cluster. A keyword can be segmented in three kernels, which comprise[10]:

1) Keyphrase,
2) Modulator and
3) Qualifier

The keyphrase tells the central theme underlying behind the concept, the modulator amends the central theme in accordance with the relevant context. The modulator modulates the manifestation of the total spectrum by the central theme to polarize it in a specific orientation. The qualifier comes after the modulator to describe the particular state of the central concept and/or amended concept without disturbing the conceptual wholeness. The keyphrase tells the central area of research. If one research generates huddle of queries to initiate more and more research projects, then more and more keywords on the said area are created. All these keywords contain a common keyphrase, though modulators and qualifiers are different as evident from the examples of Table 3, where "Hubbard-model" is the common keyphrase. A cluster, containing large number of such keywords, means so many research projects are being carried out on the said subject area. Hence number of keywords is an indicator of number of research projects. Again, if number of research projects is looked as the measuring indices for currency and relevance of a subject, both of which tells us how dynamic a subject is, then the number of keywords also can be regarded as the dynamism index of a subject, or it can be said that the number of keywords indicates energy level of a subject.

The three fundamental variables of a keyword/keyword cluster thus indicate three fundamental features of the same in the subject space as shown in Table 5.

Analytical derivation

Let us assume an arbitrary subject 'S' has been considered for this study, which may be any subject from any broad discipline. Let us now chalk out the following

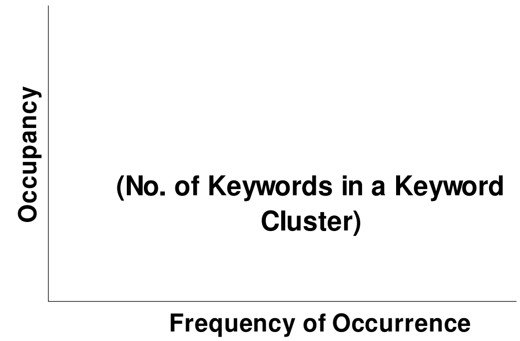

Fig. 1 — Fundamental variables associated with a keyword cluster

happenings regarding the research papers of the said subject 'S':

- The subject 'S' is dynamic in nature, i.e. various research works are continuously executed in this subject area.
- The number of journal articles came out on the subject 'S', from the year y to (y+l), is 'J'. The publication span of 'J' articles is therefore, [(y+l) – y] = l.
- The number of keywords extracted from "J" number of articles is "K", and these keywords have been divided in "r" different clusters. The clusters have been named as $k_1, k_2, k_3, \ldots\ldots k_n$.
- The frequency of occurrence of the keyword cluster (k_i) from year (Y) to (Y+l) is F_i, where I = 1 to n and $1 \leq n < \infty$
- The occupancy of the keyword cluster (k_i) from year (Y) to (Y+l) is F_i, where I = 1 to n and $1 \leq n < \infty$

The cluster k_1 contains:

n_{11} distinct keywords with total frequency of occurrence f_{11} and Occupancy a_{11}, in the year 'Y';

Table 5 — Three fundamental variables of a keyword/keyword cluster

Variable	Representative Notation	Feature indicated in subject space comprised by journal articles
Frequency of Occurrence	F_r	Stability over Space
Occupancy	A_r	Stability over Time
Total number of keywords	N_r	Energy

n_{12} distinct keywords with total frequency of occurrence f_{12} and Occupancy a_{12}, in the year 'Y+1';

n_{13} distinct keywords with total frequency of occurrence f_{13} and Occupancy a_{13}, in the year 'Y+2' and so on.

Therefore, the cluster k_1 contains $n_{1,l+1}$ distinct keywords with total frequency of occurrence $f_{1,l+1}$ and Occupancy $a_{1,l+1}$, in the year 'Y+l'.

Similarly the cluster k_2 contains:

n_2 distinct keywords with total frequency of occurrence f_{21} and Occupancy a_{21}, in the year 'Y';

The cluster k_3 contains n_3 distinct keywords; ……………and finally the cluster k_r contains n_r distinct keywords (Table 6).

Maximum possible occupancy for each keyword-cluster is $[w_i*(l+1)]$, where the suffix 'i' stands for any integer between 1 and n; and minimum possible occupancy is 1. If $f_{ij} = 0$ (Where, 'i' stands for any integer between 1 and n; and 'j' stands for any integer between 1 and l+1); then it indicates "Zero occupancy" or "No occupancy". The term "Occupancy", denoted by A_r, of a particular keyword-cluster indicates total number of appearances of all keywords residing in that cluster. Thus if a single keyword can appear maximum (l+1) times during the time span from Y to (Y+l), then the total number of maximum possible appearances of w_i number of keywords during the same time span would be, $[w_i*(l+1)]$.

Keyword characteristic indicators

Table 7 shows the eight indicators based on six variables of a keyword cluster have been defined and studied here:

1) Integrated Visibility Index, denoted by v(i), reflects the exposure of a keyword cluster over the entire journal-article space during concerned time span. This is defined as number of journal articles covered by a single keyword over the entire time span.
2) Momentary Visibility Index, denoted by m(i), reflects the exposure of a keyword cluster over the entire journal-article space in a single appearance. This is defined as number of journal articles covered by a single keyword in a single appearance.
3) Potency Index, denoted by p(i), tells the energy of a keyword cluster and defined as the natural logarithm of product of total number of keywords and frequency.
4) Frequency Density Index, denoted by d(i), tells the fraction of journal articles covered by a keyword/keyword cluster per unit journal article and defined as total frequency per unit article.
5) Occupancy Density Index, denoted by o(i), tells about occupancy of a keyword/keyword cluster per unit journal article and defined as total occupancy per unit article.
6) Keyword Density Index, denoted by k(i), tells about number of keyword/keyword cluster per unit journal article and defined as number of keywords per unit article.
7) Stability Index, denoted by s(i), tells about temporal stability of a keyword cluster and defined as ratio of actual occupancy of a cluster to the maximum occupancy of the same cluster, multiplied by 100.
8) Scattering Index, denoted by t(i), reflects scattering of keywords within a cluster and defined as average occupancy per unit keyword, i.e. amount of space occupied by a single keyword.

In short, these eight indicators define five basic properties of keyword clusters, as given below in Table 8, viz. (1) Visibility, (2) Scattering, (3) Strength, (4) Stability and (5) Density.

Table 6 — Analytical description of three fundamental variables

Keyword Cluster (KC)	Variables	Year								Variables (Integrated value over the entire time span 'l')
		Y	Y+1	Y+2	Y+3	…	…	[Y+(l-1)]	Y+l	
k_1	Freq. of Occurrence	f_{11}	f_{12}	f_{13}	f_{14}	…	…	f_{1l}	$f_{1, l+1}$	$\Sigma f_{1j} = F_1$
	No. of Keywords	n_{11}	n_{12}	n_{13}	n_{14}	…	…	n_{1l}	$n_{1,l+1}$	$\Sigma n_{1j} = N_1$
	Occupancy	a_{11}	a_{12}	a_{13}	a_{14}	…	…	a_{1l}	$a_{1, l+1}$	$\Sigma a_{1j} = A_1$
k_2	Freq. of Occurrence	f_{21}	f_{22}	f_{23}	f_{24}	…	…	f_{2l}	$f_{2, l+1}$	$\Sigma f_{2j} = F_2$
	No. of Keywords	n_{21}	n_{22}	n_{23}	n_{24}	…	…	n_{2l}	$n_{2, l+1}$	$\Sigma n_{2j} = N_2$
	Occupancy	a_{21}	a_{22}	a_{23}	a_{24}	…	…	a_{2l}	$a_{2, l+1}$	$\Sigma a_{2j} = A_2$
k_3	Freq. of Occurrence	f_{31}	f_{32}	f_{33}	f_{34}	…	…	f_{3l}	$f_{3, l+1}$	$\Sigma f_{3j} = F_3$
	No. of Keywords	n_{31}	n_{32}	n_{33}	n_{34}	…	…	n_{3l}	$n_{3, l+1}$	$\Sigma n_{3j} = N_3$
	Occupancy	a_{31}	a_{32}	a_{33}	a_{34}	…	…	a_{3l}	$a_{3, l+1}$	$\Sigma a_{3j} = A_3$
…		…	…	…	…	…	…	…	…	
…		…	…	…	…	…	…	…	…	
k_r	Freq. of Occurrence	f_{r1}	f_{r2}	f_{r3}	f_{r4}	…	…	f_{rl}	$f_{r, l+1}$	$\Sigma f_{rj} = F_r$
	No. of Keywords	n_{r1}	n_{r2}	n_{r3}	n_{r4}	…	…	n_{rl}	$n_{r, l+1}$	$\Sigma n_{rj} = N_r$
	Occupancy	a_{r1}	a_{r2}	a_{r3}	a_{r4}	…	…	a_{rl}	$a_{r, l+1}$	$\Sigma a_{rj} = A_r$

[The dummy variable 'j' in the suffix of 'f', 'n' & 'a' varies from 1 to (l+1)]

Subject-centric keywords hardly come alone, but always accompanied with their related counterparts. The research in subject-centric field is always increasing, and consecutively more research creates more problems and more problems create more keywords. But subject-generic and supporting keywords may come alone, or with few number of accompanies, as they form feeble clusters. Subject-generic and supporting keywords represent already established fields, and new researches are hardly executed in these areas. Subject-specific keywords define core research area, while subject-generic keywords indicate those areas, which have impact on core area. Supporting technical keywords indicate supporting tools of research and mode of research. The keyword clusters with high v(i) may fall under either of these categories, but clusters with high m(i) are generally isolated and at the same time myriad, in nature.

Results and analysis

The results are presented in Appendix 1 to 4. The numerical values of these eight indicators for the subject

Table 7 — Keyword characteristic indicators

Serial . No	Indicator	Denoted by	Defined as
1	Integrated Visibility Index	v(i)	F_r / N_r
2	Momentary Visibility Index	m(i)	F_r / A_r
3	Potency Index	p(i)	$\ln(N_r * F_r)$
4	Frequency Density Index	d(i)	F_r / J
5	Occupancy Density Index	o(i)	A_r / J
6	Keyword Density Index	k(i)	N_r / J
7	Stability Index	s(i)	$(A_r / A_{Max}) * 100$
8	Scattering Index	t(i)	A_r / N_r

'Fermi liquid' are presented in Appendix 1. The nature of variation of numerical values of top twenty keywords and keyword clusters in decreasing order for eight indicators are graphically presented in Appendix 2 and the details about corresponding equations obeyed by each graph are shown in Appendix 3. The comparative ranking of top twenty keywords and keyword clusters according to all indicators are given in Appendix 4.

The keyword 'Mathematical model' possesses highest momentary visibility index as seen from Appendix 1,

Table 8 — Basic properties and corresponding trends indicated

Basic Properties Studied	Corresponding Indicators		Trends Indicated at high values of the indicators
	Integrated	v(i)	High visible keyword, which may be subject-specific, subject-generic or supporting.
	Visibility	m(i)	Highly visible, i.e. myriad but isolated. Generally keywords belonging to Momentary an area that is supportive to the central area of research fall under this category.
Scattering		t(i)	Occupancy per keyword or the extension to which a keyword occupies the subject space, or 'Scattered' over the subject space.
Potency or Strength		p(i)	Cluster with large number of keywords and high occupancy indicating highly relevant and subject-centric keywords.
Stability		s(i)	Ratio of actual occupancy to maximum possible occupancy, which tells average occupancy over entire time span. High value of average occupancy indicates higher stability.
	Frequency	d(i)	A cluster with high spatial coverage.
Density	Occupancy	o(i)	A cluster with high temporal stability.
	Keyword	k(i)	A cluster with high energy.

followed by the keywords 'Electric resistivity', 'Antiferromagnetic material' and 'Quantum theory' in the second, third and fourth positions respectively. The keyword 'Mathematical model' indicates a methodology and its highest momentary visibility index indicates that this methodology is an essential way to execute study on the subject 'Fermi liquid'. This keyword occurred without any companion keyword (Unlike the keyword 'Hubbard model' in Table 3) throughout the span. The mathematical modeling is done in both theoretical and experimental research and the subject 'Fermi liquid' thus encounters both types of research works. The keyword 'Electric resistivity' although belongs to physics, yet it is a common and well-known term. This keyword is closely associated with the major working areas of this subject. The momentary visibility index thus helps in tracing those concepts, which are closely associated with the thrust areas of research. A look through Appendix 4 reveals that the rankings of same keywords are different for different indicators. For instance, the keyword 'Mathematical model' holds 1st rank in m(i), while 4th rank in v(i). This phenomenon indicates that this keyword is less significant as a potential research area in itself, rather than an associated tool for research works in this area. A subject embraces so many thrust areas of research at the time of inception, which normally decreases in course of time as the age of the subject increases. The squeeze in potential research areas gradually absolves the dynamism of the subject as an active topic of research, but it tends eventually to become an allied research topic. For instance, 'Quantum theory' was an active topic of research in modern physics at the time of its inception, i.e. during the first three decades of the last century. But today, it is a very significant allied subject for research in so many areas of physics and chemistry.

The keyword 'Quantum theory' has highest Integrated Visibility Index followed by 'Antiferromagnetism and antiferromagnet', 'Thermal effect' and 'Mathematical model'. The keyword 'Quantum theory' was present in highest number of journal articles without any companion keyword during the span of 20 years. This is a subject-related keyword, while 'Mathematical model' is general keyword. Both of these keywords have high impact on this subject.

The stability index of a keyword cluster measures the number of appearances of the keywords belonging to a cluster during the entire span of twenty years. The keyword Helium 3-4 has highest Stability and Scattering index. This keyword possesses highest occupancy in 20 years. This is a single keyword. The diversity of terms is not present here, i.e. the keyword "Helium 3-4" has no accompanying terms and this concept exists alone. But its intensity is highest in terms of occupancy. That is to say, in spite of isolation, this keyword holds strong relevance with the concern subject "Fermi liquid". Scattering Index [t(i)] and Stability Index s(i) are of similar type, both show step functions, as clear from Appendix

2. The rankings according to these two indicators also reflect almost identical pattern, as evident from Appendix 4. As a keyword occupies larger volume of subject space, it will become more and more stable.

The keyword "Fermi liquid" possesses highest "Potency index" and "Frequency density index", which is obvious because this is the name of the subject concerned and naturally forms a cluster with highest spatial coverage along with largest number of accompanying keywords. The keyword "Electron" possesses highest "Occupancy density index" and "Keyword density index". Now, "Electron" is a fundamental keyword closely associated mainly with Condensed matter physics, Low-temperature physics and Nuclear physics. The central field of the subject "Fermi liquid" also includes low-temperature behaviour of fundamental particles. The keyword "Electron" holds highest temporal stability and also highest energy within the domain of this subject. It is thus clear that "Electron" is the specifically focused area of this subject. The major dealings come from different behavioral aspects of the fundamental particle electron.

Conclusion

Some indicators have been defined here based on some primary variables of a keyword or keyword cluster occurring in journal articles, to trace out potential and relevant keywords within the domain of a subject. Sometimes, the potential keywords come alone, without any accompanying venture, whereas sometimes they occur with very large number of joint ventures, such that the root keyword may be lost in the crowd of clusters of accompanying keywords. These features are recognizable with the aid of these indicators.

The searching of information is gradually becoming too much keyword-dependent, and as keyword dependence increases context-sensitivity decreases, which is a very common feature today even for most popular search engines like Google or Yahoo. This phenomenon occurs mainly due to indifference of keywords about the relevant context. The keywords of any subject are not usually rated, so that their degree of correlation to the main subject domain remains oblivious. This study proposed some methods to rank the keywords on the basis of some indicators developed from the statistics of occurrence of keywords. These indicators will enable to determine appropriate and intensive keywords from a subject. The quantitative features of occurrence of keywords in science journals are by and large overlooked, while this study puts forward some methods to culminate on behavioral aspects of keywords in terms of quantitative measurements. The research scholars from all disciplines would be able to know respective centrally interested areas of study by analyzing the quantitative characteristic indicators of the keyword clusters.

References

1 Bertrand A and Cellier J M, Psychological approach to indexing: effects of the operator's expertise upon indexing behaviour, *Journal of Information Science*, 21 (6) (1995) 459-472.

2 Suraud M G et al, On the significance of databases keywords for a large-scale bibliometric investigation in fundamental physics, *Scientometrics*, 33 (1) (1995) 41-63.

3 Voorbij H J, Title Keywords and Subject Descriptors: A Comparison of Subject Search Entries of Books in the Humanities and Social Sciences, *Journal of Documentation*, 54 (1998) 466-476.

4 Solomon P, Use-based methods for classification development. *Proceedings of the 2nd ASIS SIG/CR Classification Research Workshop*. Washington DC (1991).

5 Hurt C D, Classification and subject analysis: looking to the future at a distance, *Cataloguing and Classification Quarterly*, 24 (1-2) (1997) 97-112.

6 Soergel D et al, Re-engineering thesauri for new applications: the AGROVOC example, *Journal of Digital Information*, 4 (4) (2004).

7 Bates M J, Wilde D N and Siegfried S, An analysis of search terminology used by humanities scholars: the Getty Online Searching Project Report, No.1, *Library Quarterly*, 63 (1) (1993) 1-39.

8 Willett P, Recent trends in hierarchical document clustering: A critical review, an:*Information Processing & Management*, 24 (5) (1988) 577-597.

9 McCaffrey A, Applied cladistics: New methodologies for information classification research. *Proceedings of the 2nd ASIS SIG/CR Classification Research Workshop*. Washington DC, (1991) 85-100.

10 Dutta B, Majumder K P and Sen B K, Classification of key-words extracted from research articles published in science journals, *Annals of Library and Information Studies*, 55 (4) (2008) 317-333.

APPENDIX 1

Ranking of keyword/keyword cluster according to different indicators along with their corresponding numerical values

Keyword	RANK								Numerical values of the INDICATORS							
	R(t(i))	R(s(i))	R(v(i))	R(m(i))	R(p(i))	R(d(i))	R(o(i))	R(k(i))	t(i)	s(i)	v(i)	m(i)	p(i)	d(i)	o(i)	k(i)
Alloy-alloying	4	4							17	85						
Alloy-compound			10		4	2	4				101.9		12.97	1.04	0.136	
Anisotropy-and-anisotropy-parameter	3	3							18	90						
Antiferromagnetic-material			6	3							141	23.5				
Antiferromagnetism-antiferromagnet	2	2	2	8					19	95	312	16.42				
Approximation-theory			7	16							125	10.42				
Boltzmann-distribution	5	5							16	80						
Boson								15								0.012
Charge							15	12							0.032	0.015
Conductance							19	16							0.027	0.012
Critical-phenomena	6	6							15	75						
Crystal-Crystallography	6	6							15	75						
de-Haas-van-Alphen-effect	3	3	11						18	90	101					
Electric-resistivity			8	2							120	25				
Electron					2	3	1	1					14.71	0.576	0.229	0.104
Electron-system					18	15							10.72	0.129		
Elementary-excitation	6	6							15	75						
Energy					17		12	17					10.73		0.035	0.012
Fermi-level				5		10						19.66		0.179		
Fermi-liquid					1	1	3	3					15.18	1.36	0.172	0.071
Fermi-liquid-theory				17		8						10.33		0.195		
Fermion					5	7	5	4					12.76	0.298	0.06	0.029
Fermion-system				9								14.85				
Fermi-surface					9	9	15	9					11.83	0.188	0.032	0.018
Ginzburg-Landau-theory	4	4							17	85						
Hamiltonian-theory				14								11.5				
Helium					15	20							10.78	0.103		
Helium-3			18								71.75					
Helium-3-4	1	1	9						20	100	116					
Hole								16								0.012
Hubbard-model					19	16							10.58	0.11		
Impurity					10		7	5					11.48		0.05	0.025

Kondo-effect				18		19						10.06		0.106		
Lattice							13	8							0.034	0.019
Liquid								18								0.012
Luttinger-liquid					20	17							10.57	0.109		
Magnetic-field					16		14	19					10.74		0.033	0.012
Magnetic-phase-transition				12								12.35				
Magnetism				15								11.2				
Mathematical-model			4	1							186.5	26.64				
Metal					11	13	10	11					11.38	0.135	0.04	0.016
Momentum-space	5	5							16	80						
normal-state-analysis	6	6	11						15	75	101					
Numerical-analysis	5	5	9						16	80	116					
Phase-diagram			17	11							72	12.52				
Pressure-effect			14								82					
Quantum-theory	3	3	1	4					18	90	355	19.72				
Quasiparticle					8	12	6	6					11.88	0.15	0.055	0.024
Renormalisation			5	6							170	17				
Scaling-analysis	3	3							18	90						
Scattering							18	10							0.029	0.017
Semiconductor					14	18	8						10.81	0.108	0.043	
Specific-heat				13		11						12.21		0.157		
Spectroscopic-analysis			16								74					
Spin					3	5	2	2					14.08	0.371	0.173	0.086
Superconducting-critical	7	7							14	70						
Superconducting-thin	3	3							18	90						
Superconducting-transition			12	19							95	10				
Superconductivity				10	7	4	17					12.71	11.91	0.383	0.03	
Superconductor					12		11	7					11.32		0.038	0.02
Susceptibility				20	6	6	16	13				9.995	12.11	0.315	0.032	0.014
Temperature					13	14	9	14					11.22	0.133	0.04	0.014
Thermal-effect	6	6	3	7					15	75	248	16.53				
Thermodynamic-property			15								77					
Thomas-Fermi-model	6	6							15	75						
Tunneling-effect			13								94					
Weak-coupling-theory	5	5							16	80						

APPENDIX 2

Graphs showing variation in numerical values of the eight indicators for top twenty keywords/ keyword clusters (X-axis : Numerical values of the indicators (Independent variable); Y-asis: Rank of the keyword/keyword clusters (Dependent variable)

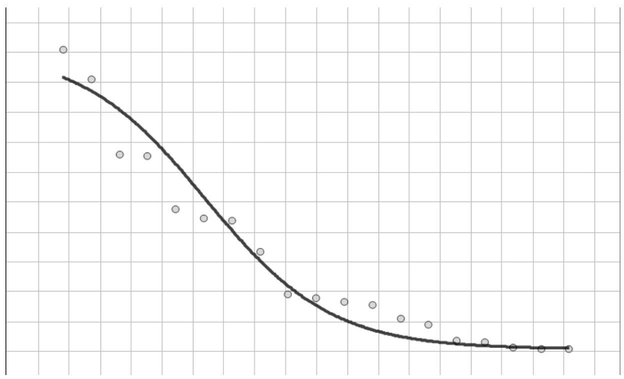

Figure A3. 1: Momentary Visibility Index [m(i)]

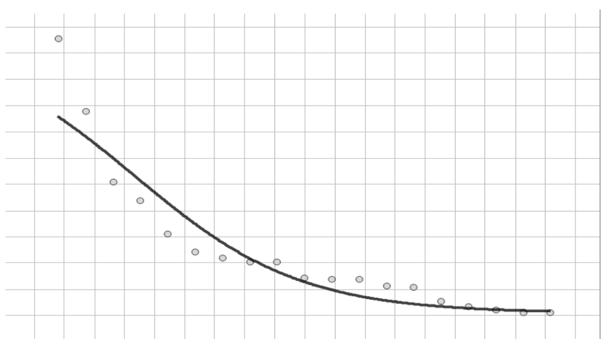

Fig. A3.2: Integrated Visibility Index [v(i)]

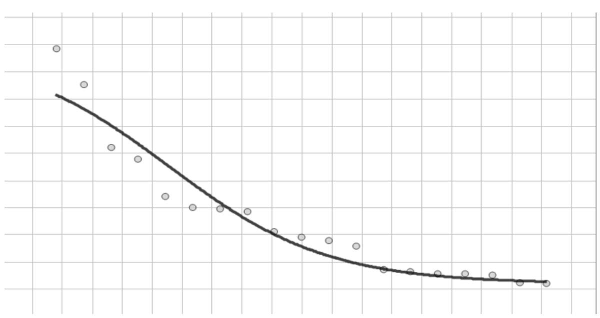

Fig. A3.3: Potency Index [p(i)]

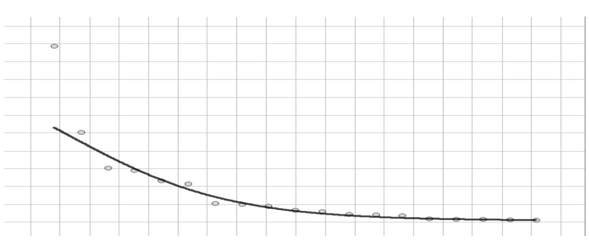

Fig. A3.4: Frequency Density Index [d(i)]

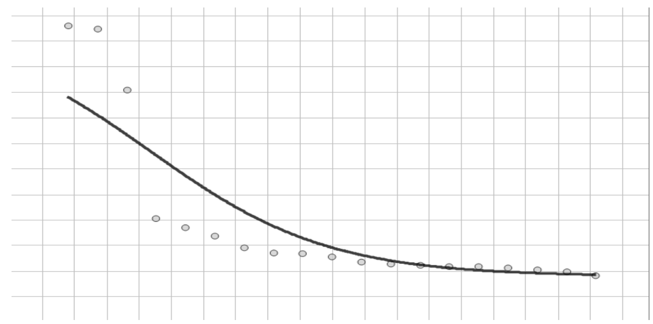

Figure A3.5: Occupancy Density Index [o(i)]

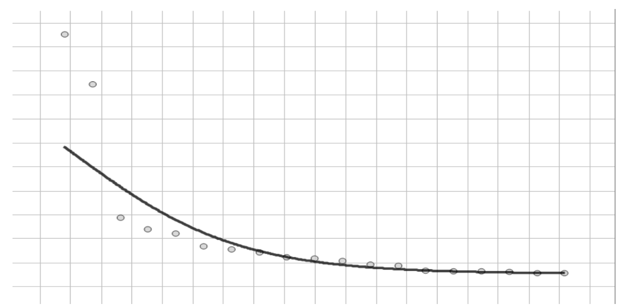

Fig. A3.6: Keyword Density Index [k(i)]

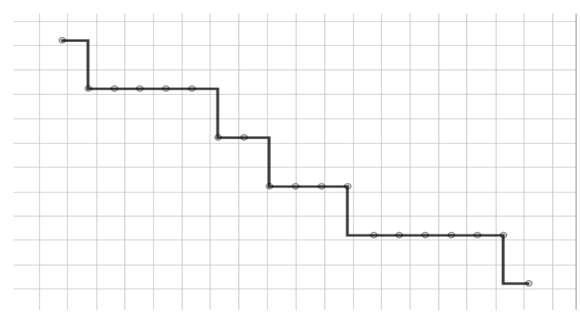

Fig. A3.7: Stability Index [s(i)]

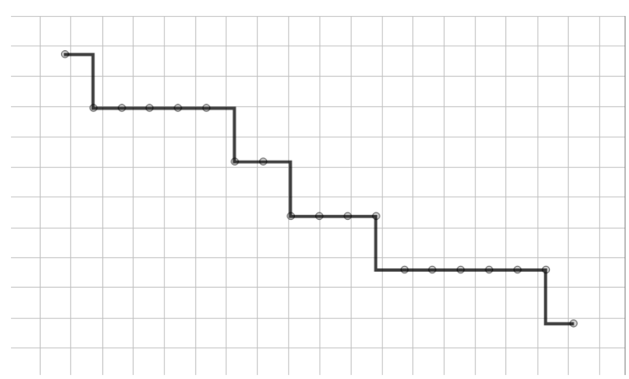

Fig. A3.8: Scattering Index [t(i)]

APPENDIX-3

Table-A-2: Details about equations followed by the graphs shown in Appendix-2

Serial No.	Indicator	Representative Symbol	Formula	Mathematical Function	Equation Type	No. of Constants Involved	Numerical Values of the Constants Involved			
							A	B	C	D
1	Momentary Visibility	m(i)	F_r / A_r	Logistic			10	15	3.19	0.45
2	Integrated Visibility Index	v(i)	F_r / N_r				71.8	240	1.59	0.33
3	Potency IndexF=	p(i)	$\ln [N_r * F_r]$	Logistic	y=A+B/(1+exp[-(C+D*x)])	4	10.6	4.14	2.11	0.34
4	Frequency Density Index	d(i)	F_r / J				0.1	0.94	0.8	0.33
5	Occupancy Density Index	o(i)	A_r /J				0.03	0.15	1.59	0.33
6	Keyword Density Index	k(i)	N_r /J				0.01	0.07	0.8	0.34
7	Stability Index	s(i)	$(A_r / A_{Max})*100$	Step	y = Constant & x = Constant					
8	Scattering Index	t(i)	A_r / N_r							

APPENDIX - 4

R(v(i))	R(m(i))	R(p(i))	R(s(i))	R(t(i))	R(d(i))	R(o(i))	R(k(i))
Quantum-theory	Mathematical-model	Fermi-liquid	Helium-3-4	Helium-3-4	Fermi-liquid	Electron	Electron
Antiferromagnetism-and-antiferromagnet	Electric-resistivity	Electron	Antiferromagnetism-and-antiferromagnet	Antiferromagnetism-antiferromagnet	Alloy-compound	Spin	Spin
Thermal-effect	Antiferromagnetic-material	Spin	Quantum-theory	Quantum-theory	Electron	Fermi-liquid	Fermi-liquid
Mathematical-model	Quantum-theory	Alloy-and-compound	de-Haas-van-Alphen-effect	de-Haas-van-Alphen-effect	Superconductivity	Alloy-compound	Fermion
Renormalisation	Fermi-level	Fermion	Anisotropy-and-anisotropy-parameter	Anisotropy-and-anisotropy-parameter	Spin	Fermion	Impurity
Antiferromagnetic-material	Renormalisation	Susceptibility	Scaling-analysis	Scaling-analysis	Susceptibility	Quasiparticle	Quasiparticle
Approximation-theory	Thermal-effect	Superconductivity	Superconducting-thin-film	Superconducting-thin	Fermion	Impurity	Superconductor
Electric-resistivity	Antiferromagnetism -and-antiferromagnet	Quasiparticle	Ginzburg-Landau-theory	Ginzburg-Landau-theory	Fermi-liquid-theory	Semiconductor	Lattice
Numerical-analysis	Fermion-system	Fermi-surface	Alloy-and-alloying	Alloy-alloying	Fermi-surface	Temperature	Fermi-surface
Helium-3-4	Superconductivity	Impurity	Numerical-analysis	Numerical-analysis	Fermi-level	Metal	Scattering
Alloy-and-compound	Phase-diagram	Metal	Boltzmann-distribution	Boltzmann-distribution	Specific-heat	Superconductor	Metal
Normal-state-analysis	Magnetic-phase -transition	Superconductor	Weak-coupling-theory	Weak-coupling-theory	Quasiparticle	Energy	Charge
de-Haas-van-Alphen-effect	Specific-heat	Temperature	Momentum-space	Momentum-space	Metal	Lattice	Susceptibility
Superconducting-transition	Hamiltonian-theory	Semiconductor	Thermal-effect	Thermal-effect	Temperature	Magnetic-field	Temperature
Tunneling-effect	Magnetism	Helium	Normal-state-analysis	Thomas-Fermi-model	Electron-system	Fermi-surface	Boson
Pressure-effect	Approximation-theory	Magnetic-field	Crystal-and-crystallography	normal-state-analysis	Hubbard-model	Charge	Conductance
Thermodynamic -property	Fermi-liquid-theory	Energy	Critical-phenomena	Crystal-Crystallography	Luttinger-liquid	Susceptibility	Hole
Spectroscopic-analysis	Kondo-effect	Electron-system	Thomas-Fermi-model	Critical-phenomena	Semiconductor	Superconductivity	Energy
Phase-diagram	Superconducting-transition	Hubbard-model	Elementary-excitation	Elementary-excitation	Kondo-effect	Scattering	Liquid
Helium-3	Susceptibility	Luttinger-liquid	Phase-separation	Superconducting-critical	Helium	Conductance	Magnetic-field