RESEARCH METHODOLOGY

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Abstract

In this manuscript various components of research are listed and briefly discussed. The topics considered in this write-up cover a part of the research methodology paper of Master of Philosophy (M.Phil.) course and Doctor of Philosophy (Ph.D.) course. The manuscript is intended for students and research scholars of science subjects such as mathematics, physics, chemistry, statistics, biology and computer science. Various stages of research are discussed in detail. Special care has been taken to motivate the young researchers to take up challenging problems. Ten assignment works are given. For the benefit of young researchers a short interview with three eminent scientists is included at the end of the manuscript.

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I. WHAT IS RESEARCH?

Research is a logical and systematic search for new and useful information on a particular topic. In the well-known nursery rhyme

Twinkle Twinkle Little Star
How I Wonder What You Are

the use of the words *how* and *what* essentially summarizes what research is. It is an investigation of finding solutions to scientific and social problems through objective and systematic analysis. It is a search for knowledge, that is, a discovery of hidden truths. Here knowledge means information about matters. The information might be collected from different sources like experience, human beings, books, journals, nature, etc. A research can lead to new contributions to the existing knowledge. Only through research is it possible to make progress in a field. Research is indeed civilization and determines the economic, social and political development of a nation. The results of scientific research very often force a change in the philosophical view of problems which extend far beyond the restricted domain of science itself.

Research is not confined to science and technology only. There are vast areas of research in other disciplines such as languages, literature, history and sociology. Whatever might be the subject, research has to be an active, diligent and systematic process of inquiry in order to discover, interpret or revise facts, events, behaviours and theories. Applying the outcome of research for the refinement of knowledge in other subjects, or in enhancing the quality of human life also becomes a kind of research and development.

Research is done with the help of study, experiment, observation, analysis, comparison and reasoning. Research is in fact ubiquitous. For example, we know that cigarette smoking is injurious to health; heroine is addictive; cow dung is a useful source of biogas; malaria is due to the virus protozoan plasmodium; AIDS (Acquired Immuno Deficiency Syndrome) is due to the virus HIV (Human Immuno Deficiency Virus). How did we know all these? We became aware of all these information only through research. More precisely, it seeks predictions of events, explanations, relationships and theories for them.

As stated by Gerald Milburn *Scientific research is a chaotic business, stumbling along amidst red herrings, errors and truly, creative insights. Great scientific breakthroughs are rarely the work of a single researchers plodding slowly by inexorably towards some final goal. The crucial idea behind the breakthrough may surface a number of times, in different places, only to sink again beneath the babble of an endless scientific discourse*.

A. *What are the Objectives of Research?*

The prime objectives of research are

(1) to discover new facts

(2) to verify and test important facts

(3) to analyse an event or process or phenomenon to identify the cause and effect relationship

(4) to develop new scientific tools, concepts and theories to solve and understand scientific and nonscientific problems

(5) to find solutions to scientific, nonscientific and social problems and

(6) to overcome or solve the problems occurring in our every day life.

B. *What Makes People do Research?*

This is a fundamentally important question. *No person would like to do research unless there are some motivating factors*. Some of the motivations are the following:

(1) to get a research degree (Doctor of Philosophy (Ph.D.)) along with its benefits like better employment, promotion, increment in salary, etc.

(2) to get a research degree and then to get a teaching position in a college or university or become a scientist in a research institution

(3) to get a research position in countries like U.S.A., Canada, Germany, England, Japan, Australia, etc. and settle there

(4) to solve the unsolved and challenging problems

(5) to get joy of doing some creative work

(6) to acquire respectability

(7) to get recognition

(8) curiosity to find out the unknown facts of an event

(9) curiosity to find new things

(10) to serve the society by solving social problems.

Some students undertake research without any aim possibly because of not being able to think of anything else to do. Such students can also become good researchers by motivating themselves toward a respectable goal. As pointed out by Prof. Rajesh Kasturirangan (NIAS, IISc) even if you work in a company or run a company, a mind inclined towards research would do better than a mind not trained for it and it was like the story of the hare and the tortoise. If you have a mind trained for research, you will be the tortoise – the climb would be slow and steady, but eventually you would win the race.

C. *Thesis Research*

In the words of Prof.P. Balaram [Current Science, 87(2004)1319] *Ph.D. degree is a passport to a research career*. The Ph.D. period often influence a research scholar to make or to break in a scientific career. Here one reaches the frontier of knowledge and begins in earnest the lifelong task of learning how to do research. As pointed out by Beasley and Jones [1] during Ph.D. course ideally one learns how to pick a research problem, how to carry out it, how to

extract new information from the results and how to publish the findings to the scientific community. Thesis or Ph.D. research inherently involves those aspects of subject that cannot be actually learned from textbooks or from lecture courses. It is the point where the values, traditions and styles of science are transmitted from one generation to another.

D. *Importance of Research*

Research is important both in scientific and nonscientific fields. In our life new problems, events, phenomena and processes occur every day. Practically, implementable solutions and suggestions are required for tackling new problems that arise. Scientists have to undertake research on them and find their causes, solutions, explanations and applications. Precisely, research assists us to understand nature and natural phenomena.

Some important avenues of research are:

(1) A research problem refers to a difficulty which a researcher or a scientific community or an industry or a government organization or a society experiences. It may be a theoretical or a practical situation. It calls for a thorough understanding and possible solution.

(2) Research on existing theories and concepts help us identify the range and applications of them.

(3) It is the fountain of knowledge and provide guidelines for solving problems.

(4) Research provides basis for many government policies. For example, research on the needs and desires of the people and on the availability of revenues to meet the needs helps a government to prepare a budget.

(5) It is important in industry and business for higher gain and productivity and to improve the quality of products.

(6) Mathematical and logical research on business and industry optimizes the problems in them.

(7) It leads to the identification and characterization of new materials, new living things, new stars, etc.

(8) Only through research inventions can be made; for example, new and novel phenomena and processes such as superconductivity and cloning have been discovered only through research.

(9) Social research helps find answers to social problems. They explain social phenomena and seek solution to social problems.

(10) Research leads to a new style of life and makes it delightful and glorious.

Emphasizing the importance of research Louis Pasteur said: *I beseech you to take interest in these sacred domains called laboratories. Ask that there be more and that they be adorned for these are the temples of the future, wealth and well-being. It is here that humanity will*

learn to read progress and individual harmony in the works of nature, while humanity's own works are all too often those of barbarism, fanaticism and destruction. (Louis Paster – article by S. Mahanti, Dream 2047, p.29–34 (May 2003)).

In order to know what it means to do research one may read scientific autobiographies like Richard Feynmann's *Surely you are joking, Mr.Feynmann!*, Jim Watson's *The double helix* and *Science as a way of life – A biography of C.N.R. Rao* by Mohan Sundararajan.

II. RESEARCH METHODS AND RESEARCH METHODOLOGY

Is there any difference between research methods and research methodology?

Research methods are the various procedures, schemes and algorithms used in research. All the methods used by a researcher during a research study are termed as *research methods*. They are essentially planned, scientific and value-neutral. They include theoretical procedures, experimental studies, numerical schemes, statistical approaches, etc. Research methods help us collect samples, data and find a solution to a problem. Particularly, scientific research methods call for explanations based on collected facts, measurements and observations and not on reasoning alone. They accept only those explanations which can be verified by experiments.

Research methodology is a systematic way to solve a problem. It is a science of studying how research is to be carried out. Essentially, *the procedures by which researchers go about their work of describing, explaining and predicting phenomena are called research methodology.* It is also defined as the study of methods by which knowledge is gained. Its aim is to give the work plan of research.

A. *Importance of Research Methodology in Research Study*

It is necessary for a researcher to design a methodology for the problem chosen. One should note that even if the method considered in two problems are same the methodology may be different. It is important for the researcher to know not only the research methods necessary for the research under taken but also the methodology. For example, a researcher not only needs to know how to calculate mean, variance and distribution function for a set of data, how to find a solution of a physical system described by mathematical model, how to determine the roots of algebraic equations and how to apply a particular method but also need to know

(i) which is a suitable method for the chosen problem?,

(ii) what is the order of accuracy of the result of a method?,

(iii) what is the efficiency of the method?

and so on. Consideration of these aspects constitute a research methodology.

To understand the difference between research methods and methodology let us consider the problem of finding the roots of the quadratic equation

$$ax^2 + bx + c = 0. \tag{1}$$

The formulas often used for calculating the roots of eq.(1) are

$$x_+ = \frac{-b+\sqrt{b^2-4ac}}{2a}\,, \tag{2}$$

$$x_- = \frac{-b-\sqrt{b^2-4ac}}{2a}\,. \tag{3}$$

These formulas are, however, inaccurate when $|b| \approx \sqrt{b^2-4ac}$. The equivalent formulas are

$$x_+ = \frac{-2c}{b+\sqrt{b^2-4ac}}\,, \tag{4}$$

$$x_- = \frac{-2c}{b-\sqrt{b^2-4ac}}\,. \tag{5}$$

When $|b| \approx \sqrt{b^2-4ac}$ one must proceed with caution to avoid loss of precision. If $b > 0$, then x_+ should be computed with the formula given by eq.(2) and x_- should be computed with the formula given by eq.(3). If $b < 0$ then x_+ should be evaluated using eq.(4) and x_- should be evaluated using eq.(5). Here the two formulas constitute the method of finding roots of the equation of the form given by eq.(1). If you use the formulas given by eqs.(4–5) instead of the formulas given by eqs.(2–3) (often used and familiar to us) to compute the roots then you should clearly explain why the formulas given by eqs.(4–5) were chosen and why the other formulas given by eqs.(2–3) were not considered. This is what we mean by a research methodology. That is, research methodology tells you which method or formula or algorithm has to be used out of the various existing methods or formulas or algorithms.

More precisely, research methods help us get a solution to a problem. On the other hand, research methodology is concerned with the explanation of the following:

(1) Why is a particular research study undertaken?

(2) How did one formulate a research problem?

(3) What types of data were collected?

(4) What particular method has been used?

(5) Why was a particular technique of analysis of data used?

The study of research methods gives training to apply them to a problem. The study of research methodology provides us the necessary training in choosing methods, materials, scientific tools and training in techniques relevant for the problem chosen.

Assignment:

(1) List out at least 10 methods which you have learned in your UG and PG courses and write their purpose or application.

(2) Distinguish between research methods and research techniques.

(3) Distinguish between research methods and research methodology with an example of your own choice.

III. TYPES OF RESEARCH

Research is broadly classified into two main classes:

1. Fundamental or basic research
2. Applied research

A. *Basic Research*

Basic research is an investigation on basic principles and reasons for occurrence of a particular event or process or phenomenon. It is also called *theoretical research*. Study or investigation of some natural phenomenon or relating to pure science are termed as *basic research*. Basic researches some times may not lead to immediate use or application. It is not concerned with solving any practical problems of immediate interest. But it is original or basic in character. It provides a systematic and deep insight into a problem and facilitates extraction of scientific and logical explanation and conclusion on it. It helps build new frontiers of knowledge. The outcomes of basic research form the basis for many applied research. Researchers working on applied research have to make use of the outcomes of basic research and explore the utility of them.

Research on improving a theory or a method is also referred as fundamental research. For example, suppose a theory is applicable to a system provided the system satisfies certain specific conditions. Modifying the theory to apply it to a general situation is a basic research.

Attempts to find answers to the following questions actually form basic research.

- Why are materials like that?
- What are they?
- How does a crystal melt?
- Why is sound produced when water is heated?
- Why do we feel difficult when walking on seashore?
- Why are birds arrange them in '>' shape when flying in a group?

Fundamental research leads to a new theory or a new property of matter or even the existence of a new matter, the knowledge of which has not been known or reported earlier. For example, fundamental research on

(1) astronomy may leads to identification of new planets or stars in our galaxy,

(2) elementary particles results in identification of new particles,

(3) complex functions may leads to new patterns or new properties associated with them,

(4) differential equations results in new types of solutions or new properties of solutions not known so far,

(5) chemical reactions leads to development of new compounds, new properties of chemicals, mechanism of chemicals reactions, etc.,

(6) medicinal chemistry leads to an understanding of physiological action of various chemicals and drugs,

(7) structure, contents and functioning of various parts of human body helps us identify the basis for certain diseases.

B. *Applied Research*

In an *applied research* one solves certain problems employing well known and accepted theories and principles. Most of the experimental research, case studies and inter-disciplinary research are essentially applied research. Applied research is helpful for basic research. A research, the outcome of which has immediate application is also termed as *applied research*. Such a research is of practical use to current activity. For example, research on social problems have immediate use. Applied research is concerned with actual life research such as research on increasing efficiency of a machine, increasing gain factor of production of a material, pollution control, preparing vaccination for a disease, etc. Obviously, they have immediate potential applications.

Some of the differences between basic and applied research are summarized in table I. Thus, the central aim of applied research is to find a solution for a practical problem which warrants solution for immediate use, whereas basic research is directed towards finding information that has broad base of applications and thus add new information to the already existing scientific knowledge.

TABLE I: Differences between basic and applied researches.

Basic research	*Applied research*
Seeks generalization	Studies individual or specific cases without the objective to generalize
Aims at basic processes	Aims at any variable which makes the desired difference
Attempts to explain why things happen	Tries to say how things can be changed
Tries to get all the facts	Tries to correct the facts which are problematic
Reports in technical language of the topic	Reports in common language

C. *Normal and Revolutionary Researches*

Basic and applied researches are generally of two kinds: *normal research* and *revolutionary research*. In any particular field, normal research is performed in accordance with a set of rules, concepts and procedures called a *paradigm*, which is well accepted by the scientists working in that field. Normal research is something like puzzle-solving: interesting, even beautiful, solutions are found but the rules are remain same. In this normal research sometimes unexpected novel results and discoveries are realized which are inconsistent with the

existing paradigm. Among the scientist, a tense situation then ensues, which increases in intensity until a scientific revolution is reached. This is marked by a *paradigm shift* and a new paradigm emerges under which normal scientific activity can be resumed.

D. *Quantitative and Qualitative Methods*

The basic and applied researches can be *quantitative* or *qualitative* or even both. Quantitative research is based on the measurement of quantity or amount. Here a process is expressed or described in terms of one or more quantities. The result of this research is essentially a number or a set of numbers. Some of the characteristics of qualitative research/method are:

- It is numerical, non-descriptive, applies statistics or mathematics and uses numbers.
- It is an iterative process whereby evidence is evaluated.
- The results are often presented in tables and graphs.
- It is conclusive.
- It investigates the *what*, *where* and *when* of decision making.

Statistics is the most widely used branch of mathematics in quantitative research. It finds applications not only in physical sciences but also in economics, social sciences and biology. Quantitative research using statistical methods often begins with the collection of data based on a theory or hypothesis or experiment followed by the application of descriptive or inferential statistical methods.

Qualitative research is concerned with qualitative phenomenon involving quality. Some of the characteristics of qualitative research/method are:

- It is non-numerical, descriptive, applies reasoning and uses words.
- Its aim is to get the meaning, feeling and describe the situation.
- Qualitative data cannot be graphed.
- It is exploratory.
- It investigates the *why* and *how* of decision making.

We measure and weigh things in the study of substance or structure. Can we measure or weigh patterns? We cannot measure or weigh patterns. But to study patterns we must map a configuration of relationships. That is, structures involve quantities whereas patterns involve qualities. If one wishes to investigate why certain data are random then it is a qualitative research. If the aim is to study how random the data is, what is the mean, variance and distribution function then it becomes quantitative. Explaining how digestion of food takes place in our body is a qualitative description. It does not involve any numbers or data and quantities.

The detection of a particular compound is a qualitative analysis. This can be done by carrying out physical or chemical tests. Determination of exact amount of a particular compound present in a volume is essentially quantitative analysis. This can be done by volumetric, gravimetric and colorimetric methods or instrumental methods. Experimental and simulation studies are generally quantitative research.

In fact, qualitative methods can be used to understand the meaning of the numbers obtained by quantitative methods.

E. *Other Types of Research*

Other types of research include *action research* (fact findings to improve the quality of action in the social world), *explanatory research* (searching explanations for events and phenomena, for example finding answer to the question why are the things like what they are?), *exploratory research* (getting more information on a topic) and *comparative research* (obtaining similarities and differences between events, methods, techniques, etc.). For discussion on these types of research see refs.[3–5].

Assignment:

(4) List out at least 10 theoretical and applied methods which you have learned in your UG, PG courses and write their features in two or three sentences.

(5) Write at least 20 questions in your subject the investigation of which forms basic research. Then point out how many of them have already been solved and how many were found in applications.

(6) Distinguish between theory and experiment.

(7) Write a note on importance of theory in basic and applied researches.

(8) Bring out the importance of inter-disciplinary research.

IV. ENTERING INTO RESERCH

How do you enter into a research career?

There are many ways to enter and start a research career. In India, one popular path is to appear for the National Eligible Test (NET) conducted by the National Education Testing Bureau of the University Grants Commission (UGC). This test is conducted twice in a year generally in June and December. The NET is conducted in humanities, languages, social sciences, forensic science, environmental sciences, computer science and applications and electronics. The Council of Scientific and Industrial Research (CSIR) conducts the UGC–CSIR NET for science subjects like mathematical, physical, chemical, life, earth, atmospheric, ocean and planetary sciences–jointly with the UGC.

One of the prime objectives of the NET is to ensure minimum standards for the entrants in the research. Those who have at least 55 percent of marks in their postgraduate degree

are eligible for writing the test. Those who are appearing for the final-year qualifying examination can also apply for the test under the Result Awaited category. Age limit for JRF is 28 years. The upper age limit may be relaxed up to five years for SC/ST/OBC/PH and female applicants. For more details, visit www.csirhrdg.res.in.

Passing the test means one is eligible for the award of Juniour Research Fellowship (JRF) for a period of five years in a university or a research institution or a college.

Research facilities are availble in research institutions and CSIR laboratories for those who got good grades in the Graduate Aptitude Test in Engineering (GATE) conducted by the Indian Institutes of Technology (IITs). There is another possible path to enter research. Scientists working in research and educational institutes prepare research proposal and submit to government agencies like Department of Science and Technology (DST), CSIR, UGC, Department of Atomic Energy (DAE), National Board for Higher Mathematics (NBHM), etc. Generally, JRF and other higher fellowships are proposed by the proposer to carry out the proposed research work. Once the proposal is approved then advertisement will be given in newspapers to apply for the research fellowships. Many universities also provide limited number of fellowships. In the above routes a researcher will get fellowship to do research. Without fellowship also one can start a research career. However, since research period for Ph.D. degree is generally a 4–6 years of work, it is not advisable to start a research life without a fellowship.

V. VARIOUS STAGES OF A RESEARCH

Whenever a scientific problem is to be solved there are several important steps to follow. The problem must be stated clearly, including any simplifying assumptions. Then develop a mathematical statement of the problem. This process may involve use of one or more mathematical procedures. Frequently, more advanced text books or review articles will be needed to learn about the techniques and procedures. Next, the results have to be interpreted to arrive at a decision. This will require experience and an understanding of the situation in which the problem is embedded. A general set of sequential components of research is the following:

1. Selection of a research topic
2. Definition of a research problem
3. Literature survey and reference collection
4. Assessment of current status of the topic chosen
5. Formulation of hypotheses
6. Research design
7. Actual investigation
8. Data analysis
9. Interpretation of result

10. Report

In the following sections the above mentioned various stages of research are discussed in detail.

VI. SELECTION OF A RESEARCH TOPIC AND PROBLEM

The starting point of a research is the selection of a research topic and problem. History teaches the continuity of the development and progress of science. The point is that every age has its own problems, numerous in number, which the following age either solves or casts aside as profitless and replaces by new one. If we could obtain an idea of the probable development of scientific knowledge in the immediate future, we must let the unsettled questions pass before our minds and look over the problems which the science of today sets and whose solution we expect from the the near future. The deep significance of certain problems for the advancement of science and society must be taken into consideration in choosing a problem of research.

There are many ways to do research as there are scientists. The choice of a thesis research area and adviser has always been a very subjective process. Identifying a suitable topic for work is one of the most difficult parts of a research. Before choosing a research topic and a problem the young researchers should keep the following points in mind.

- Topic should be suitable for research.
- The researcher should have interest in it.
- Topic should not be chosen by compulsion from some one else.

Topic and problem can be fixed in consultation with the research supervisor. In our country often research supervisors suggest a topic and state a problem in broad view. The researcher has to narrow it and define it in an operational form. One may ask: Is it necessary that the topic of a Ph.D. should be different from M.Sc. project and M.Phil dissertation? The answer is not necessary. If a student is able to get a supervisor working in his M.Sc.project or M.Phil dissertation topic then it would save about six months in the duration of his Ph.D. work.

A. *Can a Researcher Choose a Topic by himself?*

A youngster interested to start a research career wishes to know whether he/she has freedom to do research in the topic of his/her own interest. The style of research in our country and various other factors like the infrastructure facility available in a research institute, time limit, our commitment to family and social set up hardly allow a young researcher to choose a topic by himself for his PG project, M.Phil. dissertation and Ph.D. thesis. However, many research supervisors give complete freedom to choose a problem in the topic suggested by him for a Ph.D. research work. Because the normal time duration of M.Phil dissertation is about 6-8 months, it is better to work on the problem suggested by the supervisor.

If a student wishes to do research (for Ph.D. degree) with fellowship then he cannot have freedom to choose a topic since he has to work on a project the goal of which is already

defined by the project investigator. In the other way, after choosing a topic of his own interest he has to find a supervisor who is working in that topic or interested in guiding him. In this case one has severe limitation in our country for getting a fellowship and for registering for a research degree. If a student is not very much particular about the fellowship he has a chance to do research in the topic of his own interest. A researcher in India after two years of research experience with few (two or more) publications can apply for a senior research fellowship (SRF) to CSIR (for details see its and other relevant web sites). He can prepare a project under the direction of his Ph.D. supervisor which can lead to a fellowship. For details see the book *How to Get Scholarships, Fellows and Stipends* by K.D. Kalaskar (Sultan Chand and Sons, New Delhi).

Considering the above, a researcher should make-up his mind so as to work in a topic suggested by the supervisor. However, a research problem may be chosen by a researcher himself. This has several advantages. In this case

- the researcher can pursue his/her own interest to the farthest limits,
- there is an opportunity to spend a long time on something that is a continuous source of his pleasure and
- the results would prove better in terms of the growth of the investigator and the quality of the work.

If the researcher is not interested in the topic and problem assigned to him but he is working on it because of supervisor's compulsion, then he will not be able to face and overcome the obstacles which come at every stage in research.

B. *Identification of a Research Topic and Problems*

Some sources of identification of a research topic and problems are the following:

(1) Theory of one's own interest

(2) Daily problems

(3) Technological changes

(4) Recent trends

(5) Unexplored areas

(6) Discussion with experts and research supervisor

Suppose one is interested in the theory of nonlinear differential equations or quasicrystals or fullerenes. Then he can find a research guide who is working in this field or interested to work in this field and then choose a problem for research.

Our daily experiences and day to affairs have rich openings on various aspects such as the daunting tasks of AIDS, air pollution, afforestation and deforestation, child labor, problems of aged citizens, etc.

Technology in various branches of science, business and marketing changes rapidly. For example, in the early years, computers were built in larger size with vacuum tubes. Then evolution in electronic technology replaced them by integrated circuits. Recently, scientists have developed quantum dots. Now the interest is in developing efficient, super-fast and miniaturized computing machine made up of material whose particle size of the order of nano (10^{-9}) meter or even smaller. Similarly, another fascinating topic namely, *thin film* has multiple fields of applications. Recent research on fullerenes resulted in many practical applications.

Choosing a topic of current interest or recent trends provides bright and promising opportunities for young researchers to get post-doctoral fellowship, position in leading institutions in our nation and abroad.

In each subject there are several topics which are not explored in detail even though the topic was considered by scientists long time ago. For example, string theory, quantum computing, nano-particles, quantum cloning and quantum cryptography and gene immunology are fascinating topics and are in preliminary stages.

The supervisors and experts are working on one or few fields over a long time and they are the specialists in the field considered and well versed with the development and current status of the field. Therefore, a young researcher can make use of their expertise in knowing various possible problems in the topic the solving of which provide better opportunities in all aspects.

Don't choose a topic simply because it is fascinating. In choosing a topic one should take care of the possibility of data collection, quantity of gain, breadth of the topic and so on. The topic should not be too narrow. For example, the study of social status and sexual life of married couples of same sex (man-man marriage and woman-woman marriage) is interesting and of social relevance. But the intricate problem here is that we do not find enough number of such couples to study. This is a very narrow topic at the same time we will not get enough data to analyze. On the other hand, the changes in the social life of aravanis in recent times is a valuable social problem and one can collect enough data.

Further, one has to study advanced level text books and latest research articles to identify problems. Is it necessary to know all the methods, techniques, concepts in a research topic before identifying a problem for investigation? This is not necessary. After learning some fundamental concepts, recent developments and current trends of a topic, one can identify a problem for research. Then he can learn the tools necessary to solve it.

C. *Definition and Formulation of a Problem*

After identifying a problem, in order to solve it, it has to be defined and formulated properly. For this purpose, one can execute the following.

- State the problem in questionnaire form or in an equivalent form
- Specify the problem in detail and in precise terms
- List the assumptions made

- Remove the ambiguities, if any, in the statement of the problem
- Examine the feasibility of a particular solution

Defining the problem is more important than its solution. It is a crucial part of the research study and should not be defined in hurry.

D. *How do you Asses Whether the Defined Problem as a Good Problem?*

A problem in its first definition may not be appealing. It may require redefinition in order to make it a good problem. That is, by suitably rewording or reformulating the chosen problem, it can be made to meet the criteria of a good problem. This is also important to solve the problem successfully. To this end a researcher can ask a series of questions on the problem. Some are:

(1) Is the problem really interesting to him and to the scientific community?

(2) Is the problem significant to the present status of the topic?

(3) Is there sufficient supervision/guidance?

(4) Can the problem be solved in the required time frame?

(5) Are the necessary equipments, adequate library and computational facilities, etc. available?

If the answers to these questions are satisfactory, then the researcher can initiate work on the chosen problem. In addition, discuss the problem with the current doctoral students and obtain the scope of the problem and other related aspects.

E. *How are these Questions Important and Relevant to a Researcher?*

The researcher should be interested on the problem for the reasons mentioned earlier at the end of the Sec.(VI A). The problem should also be interesting to the supervisor so that the researcher can get the necessary guidance from him. Otherwise sometimes the researcher may find it very difficult to convince the supervisor on the importance and significance of the results obtained. More importantly, the problem must be of interest to scientific community and society. If not then the researcher will find great difficulty to publish his findings in reputed journals and convince the funding agency.

Next, the status of the problem, particularly the importance of finding its solution should match with the current status of the field. But, if the problem investigated is of not much interest to science and society then publications will become useless to him in his research career. Specifically, they cannot help earn a post-doctoral fellowship, respectability and a permanent job in an institution.

A researcher needs proper guidance and encouragement from the supervisor regularly. This is important for keeping the research in right track, to overcome the difficulties which

come at various states of research and also to have moral support. A researcher should avoid working under the guidance of a supervisor having serious health problems or family problems, committed his large time to administrative work and strong involvement in nonacademic matters.

The following story was told by S.L. Glashow (Harvard University) [Julian Schwinger: The Physicist, the Teacher, and the Man. (Ed.) Y. Jack Ng, World Scientific, Singapore, 1996, pp.155]:

Once upon a time, a fox came upon a rabbit who was typing away in the middle of the forest. *What do you think you are doing?* asked the fox. *I am writing my thesis on how rabbits eat foxes* replied the rabbit. *Nonsense*! said the fox, *rabbits don't eat foxes; foxes eat rabbits*. *Just take a peek in my cave* challenged the rabbit. The fox entered the rabbit's cave and was never seen again. Some time, later a wolf came to the rabbit, who was still writing his thesis. *What do you thing you are doing?* said the wolf, and a similar interchange took place. The wolf entered the cave and was never seen again. Finally, a bear came to chat with the rabbit. *I am writing my thesis on how rabbits eat bears* said the rabbit. *Nonsense*! growled the bear, who was sent to the cave never to be seen again. A wise owl watched these strange goings-on and was puzzled. Softly sneaking into the rabbits cave, he came upon a neat pile of fox bones. A bit further on, he discovered a neat pile of wolf bones. Finally, at the back of the cave behind a neat pile of bear bones, sat a very fat and satisfied lion picking his teeth with a bear claw. The moral of the story is that *it really doesn't matter what your thesis subject is. What counts is your choice of an advisor*.

An important point is that before initiating research work on a problem, a rough estimate on costs and time required to complete the work must be made. A problem suitable for Ph.D. degree should not be taken for M.Phil. degree. A problem suitable for M.Phil. degree is not appropriate for Master's degree. If the collection of data or resources or related information takes many years, then the topic is obviously inappropriate for Ph.D. degree. Controversial subjects should not be chosen. Problems that are too narrow or too vague should be avoided.

Finally, the researcher must make sure that the necessary experimental setup and materials to perform the actual research work are available in the department where research work is to be carried out. Without these, if the researcher initiated the work and has gone through certain stages of work or spent one or two years in the problem then in order to complete the task he would be forced to buy the materials and instruments from his personal savings.

VII. LITERATURE SURVEY

After defining a problem, the researcher has to do literature survey connected with the problem. *Literature survey is a collection of research publications, books and other documents related to the defined problem*. It is very essential to know whether the defined problem has already been solved, status of the problem, techniques that are useful to investigate the problem and other related details. One can survey

(1) the journals which publish abstracts of papers published in various journals,

(2) review articles related to the topic chosen,

(3) journals which publish research articles,

(4) advanced level books on the chosen topic,

(5) proceedings of conferences, workshops, etc.,

(6) reprint/preprint collections available with the supervisor and nearby experts working on the topic chosen and

(7) Internet.

A free e-print service provider for physics, mathematics, nonlinear science, computer science and biology is

http://www.arXiv.org

No research shall be complete unless we make use of the knowledge available in books, journals and internet. Review of the literature in the area of research is a preliminary step before attempting to plan the study.

Literature survey helps us

(1) sharpen the problem, reformulate it or even leads to defining other closely related problems,

(2) get proper understanding of the problem chosen,

(3) acquire proper theoretical and practical knowledge to investigate the problem,

(4) show how the problem under study relates to the previous research studies and

(5) know whether the proposed problem had already been solved.

Through survey one can collect relevant information about the problem. Clarity of ideas can be acquired through study of literature.

Apart from literature directly connected with the problem, the literature that is connected with similar problems is also useful. It helps formulate the problem in a clear-cut way. A review on past work helps us know the outcome of those investigations where similar problems were solved. It can help us design methodology for the present work. We can also explore the vital links with the various trends and phases in the chosen topic and familiarize with characteristic precepts, concepts and interpretations. Further, it can help us formulate a satisfactory structure of the research proposal.

Because a Ph.D. thesis or M.Phil. dissertation is a study in depth aiming contribution to knowledge, a careful check should be made to ensure that the proposed study has not previously been performed and reported. The earlier studies which are relevant to the problem chosen should be carefully studied. Ignorance of prior studies may lead to a researcher duplicating a work already carried out by another researcher. A good library will be of great help to a researcher at this stage. One can visit nearby research institutions and avail the library facility. Review the latest research papers and Ph.D. theses to acquire recent trends.

VIII. THE INTERNET AS A MEDIUM FOR RESEARCH

From past one decade or so the internet became an important source of knowledge and an effective medium for research. For researchers, it is providing a range of new opportunities for collecting information, networking, conducting research, collecting data and disseminating research results.

Electronic mail, e-journal, on-line submission of articles to journals, online focus groups, online video conferencing and online questionary are some of the latest tools opened-up by the internet. We note that thousands of books and other print publications have been made available online that would be extremely difficult to locate otherwise, including out-of-print books, and classic literature and textbooks that would be much less accessible in their printed form.

Some of the scientific research information available on the internet are:

- Details about various scientific and nonscientific topics.
- Titles and other relevant information of article published in various journals, possibly, from past one decade or so (full article will not be available).
- Preprint of papers submitted by researchers in certain websites.
- Information about scientific meetings to be held.
- Contact details for other researchers.
- Databases of reference material.
- Places where one can discuss topics and ask for help.

In general, academic research that has been commercially published is not freely available on the internet.

Some of the features of conducting research through internet are:

- Short time for collecting and recording data.
- Data unknown to us can be identified and downloaded.
- The possibility of conducting interviews and focus groups by e-mail, which results in enormous saving in costs and time.
- New communities to act as the object of social scientific enquiry.

While the internet contains a virtually-unlimited wealth of information not found in traditional resources, this abundance also may hinder academic research. The following are some of the new challenges for the researcher:

- Problems of sampling.
- Reliability and accuracy of the obtained data information.

- The ethics of conducting research into online communities.
- Physical access and skills required to use the technologies involved.
- The changed chronology of interaction resulting from asynchronous communication.

A major way to find whether an online source is credible is to determine how popular and authoritative the source is. If the site has a well-respected offline counterpart such as the New York Times the site will be as credible as the original. For websites and authors which have little popularity, one must consider the credentials of the source–if those are available and valid. Even though a website may be written in a professional or academic manner, the lack of central body to determine its credibility may be a prohibitive factor for serious research.

An example of an online research in which researchers have used the internet as a medium for performing research is *National Geographic Survey 2000*. In this survey, interactive survey instruments were used to study and analyse the effects of location and mobility on values and cultural tastes. Extensive use was made of public relations and community outreach to publicize the survey. In about two months time 80,000 self-selected participants from 178 countries started the questionnaire and 55,000 of them completed it. Questions were in some measure dynamically generated, with respondents automatically redirected to appropriate section based on their answers. The main survey site is

http://survey2000.nationalgeographic.com/

Some of the potential advantages of online questionnaire are:

- Low-cost delivery and return.
- Wide potential coverage.
- Ease of completion.
- Submission and data capture.
- Appropriateness to particular populations.
- high respondent acceptance for some groups.

Potential difficulties include:

- The paucity of methodological literature.
- Appropriateness to research aims.
- Target population.
- Technical difficulties.
- Sampling and response rates.

IX. REFERENCE COLLECTION

As soon as the survey of available source begins, the preparation and collection of references preferably with annotations should be undertaken. Keeping records systematically during research helps a researcher achieve various objectives. It preserves data for future use. The researcher may stumble upon something that may not be of immediate use, but would help him later. Details have to be kept in files.

The important source of reference collection is the journal called *Current Contents*. This comes once in a week. It is available in hard copy and also in floppy diskette. Almost all the universities and research institutions buy this document. It contains the table of content of research journals and magazines in various subjects. It provides title of articles, names of the authors, date of publication, volume number, starting page number of the articles and address of the author from whom one can get the reprint of the article. If the title of the article indicates that the paper is in the topic of one's interest then he can take a copy of the article if the journal is available in the local library. Otherwise, he can get it from a document delivery service centre. For example, in India INFLIBNET provides this service through six institutions. For details visit the following web sites:

http://web.inflibnet.ac.in/index.isp

http://www.iisc.ernet.in/

http://www.jnu.ac.in/

One can obtain a research article on paying the charge fixed by the INFLIBNET provided the particular journal is available in it. Articles can also be purchased from the publishers on payment. Alternatively, reprint of the article can be had from the author by sending a letter/card/e-mail to the author.

The references from current contents or from journals can be noted on a separate card or sheet with the names of authors and the title of the paper/book, etc. For a research paper, its title, journal name, volume number, starting and ending pages of it and year of publication should be noted. For a book, publisher's name, place of publication and year of publication must be written down. Instead of cards, nowadays one can store the details of the references in computers and have a copy in two or three floppy diskette. The references can be classified. For example, sources dealing with theory, dealing with experimental techniques, concerned with numerical methods, etc. can be grouped separately. The copies of the research articles can also be classified and bounded. Cross references (that is research articles or books referred or cited in a research report) should also be collected and classified. These also provide useful information.

Reference collection and keeping the collected materials have to be systematic. Unless they are organized with utmost care and discipline, one would end up in chaos. One may not be able to retrieve the required research article or any other collected material when it needed. Materials can be classified as facts, ideas, views and opinions, expert comments, new breakthroughs, quotes, journal papers, review articles, etc. It is better to have multiple copies of important materials. At various stages of research one may refer to numerous journal articles, books and web sites. Obviously, all of them are not going to find a place in the thesis or research reports. Based on the present work and future plan one has to select the relevant materials from the available collection.

X. ASSESSING THE CURRENT STATUS

Generally, it is not difficult to know the current status of research work in a specific topic. The current status of the chosen topic can be identified by reading the relevant journals and the recent papers, discussions in conferences, seminars and workshops. One can perform inquiries at several important places known for research on proposed topic.

A study of the current literature in the chosen topic explores the current status of it. More importantly, review articles point out not only to the basic aspects and features of the topic concerned but also give a brief account of its present status. For this purpose, one can survey the journals (for a topic in physics) such as Physics Reports, Reviews of Modern Physics, Physical Review Letters, Review section of American Journal of Physics, Pramana, Current Science and Proceedings of recently conducted seminars and conferences, etc.

Rapid communication and Letter sections of international journals publish articles which are very important and fall in recent trends category. There are several areas in internet where the papers just submitted to journals are placed. One can download such articles free of cost. These articles indicate the recent trends in a particular topic. Some relevant web sites are listed below.

http://arxiv.org/
http://www.ams.org/global-preprints/
http://front.math.ucdavis.edu/math.AG/
http://www.ma.utexas.edu/mp_arc/
http://www.clifford.org/anonftp/clf-alg/

XI. HYPOTHESIS

Researchers do not carry out work without any aim or expectation. Research is not of doing something and presenting what is done. Every research problem is undertaken aiming at certain outcomes. That is, before starting actual work such as performing an experiment or theoretical calculation or numerical analysis, we expect certain outcomes from the study. The expectations form the hypothesis. *Hypotheses are scientifically reasonable predictions*. They are often stated in terms of if-then sentences in certain logical forms. A hypothesis should provide what we expect to find in the chosen research problem. That is, the expected or proposed solutions based on available data and tentative explanations constitute the hypothesis.

Hypothesizing is done only after survey of relevant literature and learning the present status of the field of research. It can be formulated based on previous research and observation. To formulate a hypothesis the researcher should acquire enough knowledge in the topic of research and a reasonably deep insight about the problem. In formulating a hypothesis construct operational definitions of variables in the research problem. Hypothesis is due to an intelligent guess or for inspiration which is to be tested in the research work rigorously through appropriate methodology. Testing of hypothesis leads to explanation of the associated phenomenon or event.

What are the criteria of a good hypothesis? An hypothesis should have conceptual clarity and a theoretical orientation. Further, it should be testable. It should be stated in a suitable way so that it can be tested by investigation. A hypothesis made initially may become incorrect when the data obtained are analyzed. In this case it has to be revised. It is important to state the hypothesis of a research problem in a research report. We note that if a hypothesis withstands the experiments and provides the required facts to make it acceptable, not only to the researchers performing the experiments but to others doing other experiments then when sufficiently reinforced by continual verification the hypothesis may become a *theory* [6].

According to Poincaré, *a scientific hypothesis which was proved untenable can still be very useful. If a hypothesis does not pass an empirical test, then this fact means that we have neglected some important and meaningful element. Thus, the hypothesis gives us the opportunity to discover the existence of an unforeseen aspect of reality*. As a consequence of this point of view about the nature of scientific theories, Poincaré suggested that a scientist must utilize few hypotheses, for it is very difficult to find the wrong hypothesis in a theory which makes use of many hypotheses.

XII. MODE OF APPROACH

Mode of approach means the manner in which research is to be carried out. *It should keep the researcher on the right track and make him complete the planned work successfully*. You should keep in mind that there is always room for improvement in any human endeavor, and research is no exception. Do each and every job with maximum care. If you go for endless fine-tuning, you will never finish the job on time. You have to be pragmatic in your approach and execution. One should sharpen the thinking and focus attention on the more important aspects of the study. The scientific thinking must be more formal, strict, empirical and specific and more over goal oriented. Essentially, one must concentrate on an area of research and aim to perform better than almost anyone else. In order to make steady progress in research and to asses the progress of the research work, a research design is very helpful.

A. *Research Design*

Plan your work and work your plan is the suggestion of Napolean Hill. For a scientific research one has to prepare a research design. It should indicate the various approaches to be used in solving the research problem, sources and information related to the problem and, time frame and the cost budget. Essentially, the research design creates the foundation of the entire research work. The design will help perform the chosen task easily and in a systematic way. Once the research design is completed the actual work can be initiated. The first step in the actual work is to learn the facts pertaining to the problem. Particularly, theoretical methods, numerical techniques, experimental techniques and other relevant data and tools necessary for the present study have to be collected and learnt.

It is not necessary that every theory, technique and information in the topic of research is useful for a particular problem. A researcher has to identify and select materials which are useful to the present work. Further, the validity and utility of the information gathered

should be tested before using them. Scientific research is based on certain mathematical, numerical and experimental methods. These sources have to be properly studied and judged before applying them to the problem of interest.

B. *What are the Possible Approaches to be Followed by a Researcher?*

Being a member of a research institution alone is not sufficient to become a scientist. Every great human achievement is preceded by extended periods of dedicated and concentrated effort. As told by Mahatma Gandhi *satisfaction lies in the effort and not in the attainment*. Full effort is full victory. A researcher can exercise the following aspects regularly throughout the research carrier. These will keep him in right track and tightly bind him to the research activity.

(1) Discussion with the supervisor, experts and colleagues about the research work, particularly, the problem and its origin, objectives and difficulties faced in the execution of the problem.

(2) Reading of the latest research papers, relevant theories and possible application to the present problem and to overcome the difficulties faced.

(3) Review of the work reported on the similar problems.

(4) Theoretical calculations, setting-up of an experimental setup, numerical calculations, computer programs, preparation of graphs, tables and other relevant work related to the research should be done by a new researcher by himself without assistance from others.

(5) Have a practice of periodically writing the work done, results obtained and steps followed in a work. This is important because sometime we may think that a particular aspect will be a center piece of the problem under investigation. But once we make a write-up of it, this aspect or part of it may turn out to be only of marginal importance. In fact, writing of the progress of the work will help us better understand our work and forms a solid basis for further progress. It also points out the gaps in our work.

(6) Participation and presentation of research findings in national and international meetings.

These regular practices provide useful information like new ideas and can help the researcher

(1) sharpen and focus attention,

(2) confining to the formulation and

(3) in the interpretation of the solution obtained.

Independent Research

Absolute honesty, patience, stamina, precision and devotion to the subject of matter together with imagination and analytical ability are among the requirements for scientific research.

Each and every bit of task related to the research work has to be done by the researcher. A young researcher should not do the entire work in collaboration with others. A young researcher should have the ability *to do all by himself*. In this connection Beasley and Jones [1] wrote: *In reality collaborations are commonplace, often necessary–to get samples, to make all the desired measurements or to perform a complete analysis. But such collaborations generally arise naturally in the course of the research and define and limit themselves naturally. A true sense of camaraderie often develops, and students do not lose that sense of having made major contributions on their own.*

The researcher is advised to perform all the works starting from identification of the problem to report preparation by himself under the guidance of supervisor. Particularly, collaboration work with experts and senior researcher may be avoided. (However, he can discuss his problems with them). This is important to acquire

(1) enough knowledge,

(2) confidence and

(3) training

to carry out research independently after getting a Ph.D. degree.

Part of the dissertation should demonstrate the researcher's originality. The dissertation should reflect the efforts of a single researcher. Keeping this in mind one should avoid collaboration as far as possible in the young stage. For example, Landau never did for his students what he believed they should do themselves. Some times, after many unsuccessful attempts to solve a problem, a student would ask Landau for his help. Landau would reply, *This is your problem. Why should I do it for you?* Neither did Landau formulate problems for his students nor give title of the research work. In these ways he trained his students to be *independent* and become *future leaders of science*. Eugene Wigner, a Nobel laureate said: *One does not have the satisfaction which creative work provides, if one's activities are too closely directed by others*.

Prof.Balaram wrote *There are guides who have no interest in their discipline and leave their wards to their own devices. Surprisingly, it is these guides who produce some of the most resilient scientists, self-taught men and women, who develop great confidence in their abilities* [Current Science 87(2004)1319].

Doubt

A researcher should provide new information to the supervisor and avoid getting information from the supervisor. Towards the end of Ph.D. course he would know much more on the

topic than the supervisor. This remarkable growth has to come through nothing but his hard work. There is no shortcut to success. He should learn and collect many information related to his work. He should definitely avoid embarrassing the supervisor and senior researchers by asking doubts often. A good supervisor or a senior researcher does not provide answers to the questions but gives appropriate directions to clarify the doubts. The Nobel Laureate Richard Feynman said: *I had no fear of doubt and uncertainty. I don't feel frightened by not knowing things, by being lost in a mysterious universe without any purpose. It doesn't frighten me. Doubt is motivation. It leads to discovery and the pleasure of finding things out*.

Complete Focus

Francis Bacon said: *If a man will begin with certainties, he shall end in doubts. But if he will be content to begin with doubts, he will end in certainties*.

During the course of research, one should focus the mind mainly on the research work. Don't allow the personal life to interfere with research. Our life is mixed with happiness, sorrows, problems and difficulties. At any stage of life how much happiness we had depends on how much problems we faced and how we approched each one of them, how we solved them and so on. Most of the achievements have been made by scientists only after struggles. If we read the life history of great physicists like Einstein, Galileo, Marie Curie, Maria Goepert Mayer and Stephen Hawkins we can notice that they produced great works under difficult conditions of their families and their own health. Marie Curie got second Nobel Prize few years after the death of her husband Pierre Curie. When Pierre Curie died their two daughters were in very childhood age. Marie Curie faced severe problems in her both personal and academic career and inspite of all she not only won second Nobel Prize but also brought-up her daughter Irene Curie and her son-in-law Frederic Joliot to won Nobel Prize. Maria Goepert Mayer got a permanent job with salary only in her 50s. Till then she worked voluntarily without salary. But she came up with a work for which she was awarded Noble Prize. Stephen Hawkins, when he was doing Ph.D. in his 20s severely affected by a neuro disease. He is unable to walk, write, speak and has many health problems. But he raised to the level of one of the greatest physicists of 20th century. He is considered as the one who knows about all physics after Newton. His *Brief History of Time* became the best sold book for more than three years.

A researcher must be clear in his thoughts. He should know what he has to find out. In order to perform the work successfully the researcher should acquire proper training in the techniques of research. The training equips the researcher with the requirements of the task. Further, he should be clear about his task and possess intellectual insight. Then only he is able to find out the facts that would help him in his task. Make your research a part of your every day life.

Think about your research work in background mode, ideas will come out even when you are seeing a movie, traveling to a place, sight-seeing and shopping. For example, Ernst Rutherford quoted in London Times on 12 September 1933 as saying *any one who looked for a source of power in the transformation of the atoms was talking moonshine*. While walking through the streets of central London after reading this article – as he waited for a street

light at the corner of Southampton Row – Leo Szilard conceived the idea of neutron chain reaction which then led to the construction of atomic bomb. Hans Jensen told he got the idea of the spin-orbit coupling, as explanation for the magic numbers which led him to won the Nobel Prize, one day while shaving!

Ted Gottfried the author of biography of Fermi said: *Scientific research is like sports. To score, the focus of the scientist must be narrow and intense to the exclusion of everything else around him. The batter never takes his eye off the ball, the hoopster shuts out everything but the court, the golfer always follows through–and the scientist focuses his complete attention on the task at hand and nothing else.*

A young researcher should also have persistence, tolerance and self-control over the unpleasant outcomes such as not getting an expected result, not recognized by the supervisor and rejection of a research article from a journal. *Don't get dejected when your paper is rejected* – Prof.P.R. Subramanian. Some times one may complete a piece of work within a week which he might have expected to finish it in a month time. On the other hand, at some times one may get stuck with a particular part of the work and unable to make a substantial progress, say, in three months. Avoid feeling remorseful at these circumstances and maintain a high tolerance for poor results. Remember that failure and wasted works are also part of the research career. Often we may be moving in long dark tunnel. When we find a light at the end, we rejoice over it with a sense of fulfilment.

Maintaining Ties

A good relationship with the supervisor is essential for several reasons. It will greatly influence the quality and progress of your work. Remember that maintaining an excellent relationship with another person and working closely for a long period is not easy. You have to maintain a fine relation with the supervisor and also with your seniors and colleagues throughout your period of association. Backbiting and unwholesome arguments on academic matters, research work and other matters should be avoided. The supervisor will have a thorough knowledge of the subject of research, however, at one stage you may feel that you have acquired more knowledge than him in certain topics. But this is no reason to show-off. You have to maintain politeness and courtesy.

Professional etiquette has to be followed [7]. If your are consulting another expert on some aspect of your work, it should be necessarily be with the knowledge of your supervisor. You should also take the supervisor's criticism in the right spirit and respond appropriately; there should be no reason for emotional outbursts.

C. *Getting Joy in Doing Research*

To get a deep insight on the topic or the research problem a suggestion from Dr K.P.N. Murthy is that *one should enjoy doing research and approach it as an entertainment and a mode of getting happiness*. In the research career one should treat doing research as a way of life and not just a job. In order to achieve a goal in the research one has to work harder. The harder one works the happier one feels. One need not try to conquer the

world of science. One has to come in order to work and to find his way. Initially one must work hard. Getting insight in a research topic or a research career is like a pushing a door. It is hard to push the door open. But when one understand it, it is very interesting and joyful. Enjoyment is not a goal, it is indeed a feeling that accompanies important ongoing activity. Gauss once said:*It is not knowledge, but the act of learning, not possession by the act of getting there, which grants the greatest enjoyment.*

V.V. Raman wrote: *Associated with a selfless quest for knowledge is the excitement that comes with discovery. An inquiring mind and the excitement of recognition have always permeated the human spirit. The non-practitioner may find it difficult to understand the excitement of the scientific investigator who recognizes the inner workings of the world. But this excitement has been experienced by virtually everyone that has done even a modicum of science voluntarily and with dedication* [V.V. Raman, Resonance, November 2008, pp.1074-1081].

Eugene Wigner stated: *It has been said that the only occupations which bring true joy and satisfaction are those of poets, artists and scientists, and of these, the scientists are apparently the happiest.* Chandrasekhar pointed out that in the arts and literature quality of work improves with age and experience while in science generally it does not. He felt that it is because of doing science in isolation, very narrow focus on immediate goals and insufficient broad in interests and pursuits. In order to continue research even at old age one should develop the spirit of experiencing the beauty of science. The spirit of experiencing it is not restricted to only the great scientists. Chandrasekhar said: *This is no more than the joys of creativity are restricted to a fortunate few. They are instead accessible to each one of us provided we are attuned to the perspective of strangeness in the proportion and conformity of the parts of one another and to the whole. And there is satisfaction also be gained from harmoniously organizing the domain of the science with order, pattern and coherence.*

Sometimes research is reduced to a mundane activity when the sole intention of the researcher is to acquire a doctoral degree just to satisfy the administrative requirements to secure a promotion or getting an additional increment in the salary in the academic career. The candidate in such cases may not be motivated by a real spirit of inquiry, but by an eagerness to attain organizational stipulations. He may not enjoy the thrill at the moment of discovery of a new phenomenon or event or theory or explanation. There are, unfortunately, ignoble enterprises that dish out ready-made Ph.Ds where the recipients never enjoy the emotional peaks of a true researcher. As pointed out by V.V. Raman, the story of Archimedes running stark naked from his bathtub, screaming *Eureka!* upon discovering a scientific principle is symbolic of the heights of joy a researcher may feel in his investigation and original scientific discovery if like a delivery of a baby: intense effort and even pain, followed by immense joy.

Professor G. Baskaran stressed that group discussion is indeed an important component of doing research particularly in small and isolated institutions. He said: *One cannot explain the power and usefulness of group discussions – it has to be experienced. When I was a student at the Indian Institute of Science (I.I.Sc.), Bangalore, a few of us students of physics from I.I.Sc. and National Aeronautic Laboratory were introduced to this joyous experience by S.K. Rangarajan, formerly a Professor of Chemistry, in whose house we assembled virtually every evening to discuss such grave issues as amorphous solids and re-normalization group.*

Each one of the discussants has made a mark (Current Science, 75(1998)pp.1262).

We should able to appreciate the manner in which results are coming and notice the beauty of the methods and methodology used get the results.

For a discussion on emotional factors see, for example, ref.[8].

D. *Crucial Stage of Ph.D*

The crucial period for a research scholar doing full-time Ph.D. is the last year of the programme. During this period one should concentrate on completing the final work for his thesis and writing of various chapters. Diversions to other activities should be avoided. Further, after working about say three years and when the time has came to consolidate the work done so far a researcher should not start to work on an entirely new topic. He can complete his thesis work and then work on new topic of his interest. The woman Nobel laureate Maria Goeppert Mayer said: *If you love science, all you really want is to keep on working*.

Generally, a research fellowship is for fixed period of time, it might have ended before the final year of the Ph.D. programme. We have noticed many scholars converted the full-time programme into part-time and joined in a job. If the job is a permanent one then one can join in the job and continue the research. But joining in a temporary position may highly change his research career. This would delay the submission of his Ph.D. thesis and he may loose the interest in research. There are examples with students capable of getting a postdoctoral fellowship but failed to even continuing the research. Therefore, a research scholar should have a clear plan of what he has to do in the next few years or so. Even if the fellowship is not available at the finishing stage of Ph.D. thesis we have friends and our well wishers to give financial support to some extend.

E. *The Attributes of a Research Scholar*

Any researcher should be motivated by a noble goal. Work gets the first, second and third priority. The attributes of a good research scholar may be summarized as [7]:

- Self-confidence
- Dedication
- Concentration
- Determination
- Analytical mind
- Scientific discipline
- Global outlook
- Innovative approach

- Originality
- Intellectual curiosity
- Freedom from the obsessions of clock and calendar
- Flexibility
- Keen observation
- Intelligence
- Passion for knowledge
- Questioning attitude
- Spirit of enquiry
- Insight
- Precision and accuracy
- Resilience to withstand temporary setbacks
- Persistence
- Patience
- Social skills
- Presentation skills
- Writing skills

XIII. ACTUAL INVESTIGATION

One should aim at doing good research. *What is good research?* Which universities and research institutions in your country do the best research? How do you distinguish the great from a good, a black hole from an ordinary hole, a superconductor from a normal conductor, supernova from mere stars, poles from ordinary points, linear differential equations from nonlinear ones?

To distinguish one from another we can use various quantities. Like-wise, to identify the best from among the available, one can use various quantities to measure the quality of them. For example, to identify a best research the quality of the one's research publications, number of citations of his publications, projects completed, books published, contribution made to the science and society, etc. can be considered.

Research work

(1) published in reputed international journals,

(2) cited by other researchers working in the same or similar topic and

(3) which added new information to the existing knowledge on a topic

are generally considered as *good*.

At the beginning of research career a young researcher should aim to produce a good research, particularly, his research findings should distinguish him from other researchers and keep him one among the top young researchers in the nation. In order to encourage young researchers and motivate them to produce high quality of research work awards are given yearly by certain academic and research bodies in each country. For example, in India, Indian President Award, Indian National Science Academy (INSA) Young Scientist Award and many other awards are given every year. Some Conference/Seminar organizers also provide best papers award to young scientists.

A. *What are the Points to be Kept in Mind in Order to do a Good Research?*

Actual investigation should lead to *original contribution* and not involve objectionable duplication. Originality is the basic credit point of any research. Therefore, actual investigation must be directed towards obtaining *novel results*. A researcher should develop new ideas and obtain deep insight into the problem in order to get novel and new results which are the characteristics of a good research.

As pointed out by the physics Nobel laureate Ernst Lawrence *in scientific work, creative thinking demands seeing things not seen previously*, or in ways not previously imagined; and this necessitates jumping off from *normal* positions, and taking risks by departing from reality. The difference between the thinking of the paranoid patient and a researcher comes from the latter's ability and willingness to test out his fantasies or grandiose conceptualizations through the systems of checks and balances science has established–and to give up those schemes that are shown not to be valid on the basis of these scientific checks. It is specifically because science provides such a framework of rules and regulations to control and set bounds to paranoid thinking that a researcher can feel comfortable about taking the paranoid leaps. Without this structuring, the threat of such unrealistic, illogical and even bizarre thinking to overall thought and personality organization in general would be too great to permit the researcher the freedom of such fantasying.

Essentially, trivial analysis should not be performed. Recently introduced theories, experimental techniques and numerical algorithms have to be used instead of outdated methods. Before applying any method, the researcher should familiarize with the features of the method. It it not worthwhile to continue in a particular direction if the results are trivial and less informative. If similar problems have already been done, for instance about ten years ago, then a researcher should not consider it as important but could treat it as a useful exercise. In this connection we wish to quote the Nobel laureate Werner Heisenberg:

If I were asked what was Christopher Columbus' greatest achievement in discovering America, my answer would not be took advantage of the spherical shape of the earth to get to India by the western route – this idea had occurred to others before him – or that he prepared his expedition meticulously and rigged his ships most expertly – that, too, others could have done equally well. His most remarkable feat was the decision **to leave the**

known regions of the world *and sail westward, far beyond the point from which provisions could have gotten him back home again. In science too it is impossible to open up new territory unless one is prepared to leave the safe anchorage of established doctrine and run the risk of a hazardous leap forward... However, when it comes to entering new territory, the very structure of scientific thought may have to be changed, and that is far more than most men are prepared to do.*

We do research by conceiving information and openings from important research papers published by other researchers in the topic of interest and continue in our own directions. The work of some other researchers might have formed the basis of our research. Similarly, our research outcomes should help other researchers. That is, the work should be such that it should invite others to read and more importantly use it and cite it in their research work. Our work should lead to recognition and respect. It should fetch joy and benefits others and as well as us.

As pointed out by Professor M.Lakshmanan, generally, *each and every work of us may not produce novelty, but if we work towards novelty then definitely in the course of research there would come a fascinating and exciting breakthrough.*

The researcher must remember that ideally in the course of a research study, there should be constant interactions between initial hypothesis, observation and theoretical concepts. It is exactly in this area of interaction between theoretical orientation and observation that opportunities for originality and creativity lie.

Actual work finally leads to results and conclusions of the research undertaken. For proper results it is necessary that various steps of the work should be scientifically taken and should not have any flaw. Developed computer algorithms must be tested for the problems for which results are already available. The work should be free from mistakes. Important analysis must be repeated in order to make sure that they are free from human mistakes. Professor Devanathan suggests that *a researcher should check, recheck, cross-check, ... all the results before submitting a research paper to a journal*. Before beginning to write a part of the work done and the results obtained check and recheck the data and the results by repeating the experiment, rerunning the programs and going through the theoretical derivations and arguments.

When analysing the data, appropriate statistical tools have to be employed. The number of data used, units of the data, error bars and other necessary details must be noted in the graphs. As many statistical tools as possible should be used. Appropriate curve fitting can be done. Necessary interpretations on the results of statistical analysis have to be made.

In the case of development or modification of a theory and proposal of a new method the assumptions made, basic idea, and calculations should be clearly stated and analyzed. Various special cases of the theory or method must be identified. The validity, efficiency and applicability of it must be demonstrated with examples. Merits and demerits have to be identified. Comparison of the proposed method with the already existing and widely used similar methods should be performed.

In any experimental work, mere measurement of certain quantities is not enough. The interpretation of the kind of data observed and explanation for the particular pattern must

be made. On the basis of interpretation general principles underlying the process can be formulated. One has to check whether the generalizations are universal and true under different conditions.

Some common errors made in research are [9]

(1) Selective observation

(2) Inaccurate observation

(3) Over-generalization

(4) Made-up information

(5) Ex post facto hypothesizing

(6) Illogical reasoning

(7) Ego involvement in understanding

(8) Premature closure of inquiry

(9) Mystification

For a very interesting discussion on the above aspects with examples refer to the ref.[9]

XIV. RESULTS AND CONCLUSION

The next step after performing the actual research work on the chosen problem is preparation of results and conclusion of the performed work. Predictions, results and conclusion are ultimate goals of the research performed.

There are two indispensable rules of modern research. The freedom of creative imagination necessarily subjected to rigorous experimentation. In the beginning any experimental research on a specific subject, imagination should give wings to the thought. At the time of concluding and interpreting the facts that were collected observation, the imagination should be dominated and prevailed over by concrete results of experiments. We should analyse cause and effect. We should pay attention to minute details also. In fact keenness in observation is the hallmark of any scientific research.

Proper interpretations of the results must be made. *Interpretation refers to the task of drawing inferences from the actual research work*. It also means drawing of conclusion. Conclusion is based on the study performed. It would bring out relations and processes that underlie the findings. The utility of the outcome of the research greatly lie on proper interpretations and is the hardest part of solving a scientific problem. Interpretation of results is important because it

(1) links the present work to the previous,

(2) leads to identification of future problems,

(3) opens new avenues of intellectual adventure and stimulates the quest for more knowledge,

(4) makes others understand the significance of the research findings and

(5) often suggests a possible experimental verification.

The basic rule in preparing results and conclusion is to give all the evidences relevant to the research problem and its solution. A bare statement of the findings are not enough. Their implications must be pointed out. Discuss your answers to the following questions with experts:

(1) Are the supporting evidences sufficient?, and if not, What to do?

(2) How many pieces of evidence are required? Instead of producing all, is it possible to restrict to one or two pieces of evidence? If so, what are they? and

(3) Why are they sufficient?

and so on. Such directions can help us minimize work and the quantity of presentation of the report. Do not rely on a bogus evidence which would increase the chances of errors. The investigator has to give suggestions. These should be practical and based on logic, reasoning and fact. The suggestions should be such that they can be actually implemented.

According to Feynman (Surely you're Joking, Mr.Feynman!) if we are doing an experiment, we should report everything that we think might make it invalid–not only what we think is right about it; other causes that could possibly explain our results; and things we thought of that we have eliminated by some other experiment, and how they worked–to make sure that other fellow can tell they have been eliminated. Further, details that could throw doubt on the given interpretation must be included, if such is known. You must do the best you can–if you know anything at all wrong–to explain it. If you make a theory, for example, and advertise it, or put it out, then you must also put down all the facts that disagree with it, as well as those that agree with it.

The researcher should not be in hurry while preparing the results and conclusion. After preparing them the researcher may ask the following questions:

(1) Are the quantitative and qualitative analysis performed *adequate* for the conclusion drawn?

(2) Are the results and conclusion *general*?

(3) Are the results and conclusion *valid only for the particular situation* considered in the present work?

(4) Is the conclusion *too broad* considering the analysis performed?

(5) Is any evidence which *weaken* the conclusion omitted?

The results and conclusion prepared can be revised based on the answers to the above questions.

Each and every statement made in the results and conclusion sections must be based on evidence obtained from theoretical or experimental analysis. Baseless statements should never be made.

While doing research particularly experiments, one may land up with an unexpected result or a finding contrary to the underlying theory. Such an observation should not be ignored blindly. It may be pursued to some extent to check whether it yields some useful result. As noted by Warrier [7] the history of science records such fortuitous breaks that led to many classic discoveries.

Never yield to the temptation of fabrication of results and interpretation. Plagiarism in the form of copying data or findings from others' report without acknowledging the source will make you in trouble. Don't attempt to report the already reported findings of others as yours. Citing the original sources actually enhances the credibility of your work.

One should note that the observations, claims and the conclusions drawn in a research report are subjected to a criticism by the experts in the concerned field. Therefore, the researchers have to think twice before presenting the outcomes of the research in a journal and in a scientific meeting.

Assignment:

(9) For each of the following topics write at least two questions, the answers to which must be available in the respective topics. For example, for the topic, *introduction*, a relevant question is *Why am I doing it?*.

(i) Introduction, (ii) Review of a research topic, (iii) Methodology, (iv) Research design, (v) Results, (vi) Discussion and (vii) Conclusion.

XV. PRESENTING A SCIENTIFIC SEMINAR-ORAL REPORT

A. *What is an Oral Report? What are the Importance of an Oral Report?*

Presentation of one's research work in a scientific meeting is an *oral report*. Scientific meetings include conference, seminar, symposium, workshop, departmental weekly seminar, etc.

Researchers in certain research institutions not only discuss their own work but also have discussions on very recently reported work of other scientists.

An oral report provides a bridge between the researcher and audience and offers greater scope to the researcher for explaining the actual work performed, its outcome and significance. It also leads to a better understanding of the findings and their implications. In an oral report, the researcher can present the results and interpretations which are not clearly understood by him and may request the experts in the audience to give their opinions and

suggestions. Oral reporting at a conference or a seminar requires more elaborate preparation than the written report.

A Nobel Prize winner Paul Dirac said: *A person first gets a new idea and he wonders very much whether this idea will be right or wrong. He is very anxious about it, and any feature in the new idea which differs from the old established ideas is a source of anxiety to him. Whereas some one else who hears about this work and talks it up doesn't have this anxiety, an anxiety to preserve the correctness of the basic idea at all costs, and without having this anxiety he is not so disturbed by the contradiction and is able to face up to it and see what it really means.*

B. *Points to be Remembered in Preparing an Oral Report*

Before starting the preparation of an oral report, an outline can be drawn based on the time duration of the report and the quality of the audience. Departmental seminar is usually 45 minutes duration. In other meetings time duration is fixed by the organizer based on the number of days of the meeting, number of speakers and the status of a speaker.

For a long time report, that is, 45–60 minute presentation, one may have enough time to

(1) introduce the topic,

(2) discuss the definition of the problem,

(3) describe the method and technique employed,

(4) give technical details, and

(5) present results and conclusion.

Consequently, these aspects can be prepared in detail.

For a 15–30 minute, oral presentation one cannot find enough time to discuss complete details of the work. In this case less informative materials must be dropped. Methods and techniques used can be presented very briefly without going into technical details. Much time should be reserved for results, conclusion and further directions.

Prepare a write-up of the oral presentation. It is a good and very helpful practice to write the talk before presenting it orally. Then evaluate the written material. Ask:

(1) *Why should the audience listen to your presentation?*

(2) *Is the presentation match with the standard of the audience?*

Revise the presentation until you get convincing answer to the above two questions. Make sure that your objective would convince the audience that you have done your job well, your methodology is sound and the findings are useful.

The success of a presentation lies in making it *long enough to cover the topic and short enough to arouse curiosity*. Oral presentation can be made effective and attractive by using modern visual devises, power-points, slides and transparency sheets. Title of the report,

author's name, plan of the presentation, very important content of it and conclusion can be printed in the slides or sheets possibly point by point with bold and sufficiently large size letters. Merely reading out measured or computed data will never catch the attention of the audience. They may be displayed in the form of histograms. Important formulas, equations, tables, figures and photographs can be prepared using transparency sheets or slides. Slides and transparency sheets should not contain running matters. *Researcher should not simply read the content in the sheets*. That is, the descriptive portion of the report should not be prepared on the sheets. An abstract or a short write-up of the presentation may be circulated to the participants of the meeting. Sophisticated softwares developed for preparing the text on transparency sheets/slides are available in internet and can be freely downloaded. In order to make the presentation, more lively, the researcher could use multimedia. Nowadays, the use of *power-point* of Microsoft Windows is common. It is an easy and compact utility software especially for preparing classroom presentations. The following are the web sites from which one could download the software at free of cost:

http://www.office.microsoft.com/downloads
http://www.lb.com/download-free-power-point-presentation.org

One could use the audio aspects also to facilitate his presentation in a better way. While presenting the topic, the researcher should strictly follow the class room teaching methodology. For example, one should allow interaction; don't forget to modulate the voice as and when required and don't violate the time frame. Logical continuity is another key aspect. Move from the simple to the complex, from the known to the unknown. Your statements should sound sensible and reasonable. Do not speak too fast and compromise on clarity, or speak too slowly and bore the audience. Make the session interactive by posing questions. As pointed out by Warrier, there is a dictum to be followed in good speeches: *First tell them what you are going to tell. Next, you tell them. Then tell them what you told them.*

The most crucial part is the actual presentation in front of the listeners. Stage fright is the bane of most presenters. There is no shortcut to overcome this fear. One has to practice, practice and practice. You can improve your presentation skill by getting the feedback after you have spoken. Avoid repeated use of words or phrases such as "well", "your see", "you know", "I mean", "I think", "that is" and "basically". You should also concentrate on your body language. Smooth movements of limbs, an occasional smile and pleasing manners would endear us to the listeners. Look relaxed and comfortable. Eye contact should be maintained with the audience. Let your eyes move uniformly around the entire audience and not focus on any particular person or a particular part of the audience.

One or two rehearsals of the report in the presence of colleagues, supervisor and collaborators can be exercised in order to

(1) complete the presentation within the allotted time,

(2) improve the quality of presentation and

(3) maintain the fluency of the presentation.

During a long presentation, the speaker can stop the presentation at various stages, seek comments and questions from the audience and then proceed. This will make the presentation attractive, interesting and also allow the audience to clarify their doubts so that they

can follow the work. Your clarifications should be clear and convincing. Never go into arguments. Your confidence gets boosted, if you approach the situation with a feeling that the expert panel is there to help you. An important point is to consider the tone to adopt so that you sound genuine.

For more details on how to make your presentation more effective, see ref.[10].

XVI. ART OF WRITING A RESEARCH PAPER AND THESIS

A. *What is a Research Report?*

Research reporting is an oral or a written presentation of important and useful aspects of the research work done. Scientific writing, a thesis or a paper, is intended to present clearly the purpose and outcome of a specific research investigation. It is the last but a major part of the research study. A report helps the researcher get feedback from other researchers and experts working in the same field. It also evaluates the success and originality of the researcher's work. *Without a report, a research study is incomplete and of no use*. A report essentially conveys the outcome of a research work to interested persons. Brilliant work and most striking findings are of little value if they are not effectively communicated to the scientific world. As pointed out by Eli Maor, *in academic matters the iron rule is publish or perish*. Some times delaying a publication of a result one would lose his claim.

B. *What are Research Paper or Article and Ph.D Thesis or Dissertation?*

A research paper is a report published in a journal or magazine or conference proceedings, etc. Whereas a Ph.D. dissertation is a report of the entire work done by a researcher to a university or an institution for the award of the degree of doctor of philosophy. The central element of a Ph.D. education is the doctoral thesis, that is, the Ph.D. dissertation. It is an apprenticeship in *how to do research* and forms the unique part of Ph.D. degree course. A Ph.D. dissertation is a lengthy, original and substantial document. It should contain original contributions. Essentially, the *role of a Ph.D. dissertation is to demonstrate the research person's original thinking and contribution to the topic of research*. It should also clearly point out the research competence of the researcher in his research field. M.Phil. dissertation is designed as a practice for Ph.D. thesis. It will help the researcher learn and understand the present status of the topic and make him capable of working at the Ph.D. level. The work done for an M.Phil. dissertation need not be publishable in journals.

C. *Why Should a Researcher Report his Findings?*

Every research investigation is carried out with certain objectives. The outcome of a research work may add new information to a theory or may have technological applications. Sometimes the researcher may not be aware of the theoretical development on practical applications. His research results may be useful to another research problem. Some other researchers may be working or planning to work on the same or similar type of research work. Several researchers doing same research work is a waste of time unless the solution

of the problem is needed very urgently and is of great use. Repetition of a work should be avoided by the research community as much as possible. Unless a researcher reports his work to the world, the *correctness, validity and originality* of the work is under a question mark. The outcome of a research work will become known to the scientific community only through publications. G. Madhavan writes *a piece of research not published is as good as not carried out*.

In view of the above, it is important to report a work in an appropriate journal or magazine and in scientific meetings like conferences, seminars and symposia. Identify possible publications of your research findings after making a considerable progress on a research problem. Don't be confined with a mere Ph.D. degree.

D. *Characteristics of a Good Report*

A good report results from slow, pain taking and accurate inductive work. To attract a reader, the reading matter of a report should be clear and interesting. It should not be obscure and dull. The write-up should be logical, clear and concise. The physicist Cyril Isenberg (University of Kent) writes: *One has to present the work like a meal in a visually attractive and palatable way. It must be easily digested and, one hopes, long remembered. A paper that is difficult to understand and is not presented in a logical way, relying heavily on results in other papers, is like a dry biscuit, with little sustaining value and even less taste. It will not be digested and will be left unread or abandoned*. The basic quality or characteristics of a good scientific report/paper and thesis are the following:

(1) good presentation

(2) good organization of various chapters/sections

(3) accuracy

(4) clarity

(5) free from contradictions and confusion.

Further, a Ph.D. dissertation should be a formal and should have high level of scholarship.

XVII. OUTLINE OF A REPORT

What are the considerations to be kept in mind while preparing a report?

(1) First, an outline of a report has to be prepared.

(2) A sketch of what information to be conveyed must be made.

(3) Then, one can write down various topics, subtopics to be considered and what material to be presented in them.

(4) The sentences which are to be expanded, reworded and verified for its validity can be marked.

The outline of the report helps us concentrate on

(i) what is to be presented,

(ii) logical relationships between different parts of the report,

(iii) smooth flow of the content and

(iv) continuity in the presentation.

The outline can be discussed with the guide, collaborators, colleagues and experts in local area. Based on their comments the structure of the report can be modified.

A three stage preparation of a report is generally done by researchers. They are:

(1) First draft – *Rough draft.*

(2) Second draft – *Rewriting and polishing of the rough draft.*

(3) Third draft – *Writing the final draft.*

A. *First Draft*

In this stage a researcher can write

(1) what has been done in the research study,

(2) procedure, method, theory and technique applied,

(3) technical difficulties faced and how they were overcame,

(4) broad findings and

(5) concluding remarks.

Tables and charts can be typeset using computer and kept separately in order to avoid rewriting them. Conclusion should be precise, clear and objective. Further directions may be pointed out.

Since a research paper is identified by its title it should be brief and not more than above 10-15 words. A subject index of a paper is primarily based on the words in the title. Therefore, few key words which are helpful to classify the paper can be included appropriately in the title.

How does a reader decide whether to read the content of a paper or not? Abstract serves the purpose. By reading the abstract a reader would decide whether the content of the paper is useful to him. Therefore, the abstract should have positive information about the content of the paper and summary of the work reported in it. Further, if the abstract has final results and main conclusion of the paper then a reader who has a general interest in the subject can know the outcome of the paper without reading the entire text by referring the abstract itself.

B. *Second Draft*

This is the most important and difficult part of the writing. Extreme care must be taken in writing this draft. One convenient approach is to edit the draft imagining that someone else has written it.

Unclear points, jargons, weakness of the report have to be identified and revised. Over-generalization of outcomes should be avoided. For example, Hermitian operators have real eigenvalues. Generalizing it as eigenvalues of operators are real or concluding that to have real eigenvalues, operators should be Hermitian are incorrect. Similarly, complex analytic functions satisfy Cauchy–Riemann conditions. It does not mean that functions satisfying Cauchy–Riemann conditions should be analytic. How do you avoid over-generalization? For some details see, for example, ref.[8]. If you have introduced any graphics and tables, discuss it in the text.

Attention must be paid to the arguments made, logical flow of work presented, the quality of supporting evidences and conclusion drawn. Do these in each chapter. Don't do the entire second stage at a single stretch. Give sufficient time between revisions of two consecutive chapters. During the break time think over the revision made in the previous chapter or section.

More importantly, grammar must be checked. A careful spell check must be made. Use simple words as far as possible. Indecisive words such as perhaps, somewhat, rather, etc. should be avoided. Usage of some particular words repeatedly, for example, 'very', 'extraordinary', 'invariably' should be avoided. Expressions such as 'it seems', 'there may be', 'since', 'putting', etc. should be replaced by appropriate equivalent words.

Style, presentation and grammar can be improved by asking your friends, colleagues to read and give their critical comments, suggestions and correct English grammar.

In some universities the report is first read by an English teacher. He will correct the grammar and give suggestions. After this only a researcher can submit the thesis.

Complicated and lengthy sentences have to be rewritten and broken. Similar sentences or sentences conveying same information must be eliminated. Check whether the words used clearly convey exactly the meaning intended.

S. Chandrasekhar said: *I always sought to present my findings in as elegant, even literary, a form as possible. I select some writers in order to learn. For example, I read Henry James or Virginia Woolf, and I don't simply read the text as a novel; I see how they construct sentences, how they construct paragraphs, how one paragraph goes into another and so on.* (J. Horgan, Current Science, 67 (1994) pp.500-01).

B.S. Warrier says: *There is one clear distinction between an article and a thesis in use of vocabulary. You may find that authors of popular writing make use of synonyms to kill monotony. For example, instead of repeating the word teaching, they may use instruction, coaching, training, schooling, tutoring and education, ignoring the fine differences in the shades of meaning.*. (The Hindu, 20 November 2006 p.6 of Education Plus).

The conclusion may carry something more than a repetition of the findings indicated

elsewhere. All conclusions should be directly related to the research. Perhaps the conclusion could reveal a special insight of yours, throwing up a possibility of the findings being applied to a different situation or even different discipline. Proper references of related work should be included. Trivial matters and obvious conclusion should not be included and if there are such sentences then they should be dropped.

C. *Third Draft*

This is the last stage. In this stage, one can concentrate on *final touches and finishing*. This should be in the direction of making the report weighty, authoritative, attractive and convincing. Similar words and format should be avoided in successive sentences. Make sure that the script clearly shows the originality of the author and importance of the outcome of the study performed.

In all the three stages of report preparation one should follow a proper style of writing. Use clear and unadorned English appropriate for the readers. One has to be aware of to whom the research report is intended. *The report is not for the supervisor*. It is better to avoid the use of personal pronoun. Use of "I" and "the author" should be avoided. Some supervisors like to use "we". For an interesting fun about the usage of "I" and "we" see p.106 of *Why are things the way they are?* by G. Venkataraman (University Press, Hyderabad, 1992).

Both active and passive voice should be used wherever necessary or appropriate. However, when using them one should check whether the meaning is strictly correct. For example, when writing *The experimental results agree with the theory* we must check whether we are strengthening the experimental result or the theory. Care must be taken in using present and past tenses. Use past tense to describe the data collection and work done by others and you. For interpretation, assessments and discussions present tense is appropriate.

Since a research article is to be read by experts in the field, avoid expressions such as "In other words" and "To put it in a simpler way." Experts may not take kindly to such phrases, as they feel that they are competent to grasp even complex ideas stated in difficult idiom.

Between various stages it is advisable to give gap of few days so that you can leisurely think of the manuscript and record how to revise it. This will avoid unnecessary tension and half-hearted write up.

How do you ensure that your paper will be well received by readers? Some of the suggestions are:

- Before sending it to a journal, authors can ask their colleagues and friends working in the same field to read it and comment on it.
- The paper can be given to colleagues who are not familiar with the topic so that it can be attracted by non-specialists in the field.
- Don't feel offended if the colleagues suggest drastic changes.

- Think back to couple of papers which have made an impression on you and are still long remembered. Note down and analyse the style, presentation and other features that have impressed you.

As pointed out by David Hilbert the presentation and understanding of the outcome of an investigation is not to be considered complete until you have made it so clear that you can explain it to the first man whom you meet on the street. This clarity and ease of comprehension is so important.

XVIII. LAYOUT OF A RESEARCH REPORT / PH.D. THESIS / M.PHIL. DISSERTATION

The layout of a research report is the list of various parts of the report/thesis. Generally, a research report should consist of the following three components:

(1) Preliminary pages

(2) Main text

(3) End matters

A. Preliminary Pages

Preliminary pages include title of the report, acknowledgment, certificate page, list of publications and table of contents. Acknowledgments are written to thank those who have helped the researcher during their course of investigation. For a book it is in the form of preface or forward. Acknowledgment should be brief, simple, modest and given only to substantial assistance provided by the guide, head of the department, staff of the department, agencies which provided financial support, collaborators and institutions where part of the work has been carried out. Acknowledgments made for routine participation by members of the researcher's family, librarian, friends, clerical helpers and god are normally considered superfluous. Acknowledgment should be made at the time of public viva-voce also. There is a chance for a researcher to forget to say acknowledgment at the end of an oral presentation. To avoid this he may do it at the beginning of the presentation.

Declaration in the certificate page by the scholar is generally done using phrases such as "I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of any university or institute of higher learning, except where due acknowledgment has been made in the text.

Every research report should have an abstract. It is a necessary part of any scientific and nonscientific research report. In a research article it appears next to the author's name and affiliation. In the case of Ph.D. thesis, before its submission an elaborated abstract of the thesis called *synopsis* has to be submitted to the institution where registration for Ph.D. degree is made. Abstract and synopsis convey the essence and brief details about the report. It should contain a very short statement of the problem, methodology and

procedures adapted in the work and results of the study in a very condensed form. *The abstract can act as a tool to control the flow of ideas in the thesis*. It can help you link in a logical way the reasons for the research and aims of the work. It should contain answers to the questions: What was done in the project? Why is it of interest? How was it done? What were the outcomes of the work done? What is the significance of the results? One should emphasize the original contribution in the abstract. The abstract of a Ph.D. thesis will be about three or four pages.

Table of contents gives title of the chapters, section headings, title of appendices and their page numbers. All the preliminary pages should be numbered with lower-case roman numbers.

B. Main Text

The main text presents the details of the research work and results. This part of the thesis should provide the following, about the research work:

(1) Introduction.

(2) Actual research work performed and the findings.

(3) Summary and conclusion.

1. ***Introduction***

The purpose of the introduction is to give a brief outline of the field of research. In this part one can bring clearly the importance of the field and the current status of it. It should contain an overview of the problem, its importance, statements about the hypothesis or specific questions to be explored. This is followed by a preview of the scheme of the following chapters, that is an outline of plan of the work. Here, aim of each of the chapters and their contents can be briefly stated. Related and relevant work done by others must be pointed out. Various concepts and definitions of scientific and technical terms necessary for understanding the research work undertaken are to be defined and explained. Details of statistical tools or quantities used in the study can be given in a separate chapter.

Irrelevant and less informative materials need not be presented. For example, regular and irregular behaviour of solution of a system or differential equation can be characterized by calculating the statistical tools such as Lyapunov exponents, correlation function, correlation dimension, power spectrum, periodicity of the solution and probability distribution. If the power spectrum is not used in a research work then there is no need to discuss in detail the systematic way of calculating it. Similarly, suppose the effect of noise in a theoretical model equation is studied by including, say, Gaussian random numbers in the simulation. There are many methods available to generate Gaussian random numbers. If the Box–Muller method is used then it can be described. In this case describing other methods, for example, rejection technique is redundant to the present thesis report. The theory and experimental set up used should be clearly described with proper references. Define the technical terms used in the dissertation either by a reference to a previously published definition or by a precise definition. Such a definition should be given only once in the report.

The introductory chapter(s) should be prepared in such a way that it should interest the reader in the subject matter of research. It should not be aimless, confused and lacking in precision. Introductory part may contain one or two chapters.

To be precise, the introductory part should cover the following aspects:

(1) Features of the topic

(2) Present status of the field

(3) Some unsolved problems

(4) Statement of the problem undertaken

(5) Importance and justification of the present problem

(6) Preview of the scheme of the following chapters and their interrelationship definition of various scientific terms used

(7) Methodology used

2. ***Actual Research Work***

This is the heart of the research report/thesis. The actual research work undertaken, difficulties faced, technical details, results, conclusion and future direction form the main part of this portion. This part can be presented in a few chapters. Each chapter should contain introduction, research work, results and conclusion. Materials should be organized systematically and presented under appropriate headings and subheadings. First, write the chapters that describe your actual research work. After this, prepare the conclusion and introduction parts. When writing the actual work collect the terms and note down the matter which are to be defined and described in the introduction.

As Professor P.R. Subramanian points out, *for preparing the Ph.D. thesis report one should not simply copy word by word from his research articles*. Even if the content of the thesis is the work reported in his research publications, the student should reword the material without changing the meaning, give much more details, explanations, suggestions and possibly a better reorganization of the content.

Wherever possible, the results should be presented in the form of figures, illustrations and tables. They can make the report quite attractive. Tables should be as precise as possible. All the figures should clearly specify the variables of the axes, units used and other necessary information. Figure caption should not be a reproduction of sentences of the text. It must clearly state what it is. Figures should be clearly explained in the text. Data should be fitted to an appropriate mathematical expression. Nowadays, sophisticated softwares are available for curve fitting. After making a curve fit or plotting a set of data, proper explanation for observed variation of the data should be given. A set of data measurement without any analysis and discussion is of no use.

Arguments may be conveniently presented as a series of numbered or bulleted points, rather than as one chunk in a crowded paragraph. Mention further unexplored areas, which future researchers may conquer.

Extreme care must be taken in type setting mathematical equations, variables and parameters involved in the study. Italic or Greek letters or mathematical symbols can be used for variables and parameters. For example, x or X should not be used as a variable name. The correct usage is x or X (or typeset in italics). All the equations should be centered and numbered. Vectors should be clearly specified by an arrow over the name or by bold face name. Equations should not be repeated.

Jokes or puns should not find a place in the report. Use "correct" or "incorrect" to refer to the results of others. Don't use the words "bad", "terrible" and "stupid". Avoid use of "today", "modern times", "soon", "seems", "in terms of", "based on", "lots of", "type of", "something like", "just about", "number of", "probably", "obviously", "along with", "you", "I", "hopefully" and "may". There is no need to mention the circumstances in which the results are obtained.

An error often made is wasting valuable time for the physical embellishment of the document beyond a point, without paying careful attention to the correctness and accuracy of the content. Even a couple of typos can give the impression that you have failed to pay adequate attention to detail. Errors in the spelling or technical or general words show in the poor light an otherwise worthy thesis that tells a vital story.

Assignment:

(10) Reword/rephrase the following and give the reason for the change:

(a) Dinesh and Geethan [1] reported that ...

(b) The following algorithm represents a major breakthrough ....

(c) Even though the above method is not earthshaking ....

(d) Geethan and I obtained ....

(e) There is a method to calculate ....

(f) The program will use the data after it stored them to a CD ...

(g) The method is started by calculating the value of δ ....

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3. *Conclusion*

At the end of each chapter (except in the introductory chapter(s)), one can place a brief summary of the outcome of the work presented in that chapter under the heading conclusion. They should be clear and precise.

The relevant questions which are still not answered and new questions raised by the work of the present chapter have to be mentioned. Whether the answers to the questions are obtained or not, if obtained in which chapter(s) they are presented should be specified. Mention possible future research. It is important to make a connection between two consecutive chapters either at the end of the first or at the beginning of the second.

Chapters should not look like reports of isolated work. There should be a link between consecutive chapters and the link should be clearly brought out.

C. End Matters

The end part of the report generally consists of references, appendices, computer programs (if they are not easy to develop) and copies of research publications that came out from the research work done.

1. *Appendices*

Appendices are supplementary contents which are not placed in the main report in order to keep the continuity of the discussion; however, they are relevant for understanding the particular part of the report. An appendix may present

(1) a brief summary of a theory or a numerical method used which can be found elsewhere,

(2) a lengthy mathematical derivation or a large set of equations,

(3) technical details and

(4) a list of values of constants and parameters used in the work.

Appendices can be placed at the end of report after references. They should be numbered by capital alphabets.

2. *References/Bibliography*

References or bibliographies are sources consulted. Each reference should contain name(s) of author(s), title of the paper, journal name, volume number of the issue in which the article appeared, starting page number, end page number and year of publication. In the case of a book source its author(s), title, publishers's name, place of publication, year of publication and edition should be given. Some examples are given below.

(1) Suppose the reference is the paper of K. Murali, Sudeshna Sinha and W.L. Ditto with title "Implementation of NOR gate by a chaotic Chua's circuit" appeared in the journal called 'International Journal of Bifurcations and Chaos' in the year 2003, the volume number of corresponding issue is 13 and the starting and ending page numbers of the article are 2669 and 2672 respectively. The above article can be specified as (without mentioning the title of the article)

K. Murali, Sudeshna Sinha and W.L. Ditto, Int. J Bifur. and Chaos 13 (2003) 2669–2672.

(2) For an article which appeared in a conference proceedings a typical format is given below:

R. Harish and K.P.N. Murthy, *Intermittency and multifractality in iterated function systems*. In: Nonlinear Systems. Eds. R. Sahadevan and M. Lakshmanan (Narosa, New Delhi, 2002) pp. 361–371.

In the above *Intermittency....* is the title of the report of R. Harish and K.P.N. Murthy. *Nonlinear Systems* is the title of the conference proceedings edited by R. Sahadevan

and M. Lakshmanan. The proceeding was published in the year 2002 by Narosa Publishing House, New Delhi. In the proceedings the article appears from the page 361 to page 371.

(3) A book can be noted down as, for example

T. Kapitaniak, *Controlling Chaos* (Academic Press, San Diego, 1996).

(4) A Ph.D. thesis can be referred as shown below:

S. Parthasarathy, *On the analytic structure and chaotic dynamics of certain damped driven nonlinear oscillators*. Ph.D. thesis. (Bharathidasan University, 1993, Unpublished).

(5) For an unpublished manuscript downloaded from internet one can note down the web site where it is available (see for example the references 7 and 8 of the references section of this manuscript).

References can be either in alphabetical order according to author's name or the order in which they are referred in the report. Make sure that each reference cited in the text is correctly entered into the list of references. Repetition of references in the list should be avoided.

D. Typing the Report

Typing should conform to the set of requirements of the institution. The thesis should be double line spaced and not more than 25 lines per page. It may be typed on both sides. Chapter heading must be in large size with bold face. Each paragraph should be right margin aligned. Important terms when used first time can be in italic letters and bold face. First word of a sentence should not be an abbreviation. Latest softwares such as LATEX or WORD can be used for thesis, dissertation and report preparation. One could download the software LATEX a free of cost from the web sites:

1) http://www.ctan.org
2) http://www.miktex.org

If a report is prepared keeping all the above precautions in mind, there is every likelihood of it becoming useful for proper study. Such report enables the reader to comprehend the data and to determine for himself the validity of the conclusion.

Before or immediately after submitting hard copies of the Ph.D. dissertation to a university, show it to your colleagues, teachers, scientists of your department, your parents and friends.

XIX. ACKNOWLEDGMENT

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Some quotations on Research

Research is what I'm doing when I don't know what I'm doing. – von Neuman

After the discovery of X-rays by Röntgen a journalist interviewed him.

Journalist: *What did you think?*
Röntgen: I didn't think, I investigated.
Journaist: *What is it?*
Röntgen: I don't know.

Research is key to our long-term position. – Bill Gates

It appears at first incredible that any discovery should be made, and when it has been made, it appears incredible that it should so long have escaped men's research. All of which affords good reason for hope that a vast mass of inventions yet remains. – Francis Bacon

Enrico Fermi was asked what characteristics physics Nobelists had in common. He answered, "*I cannot think of a single one, not even intelligence.*"

All progress is born of inquiry. Doubt is often better than over confidence, for it leads to inquiry, and inquiry leads to invention.–Hudson Maxim

Whenever one of my students came to me with a scientific project, I asked only one question: "Will it bring you nearer to God?"–I.I. Rabi

Scientific discovery and scientific knowledge have been achieved only by those who have gone in pursuit of it without any practical purpose whatsoever in view–Max Planck

My success if you could call it that, lies in the fact that I have kept at my work all these years. It is not genius or anything, like that, it is merly patience. – Annie Jump Cannon

It seems to me that scientific research should be regarded as a painter regards his art, a poet his poems, and a composer his music. – Albert A. Michelson

Failing to plan is planning to fail. – Allen Lakein

The average Ph.D. thesis is nothing but transference of bones from one graveyard to another. – Frank J. Dobie

When I got by B.S., I would be able to bullshit... When I got by M.S. I would have more shit, and that finally, upon reaching my Ph.D., it would be piled higher and deeper. – S. Baker

Works are of value only if they give rise to better ones. – Alexander von Humboldt

A hypothesis or theory is clear, decisive, and positive, but it is believed by no one but the man who created it. Experimental findings, on the other hand, are messy, inexact things, which are believed by everyone except the man who did the work. – Harlow Shapley

I keep six serving men,
They taught me all I knew;
Their names are What and Why and When,
And Where and How and Who. – Rudyard Kipling

The difficulty of literature is not to write , but to write what you mean. – R.L. Stevenson

I always preferred to try to imagine new possibilities rather than merely to follow specific lines of reasoning or make concrete calculations. Some have this trait to a greater extent than others. But imagining new possibilities is more trying than pursuing calculations and cannot be continued for too long a time–S.M. Ulam

My own research life has been greatly enriched by having been broken into by periods of enforced change. I was not idle while I had my three children; far from it. But it gave me the opportunity of standing back, as it were, and looking at my work. And I came back with new ideas. – Kathleen Lonsdale

My advice to young women students: *Don't quit. Muddle through. Get your 'union card' (Ph.D.) if you want to do research. Don't think you can't succeed if you're not first in your*

class, or even in the middle; or even below that. You will increase your confidence as you go along ... – Vera C. Rubin

My advice to young women scientists: *To persevere, to love work and to love to do good work, to be independent, to be scientifically honest, and to embrace your ambitions, all the while respecting culture and responsibility to your family. Knowledge and know-how are the way of liberty and equality. Neither gender, nor religion, nor age will stand as a barrier to research.* – Zohra Ben Lakhdar

Research needs an inquisitive mind which is never satisfied with the current solution or state of affairs – R. Biswas

An age when the pizza delivery companies promise you a free dinner if they take more than half an hour to deliver is counter to the mindset needed for research. – R. Biswas

In science, self-satisfaction is death. Personal self-satisfaction is the death of the scientist. Collective self-satisfaction is the death of research. It is the restlessness, anxiety, dissatisfaction and agony of mind that nourish science. . –R. Jeyaraman

A Short interview with three eminent scientists.

1. Interview with Professor V. Devanathan

What are the requirements for a successful research career?

Prof. V. Devanathan : Motivation and innate interest in the topic of his research pursuit are the requirements for a successful research career. If a person takes the research not by compulsion but by his own choice, then he will not feel it as a burden but pursue it as a hobby. *Science is at its best when it is a part of a way of life* - this is the inscription that is found on the foundation stone of Institute of Mathematical Sciences, Chennai and truly describes the correct aptitude for a successful research career.

Is it possible for an average student to come up with novel results in a research problem? If so, what kind of approach he should follow?

Prof. V. Devanathan : Usually, the assessment of a student as good, average or bad is based on his performance in the examinations. There are some who are good in examinations with a good memory for reproduction but lack in deeper understanding of the subject and originality in approach. There are some who are not so good in examinations but show originality in thinking and follow unconventional or novel approach to the subject. There are a few who are good both in examinations and research. So, an average student with an ability of average performance in the examinations, need not feel different if he has *originality in thinking* and *self-confidence*.

During a research career, a young researcher may come across disappointing moments like not getting expected results, rejection of a research article from a journal, etc. What kind of mode of approach a researcher should have to face such situations?

Prof. V. Devanathan : *Success begets success and failure begets failure*. Success and failure

are like two sides of a coin and one is bound to face them alternatively in the course of one's research career. Elation at the time of success and depression at the time of failure are usually mitigated if one works in collaboration with others. At the time of depression, the co-workers come to the rescue and prop up the sagging spirit.

In our manuscript we have mentioned the following:
Each and every bit of work has to be done by the researcher. A young researcher should not do the entire work in collaboration with others. The researcher is advised to perform all the work starting from identification of the problem to report preparation by himself under the guidance of supervisor.
Please give your views on this point.

Prof. V. Devanathan : At the initial stages, the researcher gets the support of the research group in which he is working and he acquires the knowledge of the group effortlessly. The weekly informal seminars, if conducted within the group, will increase the pace of learning and help to clarify and crystallize the problems. This process of learning is made easier if the young researcher works in collaboration with others. This is true both for theoretical and experimental work. At present, the experimental work is almost a team work and successful research group is one in which the group leader allots the specified work to individuals taking into account his ability and expertise.

2. Interview with Prof K.P.N. Murthy

The common belief is that research is laborious and painful. Many times you have mentioned: Doing research is an entertainment. *Please, elaborate on this statement of yours.*

Prof K.P.N. Murthy : Research not only constitute a discovery or creating a new paradise but also consist of obtaining a personalized understanding of a phenomenon. The struggle that you go through for obtaining an insight into a phenomenon or getting a hold of a nuance and the extessy that you get when you get an understanding of a phenomenon or obtaining a new way of explaining of that phenomenon may be unmatched. This ecstasy is nothing to do with what yours creative have impact on science and society. However, it is the ecstasy of what Einstein got when he created special theory of relativity or Feynman when he created quantum electrodynamics or Raman when he found the so-called Raman lines. It is this makes the research an enterprise of joy. It is that makes a research an entertainment.

Is it necessary for a beginner of research to learn all the aspects of theoretical, experimental and numerical techniques involved in a topic before he take-up an actual research problem?

Prof K.P.N. Murthy : A certain basic knowledge about physics and mathematics is must for starting research. That is it. Several things you learn doing research. Ignorance of even some of the basic elements is no hindrance for creativity. What is required for doing good research is an enthusiasm, a commitment and willingness to go back to basics and learn them right.

Before preparing the final write-up of your research work, you have the practice of discussing the salient features of your findings with a few other researchers. How are you benefited from this?

Prof K.P.N. Murthy : After you have completed a piece of work I find it is a good practice to discuss with your colleagues the important findings that you have made. I have always

realized that I got a better understanding of what I have done when I tried to explain to my colleagues about my work in a convincing way. The very act of speaking of what you have done removes the cob-webs in your understandings. I always make it to give a seminar on my work to a larger audience before submitting it to a journal for publication. I feel this is a very good and helpful practice.

Enjoy doing research and approach it as an entertainment and a mode of getting happiness. This is your suggestion to young researchers. Please, brief it for the benefit of youngsters. In what way will this be helpful to a researcher?

Prof K.P.N. Murthy : In any human enterprise it is important that one likes what one does. The hard work that you have put in a problem does not tired you and rest be assured if you approach a research problem with joy and you will get a good result. Publication of that result and the acceptance that you get from your colleagues become secondary. The satisfaction that you obtained by doing a job well is a reward by itself. I would say that youngsters should have this attitude towards whatever they do.

3. Interview with Prof Sudeshna Sinha

Despite unavoidable tasks a woman of our country has, you have become one of the leading scientists in theoretical physics. What are your advice and suggestions to young researchers particularly to young women researchers?

Prof Sudeshna Sinha : It is indeed somewhat harder for women to concentrate on career planning - especially when their children are young. One will have to accept that household tasks will always be there. The hardest thing is not really the number of hours of work one can put in - but the *quality of concentration* one can achieve. Here discipline comes in. Since women will probably manage to get fewer hours of academic work done every day - they need to really plan the academic work they hope to achieve every single day. So it is most beneficial to discipline oneself into shutting off all daily chores *from one's mind* for some hours every day. The point is to learn efficiency – and to appreciate that one does not have the benefit of unlimited time (as others will make justifiable demands on your time – like children).

Also women may find it hard to pursue academic work at certain points in their life - but they must preserve the self-confidence and will to return to academic after such times are over. They must realize that in 3–4 decades of working life – a few years is not a big deal. They should not think that a break in career is *irreversible*.

Publishing in reputed journals (like Physical Review Letters) is a dream or prestige for many physicists. What are the secret of yours for regular publications in reputed journals? What type of problems one has to take up for getting published in top-level journals?

Prof Sudeshna Sinha : With journals like Physical Review Letters one must remember two things: First, always try and make a case of the general interest of your results. The commonest grounds for rejection is *lack of broad interest*. This is very subjective of course, and being Indian does not help. But still, at the outset, one should make an attractive statement of the general scope of one's work (that is, try to answer this hypothetical question: Why should someone not doing research in this exact narrow sub-field be interested in reading my paper). Second point is persistence. Take all criticisms of the paper seriously (and don't reply needlessly aggressively to the referees) and try to answer all the criticisms.

Then resubmit, and *don't give up till the last round!*

How could a beginner of research come up with novel results?

Prof Sudeshna Sinha : Well, I think coming up with *novel* results is not entirely in one's hand. There is an element of good fortune here! If the guide of the young researcher can identify a problem that is technically easy to tackle – but whose results can be of considerable potential interest – then there is a good chance for the young researcher to get a novel result. But this is not in the hands of the young researcher, and most often not in the hands of the guide either (as it depends on the subject, timing etc.).

In this matter I always tell my students: whether you get a novel result tomorrow is a matter of luck, but in a career spanning several decades, if you work steadily and think deeply about the subject, it is almost assured that at some point or the other, you will get a good idea which will lead to a novel result!

To get a deep insight into the topic or problem of research, what are the ways a young researcher can follow?

Prof Sudeshna Sinha : One should not just passively *read* papers or books! One should try to work it all out in some detail. While reading passively one feels one has *understood* – but only when one is trying to solve something does one gain any real understanding. In fact it is a great idea to look at the title and abstract of a paper, and then ask oneself how one would have attempted to work on such a problem and only then look at what the authors have done.