Scientific Approach to Research Problems

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AT a time when planning is assuming a vital rôle in every aspect of our national life, it is but natural to consider if that concept would be applicable to the solutions of our research problems. Planning implies the economic uses of limited resources ; it is obvious that our resources—human as well as institutional—are rather limited as far as research activities are concerned. Hence the need for scientific planning is stressed to be of value to the individual researcher in particular and to the institutions in general.

Evolution of Scientific approach :—

Early observations of natural phenomena led some philosophers to imagine some regularities in earthly and cosmic ways of life and matter. The experimenters challenged some of them by concrete and visual evidences and produced considerable mass of controlled observations. To provide compactness, theories and hypotheses were announced and experiments were designed to prove or disprove the same. In either case, the cause of science advanced ; the experimental knowledge and technique began to develop a regular pattern of handling problems and more advances were made in shorter time. Progressively the academic interests turned towards the commercial one. The factors of cost and value of materials and processes assumed wide significance. The new concepts of yield, conversion, recovery, space-time variables of a reaction, and economic scale of operation developed. Competition grew stiffer and stiffer and precise means of obtaining results from research were sought in preference to lengthy and inconclusive procedures which were designed mainly to satisfy couriosity. This approach matured into the present industrial civilization wherein application of Scientific approach in practically every aspect of national life brought about radical changes in economic and social environments.

Modern concept of research and training :—

A modern research problem has to be designed to fit into a larger scheme of things. Each problem is looked upon as an integral part of an organized scheme meant to attack still bigger problems. The problem therefore has to be solved and to be done so in time otherwise the comprehensive project is likely to suffer. A particular research piece is but one link in the whole chain—and that link has to be carefully and effectively strengthened so that the force exerted by the whole chain does not limit itself just because of one of its links. This is in direct contrast with old—fashioned way of selecting problems by a survey of literature looking therein for abstract matters which satisfy curiosities of the individual researcher. Modern research is a goal-directed positive method of attack which is so planned as to yield some substantial anticipated results within reasonable time.

The above outlook is not possible unless the modern scientific tools of thought and principles are applied intelligently to the proposed problem. This then leads us to the type of training a research worker should have. In the fields of chemical and technological research the thorough knowledge of the following subjects is considered necessary.

(1) Thermodynamics—particularly Thermochemistry, Laws of chemical equilibrium, and evaluation of thermodynamic properties.

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(2) Reaction Kinetics and Catalysis.

(3) Physico-Chemical Laws relating to handling of gases, liquids and solids—under various conditions.

(4) Operating Variables—their influences and procedures of controlling them.

(5) Extensive knowledge of the basic sciences related to the subject of interest.

(6) Intensive study—historical as well as up-to-date-of the subject of direct interest.

It should be emphasized that the above subjects have to be mastered and diligently studies from text-books with rigorous practical work to be of any practical use spontaneously at any time. These are difficult subjects and unless one is thoroughly conversant with the fundamentals by firsthand study, the simple reading out of literature would be of little practical value. Time spent in these studies will save much time in research later and the quality and directness of the results will be of high standard.

Fundamental components of scientific approach :—

By scientific approach one intends to cut down the wasteful efforts to the minimum right from the start thus effecting considerable savings in time, energy and materials. To accomplish this, firstly the the problem should be very clearly stated. Secondly the reasons for its study—besides the wishes of those in authority should be thoroughly grasped. Thirdly, significance of the success or failure of the problem should be evaluated so that only the proportional effort allocated to the same. Fourthly, Scientific planning of the method of approach should then follow. This includes a survey of literature and a study of reasons for success or failure of other investigators in the field. Inherent characteristics of the problem should be deeply gone into by studying fundamental properties of the system. From this on—a step-by-step scheme should be prepared with a planned programme of time and details of experiments with anticipated rate of progress at least to serve as a yard-stick. Work should then be begun and at every stage a review should be made if still one was following the right path. There should be no hesitancy to retrace steps with a view to maintain perfectly objective mental make-up. Results should obviously be beyond challenge and reproducible. Till the end, a continuous comparison of the achievements with the proposed objectives of the research project should be maintained so as to detect any deviation in time.

From Selection to solution :—

Importance of Scientific approach can be illustrated by reference to many of our present-day successful methods of synthesis of basic chemicals. In Germany, they were faced with serious shortage of petroleum and also of carbohydrates and hence had to look out for a suitable reactive raw material as a source of organic chemicals. Acetylene was selected for experiment and hence an all-out attack in its manufacture, safe procedures of handling and conversion to useful products was launched.

Acetylene is generated when Calcium Carbide is reacted with water as follows :—

$$CaO + 3C \rightarrow CaC_2 + CO + 103{,}000 \text{ Cals.}$$

$$CaC_2 + 2H_2O(1) \rightarrow Ca(OH)_2(S) + C_2H_2 - 30{,}000 \text{ Cals.}$$

$$CaO + 3C + 2H_2O \rightarrow (CaO + H_2O) + C_2H_2 + CO + 73{,}000 \text{ Cals.}$$

$$\text{Or } 3C + H_2O = C_2H_2 + CO + 73{,}000 \text{ Cals.}$$

Hence the basic reaction appears to be simple if one can get carbon and steam to react to produce acetylene and carbon monoxide. Even then carbide formation is still the standard process for acetylene. Carbon as such was however not reactive and hence gaseous hydrocarbons were selected for experiment. This developed the Fischer-Tropsch and Bergius processes for synthesis from carbon monoxide, coal and hydrogen. Acetylene was produced from methane—the most abundant hydrocarbon. The study of the following table of thermodynamic data of various hydrocarbons will reveal the possibilities of the various reactions of acetylene :—

Approx. change in Heat of Formation with Temperature.

	900°K	1200°K	1500°K	1800°K
CH_4	1000	8000	15000	22000
C_3H_8	12000	19700	27400	35100
C_6H_6	8500	10500	12500	14500
C_2H_4	13600	16400	19200	22000
C_2H_2	22000	20000	18000	16000

The following observations can be made from the above table :—

(1) All hydrocarbons possess higher free energy at higher temperature levels—only for acetylene, the free energy decreases with rise in temperature.

(2) The conversion takes place in direction of more stable compounds i.e. from higher value of heat of formation to the lower value. Accordingly, higher paraffins form the lower ones, all paraffins form olefins and all olefins form aromatics in general.

(3) However the above pattern changes with temperature. Acetylene is less stable than ethylene at temperatures below 1420°K and hence the following reaction is carried out at temperatures much below 1420°K :—

$$C_2H_2 + H_2 \xrightarrow[\text{Atm. Pr.}]{\text{Palladium}} C_2H_4 - 42000 \text{ Cals.}$$

The exothermic heat of reaction has to be efficiently removed and to improve rate of reaction, catalyst has to be employed.

At higher temperatures however acetylene is more stable than any paraffin or olefinic hydrocarbon and hence it can be produced from the latter. This is the basis for recent efforts to produce acetylene from hydrocarbons by thermal cracking.

$$2CH_4 \longrightarrow C_2H_2 + 3H_2$$

Temperatures of about 1500°C are employed. As the free elements—carbon and hydrogen represent the most stable state, the contact times are kept very short—one tenth to one thousandth of a second so that methane does not decompose into carbon and hydrogen. As there is increase in the volume of reaction mixture, partial pressures are reduced either by admixture of inert gases or by maintaining partial vacuum and dilute concentrations. From the table, it will be observed that higher paraffins give better yields than methane. Thus direct formation of acetylene has been made possible from hydrocarbons which are available from coke oven gases, sewage works, hydrogenation of coal and petroleum refinery gases.

As regards reactions of acetylene, the same table can offer some guidance.

Conversion of acetylene to aromatic hydrocarbons is possible and lower the teperature the better, as the difference in heat of formation—the driving potential for reaction is greater. However, the rate of reaction normally increases with temperature and a 100° rise will increase the rate 250 times which fact means considerable savings in equipment and efficiency. Where lower temperatures have to be used for thermochemical reasons, catalysts have to be employed. Hence the acetylene to aromatics reaction is as follows :—

$$C_2H_2 \xrightarrow[720°C,\ 30 \text{ to } 100 \text{ Sec.}]{\text{Aluminium Carbide, 90\% Conversion}} \text{Aromatic Oil}$$

Aromatic Oil composition is as follows :—

Benzene	...	50-60%
Toluene homologues	...	10-15%
Naphthalene	...	10-15%
Biphenyl	...	5-10%
Anthracene	...	5-10%

It is interesting to note that this composition compares favourably with that obtained from coal tar distillation.

Reactions of acetylene and carbon-monoxide—both the products of the same basic reaction of carbide process are well-studied and have shown the efficiency of scientific approach in handling baffling problems with unusual success. Similar developments in the synthesis of methanol, ammonia, synthetic liquid fuels from coal and several other chemical products have confirmed the utility of application of fundamental principles in modern technology.

Fundamental -Vs-Industrial Research :—

From the discussion mentioned so far, it should not be misunderstood that the objectives of research should always be utilitarian and advances in fundamental sciences be ignored. On the other hand, this emphasis on application of basic principles is intended to stimulate further research on the fundamental side, importance of which therefore will be felt more keenly. Certain research problems have been solved under the stresses of emergency times like wars and scarcity and team-work has proved more effective and speedier than the individual efforts. Modern research—fundamental as well as industrial is becoming highly specialized and therefore team-work should be encouraged in the interest of the project. Individual research effort should prove useful in case of training the workers for a career in research.

Application of scientific principles to the art of research is all that is suggested so as to keep the wasteful attempts at the minimum. The researcher should exhaust all the *pros* and *cons* of a problem from the considerations of the fundamentals which must be mastered by him and only then should the experimental work be taken up. Allocation of economic sources between alternative uses is the essence of a planned approach which should be applicable in the field of research with equal force. Our universities, institutions and laboratories are performing a great task even when confronted with stumbling difficulties and this approach at the individual level as well as the institutional one will only help them further in gaining more and more appreciation for their valuable hard work.