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Steps in Science

(undated, *c.* 1960)

1. Why Science?

The question 'Why solve problems?' is psychological. It is as necessary for some of us as breathing. Why scientific problems, not theology or literary effort, or some form of artistic expression? Many practising scientists never work the answer out consciously. A few centuries ago, questions of religious philosophy and theology ruled supreme for the intelligentsia of many countries. Those lands where the leading intellectuals persisted in these speculations remained ignorant backward and were progressively enslaved (like India) in spite of a millennial culture. No advance was possible out of this decay without a modern technique of production towards which the intellectual's main contribution was through science. There is a deeper relationship: Science is the cognition of necessity; freedom is the recognition of necessity. Science is also the history of science. What is essential is absorbed into the general body of human knowledge, to become technique. No scientist doubts Newton's towering achievement virtually no scientist ever reads Newton's original writings. A good undergraduate commands decidedly more physics and mathematics than was known to Newton, but which could not have developed

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without Newton's researches. This cumulative effect links science to the technology of mechanized production (where machines save immense labour by accumulating previous labour) to give science its matchless social power, in contrast to art and literature with their direct personal appeal. Archimedes, Newton, Gauss form a chain wherein each link is connected in some way to the preceding; the discoveries of the later would not have been possible without the earlier. Shakespeare does not imply the pre-existence of Aeschylus or of Kalidasa; each of these three has an independent status. For that very reason, drama has advanced far less from the Greeks to the present day than has mathematics or science in general. The earliest statues of Egypt and Greece, the first known Chinese bronzes, show a technical mastery of the material and of art forms that make them masterpieces even now, though the artists remain unknown; but the technique is not linked to production as such, hence not cumulative. The artist therefore survives if and only if his name remains attached to some work that people of later ages can appreciate. The scientist, even when his name be forgotten, has only to make some original contribution, however small, to be able to say with more truth than the poet, 'I shall not wholly die, the greater part of me will escape Libitina.' The most bitter theological questions were argued out with the sword; for science, we have the pragmatic test, experiment, which is more civilized except when some well-paid pseudo-scientist wishes to 'experiment' with thermonuclear weapons or bacterial warfare.

2. Natural Philosophy

I went to school and college in the USA. It was obligatory to learn several European languages in school and college. The libraries were unquestionably the best in the world for accessibility and range of books. Alexander von Humboldt's *Cosmos* surveyed the whole universe known to the nineteenth century, from the surface of the earth to those mysterious prawn-shaped figures visible through the most powerful telescopes, the spiral nebulae. The Einstein theory, arousing passions of theological intensity, had just been regarded as proved, and offered new insight into the structure of space and time. Innumerable outlines made it easy to learn something about every

branch of science. Freud had taught men to take an honest look at their own minds. H.G. Wells showed through his *Outline of History* how much the professional annalistic historian had to learn. The inspiring lives of Pasteur and Claude Bernard proved that man could gain new freedom from disease through the laboratory; the deadliest poison became a tool for the saving of life through investigation of the body's functions. Such were the real *rishis* and *bodhisattvas* of modern times, the sages whose social achievement added to man's stature. This contrasted with the supposed individual perfection of mythical Indian sages, expressed in incomprehensible language and fantastically interpreted by commentators. It is fatally easy to preach about the spiritual superiority of India to the materialistic West; the ability to replace incomprehensible Sanskrit words by still longer and equally meaningless English terms can make a prosperous career.

Engineering is based upon physics and chemistry, which are qualified as 'exact sciences' precisely because they admitted a mathematical basis. No other discipline unlocked the door to the atom or to the movement of celestial bodies equally well, as mathematics did. Aptitude granted, mathematical research needed the least financial resources of any science. However, I chose mathematics because I could not resist its fascination. Mathematical results possess a clarity and give an intellectual satisfaction above any others. They have absolute validity in their own domain, due to the rigorous logical process involved, independent of experimental verification upon which applications to the exact sciences must depend. Mathematics was the language of nature, *scientiarum clavis et porta* as Roger Bacon put it.

Unfortunately, not every kind of mathematics unlocks every door to nature's secrets. For some twenty years, my main work lay in tensor analysis and path-geometry (my own term). Though fundamental for the theory of relativity, the discipline is of interest only to a few specialists. In 1949, Einstein pointed out to me during one of several long and highly involved private technical discussions that certain beautifully formulated theories of his would mean that the whole universe consisted of no more than two charged particles. Then he added with a rueful smile, 'Perhaps I have been working on the wrong lines, and nature does not obey differential equations after all.' If

scientist of his rank could face the possibility that his entire life-work might have to be discarded, could I insist that the theorems whose inner beauty brought me so much pleasure after heavy toil must be of profound significance in natural philosophy? Fashions change quickly in physics where theory is so rapidly outstripped by experiment. It seemed and still seems to me that non-associative linear algebras and Markov chains would remove many of the physicists' theoretical difficulties; the experimenters are satisfied with abandoning the principle of parity. The 'red shift' of distant stars will perhaps be explained one day as due to the absorption of energy when light travels at cosmic distances through extremely tenuous matter, not as evidence for an expanding universe. Such speculations are of no use unless tallied in mathematical detail with observed data.

3. Chance and Certainty

Borderline phenomena of classical physics illustrate the inexhaustibility of the properties of matter. Ice, according to the textbooks, melts and water freezes at zero degrees Centigrade. But when carefully purified samples of water are slowly cooled and the ice slowly melted again, a considerable gap is found between the melting and freezing points. Fundamental particles that make up the atom and its nucleus show another type of aberrant behaviour. An electron can cross a potential barrier, as if a stone were of itself to roll uphill against gravity, and down, the other side. Even the observation of isolated particles becomes difficult, for the very act of observation means some interaction and effect upon the observable. The certainty of classical physics comes only when many fundamental particles are organized into higher units with clear patterns. In the same way, individual molecules of water may move in any direction with almost any speed, but the river as a whole shows directed motion in spite of eddies. So also for aggregates of living matter. In human society, the net behaviour of the group smooths out the vagaries of individual action.

The mathematical analysis best suited for handling such aggregates is the theory of probability, the estimation of chances. Variation is as important a characteristic of the collective as the mean value. Prediction can only be made to within a certain probability, which sounds

like the language of the race course. But when the chances of a mistak amount to one in a million, most people take the effect as certain. Th level of significance desired may be a personal matter. For example there is a chance of a letter being lost in the mail; whether or not w register or insure it depends upon our estimate of the risk involved and the expectation of loss. Thus, modern statistical method can b an excellent guide to action. It extends the assurance of exact scienc to biological and social sciences. Though no man can say when deatl will come to him, as it certainly must to all men, it is fairly easy t predict within a reasonable margin of error about how many men ou of a large group will die after a set number of years. That is why lif insurance manages to be a highly paying business, without recours to astrology. It is further possible to say how occupation and livin conditions affect longevity. The man who has to work in a lead min (without special protection) has his expectation of life reduced by predictable number of years, more surely than those shot at by lea bullets on the battlefield.

The methods of proof for deductions based upon probability dif fer radically from those of pure mathematics. Conclusions cannot b 'true or false' without qualification, when the variation inherent in th trials is assessed. The standard method is to set up a 'null hypothesis take the observed results as due to purely random independen variation. The theory suitably applied (and the application need profound grasp) then gives one of two conclusions: that the numerica observations are compatible with the hypothesis; or not. But eithe conclusion would be true only with a certain calculable probabilit which tells us about how often we would go wrong in action. The tric is to set up the experiment in such a way that the desired action ma be taken if the null hypothesis is contradicted; for, the incompatibilit implies falsehood whereas compatibility need not imply truth.

This leads to difficulties in dealing with phenomena where th experimenter's will to believe is stronger than his common sense. Para psychologists test *ESP*, 'extra-sensory perception' (such as telepathy) by having two people match cards at a distance. The effect is so fain and irregular as to call for recondite statistical tests, which apply o the null hypothesis that the matching could have been obtained b mere chance. The tests then show that the chances are very smal

wherefore the parapsychologists claim victory. The null-hypothesis is contradicted, but the reason given is not necessarily true. Shuffling the cards does not randomize them efficiently, i.e. pure chance is not fully effective. There are excellent statistical tests for such randomization, and it was shown by my own experiments that the kind of shuffling practised for *ESP* is inefficient when judged by the same kind of statistics that is applied to card-matching. Cards originally next to each other tend too often to stick together. Claims for *ESP* would be more convincing if one produced supplementary evidence (say matching encephalograms for sender and receiver) for a physical mechanism of transmission. Some regard the effect as beyond the normal sensation, transcendental, not accessible to material analysis. In that case, there is no logic in any laboratory tests; the statistical 'proof' becomes mere ritual.

One of my theoretical papers deals with probability, and statistics in infinitely many dimensions. There has been no effective use, because the attempts at getting a special electronic calculating machine to translate this theory into practice failed. No one with the requisite resources has yet felt the need. On the other hand, a paper on genetics was unexpectedly successful. Professional geneticists use it for all kinds of investigations such as heredity in house mice. It seems to have given a new lease of life to genetical theories which I, personally, should like to see revised; so that I am accused at times of not appreciating my own formula. It would have been pleasant to see the formula applied to the increase of food production; but the pure scientists of a country which grows the world's greatest food surpluses and destroys them to keep grain prices high in a hungry world sneer at 'clever gardening'. There is some difference of opinion here as regards the proper relation of theory to practice.

4. Ancient Indian Culture

To teach myself statistics, I had to take up some practical problems from the very beginning. One such was the study of examination marks of students. It turned out that even the easiest of examinations in India (the first-year college examination) was based on a standard that differed from that of the instruction, if in twenty-five years no

student of the 90 per cent or more who passed could score more than 82 per cent overall while the professors who taught and examined had scored much less in their own time. Improvement of the system (whether in examination or instruction) was out of the question in a country where the teaching profession is the waste-basket of all others, and the medium of higher instruction is still a foreign language.

A more fruitful problem was the statistical study of punch-marked coins. It turned out that the apparently crude bits of 'shroff-marked' silver were coins as carefully weighed as modern machine-minted rupees. The effect of circulation on any metal currency is obviously to decrease the average weight in proportion to the time and to increase the variation in weight. The theory of this 'homogeneous random process' is well known, but its applications need careful work on whole *groups* of coins. Moreover, it is necessary that the history of the coins be closed in antiquity, at one time; this means deposit in a well-preserved hoard. The main groups of punch-marked coins in the larger Taxila Hoard could be arranged in definite chronological order, the oldest groups being the lightest in average weight. There seems to have been a fairly regular system of checking the coins in antiquity. As control, I personally weighed over 7000 modern coins (taken from circulation) one by one, on slow analytic balances. It was then possible to lay the foundations of numismatics as a science, as contrasted to a branch of epigraphy and archaeology. Taxilan economy of the period was beautifully revealed by the coins though the coins bore no legends.

Arranging coin-groups in order of time led naturally to the question: Who struck these coins? The hoard was dated to about ten years after Alexander's death. But who were the Indian kings, if any, who left the marks on the coins? The written sources display a shocking discordance. The *Puranas*, Buddhist, and Jain records often give different names for the same king. Study of the records meant some mastery of Sanskrit, of which I had absorbed a little through the pores without regular study. Other preoccupations made it impossible to spend as much time as the average student on the classical idiom. So, the same method was adopted as for study of statistics: to take up a specific work, of which the simplest was Bhartrihari's epigrams (*Subhashitas*). The supposed philosophy of Bhartrihari, as

glorified by the commentators, was at variance with his poetry of frustration and escape. By pointing this out in an essay which made every Sanskritist who read it shudder, I had fallen into Indology, as it were, through the roof.

There was one defect in the essay, namely that the existence and the text of Bhartrhari were both rather uncertain. This meant text-criticism, which ought to have been completed in a few months, as the entire work supposedly contains no more than 300 stanzas. Study of about 400 manuscripts showed numerous versions with characteristically different stanzas, as well as divergent readings in the common verses. It took two and a half years of steady collation work to realize that I should not have undertaken such a task; but abandoning it then would mean complete loss of the heavy labour, which could yield nothing to whoever came after me. It took some five years to edit-Bhartrhari, with results that have received professional approval. The methods did not apply when the oldest known anthology of classical Sanskrit verse, composed about AD 1100 under the Pala dynasty, was edited (with a very able collaborator) from atrocious photographs of two manuscripts, one in Tibet, and the other—most corrupt—in Nepal. My judgment of the class character of Sanskrit literature has not become less harsh, but I can at least claim to have rescued over fifty poets from the total oblivion to which lovers of Sanskrit had consigned them, not to speak of adding to our meagre knowledge of many others.

All this gave a certain grasp of Sanskrit, but hardly of ancient Indian history; the necessary documents simply did not exist. My countrymen eked out doubtful sources with a powerful imagination and what L. Renou has called 'logique imperturbable'. One reads of the revival of nationalism and Hinduism under Chandragupta II, of whom nothing is known with certainty. Indian nationalism is a phenomenon of the bourgeois age, not to be imagined before the development of provincial languages (long after the Guptas) under common markets. Our present-day clashes between linguistic groups are an index to the development of local bourgeoisies in the various states. Hinduism came into existence after the Mohammedan invasion; clearly, one of two positions had to be taken. India has no history at all, or some better definition of history was needed. The

latter I derived from the study of Karl Marx, who himself expressed the former view. History is the development in chronological order of successive changes in the means and relations of production. This definition will have to be abandoned for a better one if we cross the threshold to a radically new and better form of society. Then and only then will human history really begin, but till that time my definition will have to serve. We have, therefore, an Indian history without the episodes that fill the history books of other countries. But where were the relevant new sources? Granted that the plough is more important than a list of kings, when and where was it first introduced? What class took the surplus produced thereby? Archaeology provided some data, but I could get a great deal more from the peasants. Field work in philology and social anthropology had to be combined with archaeology in the field as distinguished from the site archaeology of a 'dig'. Our villagers, low-caste nomads, and tribal minorities live at a more primitive stage than the city people or even than the brahmins who wrote the *Puranas*. Their cults, when not masked by brahmin identification with Sanskritized deities, go back to pre-history, just as Romans at their sacrifices used stone axes and bronze knives. Tracing a local god through village tradition gives a priceless clue to ancient migrations, primitive tracks, early trade routes, and the merger of cattle-breeding tribesmen with food gatherers which led to firm agricultural settlement. The technique of observation has to be developed afresh for every province in India. The conclusions have had a mixed reception because of reference to Marx, which automatically classifies them as dangerous political agitation in the eyes of many. At the same time official Marxists look with suspicion upon the work of an outsider.

The method continues to give new and useful results. Experts say that my collection of microliths is unique, not only in range of sites but in containing the first-known pierced specimens. A totally unsuspected megalithic culture came to light in this year's field work. It fell to my lot to discover, read, and publish a Brahmi inscription in plain sight at the Karle caves which had passed unnoticed though some 50,000 people visit the place every year. My suggestion for using the Malshet pass should give Maharashtra a badly needed key road from Bombay to Ahmednagar, and save a few million rupees

that would have been wasted by a projected spectacular funicular railway down Naneghat.

5. Social Aspects

The greatest obstacles to research in any backward, underdeveloped country are often those needlessly created by the scientist's or scholar's fellow citizens. Grit may be essential in some difficult investigation, but the paying commodity is soft soap. The meretricious ability to please the right people, a convincing pose, masterly charlatanism, and a clever press agent are indispensable for success. The Byzantine emperor Nikephoros Phokas assured himself of ample notice from superficial observers, at someone else's expense, by setting up in his own name at a strategic site in the Roman Forum a column stolen from some grandiose temple. Many of our eminent intellectuals have mastered this technique.

There is little point in discussing personal experience of the scum that naturally floats to the top in a stagnant class. The deep question is of fundamental relationship between the great discoverers and their social environment. Conservatives take history as the personal achievement of great men, especially the history of science. The Marxist assertion is that the great man is he who finds some way to fulfil a crying social need of his times. Thus, B. Hessen explained Newton's work in terms of the technical and economic necessities of his class, time, and place. The thesis was successful enough to be noticed and contested by a distinguished authority on seventeenth-century European history, Sir George Clark. Clark's knowledge of the source is unquestionably greater than Hessen's; but the refutation manages to overreach the argument. According to Clark, 'the scientific movement was set going' by 'six interpenetrating but independent impulses' from outside and 'some of its results percolated down into practice and were applied'. The external impulses were 'from economic life, from war, from medicine, from the arts, and from religion.' What is left then of the independence of science? The sixth impulse was from the 'disinterested desire to know'. So far as I know, all six impulses applied from the very earliest civilizations of Mesopotamia, Egypt, China, and probably the Indus Valley, without producing what

we recognize as 'science' from, say, the time of Galileo. What was th essentially different factor? The Marxist answer would be: 'the ris of the proto-bourgeoisie in Europe'. No Marxist would claim tha science can be independent of the social system within which th scientist must function.

Much the same treatment may be given to literature. Disregardin oversimplification, can one say that Shakespeare's plays manifest th rise of the Elizabethan proto-bourgeoisie, when the said dramas ar full of kings, lords, and princes? The answer is yes. Compare Hamle or Richard III with the leading characters in the *Chanson de Rolanc* Not only Pistol, Nym, and Bardolph but the fattest Shakespearea parts like Shylock and Falstaff are difficult to visualize in feudal litera ture. The characters in those plays have a 'modern' psychology, whicl accounts for their appeal to the succeeding bourgeoisie, and hence th survival value of the dramas themselves. Troilus and Cressida are no feudal characters any more than they are Homeric; Newton's Lati prose and archaic geometrical proofs in the *Principia* make that worl unreadable, but do not make it Roman or Greek science.

Talking with Indian peasants gives a grim view of modern Indi and of the service science can render to any society based upon th profit motive. The demoralization of the poor and middle peasant (the vast majority) is explained by the miserable diet on which the have to subsist, year in and year out, generation after generation with no hope of better. The passive, unresisting stratum thus create may provide the foundation for a dictatorship that could be evoke by the naked greed of kulak and petty-bourgeois, the cynical garl of Big Money, the facile opportunism of pliable intellectuals, an the leaden foot of bureaucracy never remarkable for honesty an efficiency. Surely, the problem of a better food supply is crucial, no only for attaining the socialism which is announced as India's goal but even to preserve what democracy the country possesses. But wha can the scientist do?

India, the experts tell us, is overpopulated and will remain poo unless birth control and population planning are introduced. Bu surely, overpopulation can only be with respect to the available fooc supply. Availability depends upon production, transport, and th system of distribution—here under private control. What is the tota

amount of food produced? We have theological quarrels between two schools of statisticians, but no reliable estimate of how much is actually grown, and what proportion thereof escapes vermin—including middlemen and profiteers—to reach the consumer. If shopkeepers can and do raise prices without effective control, what does a rise in the national income mean? Is it the scarcity of grain or of purchasing power? A great deal is said about superstitious common people who must be educated before birth control becomes effective. No superstition which runs strongly counter to their fundamental economic interests continues for long to grip the 'common people'. Children are the sole means of support for those among the common people who manage to reach helpless old age. The futility of numerical 'planning' for the population, when nothing is done to ensure that even the able-bodied will have a decent level of existence, is obvious to anyone but a born expert. It is not that our poverty is due to overpopulation, but rather that the overpopulation is due to poverty. Convince the common people that they will be fed and looked after even when they have no children, and birth control will immediately become popular.

Let me give two small examples of scientific effort which could easily have been turned to better account. Considerable funds will be devoted during the Third Plan to research on the uses of bagasse (sugarcane pulp). At present, it is used as fuel, and the ashes as fertilizer, whereas paper and many other things could be made from it. But are the other uses (quite well known) the best in the present state of the Indian economy? The extra money to be spent on fuel, not to speak of difficulties in getting fuel, would increase the already high cost of sugar manufacture; new factories for byproducts mean considerable foreign exchange for the machinery, and for the 'experts'. But Hungarian scientists fermented the bagasse in closed vats. The gas given off can be burned, so that the fuel value is not reduced; the sludge makes excellent fertilizer for the fields, without any further treatment; this saves money on chemical fertilizers and improves the soil. The scheme has apparently been pushed into the background. Again: the proper height of a dam is important in order to reduce the outlay to a minimum, without the risk of running dry more than (say) once in twenty years. The problem is statistical, based upon the

rainfall and runoff data where both exist. The principles I suggestec were adopted by the Planning Commission, though not as emanat ing from me. Neither the engineers nor the Planning Commissior would consider a more important suggestion, namely that many cheap small dams should be located by plan and built from loca materials with local labour. Monsoon water would be conserved anc two or three crops raised annually on good soil that now yields only one. The only country where I have seen innumerable small dam spring up during the last five years is China, which has not failec to construct giant dams wherever necessary. However, it is futile tc speak—even from my personal observations in the field—of thc exhilarating achievements, social and material, of the Chinese sincc liberation. Here, the obstacle is not ignorance, but private ownershij and lack of co-operation.

This country needs every form of power available, but is too poo to throw money away on costly fads like atomic energy merely be cause they look modern. A really paying development will be of sola energy. The advanced countries have not so much sunlight as we do hence care less for the development. The problem lies deeper than i imagined. The reforestation indispensable for good agriculture wil not be possible without fuel to replace firewood and charcoal. Coa mining does not suffice even for industry, fuel oil has to be imported An efficient solar cooker would be the answer; such cookers exist anc have been used abroad. The one produced in India was hopelessl inefficient (in spite of the many Indian physicists of internationa reputation). Tremendous publicity and a faked demonstration mad the gullible public buy just enough useless 'cookers' for a quick profi to the manufacturer.

In one matter, it was necessary to speak out though it meant con siderable damage to finances, health, and research. Atomic war anc the testing of nuclear weapons must stop. A flimsy 'Indian Repor on the effects of atomic radiation shows our moral and scientifi bankruptcy by ignoring the extensive data compiled since 1945 i the one country which has had the most painful experience of atomi radiation applied to human beings—Japan. The real danger is nc death, which is a release for most Indians, but genetic damage to a humanity. We know what radiation does to heredity in the banana-fl

Drosophila melanogaster, with its four chromosomes and life-cycle of eleven days. A good deal was found out in the USA about what happens to laboratory mice. What little has been released for publication is enough to terrify. Man is as much more complicated than a mouse as the mouse than the fruit-fly. Humans take a proportionately longer time to breed and to reach maturity, giving fuller scope for genetic derangements to develop. It may take some twenty generations to find out just what these derangements amount to. By then they will have been bred into many millions of human beings, not as a disease but incurably as a set of hereditary characters. Mankind cannot afford to gamble with its own future in this way, whether that future lies in the hands of communists or not.

2

The Kanpur Road

(1924/1939)

He sat there in his doorway like some great idol. A sad, benigr smile—a smile of pleasure, not necessarily—on that strong browr face heightened the impression. But his stiff white beard, parted anc curled away from the middle, wide shoulders that bore their year: lightly, the shining medals strung across a mighty chest, all showec a fighter.

'Sardar', for I saw that such was his rank, 'do you know the Kanpu Road?'

'Aye, *baba* (my son). I have a scar for every mile of the way.'

'You fought in the Mutiny?'

'A little.'

'No, I know better. Tell me about it. Please!'

'Nay, there is nothing to tell. We held the enemy while the mair body retreated. Yes, even as you say, it was there I earned this star How? There was little to do. The heart ached more than the arn after it was done. A rebel cut down the brigadier as he and I were re connoitring one night. I fought and killed that rebel with this sam sword. I carried the brigadier to his own men. It was not very hard

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