ARE WE SAFE?

A Layman's Guide to Controversy in Public Health

FLUORIDATION
SMOKING
INSECTICIDES
X-RAYS
CHOLESTEROL

John Polya

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In this age of mass-medication and controversies of public health, can the layman resist pressures brought on him in the name of 'science'—while critical scientists may be muzzled or misquoted in parliaments? Here is a book written for the layman who wishes to counter the improper use of terms and deceptive statistics without having to stoop to the same arguments himself. Although some of these controversies cannot be settled on existing knowledge, the layman has the right to learn how to assess claims and counter-claims and the elements of scientific method are here presented so that the opinions of 'experts' may be tested. Most attention is given to the problem of fluoridation —the least scientifically based and most fanatically argued of the current controversies. No less important are the arguments concerning the safety of drugs, food, smoking and radiation.

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CONTENTS

INTRODUCTION

Safety from ill-health is the subject of this book. The art of avoiding pain, loss of physical perfection and the techniques of restoring health are treated in the vast literature of medicine. There are many books written by engineers, chemists, biologists and other scientists on methods and devices that help us to anticipate, detect and escape natural or technically contrived dangers to the human body. The following pages are not intended to protect the reader against any immediate cause of ailment or mutilation but to induce him to think of safety in a versatile manner.

Two general problems of safety will be discussed from various angles. One of these is the nature of safety: rather a choice of lesser or more distant evils than an absolute, unbreachable rampart of hygiene. An understanding of this problem may help one to control the impulse of neglecting all other considerations when faced with any one of the numerous threats to perfect health.

The most important problem of safety, to be treated in greater detail, arises from its position in time. Safety rests in the future, it exists in the form of predictions. Safety measures are imposed or accepted on the promise or in the hope that they will prevent the occurrence of some form of bodily harm. One has to act *now* if the promise or hope is to be fulfilled *later*. All promises and hopes are not equally justified, and we clearly need a guide to estimate the value of predictions. This is particularly important in this century when promises of good health are widely used for the promotion of political and business interests. Science is the rational process of making predictions. The main aim of this book is to introduce the scientifically untrained reader to scientific method, which may enable him to use common sense in self-defence against scientifically unfounded propaganda broadcast in the name of science.

When communal wealth was barely sufficient to ensure survival, health was a matter of luxury, to be secured by individual luck, wisdom or affluence. After a short period, during which good health had been regarded as the right of every human being, we have moved into an age which, as foreseen in Butler's *Erewhon,* imposes on us the duty to keep in good health.

Ill-health used to be dreaded as a messenger of death, as a source of physical frustration and pain which deprived a person of his livelihood and social privileges. With the lengthening of life-span the dread of death has receded somewhat. Great advances have been made in the arts of controlling pain and providing aids or substitutes for defective organs, but one scourge of ill-health has become a more important feature of human destiny. Not only do minor physical imperfections prejudice provision for one's old age, but may exclude the best candidate from sedentary positions and interfere with vital rights of free movement. Most of the ten thousand refugees from Hitler who found safety in Australia could have perished in Nazi gas chambers had the Australian government acceded to the representations of a medically qualified political leader who demanded that persons with glasses be denied asylum lest their genes affect the eyes of future boundary riders and jackeroos. In more serious cases, a person suspected of infectious disease will have his freedom restricted without any of the charitable considerations which have been known to secure freedom on parole for dangerous criminals between violent crimes.

It is unprofitable to debate whether freedom or A1 health is the greater blessing; modern man has already decided for the latter alternative. In western communities the worship of health is served by an increasingly powerful branch of the civil service and by the privileged members of the medical and dental professions. In an anti-clerical age we are becoming subject to the new monks, priests and prelates of hygiene; our respect for their saints also adds power to their inquisitors. One could argue that the fight against disease justifies the emergency powers conceded to the champions of health, but there are some objections to this view.

Normal medical and dental training imparts skill in the application of drugs, treatments and diagnostic rules tried in the past. Accordingly, medical and dental predictions are seldom more reliable than those of scientists and intelligent laymen. Doctors and dentists rely increasingly on chemical and physical aids, but often with less knowledge of physics and chemistry than a normal senior pupil of a secondary school. Voltaire's jibe at doctors 'who use drugs which they understand a little on the human body which they do not understand at all' has to be turned around these days. Most doctors and dentists know some anatomy and physiology; it is the chemistry of drugs, the physics of radiation and their effects on living cells they do not understand as a rule. To make matters worse, physicists and chemists are often ignorant of biology and do not suspect what effects their discoveries could have on man and his surroundings.

We are all laymen playing with imperfectly understood inert and biological matter like children let loose among matches and medicine bottles. It is this ignorant meddling that threatens our safety far more than a few cases of undetected tuberculosis.

There is so much to know about any subject that nobody can hope to learn everything. It would be wrong to aim at teaching laymen how to teach doctors and dentists their business. An attempt to provide members of one profession with a complete understanding of what other professions are doing would appear futile at present, but this book has been written in the belief that the common sense of scientific method could provide a bridge between part-experts separated from one another by unavoidable ignorance of each other's techniques. Appreciation of the nature and main principles of scientific method does not enable one to see through every professional mistake or to reject every rash claim motivated by vanity or greed, but it helps the laymen to check arguments used to lead from purely technical considerations, the business of a few, to compulsion which concerns all.

Some may correctly guess at the future but knowledge comes only with experience. Unless individual or collective experience is complete there are risks to face. Some risks must unavoidably be taken, others can be avoided by choosing better understood or more easily controlled alternatives. In choosing between two different risks one often can decide between the scientific standing of the opposing views. The absurdity of some arguments can be detected without any technical knowledge. Scientific methods can indicate whether acceptance of a health measurer relies on evidence of general value or on some personal manifestation of faith.

The guidance of scientific methods did not come to man either through revelation or by counting votes in a scientific parliament; at all times it was experience that led to it. A book on scientific method for those who have this experience, would aim at the justification of fundamental assumptions and rules of operation from which undoubted conclusions follow; it would use the terse language of formulae to offer the utmost amount of useful knowledge in compact form.

This book, written especially for those who make little use of scientific gifts common to all, cannot assume conscious experience of scientific methods. On the contrary, it must present substitutes in the form of cases on which the reader can practice the arts of criticism and agreement. Short as it is, the book has been designed to provide a certain recurrence of ideas in slightly different contexts, since systematic repetition is the main difference between the unheeded chance observation and the power of scientific experience.

The choice and order of topics were determined by the structure of concepts: fundamental notions have to be discussed before more complex ones and the discussion of the former can avoid the formality required in the efficient treatment of the latter. The examples were chosen mainly from subjects on which there is insufficient knowledge to give 'experts' a great advantage over 'laymen'. Another aim of the book is to show the importance of scientific method in relation to subjects of considerable public debate. If the interest in scientific method thus kindled will move the reader to explore the literature of such subjects, neither the writer nor his readers will have wasted their time.

All the blessings of science we enjoy are the fruit of individual schemes of trial and error, intellectual tussle and adventure. Not only war can endanger further progress but also peace and prosperity if they bring sloth and refusal of responsibility. It is the ignorant and irresponsible whose craving for a magic solution puts tyrants in power. Racial magic did not free the German people from their hysterical fear of encirclement; it made their condition worse. Magic stones and pills will not help the masses who have been talked into a morbid preoccupation with their health, but may damage their health by delivering them into the hands of hygienic demagogues.

This book may disappoint those who believe that a new Jerusalem can be built with a few do's and don'ts. It is offered to those who hold that the intellectual, moral and physical good of the individual requires the beneficiary's own effort, courage and wisdom.

1 Problems of Safety

The humblest living being is a marvel of architecture. A single cell is a landscape of hills, valleys and ridges separated by abysses and slopes pitted with caves. Its passes, dams and gates control the flow of thin streams and thick sludges that carry many different kinds of brilliantly coloured specks. On closer investigation the landscape turns out to be a factory which puts the most intricate industrial installations to shame. A constant stream of information, like ticker tape printed in a code of four symbols, links thousands of specialised tiny engines into an organic whole. Material is being snatched from the outside world, sorted, taken to pieces and reassembled. The engines produce energy that can be stored, also replacements to maintain and regenerate the worn parts of the amazing little factory; they build, service and operate a system of signals and defences.

The main function of a living being is to preserve its own pattern against rival islands of order and against the much less orderly universe of dead matter which seeks to engulf and quench the sparks of life.

In order to survive, even if only for a brief moment, every living creature needs built-in information, instinct, to protect itself, or its kind, against the hostile surroundings. The stage of life changes in the course of geological ages; instincts change too through evolutionary mechanisms. Unfortunately for some species, the two rates of change need not be the same: fast external changes overwhelm individuals and species that were too slow to make themselves secure.

The safety of man owes much to instinct. Through millions of years of evolution, through lower animal forms, the line of existence that eventually emerged as man was preserved by instinct and through the good fortune of circumstances not beyond powers of endurance. With the appearance of rational man the race is no longer fully at the mercy of instinct and environment. Intellectual power exercises some control over both our environment and instincts. The discoveries of fire and clothing gave some independence of climate; boat building and riding removed limitations of habitat; weapons conquered the instinctive fear of physically superior animals and reduced the threat of starvation; herbal remedies and fermented beverages helped to control anxiety, diffidence and the instinctive warnings of pain.

This is not the occasion to argue whether human intelligence is a rare kind of animal instinct or a gift of different nature. It is beyond doubt that human intelligence is responsible for man's unique position among thousands of physically comparable animals and that science originates from man's efforts to use his intelligence in search of safety. Scientific power known to our age greatly exceeds that of our ancestors, but both the primitive and the modern scientist were and are inspired by the kindred emotions of curiosity and search for safety.

Science, the tool, and safety, its product, have grown through the ages, but their development has not been of the same nature. The growth of science implies many changes, all of them positive advances. The growth of safety is characterised by both advancing and receding fronts.

Science (in the colloquial sense of quantitative sciences) is based on *sensory observations*. Lower animals can observe but lack science because they do not possess the power of *abstraction* which enables us to make use of unobservables, e.g. observations made by others or events of the past and of the future. We can plan experiments and devise proofs linking the evidence of our senses with symbolic records of such evidence and also with the truths of mathematics and logic which are unobservable by the senses. The growth of science means that, as time goes on, more observations are made, and recorded; an ever-growing body of data leads to increasingly reliable logical and mathematical inferences. As a practical measure of the growth of science we may quote the synthesis of new compounds, the construction of new machines and instruments, and the discovery of new cures. Nothing short of a holocaust will halt this growth.

In a superficial way one may claim a similar unbroken growth of safety. Even the most primitive men of our times enjoy more protection against hunger, epidemics and mechanical damage to the body than in the past, when health sciences were in their infancy or when the mechanical sciences were not advanced enough to channel the benefits of science to backward regions. In civilised countries one may point to the increased, and still increasing, safety of infants and mothers, the growing span of adult life and the rarity of some formerly common diseases. We are also witnessing the development of methods for the restoration or replacement of limbs and organs. These and many more are positive advances of safety and possibly the most important conquests of science.

Yet it is true that more knowledge always adds to science, while safety increased in one respect may threaten safety in another.

A measure taken to promote safety may have its own risks. An operation aimed at the removal of an inflamed appendix is undertaken for the safety of the patient, but it creates risks through anaesthesia, unexpected surgical complications, also surgical and nursing mistakes which will occur from time to time. Immunisation against poliomyelitis is a safety measure, but occasional samples of defective serum have been known to result in the very disease against which some children and nurses were to be given protection. Most drugs have undesirable side-effects; e.g. safety from infection by administration of sulpha drugs or antibiotics is sometimes obtained at the expense of damage to kidneys. Many related examples will occur to the reader. In an emergency the lesser or more distant risk is taken as a matter of course. In other cases, a choice of risks is not always easy.

Safety is achieved sometimes by suppressing a source of both risk and safety. Operative removal of diseased organs which are still functional is in this category. Destruction of rabbits may turn carnivorous animals against the farmer's sheep and poultry. Enthusiastic use of insecticides after World War II left some resistant strains of pests which then multiplied without competition and unchecked by the beneficial species that fell victim to rash campaigns. Frivolous prescription of penicillin in ignorance of the chemical nature and biological action of antibiotics resulted in spreading resistant infective micro-organisms through hospitals.

The last two examples illustrate the relative nature of safety; what is safe for one need not be so for another. To show their appreciation of free milk distributed in schools, some teachers forced their pupils to drink their daily bottle. This undoubtedly benefited many children, but others were allergic to cows' milk and had to choose between getting caned or putting up with unsightly and uncomfortable eczema.

This brings us to the special aspects of safety to be discussed in this book. There are important differences between the safety of the individual and that of a group. Even if one is concerned mostly with the latter, there must be some connexion between safety for a citizen and his community. Much of the violence of debates on group safety is due to confusion of some issues which we must sort out before coming to detailed arguments.

Intellectually, it is easier to make acceptable assertions on group safety. In a community of sufficient size (e.g. a major city or state) it is possible to characterise many aspects of safety by statistical figures (cf. p. 58). Thus, mortality statistics will be a reliable guide for funeral directors, insurance companies and others interested in the economics of death. Any circumstance bringing about a sudden change of mortality will be taken seriously by the community, while measures without an immediate influence on death rates will be assessed on other points. The same kind of consideration applies to other statistics of safety, especially those of incidence of common or much advertised diseases. Later we shall examine the meaning of statistics; for the moment let us consider the individual's point of view.

Whatever the value of statistics to indicate the safety of the community, the value to individuals is slight. However low the mortality, any particular person could drop dead next moment. The incidence of a disease could be as low as one in a million, but again any particular person could be the unlucky one. Statistics cover only matters of interest to statistic-makers. There cannot be statistics of unknown, undiagnosed or not yet eventuating conditions. If one could prove that the increasing incidence of lung cancer is due to cigarette smoking, it would be true that statistics of thirty years ago had failed to indicate such danger to young people who had just begun to smoke at that time. Or if one could disprove the link between lung cancer and cigarette smoking, the grim statistical picture would have to be ascribed to 'unknown causes'; such terminology would gloss over the disturbing inference that something causing lung cancer on a growing scale is still being regarded as 'safe'.

Not so many years ago the individual had a chance to look after his own safety irrespective of the community's views on the subject. Today, at least in the more advanced countries, it is difficult to think of individuals in a state of biological independence of the group. Air, water and food are all affected by military, industrial and agricultural techniques. Radioactive fall-out from Northern experiments affect the Southern Hemisphere. Insecticides and weed-killers are carried by wind, and in the products treated by them. Immunisation, regular exposure to radiation, or national service demanding the handling of highly dangerous materials are often enforced by law.

The group as such does not think either about safety or about much else: it voices a minority decision, but it can impose on all its members dangers which the rational individual would try to avoid. Few individuals are accustomed to rational thought and a little pressure is enough to make them accept group ethics. The thinking minority may be repelled by group ethics but the divided loyalty which results has dangers of its own. One of these is the tendency of loyalists to obstruct individual thinking and criticism by fair means or foul. It is well known how Fascists, Nazis and Communists went or still go about neutralising critical individuals, and, as a preventive measure, any activity and aspiration likely to foster individual thought and will. It is less commonly appreciated in countries with ballot boxes in regular use that mass education by propaganda through press and broadcasting monopolies is directed against the rational and responsible individual. Although safety as canvassed in arguments is usually treated in terms which seem to be concerned with natural sciences, one of our tasks will be to detect the anti-rational background of some of these arguments.

Although the tendency to suppress individuals is directed mainly against critical scientists, it thrives on some attitudes common in scientific circles. All sciences must develop their own precise language as one cannot always express an intellectual structure built up in centuries in one sentence of ten words known to every housewife. Yet failure to attempt explanations, excessive use of scientific jargon and other pomposities can frighten the layman into uncritical attitudes and determine his support for the mountebanks against scientists. Laymen have as much right as scientists to worry about their safety. They have not only the right but often the ability to sort out the true, imaginary and faked varieties of evidence used to woo their votes.

On the other hand, one should get acquainted with some key words in discussions on safety, indeed the meaning of the word 'safety' itself. Since both the best and the worst evidence are usually presented in the name of science, we must learn something of scientific method.

Discussion of actual problems of safety cannot proceed without a few technical data. A summary of all relevant technical information would go beyond the scope of this book. Fortunately, there are some problems of public safety which have received so much publicity through press, radio, TV, pamphlets and public meetings that most readers will have heard of the major claims and counter-claims, at least in principle. These then are the problems which will supply most of our examples: fluoridation of public water supplies, radiation, synthetic additives to food, smoking and the use of drugs.

When scientific arguments fail, we must rely on authority. Although the threat of sulking and vindictive authority is not always absent from arguments between scientists, reference to some infallible person or body is the normal ending of a dispute between a moderately well trained person, whose case rests on science fiction, and an intelligent layman, whose common sense detects contradictions and other absurdities. Thus a natural history of real and imaginary authorities on scientific matters will be necessary.

Words, facts, claims and inferences can be discussed in a quiet, neutral atmosphere. Verbal mistakes can be checked, discussed and corrected to the ultimate benefit of all concerned. It is different when action is involved. Few actions are completely reversible, hence ethical and legal errors are more serious than lapses of tongue, bad memory or muddled thinking. It is not the author's aim to talk his readers into adopting or banning certain practices which affect safety. In a world of 3,000 million people there are so many personal, racial, regional, professional and other differences that the desirability of one single procedure on any matter is open to serious doubt. On the contrary, enforced uniformity may usher in another dark age.

2 Some Key-Words of Science

The benefits of science are real events occurring in space and time and accessible to our senses. While science is concerned with sensory events, it is recorded and discussed in words. Words are the currency to facilitate the exchange and storage of scientific knowledge and must be treated with the care lavished by businessmen on money. Every newcomer to commercial life knows that not every piece of green paper is worth a dollar; that U.S., Canadian, Hong Kong and Singapore dollars are not of the same value, and that many richly illustrated chits issued by new or imaginary countries and companies are not worth a farthing. It is impossible to treat in a brief chapter all the verbal tricks that confuse scientific issues and hold up recognition of new views and discoveries. In this chapter we shall consider the meaning of a few words that affect scientific communication in general. Other terms will be examined in later chapters in the context as they arise.

Whenever two human beings meet they try to influence each other. Mutually exclusive views and practices are battling for the assent of all who hold power as executives or electors in a community. Safety has been one of the common catch-cries of practical or ideological tussles through the ages. The controversies remain, and only the rationalisation has taken on a new aspect in our days. On first acquaintance, an argument may appear very simple. Statements like 'fluoride helps your teeth' and 'smoking hurts your lungs' may suggest that it should be easy to accept or reject them. As one begins to think, one realises that teeth or lungs are not the only consideration, and that a cheerful vote of 'yes' or 'no' does not do justice to all that is involved. Problems when tackled honestly and thoroughly go through a stage of confusion. Further efforts often restore clarity and shed light on originally unsuspected depths, but not everybody has the patience, strength or luck to work his way through problems that are not trivial. Some emotional appeal to allegedly 'obvious' truths, traditional saws or loyal declarations of faith used to be the way to prevent efforts to solve problems. The growing realisation of the futility of keeping problems unsolved and the amazing rewards of objectively solved problems ushered in our age of science.

For some time the solving of practical problems and reliable prediction of observable effects was left to the few whose innate gifts and curiosity, aided by able masters, persistence and the kind of luck that appears to favour the single-minded, demonstrated the power of scientific methods. Doubters were not lacking at first, but there are few who hold at present that the human mind cannot devise machines nor make accurate predictions without the assistance of the devil. Indeed our troubles stem more from faith than disbelief in science. The material rewards of science are so plentiful that new discoveries are taken for granted and the part played by searching is no longer appreciated. Thus science—which is a mode of searching—is rapidly becoming a magic word to settle an argument. Science in the name of which we are urged to accept other people's views, medicine, waste products and meddlesome care is a false god which must be destroyed if reason is to prevail.

The first practical advice to the layman who wishes to protect himself against deception practised in the name of science is a simple matter of language: ignore statements ascribed to Science personified. Assertions such as 'Science teaches us...' etc. mean much the same as 'Quetzalcoatl[1] has established, proved and taught . . .'

There is no person, organisation, document or object to be identified with Science. Scientists endeavour to establish truths, have proofs to offer on certain matters and often feel confident enough of their observations and inferences to feel that others should share their conviction. On the other hand, scientists often disagree; some unqualified persons may pose as scientists; many scientists are wrong on scientific matters. Thus a scientific statement cannot be taken seriously unless stated in a form which permits eventual verification of the assertion and makes criticism of the source possible. Recourse to causes that are undetectable by definition may lead to interesting and productive disputes but are beyond the boundaries of scientific discourse. Statements such as 'Newton claimed', 'Pasteur taught', 'the majority of Australian dentists agree' and 'the innkeeper of Woop-woop feels certain' are *significant* in the sense that the competence of the sources may be assessed.

The term *proof* has just been used. It is a commonly used word with different shades of meaning. Given some *axioms* of mathematics we may prove a number of theorems without any doubt. Some frequently recurring observation may prove a rule, but without excluding the possibility of exceptions however rare (cf. p. 36). A proof of candour or innocence by demeanour, on the evidence of a dew drop on a pretty girl's face, carries less general conviction. This book would be easier to read if words could be used in a colloquial manner, leaving a strict or elastic interpretation to the reader. Since proofs are offered to obtain agreement, this easy-going approach to words would fail: few mathematicians are romantic enough to accept proofs resting on feminine charm, and some servants of justice have been known to rely more on passionate pleading than on the dates, places and measurements before the court.

For the purposes of this book one might agree to leave the term *proof* with its vague colloquial sense, using some other term, e.g. *demonstration* or *demonstrative proof*, in cases when something of high convincing power is meant. In the context of our discussion this procedure appears unnecessary. The proofs we are concerned with are examined in order to decide how compelling they are in the light of scientific method and hence how much legal compulsion to act on the alleged proof could be justified in the name of science.

No proofs are truly absolute. All proofs rely on a certain amount of agreement on axioms, rules, commonly held beliefs. If you can agree with a child on a method of counting, you can prove to him that $1+4$, $2+3$, $4+1$, 5 etc. are the same. There are other methods of counting which make $1+4$ differ from $2+3$. A ship travelling in a straight line a lap of one mile followed by another one of four miles moves five miles from the start; another journey, in a straight line, in laps of two then three miles would take it the same five miles. But if the ship travels first one mile due east, then four miles due north, its displacement from the start will be a little over four miles, or less than four miles with an eastward lap of two miles and a northward lap of three miles.[2]

Given agreement on the rules of chess, one might prove that a certain situation leads to checkmate in three moves no matter how the defence is conducted. A trivial way to avoid checkmate is to make one's own rules of the game as the play develops.

Once we see that even such an obvious truth as $2 + 3 = 1 + 4$

is not necessarily true, we learn to accept far less transparent truths with caution. The example of the game of chess is meant to show that without a common understanding of and common respect for certain rules, one cannot speak meaningfully of proof.

There is an exasperating but nevertheless real difference between truth and its proof. If you were John Smith, a native of London, an Australian citizen, thirty-seven years old, unmarried and—apart from three parking offences—of unblemished record, how would you prove it? If you have lost your papers and must convince the police of a strange country, the dangers of the situation are obvious. Some of the true claims of John Smith will be easy enough to prove in London or Australia where certificates of birth, residence and citizenship issued in the British Commonwealth are either accepted without query or easily verified. But even then the unblemished record and the status of bachelor could not be proved: some people marry or are sentenced under an assumed name. Failure to locate a certificate does not necessarily mean that the certificate does not exist; it may be in the interest of a guilty John Smith to hide or destroy incriminating records, and a suspicious detective may well lack the interest, time, funds and staff to search the whole world for the documents or their remains.

This awkwardness of proving that something unobserved has not happened is one of the fundamental problems of safety. If a drug or an additive to food is being used for years without anyone realising the harm it causes, advocates will describe it as 'safe'. Its dangers may be suspected, but as in the case of John Smith without a criminal record, unsubstantiated suspicions are not enough. Even if one obtains evidence that a number of persons suffered after taking a certain drug, one will have to admit as a rule that the victims shared also other factors, e.g. food, climate, treatment by the same doctor or in the same hospital, and that the effect could be due to some of these causes singly or jointly. When the symptoms are relatively minor or when the link is not suspected and people have good practical reasons for not wishing to notice inconvenient links, we have safety of a kind that appeals to the ostrich in danger. The undoubted story that it took years to recognise the link between thalidomide and the spectacular malformations it brings about, and the numerous testimonials to the safety of thalidomide by specialists writing in learned journals and books at a time when thousands had already been affected, show the practical consequences of equating lack of proof of harm with proof of safety.

Another common error is the confusion of *evidence* with proof. Once I had an argument with a dentist whose mission in life is to persuade or force people to dose themselves with fluoride. Being a man devoted to his cause, he called me a string of bad names for not sharing his enthusiasm, and declared that I must be a fool or a liar to assert that all the evidence in favour of fluoride is false. I have not made such an assertion, of course: there are many sincere and intelligent supporters of fluoridation, and some of their many assertions on the subject appear to be correct. '*Well, if one accepts the truth of a single argument for fluoridation, one must become a missionary for fluoridation,*' advised the zealous dentist. Had he given a little objective thought to almost any well-documented controversial topic he would have been struck by many instances of evidence to be taken seriously but still insufficient to clinch the argument.

There is much incontestible evidence for the technical skill and efficiency of the Nazi regime, but even if we accept skill and efficiency as virtues, the overall merit of Nazism remains to be proved. We can accept the evidence showing that Mohammed was an extraordinary person without having to subscribe to all the tenets of Islam. The recognised advantages of a drug in themselves do not justify its unchecked distribution, nor do the recognised dangers and unavoidable ill-effects of some operations exclude them totally from surgical practice. In order to justify prescriptions of the dangerous drug or employment of the dangerous operation, some evidence of advantage is *necessary*, but this in itself need not be *sufficient* to warrant universal acceptance or compulsion.

The distinction between necessary and sufficient is seldom appreciated by the many speakers and writers who have little or no scientific training. A few more examples may help us to remember this essential distinction. In order to travel from London to New York it is necessary to travel at least 1,000 miles, but a journey of 1,001 miles would not be sufficient. To prove the medicinal value of some mineral waters, evidence of some cures is necessary; one or two such cures, no matter how well attested, would be insufficient, and even the testimony of a great many cures would have to be supplemented by other evidence (e.g. to show that rest, change of air and increased medical attention did not contribute to the cure in a significant manner).

Some debaters think to anticipate criticism on grounds of insufficient or non-existing evidence by sweeping claims to *all* evidence, *every* witness or some equivalent *absolute,* universal, unsurpassable support. A good example[3] reads: '*Alderman Abbott submitted that all the evidence from reliable and reputable scientific sources showed that fluoride was immensely beneficial to dental health, and was absolutely safe in the proportions in which it was proposed to put it into the water supply.*' If the statement is to be regarded as reliable, it should be true; if reputable, it should not go beyond the evidence obtained and critically sifted by the author. How does our quotation fare in these respects?

'*All the evidence,* etc.' suggests that the alderman managed to find time to read *all* the books, papers, pamphlets and reports of addresses for and against fluoridation in English, German, French, Dutch, Swedish, Russian, Ukrainian and a host of other tongues, then sorted out the massive evidence into the categories of (1) reliable and reputable; (2) reliable and disreputable; (3) unreliable and reputable, and (4) unreliable and disreputable, with the result that all evidence under (1) agrees with fluoridation under the conditions proposed. There are at least 10,000 books and papers on fluoridation to read and sort out; there could be many more. Even if one spent ten years on the job full time, or perhaps thirty years in the case of an alderman who is also a general practitioner and lawyer, one would not know how much more evidence is lacking from the *all.*

The sources placed in category (1) by the industrious alderman are supposed to show that a measure is '*absolutely safe*'. This means that the persons our alderman regards as reliable and reputable have tested every person now alive and all the unborn whose future safety forms part of 'absolute safety', and found that a life-long ingestion of fluoride (as proposed in his city) did not and will not cause disease nor aggravate existing ailments nor hasten the outbreak of diseases due to hereditary disposition or to future circumstances. The testing of 3,000 million odd living people (never mind the unborn!) in relation to the thousand or so diseases mentioned in a medical dictionary and all through their lives would have been beyond the capacity of the medical profession. Also these people should have been tested simultaneously on diets with and without fluoride. If all this has not been accomplished, one cannot claim *'absolute safety'*, only safety in relation to a few major diseases in the large majority of the few thousand people who were examined on a few occasions. Authors who confuse absolute safety with high confidence in safety are not reliable, hence cannot figure in categories (1) and (2). When we learn that the high confidence is based on observations relating to one per cent of the better known diseases in about one per cent of mankind, of whom less than one per cent was medically examined in relation to fluoride sensitivity, and then on a few occasions only instead of a period of thirty to forty years, protest from 'reliable and reputable' sources might be expected.

Now, Professor Theorell, a recent medical Nobel Prize winner, writes:[4] *'For water fluoridation at 1 p.p.m. the short distance to toxic dosage seems to imply a serious hazard. We have even to pay attention to the great individual variation in sensitivity and in consumption of drinking water.'* There is no need for the many similar statements from other eminent scientists: clearly we have one eminent scientist's denial of the *'absolute safety'* of fluoride. Theorell may be wrong, of course, but where is the proof that he is not reliable or reputable? Einstein, Pasteur, Newton and Galileo were wrong at times but were they unreliable or disreputable? So we come to the sad conclusion that the enthusiastic statement we are criticising makes assertions on fluoridation on unobtainable evidence; attacks the knowledge or character of at least one great scientist without any evidence; and its author pretends to absolute knowledge, the privilege of a divine person.

It may appear that we have wasted a great deal of time over the absurdities implied in the possibly unprepared words of one who has not the leisure for scientific thinking. Yet it is useful to see how an unfortunate word or two can kill a statement and does away with the need of technical knowledge to refute it. The first question a layman should ask about scientific utterances involving terms such as 'all', 'every', 'absolute' is: 'How many make "all"?' When 'all' is a small, surveyable number it can be used properly (e.g. all my children, all members of this committee, all the three books I have read on the subject, etc.). Uncountable 'all's' may be justified in mathematics (e.g. all multiples of 2 are even numbers), but are unjustified or at least very dangerous in arguments that rely on experimental proof. Einstein is credited with the aphorism *'No amount of experimentation can prove my theory but one experiment can disprove it.'* This is the proper attitude to the natural sciences, especially those that concern such variable matters as health, sensitivity and safety. The experimental scientist may prove matters about 'at least one', 'some' and 'many' (the latter has its difficulties though); he cannot prove 'all' except in certain clearly limited contexts (e.g. all the houses in this village have been demolished; this man has lost all his teeth).

The use of negatives in arguments requires care. We have seen that 'there is no evidence of harm' does not mean that 'this is safe'. For nearly forty years the dangers of radioactive substances were not suspected. One of the first spectacular cases that drew attention to the perils of radioactivity was the death of a fifty-two-year-old man in New York in 1932. This man, not content with his excellent health, took to a tonic water (sold under the name of Radiothor) which contained radium. He regularly drank the tonic for years, and was satisfied that he had achieved greater efficiency in this manner. After having drunk 1,400 bottles he became severely ill. His disease could not be diagnosed until it occurred to one doctor, among the thousands who were baffled, that somewhat similar symptoms had been observed in women employed to paint luminous clocks with radium paint. The diagnosis did not help; after a few months the man died a painful death from an accumulation of 1/2000000 grain of radium.

Expressions beginning 'no reliable or reputable person would deny, query, assert, etc.' are just as dangerous as the assertions about 'all reliable and reputable' persons. If we must make extreme statements, it is better to say 'I know of no instance or evidence' than 'there is no instance or evidence'. There is much a diligent and gifted scholar does not know in his own field. If he has no right to assume that what he does not know is not knowledge, persons lacking his training and devotion to the subject should not build too confidently on their own ignorance. On the other hand 'not all' is often easy to prove (e.g. not all smokers die of lung cancer): one instance is sufficient proof.

Truth is a deceptive word. We have seen that lack of evidence, insufficient evidence and too much evidence may all shake one's faith in a supposed proof. When we make decisions that force us into action we should like to feel that the decision is true. To decide whether we have the right kind of evidence in just the right amount is often difficult or impossible. Some people get over this difficulty by ignoring truth. Not that they set out to lie but they are determined to win a definite case. Such a determination receives much social support although it is an attitude that does harm to intellectual honesty. A person may have a number of excellent reasons to wish that some result be revealed as the ultimate truth, but he must not silence his critical faculties.

As a short-range policy it is common practice to stand on proofs which point in the desired direction, dismissing all others as unreliable, or immoral. For example, a provincial surgeon attacks a Nobel laureate in medicine together with professors of dentistry, physiologists and toxicologists of world fame, internationally known experts on nutrition, writers of some of the leading medical text-books used in the English-speaking world and also the prevailing scientific opinion in some of the world's leading scientific nations:[5] '*Too many cranks are again expressing uninvestigated and incompetent opinions about fluoridation, in contrast with the observations, experience and goodwill of both the dental and medical professions. It is up to the public to support us in our endeavour to assist the children in this field.*'

The point is not that famous people must not be criticised by obscure amateurs; nor is it relevant that many a gift from scientists has been misused by professions, few members of which are scientifically equipped. Even if the famous scientists opposing an angry politician should be wrong, they are entitled to thanks for critical remarks which are in healthy contrast with the gullibility of self-righteous professional men. Refutation of technically stated criticism will do more to establish the rationality of one's faith than abusive language that has become parliamentary in some places.

Selected at random, a typical example[6] reads: '*FLUORIDE ENEMIES PSYCHOS—**People who opposed fluoridation had been proved to be psychopathic, an American dental expert said yesterday.** He said scientists at the University of Manitoba had come to this conclusion after putting a group of anti-fluoridationists through thought process tests. People should demand water fluoridation for their own protection, he said. "There are no scientific grounds for opposition to fluoridation."*

The expert, Dr Miles R. Markley, of Denver, Colorado, is here as a guest of the Australian Dental Association's convention at Lismore.'

Let us analyse the passage as a matter of words.

The headline is journalism meant to attract the pennies of both supporters and opponents of fluoridation; it would be unfair to regard it as a quotation reflecting on the grammar and manners of a distinguished visitor. The third sentence is the professional opinion of a leading dentist from an American city comparable with Adelaide, contradicted by the views of at least two of the leading dental scientists in Melbourne. As laymen we have nothing to contribute to a dental argument. But dentistry is not the only science, and a dental practice in Denver, Colorado, is not in itself sufficient qualification to deny scientific grounds to the criticism of fluoridation by leading biochemists, physiologists and experts on nutrition. When it comes to psychiatry, there is no reason to assume that Dr Markley is anything else but our fellow-layman in that field.

Indeed, is Dr Markley as critical as an objective layman should be? Supposing it is true that *some* psychiatrists in Manitoba were dissatisfied with the thought processes of *some* opponents of fluoridation, how does the *general* proposition follow? With printed evidence to show that *some* dentists disregard chemical and physiological evidence against fluoridation, has one the right to say *in general* that dentists are enemies of better founded sciences than their own? If workers in, say, the University of Saskatoon disliked the thought processes of their colleagues in Manitoba, would this invalidate also the thought processes in favour of fluoridation?

To go one step further, let us assume that the aluminium and phosphate industries, which would be the main beneficiaries of fluoridation, provide research funds sufficient to prove that all opponents of fluoridation—from Nobel Prize winner down to the leading American fluoridator who uses distilled water for his own consumption—are raving lunatics. Locking up the opponents will make it easier to fluoridate but it will not prove fluoridation right. A sane person can be wrong on many things, fluoridation included. On the other hand, lunatics have been known to be right. Semmelweiss, the first champion of aseptic maternity hospitals, was obsessed with the problem of puerperal fever, behaved in an eccentric way throughout his career and died in a lunatic asylum. Shall we write therefore: '*PUERPERAL FEVER ENEMIES PSYCHOS*'?

Another incorrect attitude to incomplete proofs is one of sterile scepticism. Having realised the impossibility of arriving at irrefutable truths, the sceptic abandons any approach towards truth. In the realm of experimental sciences, gradual approach to truth is the only possibility. The advances of modern techniques indicate the practical value of this attitude; humility and a recognition of the need for further progress provide its moral justification. Among scientists this is almost obvious. To non-scientists this respectful and active approximation of truth can be distasteful. Judge and jury usually prefer cocksure answers, and distrust the careful, honest witness who qualifies his statements, realising the defects of human memory and the ambiguities of simple words. Many judicial and electoral mistakes are due to impatience with search, the desire to be led and the (unjustified) hope that truth must be simple. The sooner we learn that truth on experimental matters must be qualified, the safer we shall be against the enthusiasms and deceptions of rash meddlers with our bodies and souls.

Ideally every assertion meant to be true should show how much of it rests on unquestionable observation; how much of it could be affected by the deficiencies of the observer's senses; what is the known and what the guessed influence of instruments used; how much has been rigorously inferred; how much guessed and on what grounds; how much is a pure wish without a rational basis. Scientific papers published in first-class, critically edited journals are supposed to show all this. In ordinary conversation and in propaganda conducted by people who never had to justify their beliefs to a panel of competent critics one cannot hope for all these niceties. Paradoxically, people who have never learnt how to assess the accessible but partial truths of science are the ones who talk most of the '*absolute truths*' beyond the reach of humans.

Truth must be distinguished from *validity*. In the absence of further explanations, the statement X = Y is neither true nor untrue, but it can be validly extended to 2X = 2Y, the truth or untruth of which again depends on what we mean by X and Y (cf. p. 52). For example, on arrival in a strange port a vendor offers to us an object which he describes as an unfailing charm against bullet wounds. He further asserts that the officially prescribed price of the charm is one dollar. Ignoring discounts for bulk purchases, we may validly deduce that the 'officially prescribed price' of two 'charms' would be two dollars. The validity of this deduction does in no way establish the truth of the vendor's assertions concerning the magic power of his ware and the existence of price regulations made by the rulers of the country.

A more common example of the difference between truth and validity is found in many primary books of arithmetic. Many of us will remember the days of our childhood devoted to the calculation of the cost of a certain ditch and to estimates of the time required for its completion. If three men took a day to dig 400 yards (3 feet deep and 17 inches wide), how long will one man take to dig another stretch of even crazier dimensions? As a matter of arithmetic, one arrives at valid answers. However, the truth of three men's capacity to dig the ditch of the given dimensions in one day does not follow; indeed, it will depend (among other things) on the tools or machines used in the process.

Still another kind of example is provided by grammar. 'Admirably seven' is not an English sentence: it is grammatically invalid. 'Peter likes dogs', 'I am dead', 'Thou art the fairest and most precious jewel' are grammatically valid English sentences. Their truth does not follow from English grammar, except that the second sentence must be false when spoken.

Finally, the legal distinction between validity and truth is common knowledge. When a man is pronounced guilty by the jury or when a judge attributes a certain deed to him, he will suffer *as if* jury or judge were right even if he is innocent. A court of appeal is more concerned with the validity of the first judgment than with its truth. Validity is a matter of *form* on record, while truth obscured by contradictory pieces of evidence can seldom be established beyond some residue of honest, rational doubt.

Although we seldom know what is really and fully true, most of the practical situations we meet force us to make a number of assumptions, treating certain ideas *as if they were true*. Such assumptions can be of great use, and reasons to challenge them need not arise for long periods within the life of individuals or civilisations. Even then it can happen that a successful challenge does not deprive some assumptions of a certain amount of usefulness. Thus the mechanical assumptions of Newton are still of great practical value even though it is necessary to look to the more complex assumptions of quantum and relativity theories when dealing with some newer problems of physics.

Granted a number of meanings attached to events and mental pictures that ultimately derive from observed events, there appear rules that link them. Practically, events are more important than their mental pictures (a meal eaten is more nourishing than one imagined), but it is safer and more efficient to test patterns of mental images before bringing about patterns of corresponding events. Before the surgeon operates he envisages several possibilities, weighs their advantages, makes a mental decision and only then proceeds to action. This kind of procedure is made easier by suitable symbols—words, letters, numbers, diagrams and so on. Mathematics and logic are concerned with rules that link such symbols validly, in a reliable, consistent manner. The economy and power of this approach are enhanced by the suitability of a certain mathematical or logical form to deal with a large variety of problems. For instance multiplication (by head, tables or instruments) provides the price of any amount of any article at any unit price. The same table will do for pigs and apples during inflation and deflation.

Since we have powerful mathematical and logical tools to test the validity of patterns of ideas, we use these to help us through the material events that are brought to us by our senses. A practical problem of how to cause or how to avoid a certain pattern of material events is translated into symbols. The symbols are manipulated in valid operations of the mind and afford some symbol or symbols as the product of this activity. If we can translate the resultant symbol or symbols into material reality, we have our practical answer. For example, the problem of traversing a river is translated into mathematical language by the engineer; manipulation of his symbols results in new symbols for a certain shape made from parts of certain properties. It may turn out that properties of the specified nature are unknown. Chemists and metallurgists employ their own symbolism and arrive at further symbolic statements which translated into observed terms mean that certain known materials must be mixed or otherwise processed in a certain order so as to provide material with properties required by the engineer. If all concerned made their translations between material and mental objects correctly, and if their manipulations of the mental objects were valid, a bridge will be built and it will stand. If the bridge cracks, errors of translation or invalid manipulations will be indicated. We shall return to this process in other connexions.

Fact is a commonly used word with many colloquial meanings. For the purposes of scientific thought these meanings must be restricted, but an adequate definition of a fact turns out to be exceptionally difficult. In order to avoid the complexities of a formal definition, and also because of the practical needs of many readers, we shall consider a working definition of the concept through tests enabling one to distinguish between facts on one hand and guesses, beliefs, tendentious assertions, etc. on the other.

As a matter of language, the term fact (derived from Latin) conveys the notion of something finished, completed, perfect. Something that has happened and something that is (or has come to be) could be a fact, but something that will happen is not a fact but an expectation. Safety (e.g. 'this pill will not harm you') refers to the future and thus is not factual.

When speaking of facts we are often confusing two languages. In one language fact refers to events outside us, e.g. to the existence of the sun and its path across the sky irrespective of our presence to watch it; in a second language, the facts concerning the sun and its path are inside us as sensations, memories, inferences and imaginative manipulations. The outside fact can be shared in the shape of common sense: in the blazing midsummer sun we are all hot, fires threaten all of us, water runs short for the whole community, butter melts in sandwiches, and so on. The inside facts remain hidden: there is no common way to infer what exactly my senses and thoughts are doing with the sun in my mind. It would be tempting to restrict the concept of fact to outside facts but this would make intellectual life virtually impossible. The most important outside facts come to us through written and spoken records of others, that is having passed through the state of inside fact in other minds. On the other hand, the unavoidable reliance on inside facts is often abused by persons who jumble together the common and private elements of a fact. Thus the actual change of position of the sun (as viewed through a fixed telescope or noted through changes of shadows) is a common element of *observation* and may be called a fact unless one insists on sterile pedantry. However, the notion that the sun moves around the earth which is the centre of the universe is not a fact but an *inference* of some merit, although of far less use than some other explanations. The idea that neither the sun nor other observers exist but are mere figments of my imagination is obviously not a fact but an inference of little practical value.

In a discussion of facts the real question is the degree of correspondence of inside facts to outside facts. The test is what are the *events* involved? Were they or could they have been observed and verified by means of common powers of observation?

A statement about events that have been or could have been observed in a manner to provide agreement on which to build further arguments is a *factual statement*. To make the statement true the observables must be correctly reported; also the non-factual portions of the statement must stay within the boundaries of truth. An astrologer's assertions as to the time of birth of a person and the relative positions of heavenly bodies at the time may be factually true, but the inferences drawn as to the person's character and fate are neither factual nor true by any definition of truth tenable in common. The astrologer's prediction may come true, of course, but the factual parts of his statement do not justify his prophecy. Indeed we may find that persons born at the same time and place have fates and characters different enough to doubt the forecasts of astrology.

To turn to a practical example, let us attend a meeting on fluoridation and listen to the speakers:

> Mr For: '*It is a well-known fact that fluoridation is of great value to the individual. I have facts of my own to prove it. My brother who lives in a fluoridated town has few of his teeth missing, but I have dentures because the City Council is too backward to supplement the deficient fluoride content of our drinking water.*'

> Mr Against: '*I have a letter from my sister which will give you the facts against fluoridation. She was a healthy woman a few years ago, but when they fluoridated her town's water supply she began to lose weight and became depressed. At times she feels as if she was on her way to the loony-bin or something. . . . And another fact, I've seen it myself, even her tulips don't grow well since they have fluoridated her water. Also her saucepans are rusting.*'

The points made by Messrs For and Against are *data*, things *given* to be processed in your mind. Your intention, of course, is to start from events and through the process discussed above arrive at a symbol which you can translate into the event of your decision. Strictly speaking facts are the symbols of real events fed into your mind for processing. Assuming (perhaps with more charity than wisdom) that all the speakers and their informers are truthful, we arrive at the following facts: Mr For's brother has a few teeth missing; Mr For has dentures; Mr Against's sister is losing weight and is complaining of feeling depressed; her tulips and saucepans are unsatisfactory.

Statements to the effect that two towns mentioned by the speakers are fluoridated are not facts in a strict sense. It is factual that the towns have machinery for fluoridation and that such machinery operates when it is not out of action; it is also factual that both towns receive barrels labelled 'fluoride' from time to time; also that Mr James Blow in the one town and Mr Michael Mud in the other periodically transfer the contents of the barrels to the machinery. It also may be factual that somebody performs chemical analyses (that is a string of operations, pure magic to Messrs For and Against). However, the result of analysis is not a fact but an *inference* subject to a great many if's and but's, fully appreciated by experts only. It is not a fact but a probable guess that small towns bent on fluoridation cannot afford to keep leading experts with staffs and well-equipped laboratories to perform frequent fluoride analyses. Even if the analyses are sufficiently accurate, this is not factual either to Messrs For and Against nor to the majority of their audience.

The same applies to the alleged fact of drinking water deficient in fluoride. Its fluoride content may be factual in the already criticised broad sense, if we are willing to accept chemical inferences as facts. Whether a given concentration of fluoride is to be regarded as deficiency or excess is a matter of unsettled argument with distinguished experts on all of the many sides of this problem. The backwardness of the City Council is not a fact but an inference or a piece of mud-slinging. Feeling low can be a fact, but prophecies are not facts until fulfilled, and feeling oneself on the way to an unreached goal is certainly not a fact. Linking dental and mental health, horticulture or damage to saucepans with presence or absence of fluoride does not provide facts, but true or false inference, guessing or wishful thinking. When Messrs For and Against insist that their reports, inferences and guesses etc. be taken with the faith one reserves for one's senses, they are making *claims.*

The point is that there should be something reliable, about facts so as to throw the onus for correct thinking on the thinking process alone. The evidence of senses is not absolute but it is more certain than a muddled inference. Also the normal person can estimate the value of sensory evidence while the assessment of inferences may be very difficult. It takes much optimism to mix undoubted facts and very weak inferences with much else in between them and expect that a uniformly valid pattern of thought will rise from the mental porridge.

Another example is heard in connexion with the problem of smoking. It is often stated, even by eminent persons who should know better: '*It is a fact that cigarette smoking causes lung cancer.*' We shall consider the evidence later. For the moment let us sort out our words. It is a fact that Tom is a smoker. It is a fact that he suffers from an affliction, recognised in a number of ways, which we call lung cancer. The smoking having caused the cancer is not a fact but an inference based on some unproved assumptions. The assumptions and with them the inference may turn out to be wrong but there is something final about facts. Confidence in one's claims does not supply missing links in the proof.

Inferences are of different kinds. The inference of a link between cigarette smoking and cancer is based on many data originally observed as facts. Unless one wishes to be awkward, one cannot deny the status of facts to some reported data. Unfortunately, people have been known to tell lies,[7] and it is almost impossible to check in detail whether every item of a large body of factual data corresponds to a real event in the manner reported. There are also typing and printing errors propagated as reported data are circulated, combined and extended by the addition of data of one's own.

It can also occur that a powerful interested party allows the circulation of some factual data but suppresses others. Even if the released data are all correct, suppression of part of the evidence may furnish a wrong answer. This can happen where the introduction of compulsory X-ray surveys detects a few dozen curable cases of tuberculosis and coincides with the doubling of incurable cases of leukaemia. Should this happen, the inference that the increased incidence of leukaemia is due to X-rays does not automatically follow. If there were further considerations supporting such inference it would still be wrong to say that 'it is a fact that X-ray surveys increase leukaemia'. However, while it is wrong to jump to factual conclusions, one must not deny to others the right to suspect a link between medical X-rays and leukaemia.

Suppression of awkward data may protect a health measure against both justified and unjustified criticism. Stifling of the latter cannot add much to the sheepish docility of modern man whose neurotic preoccupation with health lays mountains of golden eggs. The curbing of justified criticism has been expensive in the past. Nazis in brown shirts learned this lesson too late for themselves and for their subjects. Let us hope that men in white coats will learn on this side of disaster.

Critical approach to truth often demands that some data be rejected. This causes much bitterness between experts in debates on health matters. Laymen involved in such debates become confused when asked to sift data. To some it is a flattering thought to arbitrate between hostile teams of experts: whatever the choice, arbitration by ignorance depreciates knowledge. Others, more responsible, feel that until the great majority of experts agree, no decision should rest with laymen. This is honestly thought but not always wisely. Benjamin Franklin was a respected expert in his time, but his opposition to vaccination against smallpox cost his own son's life, while some of his foolish contemporaries chose more wisely. There are many cases in which laymen have no chance to sort out facts fit for thinking from false data, erroneous observations, unproved inferences, crude guesses and plain nonsense, or more briefly, facts from claims. In some other cases, to be examined in the next chapters, the layman can use scientific tests of validity to distinguish factual data from claims of no standing or of only potential standing.

Some claims can improve their status. The atomic nature of matter as claimed by Greeks or the transmutation of elements as claimed by alchemists were ill-founded at the time they were put forward. Today there are many facts and factual data to support their truth, and we may yield to the temptation to say that the existence of atoms is a fact. The existence of some elements is easier still to interpret as a fact, so unfortunately is that of nuclear explosives operated through agents interpreted as fission and transmutations of elements.

When a guess has something to commend it, especially when it implies some way it can be tested, we speak of a *hypothesis*. When a hypothesis (e.g. the atomic hypothesis of Dalton) is confirmed by an extensive and consistent body of evidence we speak of a *theory*. If a person pretending to be scientific informs you that he 'has a theory', you can safely ignore his message: he is either untrained in science or is about to fool you.

The comments of Professor E. B. Wilson[8] are worth remembering:

'The difficulty of testing hypotheses in the social sciences has led to an abbreviation of the scientific method in which this step [*testing*] *is simply omitted. Plausible hypotheses are merely set down as facts without further ado. To a certain deplorable extent this same practice occurs in medicine as well.'*

3 Shadows of Facts

A true statement should provide valid links between facts. A good argument should use true statements to bridge relevant facts and predictions we need for our guidance. These ideals are seldom achieved, particularly when our concern is with safety.

Safety is never a fact. Even if the term is understood as personal safety, that is freedom from well defined effects, the best one can say is that such effects have not come to light so far. If the term is to be understood as applying to one's family or community or to the whole of mankind, failure to note adverse effects becomes less significant as the number in the group grows. A man could say sincerely: 'I had no headache today,' and—trusting his sincerity—one could accept his statement as true. If the same man had said: 'No member of my family had a headache today,' the same faith in his sincerity would leave us in justified doubt. How is his family defined? Did he mean his household or all his blood relations to some unspecified degree of kinship? Did he ask all those who constitute 'his family'? Did all he asked give a true answer? Even if we trust the man's sincerity, it does not follow that his wife is truthful. On what evidence was the baby certified free from headache? It is easy to see how such awkward questions become more important as the group increases.

Predictions are not facts; on the contrary they are inferences, guesses, wishes or fears relating to events which have not occurred and could not have been observed. If today's record of a family's headaches is open to doubt, the predicted record for tomorrow (or the next five minutes) is even less certain.

If we sacrifice 'all' facts in favour of 'some' or 'many' we lose the right to claim 'absolute' truths, 'absolute' safety and the like, but we may still arrive at qualified truths. Such truths may be valuable from a practical point of view and their very qualifications could imply relevant facts. We have seen that it is unlikely that any man has the right to say, 'This drug is absolutely safe.' When we are told that the drug in question is safe in *most cases* or was safe *in all cases studied by the author* or *in all cases the Health Department wishes to consider,* we are given some information as to the difference between 'absolute' safety and probable safety in this instance. This difference is a measure of our responsibility in prescribing or taking the drug or voting for its compulsory administration enforced by legal or economic pressure.

Even a sensible, humble approach to facts is barred by an obstacle one cannot always pass. In situations when 'all' means an unimaginably large number or infinity, common sense strives for the alternative of 'many' facts. Because of the short span of human life, lack of opportunities and the great diversity of calls upon our powers of observation, few of us can accumulate many facts relevant to some particular issue. Not only that, but the fact of this moment becomes a memory in a short while. Thus the 'facts' of common parlance are mostly *factual data* constituted of memories, records, claims, articles of faith, with reports of all these coming to one first-hand, second-hand or worse. It is from such *shadows of facts* rather than the facts themselves that we have to construct our practical truths.

In the first shock of coming up against elusive grey shadows where idle talk has led us to expect the presence of brilliant and solid facts, one may doubt the possibility of exploiting this ghostly world. Yet this is the fundamental purpose of science, which we practise through hunting, sorting and rearranging the flickering shadows of near and distant facts so that we may be guided towards future facts of our own choosing.

This activity is the birthright of all and is not reserved for graduates or members of learned bodies. The actual observation of certain facts is conditional on qualifications: one must pass certain tests before being allowed to perform surgical operations or manipulate valuable or dangerous equipment. Regular exposure to the observation of facts of a certain kind generates all the manual and intellectual power summed up in the term *experience.* Now such experience is an undoubted fact to the person who possesses it and perhaps to a few others. Unfortunately, the majority of us lacking a specific experience (e.g. competent handling of X-ray apparatus) cannot accept the experience of others as a fact, only as a more or less satisfactory inference. We may see Tom (the expert) and Dick (the mountebank) manipulating an assembly of wires, screens, push-buttons and switches. We may have heard of the potential danger of X-rays, in which case we can be just as apprehensive of Tom's activities as those of Dicks. If none of the dangers eventuates during the years that follow, we cannot judge the relative experience of the two operators. If a few years later we develop leukaemia, there would be nothing to show whether our misfortune is due to the expert or to the mountebank or to some quite different causes. We could draw inferences from the demeanour of the two manipulators or from mishaps during their operations but all this could lead us astray.

The difficulty of detecting experience as a fact by persons lacking the same experience is the most common defence of professional persons against criticism. Since criticism implies a responsible effort, and since most people dislike both effort and responsibility, the defence usually succeeds to the detriment of the community. The defence fails if we remember that truth or even validity cannot be limited to coincide with the experience of a certain person or of his professional brotherhood. Since the knowledge of the expert comes from different sources, the lay critic must look for some common intellectual field on which the critic and the criticised can meet without special immunities. Let some examples clarify the approach.

Six witnesses before a judge swear that a certain event has occurred, but a seventh witness cannot remember whether it occurred or not. The judge rules that the six witnesses are unreliable, and that the memory of the seventh has such a good reputation that what he cannot remember could not have happened at all. The legality of the decision is one for experts. The privilege of the judge to trust or mistrust witnesses on demeanour is not shared by his critics. Possibly the judge has executive power to enforce some decision such as 'two farthings make a penny'. However, in the domain of truth and validity, a judge who is wrong is defeated by a criminal who is right. If the six witnesses are regarded as liars (that is the judge's privilege) while making a statement, the negation of the rejected statement must be regarded true as a matter of logic. However, attributing an infallible memory to a person is one of those assertions about 'all' that we have criticised in the last chapter. Think about it again: how much evidence would be required to justify the assertion that the seventh witness *always* remembers *everything* that has *ever* occurred within the reach of his senses? Also the same event does not always present the same observation to all witnesses. The judge's decision is reasonable only if the seventh witness is so closely connected with the event that he could not forget it without a serious defect of memory. So if the event is a major fire or burglary affecting the fortunes of the seventh witness, the judge may have something, although one could wish that he made his statements sound more rational. On the other hand, if the event in question concerns a casual meeting or something shameful our witness prefers not to remember, the judge is intellectually unreliable.

The layman cannot properly judge when a tooth should be extracted and how the operation should be accomplished; nor has he an automatic right to blame the dentist for the discomfort suffered during the extraction or even if something goes obviously wrong. Even if a dentist cannot stop the flow of blood and has to summon medical help, the incident need not reflect adversely on his professional competence. If the same incident recurs with the same patient, one need not have a dental licence to suspect that there is something wrong with the dentist's records, memory or sense of responsibility. If then the same dentist publicly proclaims that fluoridation is a purely dental matter on which members of other professions have no right to comment except by approving it, the patient would have a right to recall the medical help and chemical supplies that were required to keep the dental matter of extraction from becoming a matter also for the profession of funeral directors. The patient need not have the chemical or medical training conveying to one that fluoride increases bleeding time by delaying the process of clotting, nor does he have to be an expert to realise his dentist's inconsistency.

A woman is afraid of the first signs of a cold and takes a tablet from a bottle sold to her by a chemist. The bottle bears some fancy name in large letters and the words 'acetylsalicylic acid' in much smaller type. The stuff is supposed to help against a wide range of discomforts, but she has a very bad night with a burning stomach and palpitating heart. She suspects the tablets: they feel a little softer than another brand of tablets she used to take without ill-effects in the past. Not being a chemist she cannot analyse her tablets but recalls how she can tell good meat from bad by sniffing. The suspected tablets smell like vinegar. Has the chemist put her tablets in a dirty bottle? She is (justifiably) annoyed with the chemist and takes the tablets to an analyst. The expert answer is that the tablets are bad. They have partly decomposed to acetic acid and salicylic acid; the former accounts for the smell, the latter for the symptoms. Further inquiries reveal that the tablets did not come from one of the more reliable makers and they were not wrapped in moisture-proof wax paper as a precaution against deterioration on long standing in the moist atmosphere of bathroom or kitchen (where most women keep their medicines). Here again experts can add detail and conviction to the criticism of trained manufacturing and retailing chemists by a technically untrained woman, but the criticism stands on its own merits.

At a time when religious values tended to disappear from sight under heaps of superstition piled up by a clergy which was by and large ignorant and cynical, utterly destructive anti-clerical criticism appeared to be of value. Now that such criticism has achieved its purpose, it is becoming increasingly clear that, considerable as the gains have been, the losses were of a greater order. The same kind of problem has risen in our days, this time in connexion with science and its priesthood. We must set our face against the begging monks of science whose only vocal purpose is to sell us beauty, health and social success in the form of magic ointments, pills, drops and treatments, and who are making much progress in achieving the silent aim of depriving us of the free use of our own bodies. However, purely negative fight against cosmetic and hygienic authoritarianism would endanger our physical freedom in other ways if we rejected real science together with scientific superstition. Since we have seen that real science, which gives us some power over facts, is understood through the shadows of facts, we must learn not so much how to reject some shadows or how to defer the acceptance of others but rather how to choose the best.

Any choice implies a decision between two directions, good or bad, better or worse, true or false, pleasant or unpleasant and so forth. When the choice is a purely personal one, it is unusual to speak of science which is tacitly understood to have a general meaning. Science is indeed the art of general agreement. Disagreement between scientists is as common as between laymen, but scientific disagreement is more than lack of a common faith or divergence of interests; it indicates the way to some agreement. A scientist does not merely say to his colleague: 'I don't agree with you.' He adds: 'I would accept your view if you could show how your statements follow from some truths we hold in common or if an experiment conducted under certain safeguards would give such and such positive or negative results.'

This indeed is the essence of scientific method—agreement by common powers of observation and thought. A simpler term would be *common sense,* even if the term is often used to justify uncommon nonsense. Common sense is the enemy of professional privilege, which is again the enemy of scientific argument and progress. Indeed, one finds that the least scientific professions are the most reluctant to face argument on common grounds with others. There is no need to waste words on the status of assertions that are 'unethical' to discuss without the protection of privilege.

Another quibble against common sense can lead to much argument but we must content ourselves with a sketchy defence if we are not to be diverted into the realm of pure philosophy. There are two main limitations of the rule of common sense. One is that the power of the senses is not the same for all of us, or even for the same person at different times. The use of instruments largely overcomes this objection but there are degrees of sensory weakness that cannot be helped by instruments. A person born blind cannot judge matters which rely on the common visual sense alone, but if there are acceptable ways to translate from one sense into another, this argument falls. Indeed many blind persons have a superior understanding of the physical universe which most of us normally explore with the help of our eyes.

The other argument against common sense concerns difficulties of language, not only of foreign tongues but also of one's normal idiom with its more or less loose usage of words. We have encountered some problems of this kind in the last chapter. Problems of this nature constitute the main difficulty of learning a science: the mastery of technical terms and precisely used symbols. Thus, in effect, the only limitation of common sense is self-imposed, through avoiding the observation of some observables or refusal to learn and use the language designed and tested for its power to help agreement between those who have much experience to check and exchange with their peers.

A relatively easy field of agreement is that of recurring events. The following assertions were common during the early part of the nineteenth century: one cannot transmute elements; substances characteristic of living organisms cannot be made artificially; one cannot construct a machine that can operate without wasting energy. The first two assertions have been refuted by frequently occurring events, witnessed, checked, re-checked and repeated by critical experts. There are nuclear reactors for all to see and one can inspect factories which synthesise vitamins or dyes, formerly extracted from plants, by the ton. On the other hand, there is no example known and ready for general inspection of a machine running without having to be fed with energy. One cannot prove (cf. p. 13 ff.) that all men are mortal or that all humans require a father, but such is the weight of recurring events that one can rely on the truth of such statements, and mistakes made by accepting these statements are expected to be few and excusable.

Just because an event does not recur, it is neither unbelievable nor untrue: all historical events (including our own personal history) are of this nature. However, such unique or rare events are not easy to discuss in a scientific manner unless they have some recurring elements, e.g., the records of a certain comet's path are similar to records of many other comets. The recurring regularity detected in a number of events not recurring as a whole makes us confident that the records (each of which is unique) have been properly kept. This confidence assumes that the many astronomers involved were both competent and honest enough to keep good records. This assumption again is based on human experience derived from the very commonly recurring event of contradiction between incompetent or dishonest records. A few false witnesses in court often contradict one another; worse contradictions would be expected if the hundreds or thousands of astronomers of different ages, of different countries and subscribing to a great variety of doctrines were false witnesses indeed.

We have seen that few if any of the data relevant to an argument are due to one's own personal observations. Even when such observations exist it is the custom of scientists to treat their own records as if they were other people's. Without such a safeguard the scientist who makes a bad experiment, possibly without knowing that he is in error, could rely on his own, in this instance misled, senses and reject all the correct records of his fellow-workers. On lumping his own results with those claimed by others, some discrepancy will appear. Then all the records that figure in the comparison must be analysed until the most likely sources of discrepancy are detected. It can happen then that all records are found unsatisfactory, not necessarily all in the same respect, or that one of them appears to deserve more confidence than the others. In either case a provisional agreement by critics is possible. Such an agreement seldom takes the form of a rigid doctrine or of a clear yes or no. As a rule the agreement defines the field on which common sense can agree and highlights the domain where further information is needed.

Domains of doubt are among the most powerful sources of scientific stimulus. Their value is such that it often pays to dig up 'undoubted' assertions and to analyse them until serious grounds for disagreement appear. Pleas to stop further inquiry, such as the following,[9] are comparable with the reactionary policy of keeping men ignorant lest they discover that their own interests are against those of their leaders:

'*We are striving to reach the minds of men so that they will take action. A thousand, ten thousand more experiments will not help. A dozen or fifty pronouncements by scientific or professional leaders will not provide a solution. Twenty bales or 20,000 bales of literature, research papers or pamphlets will not prove any more than has been proven.*'

This plea for fluoridation is the opposite of Einstein's dictum and can be summarised as: '*One experiment can prove me right, no amount of experimentation can prove me wrong.*' This attitude would be dangerous even in the author of 20,000 research papers, but coming from one with far fewer research publications, it is unwarrantedly optimistic to hope that his views will resist correction more thoroughly than those of Newton, Pasteur, Darwin and Einstein.

There are several scientific ways to assess data; the most satisfactory one of these is observation. We have seen that one's own observations should not be accepted uncritically. Individual observation can achieve a great deal more than a vast compilation of records from other sources. Since most of the great advances of science come about by this method, let us inquire more closely into this matter.

A single observation by itself may give rise to great thoughts but it seldom proves anything. Most of the observations that enrich scientific knowledge are made in sets. The planning of observations as to their kind, number, order and circumstances is one of the most important tasks of scientific method. The aim of scientific assertions is *generalisation* from the necessarily few observations to many or 'all' cases. Clearly, the few observations on which we propose to build a broad generalisation must be chosen with great care. In a sense, a single observation is a non-recurring event. Even if I repeat most carefully an observation (say, the reading of an instrument) at short intervals, draughts in the room may change; there will be fluctuations of temperature; skills demanded by the observation may increase with the added experience of each past observation, but alertness and ability to concentrate may decline with repetition and as an effect of bodily needs which may have nothing to do with the object of the experiment. Thus it will be necessary to take into account the variations of the experimenter and his surroundings while looking for the common, recurring features that link all the observations. When the experiment is conducted by a team, the problem is even more complex, of course.

The problems we have just raised are those of *bias* and *observer variability*. The latter term has just been explained for the reader, but many scientists so-called ignore its existence and possible consequences.

Many investigations in physics and chemistry are not much affected by observer variability: the experiments are reported in a manner so as to encourage repetition by others. The variations reported by substantial numbers of members of competitive professions deeply concerned with numerical data provide a reasonable measure of variability. In biology results are often less quantitative, and some experiments which vitally concern questions of safety are almost impossible to repeat. Hence much greater care would be needed to estimate and minimise observer variability in biology than in physics or chemistry. Unfortunately, it is the other way in practice.

Bias sounds offensive to one unaccustomed to scientific terms. Nothing personal is meant though. Except in a few chance observations, the scientist expects to observe something definite or anticipates that some events will not be observable under the conditions of his experiment. His background of theory increases the chances of observing the expected and of missing the unexpected. In other words, if he planned his set of experiments at all, our scientist must have a bias. Some observations are estimated. For instance, we are to measure the length of a rod against a yardstick; the measured end of the rod is between two graduations of the measure. In the absence of sub-graduations or some equivalent device we have to estimate the fraction between the two graduations. As we are hesitating whether to record 0.4 or 0.5 our decision may be influenced by our expectations.

To make this important matter clear with particular reference to safety, imagine that you are a scientist testing a new method of diagnosis. Let us say patients at a certain hospital, not all of whom have the disease in question, give samples of blood or urine; the sample is processed until it is ready to be placed in an apparatus which gives a meter reading. The originator of the method claims that persons with a meter reading of 2.5 and above have the disease and those with readings below 2.5 are 'normal'. Ideally you should feel neutral about the method, but practically you cannot help your emotions relating to it. The originator of the method could be yourself or someone similarly dear to you; or else you know that the director of the laboratory, who has invested a great deal in the apparatus, will suspect your competence if your results do not come up to his expectations; or again you have convinced yourself that the method is ill-founded and useless.

If you are responsible not only for the instrumental testing but also for the clinical diagnosis, which is tedious but considered reliable, you cannot avoid bias. If your needle is between 2.4 and 2.5 you will know from your own clinical diagnosis whether the reading 'should be' the former or the latter. Your subconscious wish to make the method succeed or fail in the test will then direct your choice. Even when the pointer is clearly at a distance from 2.5, say 2.3 or 2.7, you will honestly record your reading, but when it comes to interpretation you may say something like this: 'One should allow for personal variations and for the oscillations of the building caused by the traffic in the street; a correction of about 10% is to be expected.' This rationalisation enables you to treat 2.3 as 'possibly 2.53 hence clearly over 2.5' and 2.7 as 'most likely 2.43, distinctly below 2.5'.

Obviously this difficulty is not avoided by allowing others to make the diagnosis if you learn of their findings before making or interpreting your observations. The correct way is to test the samples without any knowledge whether they come from pathological or normal subjects. Even this will not completely exclude bias for or against the method of testing, but it will give your work a significance which is lacking in the overwhelming majority of research publications devoted to medical science.

Your township could be selected to be either the fluoridated or the unfluoridated area in an experiment on the benefits of fluoridation. As a layman you have no choice but to take on trust the analytical reports on the fluoride content of water supplies. You cannot very well query the dental findings of so many decayed, missing and filled teeth in the surveyed region. However, if the dental findings were made by dentists who knew whether they had been examining fluoridated or unfluoridated children, their whole report can be rejected as an unscientific farce performed either by amateur scientists unaware of fooling themselves or by showmen attempting to influence laymen supposed to be ignorant of scientific method.

Obviously the results of the survey area are to be rejected whether they are said to support or refute claims for fluoridation. Protestations of good faith are irrelevant: it is not the deliberate cheating but the subconsciously operating wish to cheat that is the danger. Biassed results are acceptable only in cases of dire emergency. The waste of time and energy on 'experiments' without adequate guards against bias is regrettable but not an emergency great enough to legitimate a little brother of faking. We can sum up our brief discussion of observer variation and bias in the advice that the first thing to be checked in data presented to us as factual claims is evidence as to how the observer tried to observe with senses common to all.

The next group of checks is concerned with *causes*. Some philosophers dislike words such as 'cause' and 'causality' which have important theological consequences. In the realms of pure mathematical thought there is no need for causality. The natural scientist interested in real events can use the other words to spare sensitivities but must retain the notion of causality in some form. Most of the questions of science imply causes. What do we have to do to bring about a certain effect? How is this event explained? What would be the consequence of swallowing this pill or of giving up smoking? What brought on your headache? These and many possible related questions assume that some pattern of events will give rise to other patterns or that it is possible to infer from a set of events others that had to precede them. Causal connexions are not always easy to find, some may be impossible to locate, yet the notion of causality inspires some of the most powerful methods of scientific checking of data.

The more fundamental but less generally useful check is to ask whether the data appear to follow from something that one can (for the moment at least) take for granted. For example, a chemist offers to his medical friend a 'possible cure for cancer'. Any one of the millions of hitherto untested but known substances is such a 'possible cure' of cancer and of a host of other diseases. Before trying a substance the doctor will want to know what *reason* there is behind the suggestion that it could have the suggested effect. Is it similar in structure to some other substance known to have the right effect? Has it been shown to kill some organism which has some properties in common with cancer cells? Does it influence one of the biochemical features involved in the existence or growth of malignant tumours?

Useful discoveries are not always made in this fashion. The effects of penicillin were discovered through the observation that penicillin moulds inhibited certain micro-organisms. The chemical nature of penicillin and its mode of action were elucidated much later. If the advocate of a new treatment cannot explain why his remedy is as good as he claims it to be, this does not automatically cancel his claim. On the other hand, one is entitled to regard with a certain amount of scepticism claims that do not follow from more or less well understood principles.

One common problem of safety is concerned with this matter. A spectacular biological effect implies that the drug or treatment which is supposed to have produced it is responsible for some important change in the organism. As it is known that many minor changes applied to one part of the organism have measurable effects all over the body, one would expect that the cause of the spectacular effect would have many other, not necessarily spectacular, effects. When it is alleged that no effects are caused apart from the one spectacular effect, one has good reason to suspect the truth of the claim. When it is further asserted that the almost certain but as yet untested or unnoted effects cannot cause further effects themselves, one must make a choice between the principle of causality and the friendship of optimistic advocates.

The more practical questions concerning the causal status of claims revolve around the notion of *control*. I am ill, I take a pill and subsequently recover. These are facts but they are quite uninteresting in themselves. If we are concerned with matters of health and safety, the interesting question is what my recovery owes to the pill. From the three stated facts alone, this cannot be inferred; it is possible that my recovery was due to a change of weather or something I had eaten or merely a day's absence from my laboratory. If we want to know how useful or useless the pill is, it is necessary to find a number of people suffering from the same complaint, give the pill to some of them and see whether the treated or the untreated group makes better recovery; it is important to ensure the same circumstances for all experimental subjects.

For another example let us consider a chemist analysing a sample of water for fluoride. He measures a certain volume of the water, adds to it chemicals, treats the mixture in his apparatus and eventually arrives at a meter reading corresponding to so many parts of fluoride per million parts of water. But it is possible that the chemicals he used in the analysis also contain fluoride. Small traces of impurities may occur even in the most expensive grades of laboratory chemicals and one cannot estimate the impurity of the chemicals by using the same chemicals in the analysis. The use of other brands of chemicals would still raise the question of possible impurities. In addition to the analysis of the water sample a similar analysis is carried out on a *blank* consisting of the laboratory water and chemicals used in the analysis. The difference between these analyses is ascribed to the real fluoride content of the sample.

It is easy to smile at the savage who pretends that his drumming at dawn is responsible for the sunrise: if he were scientifically minded, he would omit the drum play some morning to see whether the sun rises nevertheless. Unfortunately many who regard themselves as scientists and claim scientific significance for their 'experiments' omit controls. Much of the evidence in favour of fluoridation relies on uncontrolled experiments. It is not a tendentious joke but a sad reflection on the scientific superstitions of this reputedly rational age that a medically trained man, a self-declared expert on the literature of fluoridation, can hold in a municipal debate that the controls of a fluoridation experiment are the levers that regulate the addition of fluoride. Compare this example of ignorance from a professional man with the scientific method of prehistoric Gideon. [10]

It is not enough to use controls—they must be adequate; in particular they must not introduce bias. Let examples clarify this proposition. Members of a municipal council wish to explore the value of distributing free milk to schools. Before committing themselves to the cost of the scheme, they institute a survey into the health and scholastic record of children from two schools, only one of which has free milk issued to every pupil. To guard against observer bias the health examinations take place in the municipal chambers by visiting doctors and dentists, and the school work is tested through written papers identified by numbers and examined by teachers not connected with the schools. One way to conduct the experiment is to use an identical control by selecting schools which are as closely similar as possible in all relevant respects. In other words, the two schools have comparable enrolments, staff, buildings and facilities; also the children come from similar racial and social groups with similar living conditions, dietary habits, etc. Before commencing the supply of free milk, the two schools are surveyed for some time to see whether they are really comparable. If, after these precautions, the children that receive free milk overtake the pupils of the school used as control, the merits of free milk supply will be demonstrated.

One objection to this *experimental design* could be that it is difficult and occasionally (e.g. in a small community with few schools) impossible to find two exactly equivalent schools. To avoid such a criticism it is possible to test the value of free milk with two completely different controls, e.g. a school for children from well-to-do families and another one serving the poorest slums. In this case too it is necessary to conduct a *preliminary survey*, the results of which can measure the relative advantages of the two groups, e.g. the better fed children could have a 10% higher weight average than the others, or gain average marks 40% over the average of the undernourished group. The next step in the experiment is critical.

If milk is issued to the privileged children who already get enough food at home, it is not likely to add a great deal to their existing advantages. Even if their advantage increases a little, not much will have been proved. On the other hand, if the milk is issued to the poor children, they need not overtake the controls: overcoming 20-30% of their former disadvantage will be sufficient to support the value of free milk.

Unfortunately, it is a common feature of propaganda masquerading as science to choose biassed controls, similar to the issue of free milk to the well-fed children. The only thing such experiments prove is that those responsible for them have no great faith in their drug or treatment which must borrow its value from already existing advantages. The classical example is that of the drug against sea-sickness which the manufacturer tested in an experiment relying on biassed controls. The drug was issued to a sea-captain and his seasoned crew, leaving the passengers, many of them on their first trip through stormy seas, as controls.

Another common misuse of control is due to the introduction of additional features which falsify the experiment. Let us return to the experiment of free milk supply in an imaginary town where all children enjoy comparable, adequate food and living conditions and where the two schools participating in the experiment are sufficiently similar. It may be that the town in question is in the country where children are already well supplied with milk at home. An influential member of the municipality hopes to benefit from subsidies payable by the government to dairies which supply the milk to schools. He persuades the municipality to carry out the experiment, then provides the schools that get the free milk with educational facilities not available to the controls. When the survey is completed, by independent investigators, it is found that there is little difference physically between children from either school, but children who had received free milk have done better in some school subjects.

Shrewd observers in the town will know that it was not only the extra milk but also the extra books, radiogram, film projector, wall maps and charts that contributed to the result, but a propagandist for the dairy industry will report: '*A carefully controlled experiment conducted by impartial observers with all conceivable safeguards against bias has shown that a child's performance in examination of history and geography can be raised by 34.72% by the daily supply of one pint of milk.*' The claim will be repeated by all who are interested in selling milk to the government for compulsory distribution to all children. Repetition will strengthen faith in the claimed result, the promise of which will kill interest in the method on which the result rests. If the press is willing to support the racket, the improper claim will expand to the completely unfounded myth that a daily pint of milk is *essential* to pass examinations in history and geography. The few who take the trouble to look into the experimental foundation of the myth will be called enemies of progress, fiends who wish to see children starved and deprived of the means of passing examinations in subjects essential to their professional future. By the time the 34.72% of the original claim has grown to 74.32% nothing in relation to scientific proof seems to matter. The benevolent authorities fiddle or hush up passes in history and geography, or when information reaches the public that milk has nothing to do with such passes, they add: '*In some cases, for reasons still under investigation, a daily meal of bacon and eggs with not less than half a pound of butter is also required to aid the developing brain's compartment for social studies.*' This story is rendered fictitious by speaking of dairy products. You may substitute poisons and radiation if you prefer history of health.

Another example of confused controls is the often heard story of the man who got drunk on whisky and soda, then on brandy and soda, gin and soda, even toddy and soda, to mention the outstanding items in a long series of experiments. He blamed his drunken states on the common feature of his experiments—soda. Had he modified his experiments by mixing alcoholic beverages with soda and sugar, he could have had a choice of blaming soda or sugar. This ridiculous story has a common practical counterpart. Many people feel that their health deserves a great variety of 'health foods' and medicines. If despite all of this they enjoy good health for a time, they are unable to say which component or what combination of constituents in their hygienic hog-swill is responsible for their well-being. Most doctors make the same mistake, although for different reasons. If for one disease they prescribed one remedy at a time they would discover in due course the advantages or disadvantages of the treatment, and the discomfort of their first patients would secure the comfort of others. By prescribing mixtures of imperfectly understood drugs, they bar their minds against the very possibility of scientific treatment, not to mention that the possible good done by one remedy of unknown composition can be undone by a simultaneously ingested second remedy, also of unknown nature as far as the general practitioner is concerned. Often the 'health foods' and drugs act like the soda and sugar in our first example: they blind one to the principal cause of trouble.

There are many critically made observations, properly recorded and presented as data which earn one's confidence. When this happens we regard the data as if they were facts. Unfortunately many such data prove to be false: a temporary failure of one's senses or of instruments could have occurred or some unseen, unsuspected factor may have intervened. Colleagues of mine were engaged in delicate electrical measurements and were obtaining results that appeared consistently reliable. Then suddenly everything went haywire. A new assistant was suspected. Careful check of her work showed her to be just as skilled and conscientious as her predecessor yet the wild results were somehow connected with the change of personnel. Eventually it turned out that the new girl wore undergarments made from nylon which readily electrifies and can interfere with fine electrical work. In the majority of cases the trouble is not underwear and too many people are involved to check the reason for wild results. Not every wild result is wrong, but it is not right to regard such a result as normal just to suit one's convenience.

A detailed description of all the circumstances of observation helps one to check the validity of data. Next the strength and weaknesses of the experimental design must be scrutinised. We have already discussed some of the major features of experimental design to minimise false conclusions, but we must look more closely at the nature of an experiment itself.

A casual observation does not guarantee us against being fooled by someone who set the stage, so to speak, to induce us to observe in a way suitable for him. A crook may frame an innocent man by allowing honest but rash or otherwise incompetent observers to 'see the damning evidence for themselves'. In an experiment we choose the conditions: we set the stage ourselves and take every precaution against interference. Complex experiments can be sabotaged without the experimenter's knowledge, and members of a team jointly working on an experiment are not always equally scrupulous. We can fool ourselves. Unexpected interference may be at work. Thus experimentation does not offer absolute safeguards; still it is preferable to chance observation.

All experiments are not of equal value. One that has been repeated often carries more conviction than one that cannot be repeated at all. An experiment that produces objective records which can be checked and interpreted by others is preferable to one which produces subjective data only. Results that lead to similar conclusions, as those from experiments designed for different reasons, conducted under different conditions by different persons and interpreted without reference to the results in question, increase our confidence. These are among the criteria of a good experiment that constitute the *internal evidence* in favour of the work. The normal way for a scientist to judge another's work is to rely on such internal evidence.

Fundamentally, the question we try to answer by scrutinising the internal evidence is, how general are the claims or their consequences? The progress from a few experimental data to generality is not at all obvious. Clearly, the steps to be taken are not experimental but intellectual, hence Mach's view of science as an economic measure, a few intellectual short-cuts taken to obviate the need for a great many or an infinitude of expensive and time-consuming experiments. The nature of these short-cuts is the subject of the next chapter.

4 Buckets to Scoop Up the Sea

The transformation of a few observations and a few hours' thinking into the practical understanding of a great many events is little short of a miracle: one could doubt its possibility if it were not for the evidence of giant structures and amazing new discoveries rising from sheets of paper untidily covered with symbols. Great discoverers were often amateurs, frequently without any formal professional training. Creative gifts are not the privilege of occupational or social groups, and the less exacting effort of critical understanding should lie within the power of all endowed with common sense and curiosity.

Real events do not exist in isolation. When we speak of any matter, time is short to mention all that is implied, but an apparently brief statement may carry a great deal of information. When we are told that X conducted the Vienna Philharmonic Orchestra in 1943, the eight words imply not only that X is a musician of considerable ability, but also a great deal about his race, politics and possible travels around the time of the event. When Sherlock Holmes constructs a complex situation from a few clues, he is illustrating the methods that are to be considered in this chapter. Certain claims cannot be checked directly but one can search for their *implications* which reveal something of their credibility.

Let us take the following passage[11] which is preceded by a short list of small American towns with fluoridated water supplies:

'*In ten years it was found that children drinking fluoridated water had between 54% and 65% reduction in caries as compared to children in similar cities without fluoride in water.*

In Brantford (Canada) where the fluoride level is at 1 part per million the percentage of children aged 12-14 with all permanent teeth decay-free was 20.68%, whereas in adjoining Sarnia, with no fluoride, the percentage was 3.30%.

Beaconsfield in Tasmania began fluoride control in 1953. After five years of fluoridation, a similar trend has been demonstrated *in the teeth of those children aged between 5-8 years. For example, in 1953, 16.6% of these children had decay-free permanent teeth. In 1958 this figure had risen to 52.7%. It is of interest to note that the decay level of the permanent teeth at this age in 1953 at Beaconsfield (before fluoridation) was between 36% and 90% greater than the figures for similar age groups in North America before fluoridation.'*

If you are not interested in figures, you may accept or reject the claims of this passage on emotional grounds. If you are a fanatical anti-fluoridator, you will scornfully reject claims hostile to your own beliefs. Fanatical fluoridators will welcome the per cent reductions with the same joy as the devout receive the latest statistics of the healing power of their favourite shrine. As a neutral one might anticipate with joy the day when a few shovelfuls of chemical magic will condemn dental drills to the rubbish heap. In any case, the interested citizen could hardly go on a tour of Grand Rapids (Michigan), Marshall (Texas), Sheboygan (Wisconsin), Evanston (Illinois) and so on; even a journey to these places would do little more than acquaint the traveller with oral claims instead of the printed ones before us.

Before we succumb to fanaticism or despondency, let us look at the data again. The American figures sound impressive enough; let us assume that they are true. But are they *typically* true or picked from less impressive figures for reasons of propaganda? The pamphlet from which the passage is quoted makes no secret of being intended to persuade people, but not all propaganda is dishonest. Let us assume therefore that the pamphlet presents true figures which are typical. In fact if the authors of the passage thought that fluoridation in Australia would not have the same kind of effect they claim for America, they would have no right to advocate fluoridation.

Age groups of children are mentioned in the last two paragraphs but not in the first one which speaks of reductions between 54% and 65%. If the authors quoted just one age group for which fluoridation happens to work and kept silent about age groups which do not benefit from fluoride, this would be dishonest (although limiting the argument to children is fair enough). Again, we must not impute dishonesty to people we do not know, although anonymous authors need not inspire confidence.

Turning to the figures from Canada, if 20.68% of children's teeth were free from decay in Brantford with its satisfactory fluoride content, 79.32% of the teeth were diseased. In unfluoridated Sarnia, 3.30% of the teeth were free from decay, hence 96.70% were unsound. Therefore the passage claims that 1 p.p.m. fluoride reduced the incidence of dental decay from 96.70% to 79.32%. If Brantford and Sarnia were not comparable as test-area and control, the claim is meaningless, and the pamphlet becomes suspect of ignorance or deceit. Since we trust the authors, we must assume that the figures mean a reduction as calculated, that is 17.38%. This is quite impressive, but how does it connect with the 54% to 65% we were quoted before? 17.38 is evidently not the same as 54%-65%, nor is 17.38% the same as 54% or 65% of 96.70% or 79.32%. Our pamphlet is in trouble! We need not decide what is wrong, the 54%-65% reduction or the figures from Canada or our assumption that typical rather than picked figures are being presented. Irrespective of the answer we have discovered that the evidence is unreliable.

Let us turn now to the figures from Beaconsfield. If decay levels before fluoridation were 36% to 90% greater than in America, also before fluoridation, we can calculate rates of decay from the figure given from Sarnia (which, let us remember, is either typically or dishonestly quoted). 36% above 96.70% means either 132.7% (adding up the figures) or 131.5% (adding to 96.7% 36% of itself). At the other limit of 90% we get 186.7% or 184.7%. Here we stop in amazement: how did the children of Beaconsfield get 132-187% of their teeth in a mess? How does one get more than 100% of his teeth good, bad or indifferent? Again we come to the conclusion that the figures are wrong.

The space devoted to this matter is not due to the importance of the criticised pamphlet alone. The kind of argument that demonstrated its unworthiness for serious consideration was within the means of a child able to calculate percentage figures, yet claims so patently absurd are readily endorsed by persons and bodies claiming the status of expert. The matter goes well beyond provincial propaganda in favour of fluoridation. The literature of medicine is full of figures which at first sight suggest painstaking observation, but on a second look reveal absurdities proving that the figures were invented or picked with a bias or printed in error.

The unreliability of figures sometimes requires wider reading. With the exception of the investigators, nobody knows for certain the number of children examined in the fluoridation experiments in Evanston. Without good reasons we cannot reject the investigators' claim that they have tested so many children. But when we are told that the total number of children between 6-8 and 12-14 years examined in 1946 was 4,375[12] and 3,692[13] and 3,310[14] something must be wrong. Of the three sets of figures one (at the utmost) can be right; hence at least two are wrong. The discrepancy was not noted by 'experts' until 1959 when Dr Sutton exposed self-contradiction between claims [12], [13], [14] which are still commonly quoted as evidence for fluoridation. It is immaterial that other evidence in favour of fluoridation is not always false; the point is that persons, bodies and arguments that knowingly or in simplicity acquiesce in one blatant falsehood are unreliable witnesses before a jury either of scientists or of lay common sense.

The scandal created by the exposure of this absurdity resulted in the admission that the first figure (4,375) was correct. In defence of the other claims it was explained that '*out of range*' children were eventually excluded from the survey, but then further critical check revealed more numerical inaccuracies, not to speak of the magnitude of a correction exceeding 1,000. In better examples of scientific work the author sticks to his experimental group; discarding on the scale quoted strongly suggests that the experiment had to be altered to fit preconceived results. This is one of the common consequences of working without control of observer bias.

Another way to find weak spots of unsoundly based propaganda is to look for what is obviously missing or to seek the reason for assertions made in a bizarre form. The pamphlet criticised earlier quotes American cities that fluoridate their water supply:[15] *'In fact, Chicago, Philadelphia, Washington, San Francisco, Des Moines and many others with populations of up to 1,000,000 and over have adopted this measure.'* New York with a population comparable with the total of those mentioned is missing, so are Los Angeles and Detroit (both similar in size to Philadelphia); Des Moines has a population of about 200,000; fourteen of the eighteen U.S. cities with populations over 500,000 are not fluoridating. All this is no argument against fluoridation, since truth is seldom found by a simple count of heads, but it is even less of a proof to claim that only a small minority has taken up a health measure. Failure to mention the majority is suspicious.

The reference to *'populations of up to 1,000,000 and over'* has nothing to do with the argument but is a mark against the author. What does he mean? A population of thirteen is one of those *'up to 1,000,000'* but having mentioned Chicago and Philadelphia (the only two multimillion cities in the world which have been fluoridating for a few years) his phrase presumably does not exclude populations over 1,000,000. All this is not very serious, and may sound like quibbling, but it is useful to remember that an author who cannot make clear what is counted by the numbers used in his argument is not altogether reliable.

In the preceding analyses we made tacit use of logical rules. *Logic* is one of the oldest scientific disciplines and one of the most spectacularly developing ones in our days. A few remarks cannot provide the reader with even an elementary introduction to technicalities of the subject, but they must be made if the place of logic in scientific method is to be appreciated.

A common use of the term 'logic' is to give it the meaning of being right or having made the most probable guess. One hears 'it is logical to give up smoking'; 'the gate is open, it is logical that the postman has been'; 'the logical defence against tuberculosis is X-ray examination of the chest'; 'the logical choice of a name for the Australian currency is a Brick of ten 'Arfers' etc. Some statements can be used logically, but a statement in itself is neither logical nor illogical. *It is a pattern of statements constructed in certain ways that is logically meaningful.*

'All men are mortal (1); *Peter is a man* (2); *Peter is mortal* (3).' These are three assertions; they can be, but in themselves are not necessarily true. For instance, Peter could be a cow or the statements could be made after the discovery of a drug which bestows immortality on man. However, the three assertions taken together form a correct logical pattern. The assertions *'all flowers are plants* (4); *this is a flower* (5); *this is a plant* (6)' form the same logical pattern, although (1), (2) and (3) are quite different from (4), (5) and (6). More generally we have the pattern: *'all P are Q* (7); *R is P* (8); *R is Q* (9).' We can give P, Q and R all kinds of meanings so as to make some or all of the assertions (7), (8) and (9) true or false, yet the logical pattern will remain valid. Some feel that it is more satisfactory to prefix (7) and (8) with 'if' and (9) with 'then'. *'IF all grocers are pianos* (7), and *IF the Atlantic*

Ocean is a grocer (8), *THEN the Atlantic Ocean is a piano* (9).'

The examples chosen may sound trivial, crazy, pedantic, altogether useless. They have been quoted as a warning against the overvaluation of logic. A form of words or statements does not guarantee truth of the parts, only the validity of their connexions. If we start with assertions that are untrue and proceed logically, we shall arrive at other assertions which may be true or untrue. For example, the argument: '*all numbers ending in 0 are odd* (10); *3 x 3 is 10* (11); *3 x 3 is an odd number* (12)' deduces a true statement from two falsehoods. This is a very important matter to grasp since many forms of propaganda directed at laymen pretend to 'prove' the correctness of assumptions by displaying an undoubtedly true result. A common example deserves brief mention.

'*All fluoride-drinkers have good teeth* (13); *Peter is a fluoride-drinker* (14); *Peter has good teeth* (15)' is logically correct; it is a valid argument. The truth of (15) may be ascertained by inspection; the truth of (14) could be accepted without much trouble in a city with fluoridated water and a ban on drinks with the normal low content of fluoride; the truth of (13) would be very difficult to establish. Indeed, if the argument is to be logical, the 'all' must mean 'all, without exception', otherwise the argument becomes '*some fluoride drinkers have good teeth* (13a), *etc.*' If only *some* fluoride-drinkers have good teeth, statement (14) is insufficient to show whether Peter is the kind of fluoride-drinker with good teeth or the other sort. Hence the conclusion (15) does not follow—it begs the question.

We have established the logical validity of conclusion (15) from *premises* (13) and (14), but conclusion and premises cannot be jumbled at will. It would be wrong to argue: '*Peter has good teeth* (15); *Peter is a fluoride-drinker* (14); *all fluoride-drinkers have good teeth* (13)'; unfortunately, this is a very common type of invalid argument.

How vulnerable is a logically sound argument to criticism on the aspect of truth? When the logical pattern depends on 'all', a single exception makes an essential premiss untrue. If we can find Paul, a fluoride-drinker with bad teeth, premiss (13) becomes false and the logical argument (in this case called a *syllogism,* i.e. a taking of statements together) collapses. Logical patterns involving *some* or *not all* are more secure against hostile results but the conclusions they yield are often too weak for effective argument. Beware of negatives. The argument '*all fluoride-drinkers have good teeth* (13); *Paul is not a fluoride-drinker* (16); *Paul has bad teeth* (17)' is invalid. To make such an argument logically sound, one should put in thus: '*nobody other than fluoride-drinkers has good teeth* (18); *Paul is not a fluoride-drinker* (16); *Paul does not have good teeth* (17).' However, if Paul happens to have good teeth, the logically valid argument becomes untrue.

An important logical principle is that of the excluded middle: an assertion and its negation cannot be simultaneously true. Admittedly the true answer is not always known, but this does not upset the principle, merely defers the proper time of its application. John is either dead or alive; if he is the one, he cannot be the other. His doctor may hesitate to pronounce him dead and it might be impossible to define the exact criterion of the border between the two states, but for practical purposes the principle holds; while John is held to be legally alive his estate is not liable to pay death duty, when legally dead he cannot be fined for failure to cast his vote in a compulsory ballot. We used this principle when criticising figures from the fluoride survey in Evanston: the number of children studied was either 4,375 or not-4,375 (any number other than 4,375 is not-4,375); both could not be true, hence at least one claim of the survey was false.

The principle can be misused by insisting on a yes-or-no answer when the question is vague, not completely understood or when the answer has clearly distinct parts. Thus one cannot answer with a yes or no the question 'Is thalidomide good?' Good for what? Good for all patients, some patients, the chemist, the manufacturers, the reputation of the doctor prescribing it? Does 'good' refer to health or wealth or moral values? This is particularly the case whenever human sensitivities, rights and tastes—all extremely variable—are involved. Variabilities of this nature make all forms of compulsion 'bad', against which one has to measure the 'good' of making things easier for public servants, who have no time to make decisions and to hear appeals on individual grounds.

Related to this problem is the shifting use of words as in the following false argument: '*all drinkers are prone to liver damage* (19); *Peter is a fluoride-drinker* (14); *Peter is prone to liver damage* (20).' Clearly, drinking in (19) is supposed to refer to alcohol-drinking, in which case there is nothing to link it with fluoride-drinking; or it refers to all forms of drinking, in which case it is irrelevant whether Peter takes fluoride in his drinks or not.

The examples discussed so far could suggest that logic is merely of negative value and serves only to show up cases of emotional, sloppy thinking. In the hands of beginners a tool may be put to trivial uses only, which does not disprove its potential value. The main uses of logic are to test the validity of a substantial group of assertions taken as a whole and to develop from a few undoubted assertions consequences that are not obvious.

The criticism of some claims made for fluoride (pp. 49-51) is an example of the former use. Taken individually, one cannot query the figures without unwarranted hostility to the authors, but taking the group of figures one can demonstrate that the assertions favourable to the authors and to the reliability of all figures quoted cannot be true simultaneously.

The second use is one of the best known features of mathematical problems: some data are given and from them we must establish something not at all obvious. We can visualise a triangle with three equal sides; its circumference is obviously three times the length of a side, but what is its area? Taking some geometrical statements as true (*axioms*), we can deduce from them the area in terms of sides by logical means. One can easily think of prime numbers, that is those that cannot be divided by numbers other than 1 and themselves (e.g. 5, 11, 37) but it takes logical operations to prove that there is no largest prime number. Similarly the elaboration of reliable experimental data proceeds by logical methods. The mathematical techniques normally used may be regarded as applied logic. It is the task of pure mathematicians to establish logically justified procedures; some of these find ready application by natural scientists who need not test all the thoroughly examined mathematical routines which extend the otherwise limited usefulness of their work.

Mathematical techniques and formulae cannot be used uncritically. They are in a sense modest buckets that can scoop up seas, but unlike buckets they must be handled with precision. This requires mathematical training, which until recently most medical and dental students were allowed to escape. As a result of this, much of the medical and dental research is hampered by incompetent mathematics. The only advantage is that the trained scientist is quick to pick up contradictions and other blunders implied by the numerical claims of amateurs who litter the field of biological research with useless papers. The danger of this situation is that the layman in general cannot understand criticism based on a mathematical appreciation of quantitative science, and thus tends to support the medical 'experts' who, like himself, are incapable of detecting faked figures which would hit an undergraduate scientist in the face. As a result of this, ill-founded medical and dental discoveries can assume the aspect of a crusade against scientists who can criticise at a logical level.

This is not entirely new. Tsar Ivan the Terrible had an architect who could calculate the amount of material that had been used in public buildings and predict accurately the amount to be used in those about to be built. He was put to death as a wizard, to the great satisfaction of those who disliked a mathematical check of their misappropriations of building materials.

Details of mathematical methods go far beyond the scope of this book. We shall deal briefly with two mathematical approaches to scientific problems mentioned in chapters on special topics.

In most experiments the scientist records how different values of a *variable* (e.g., time, temperature, dose of a vitamin) are accompanied by changes of another variable (e.g. body weight, blood sugar, loss of hair). The relation between the two variations can be expressed in a number of ways, but *graphs* are the most common of these. Most readers will be familiar with certain graphs, e.g. those showing the variation of income, profits, exports, etc., with time. A horizontal axis is marked off to show time-points (these could be days, weeks, months, years or even centuries). Above each time-point for which an observation is available, the latter is placed at a distance corresponding to its magnitude; e.g. an export of £10,000 would be plotted twice as high as one of £5,000. The resulting points are linked by a line. Although the line usually has ups and downs it indicates a certain *trend* which is visible at a glance. Many other kinds of graphs are possible; in all cases an awkward conglomeration of numbers is given a geometric shape.

The shape of the graph stimulates discovery of possible explanations of the observations. The scientist tries to think of a *model* which would give the same graph. Such a model would be in some way *analogous* to the system observed, also much simpler and easier to extend to other predictions by logical methods. A particularly simple model which is widely applicable to a great many independent and well-checked observations can be expressed as a *law of nature*. The discovery of a successful model of this kind does not guarantee that it is unique. The same evidence can be in agreement with a number of distinct laws of nature; this is indeed common in relatively early stages of an investigation.

How is this possible? Let us imagine a model the behaviour of which would result in variations graphed as a straight line, then let us consider a second model which leads to a graph in the shape of the arc of a circle. If the circle is very large, its arc does not differ a great deal from a straight line, and both models can be used. Thus a straight line drawn through a flat desert on the earth is really part of a circle since the earth is a sphere. For local measurements, e.g. when laying out the foundations of a house, one may consider the earth flat, but for measurements of large terrestrial distances (e.g. in maritime navigation) it is necessary to use the model of a sphere for the earth.

With the spreading of scientific education in the community, graphs are becoming frequently employed and figure in a great variety of arguments as evidence. Obviously a graph is no better than the information it is based on. Unfortunately it is easy, hence common, to use graphs in a way that hides the weakness of the evidence. A graph plotted one way may show a great deal of variation so as to suggest lack of regularity. For example, the weekly income of a business varies between £5 and £50, a range of £45; if now one plots with a scale on which a variation of £45 corresponds to a barely visible fraction of an inch, one obtains a graph falsely conveying the impression of a steady income.

Or else evidence for the benefits of a drug is to be presented by an amateur scientist. He uses 5 control animals that do not receive any drug, 5 others get an injection of 1 unit, 5 others again get 2 units. Of the 5 controls 2 remain healthy after exposure to some deprivation or germ, of the 1-unit animals 3 remain healthy and of the 2-unit animals 1. By plotting so that a change of 1 animal remaining healthy corresponds to ten inches one hypnotises the reader into accepting the claim that a tremendous improvement has occurred at a 'demonstrated' optimum of 1 unit.

This can also be underlined by claiming a '50% improvement' or '150% improvement' (meaning a change from 2 observations in one case to three in another). The same kind of mathematical imcompetence or trickery is involved in a claim of 57.14285% improvement, meaning that of 7 patients treated 3 died but 4 survived. The many decimals suggest that they have a meaning. Try to omit all figures beyond the decimal point; the remaining 57% will be good enough to indicate 4 out of 7. Once you realise that 0.14% of 7 is about 0.01, you understand that hundreds of cases are needed to justify these decimals. Solve this problem for exercise: how many cases would be needed to justify 5 decimals?

Another trick with graphs concerns dimensions. One dimension (line) or two dimensions (an area) are readily represented on paper. In general it is best to use lines to compare magnitudes graphically. If you want to compare 4 and 9, the line for the latter will be more than double of the former. If you compare the same figures as areas graphed as squares with sides of 2 and 3 respectively, the difference is less impressive. If then one represents the same numbers again as projection drawings of cubes the difference becomes barely noticeable.

Graphs and other numerical information are strictly scrutinised by editors of good scientific journals, but a great deal of numerical sharp practice escapes the notice of editors whose mathematical training and perspicacity are slight. Although progress is in sight within a generation or so, for the time being it is wise to treat most medical and dental statistics and graphs with the greatest suspicion until they can be checked thoroughly by trained critics.

Outside the world of science, the ordinary meaning of *statistics* is a set of numbers presented in a systematic manner. The system could be one designed for ease of reference, like listing the items in alphabetic or chronological order; or for the sake of the internal order of the subject, like listing salaries attached to public offices in order of precedence. Very often the system is inspired by the desire to influence the reader, and takes the form of omissions and specious groupings. For instance two drugs, A and B, are compared: they have been tried against a substantial range of infectious diseases, and the instances of success, failure and doubtful outcome are on record. In two diseases A proves superior, but B is better against the other twenty-three complaints. If the statistical table is given in terms of cases (e.g., 17 successes, 3 failures and 6 doubtful effects against dysentery with A) a single look may convince one that B, on the whole, is better than A as a drug for general use, especially in emergencies when treatment may have to precede correct diagnosis. On the other hand, a writer paid to boost A would give per cent values, showing separately the data for A in the two cases where it appears superior, and lumping all the other conditions into one to show the advantages of B. As a result, a superficial study will suggest two lines of entries in favour of A and one line of entry in favour of B.

A similar dodge is the presentation of such comparisons only that suit one's case, e.g. anti-Semitic statisticians have many figures to show the relatively high crime rate of Jews in respect of business transactions but they keep silent on the low incidence of homicide and crimes against women and children committed by Jews. Where numbers are too difficult to fiddle, tactful naming of statistical items can help: the column labelled 'unsuccessful' in a statistical table of drugs may include not only cases in which the drug did not afford relief but also those in which crippling or lethal side-effects were noted.

Statistics in the sense of figures arranged for a certain purpose are a major feature of pseudo-science. In general it is prudent to ignore tendentious statistics compiled and quoted to prove some point of policy. At the same time there are some criteria which allow one to accept statistics without making oneself guilty of almost criminal gullibility. If you are presented with statistics, say, for the purpose of talking you into fluoridation or out of it, ask the following questions: *Can I check the data from independent sources?* Statistics of population data, sporting events, fluctuation of prices, etc. are available from many independent sources—encyclopaedias, newspapers, club and business records and so on. The nature and extent of disagreement between such sources (this often comes to light on checking) is a measure of the reliability of such statistics, and helps one to distinguish between the almost unavoidable occasional printing errors and systematic deception.

Are the data based on neutral sources? Numbers of marriages at different times of the year are reported from many registry offices and parishes, each of which may be assumed to be unconcerned with national totals; the resulting statistical information may be taken as not biassed. Therapeutic statistics based on individual doctors' own declarations of success and failure are less reliable: it looks better to claim twelve cures than to admit that the same patient had called twelve times and on each occasion was given a treatment that kept the most uncomfortable symptoms in check until the next visit. Uncertainties of diagnoses made by a G.P. on the strength of a brief examination, the counterpart of which would not do in a garage or a TV repair shop, are another weak spot of medical statistics. Even then there is a difference between statistics produced by one doctor in support of a hypothesis of his own and statistics gathered from a number of hospital records which had been compiled without suspecting that the evidence will be used for a certain purpose. Some important examples on this point are often heard in public debate.

A dentist sets out to prove the value of fluoridation and publishes such data of his that support his case. The matter cannot be checked independently, and the source is not neutral. The information could be perfectly true nonetheless but it has no more scientific value than Mohammed's statement that he had received a personal message from the archangel Gabriel, another matter that can be believed but not checked. Or again the anti-fluoridator sets out to prove that a single sip of fluoridated water produces 'Spira's syndrome', and comes up with his own biassed statistics beyond reasonable check. The same criticism applies, of course.

For a third, somewhat different case consider the survey of Dr Rapaport, a French doctor who obtained data from American hospitals, State Health Departments and official analysts on the fluoride concentration of drinking waters in some American states and on the incidence of mongol births.[16]

This is a better procedure than the other two mentioned before because it relies on data which were obtained by several people without a bias for or against the survey instituted after they competed their records. If Rapaport's statistics do not appeal to one, it is possible to check the records he used and to extend the survey to other states. The weakness of his statistics is that neither the records of birth nor the fluoride analyses of water samples drawn so many years ago can be fully checked. However, while his statistics are far from convincing, they encourage the belief that new observations, fully guarded against bias and using reliable controls, could strengthen his claims based on neutral data.

The most important questions one must ask when faced with statistical data of medical and dental tales or serious research reports (for there are many doctors and a few dentists among the best scientists in the world) are technical and flow from a concept of statistics different from the one discussed up to this point. Statistics in this more sophisticated sense is a mathematical science that tries to establish relations between *population* and *samples*. Population does not refer to humans only but to whole groups on which information is sought, e.g. a year's production of light bulbs in a factory, all the days surveyed in a meteorological project, all sparrows alive and so on. A sample of a population could consist of one specimen or more. Even when the population is large, we can infer properties of the whole from a small sample. This idea is familiar through the Gallup polls; one cannot hold a pre-election to forecast how the real election will go, but by interviewing a small sample of the electors, a more or less accurate forecast is often possible. One cannot test the effects of a new drug on all mankind, but a relatively few tests on a sample of volunteers allow some useful predictions to be made.

Conversely, a knowledge of populations may give one estimates of samples: knowing the number of lottery tickets, the number and nature of prizes one can estimate the chances of winning a certain amount if one holds a sample of so many tickets. An insurance company from its knowledge of a population or events estimates the chance that a sample of these will eventuate; accordingly, the premium for insurance against death from motor car accidents will not be the same as that of insurance from falling to one's death from the pulpit.

Calculations of statistics are based on the mathematics of *probability*. In ordinary speech probability refers to a more or less vague expectation: domestic accidents are more probable than first prizes won in a lottery; it is more probable that a Londoner will understand English than Welsh; it is more probable that the younger and heavier man will win the boxing championship. Such expectations can be measured by frequencies. Infant mortality per 1,000 births is 20 in Australia and 40 in Greece; it is reasonable to consider the loss of an infant twice as probable in Greece as in Australia. In a game of dice with six winning and any other number losing, one would have one chance to win against five to lose; the expectations would be in the ratio of 1:5, hence stakes in the ratio of 5:1 would be needed to make the game fair.

We cannot discuss here how the results of mathematical statistics are calculated, but merely mention some important kinds of result that closely concern considerations of safety.

An observation is *accurate* if it is as close to truth as senses and instruments can make it. When you measure a distance in feet, neglecting the inches, the measurement is not too accurate; if even 1/1,000 inch is being considered the measurement is more accurate. Of course, one is never absolutely certain of any measurement, at least if one is a scientist, but one can estimate the probability of a measurement being accurate within certain limits. One of the doubts directed against the accuracy of a measurement is due to variability. Try to measure the side of a table with a well subdivided foot-rule, aiming at an accuracy of 1/64 inch. Repeat the measurement a few times; you are likely to find that, unless you are experienced in this kind of measurement, the results will vary slightly on repetition. If they do not, they are sure to vary if you aim at a higher accuracy still.

The ability to keep measurements within close bounds is termed *precision*. Since it is easier to measure the table correct to the number of feet without variation than to avoid variation when measuring to 1/1,000 inch, it is seen that precision and accuracy are not independent. At the same time it is possible for a measurement to be precise without being accurate. If the ruler used to measure the table was wrong, no matter how carefully one repeated the experiment and no matter how close the measurements were, they would all be inaccurate. On the other hand, if one does not know anything about the possible defects of senses and instruments involved in measurements conducted by different persons, one tends to trust the more precise observations.

Mathematical statistics provides estimates of the most probably accurate result and of the degree of precision and trustworthiness of a set of observations; it also allows one to determine the optimum number of experiments in order to achieve a desired *level of confidence*. Clearly more experiments and a higher level of precision are required if we are to consider a result very probable than if we are satisfied with a lesser probability. Not all measurements are of the same order of reliability; in some cases it is cheaper to take a relatively large risk of making a mistake, in others no effort must be spared to minimise the chance of error. A garden bed need not be measured with extreme care; correction of a mistake that shows is easier than the setting up of complex surveying operations. On the other hand the measurements preceding the cutting of an expensive diamond must be painstaking to avoid irreversible errors.

An important feature of mathematical statistics is the estimation of the *significance of correlations*. Imagine a drug tested in 100 cases using 100 untreated cases as controls. If all the treated cases recover and all the untreated ones die, one does not need statistics to assess the result. It is more likely that the results will be something like this: 70 of the treated cases recover but only 50 of the untreated ones. It would be rash to claim that the drug is effective or that it reduces death by 40% or to 60% of the fatalities in the untreated group. The difference between the treated and untreated groups could be due to chance, e.g. some of the people in the treated group could have stronger constitutions in some respect unknown to the investigator. The scientific investigator assumes that the drug is ineffective (this is called a *null hypothesis*) and proceeds to calculate the probability of the results having been obtained by chance. If the probability is 10% (i.e. as high as winning a raffle with ten participants), it is usual to regard the drug as ineffective. If the probability is 5% the situation is regarded as doubtful, and more experiments are indicated. If the probability is 1% or lower, one is entitled to assume that the drug is effective at a level of 1% or less. In the example given the probability of a chance result is rather less than 1%, hence we can be over 99% sure that the drug is effective.

Statistical analysis can be extended to experiments and observations with more than two factors. Indeed one of the greatest services of statistics to science is the design of experiments. The best known experiments on fluoridation involved thousands of children but remained inconclusive because they were designed by amateurs. On the other hand, a statistically designed experiment involving a few hundred children only could prove much more. Remember, however, that statistical methods do not prove absolutes in the manner of old theologians and modern dentists. The results come out with certain statistical weights. Scientifically speaking it is much more encouraging to know that a treatment is satisfactory at a 5% confidence level than to be told that '*all but ignoramuses and cranks admit that the unsurpassable value of the treatment has been unshakably proven by the most advanced methods known to modern hygienic* *science*'. Admittedly the acquisition of statistical skill is harder than to shout for tar and feathers, but it is within the means of all whose intelligence is sufficient for scientific research.

As the layman cannot be expected to turn himself into a statistician before sifting the mixed bag of chaff and grain of medical and dental research, he must rely on experts. This raises problems of authority; the layman's approach to these in our days could determine the very future of science.

5 Clutching at Straws

The worst instances of unreasoning violence that frustrate discussion on scientific topics occur when arguments rest on authority. Scientists do not recognise proof by authority except in a rather limited sense that seldom concerns laymen disputing with them. On the other hand, one must turn to experts when an argument hinges on points of technical experience. It is less proper but human to avoid responsibility for a predictably risky decision by leaving it to the experts. Scientists as well as laymen are readily coaxed into potted thinking with the help of quotations, often cited out of context, ascribed to persons who enjoy good reputations, not always in respect of the subject under discussion. Worse still is argument by reference to the authority of bodies and institutions, which are not subject to the same scrutiny as individual experts.

When a person is named as an authority it is possible to find out whether the opinion attributed to him appears in his writings; if so, in what context and on what evidence. The greatest men are not immune against arithmetical errors, misprints and lapses of reasoning power. Their experimental claims often rest on the contributions of junior collaborators who are not always as trustworthy as they are considered by their seniors. Or again, a view which brilliantly and satisfactorily explained earlier or local data is no longer adequate to explain a flood of new claims released through increasing interest, more advanced facilities for observation or simply the freedom to investigate once forbidden topics. Thus Galileo, Newton, Pasteur and Einstein could be and have been found wrong, and many a brilliant scientist's ultimate achievement has been the refutation of a theory to the construction of which he had devoted his whole working life.

On the other hand, there is no easy way to refute a government department, a committee or the spokesman of a medical association. There is no way to find out how exactly they came to their conclusion, what they read, what they refused to read and how they assessed evidence in favour of and against the controversial statement. Often it is difficult even to find out what qualifications the anonymous persons responsible for the authoritative declaration possess. Worst of all, when bodies act as authorities there is no way to ascertain what command, political pressure, considerations of personal advantage, friendships or intrigues have contributed to the stand taken, while pressures on scientific experts identified as individual scientists are not too difficult to estimate.

The power of government and professional bodies to impose scientifically unproved fads on the public derives from the confusion of democracy with irresponsibility. The scientist pressing his fellow-citizens to exercise their critical powers meets opposition not only from impersonally operating pressure groups but also from the man in the street who wants health, or at least the hope of it, through magic and magicians.

The responsible layman has a difficult choice to face. It is his democratic right to choose experts, either directly (as in a referendum on a health measure) or indirectly by making support of or opposition to fluoridation, compulsory X-ray examinations or ban on cigarette smoking an electoral issue. But how is the layman to choose his experts? Neither the gift of oratory nor the means to conduct a press or broadcasting campaign is a proof. The majority view of experts that the earth cannot be circumnavigated did not make Christopher Columbus wrong. At a time when Soviet Russia opposed the whole science of genetics, other powerful states supported genetical research; hence either the official experts of Russia or those of the West were wrong on the value of genetics.

There is no easy general answer to the layman's problem, but some hints could help in most cases. If there is evidence that scientists with comparable degrees, positions and membership of learned bodies cannot agree, legislation on the matter is almost certainly premature. Opposition by a substantial number of scientists of high standing need not deter individuals who wish to try a new drug or a new treatment, but it is better that compulsion follow rather than precede agreement. The principle fails in certain emergencies when all or none is the only choice, e.g. in the case of immunisation as a compulsory requirement for entry into the country.

A second principle is to ignore the scientific authority (a contradiction in terms) of bodies which admit members without scrutiny of their scientific standing. Such bodies may have the legal right, they often do, to enforce hygienic measures, but this is not the same thing as proving the underlying hypotheses. The Nazi race doctrines were supported by government and professional bodies and it would have been foolhardy to criticise them while the stormtroopers were in power; some benighted states gaol schoolmasters who teach the doctrine of evolution. Unfortunately such barbarities are possible and it is usual for the majority to respect even barbarous laws, but let us not call intimidation 'science'.

Related to the second is the third principle that it is prudent to reject claims made in the name of science if it is known that they have not been made freely. Lack of opposition to a view does not signify general agreement if there is reason to believe that pressure other than that of scientific reasoning secured unanimity. Victimisation of a single opponent discredits the scientific status of the opinion protected against heretics, since one martyr is sufficient to intimidate a great many cautious people. The use of intimidation to silence its opponents does not prove a proposition wrong; it merely shows that experimental evidence and reasoning are not yet in the position to make a hypothesis universally acceptable.

When an issue becomes economically or politically important, it can happen that some information is suppressed by interested parties if they happen to control means of communication. Once there is the slightest suspicion that arguments for one side are not allowed to reach the public, arguments based on the relative amount of evidence for and against the matter in question carry little weight. A monopoly of information counters the normal reaction of common sense by allowing publicity for weak evidence against the case supported while imposing a ban on better qualified witnesses. This trick could give an impression of fair chairmanship, but it is nothing but mockery of the freedom which must be the right of a responsible press or broadcasting service, and to which muzzlers of expert opinion are scarcely entitled. Nationalisation of oppressive journals is not the answer: on the contrary, a state monopoly of truth cannot be controlled through a suspension of a newspaper's licence, which is probably the best way of dealing with unethical editors. This problem is not supposed to arise in the free world but is a common feature of public arguments in the press of Australia and the United States. The subject deserves attention that goes beyond the scope of this book.

It is hardly necessary to point out that support from eminent people who have no standing in the matter is no more authoritative than any other layman's opinion. A Minister of Health with medical qualifications is not always an expert on matters of health; e.g., experience in a general practice of dermatology and gynaecology is not sufficient to predict the long-range effects of radiation or fluoride intake under the unpredictable conditions of, say, thirty years ahead of us. A Minister of Health without medical qualifications is a complete layman. He may rely on medically qualified officers of his department, but he cannot avoid the layman's problem: does he rely on scientifically well-trained experts who have made notable contributions to medical knowledge or on persons with humble qualifications who have steered clear both of research work and practical medicine? It is not an answer that he must consult civil servants in his department. Ignorance and compulsion do not add up to the status of an expert on experts.

One would think that the absurdity of President Eisenhower, Eleanor Roosevelt, the editors of *The Times* and of the *Hobart Mercury,* a TV clown or the secretary of a trade union in New South Wales lending their authority to hypotheses on the value of fluoridation would be patent, or that citing such support would suggest the lack of it from internationally known scientists with relevant experience. Yet such 'experts' on scientific issues are being quoted, presumably because the hurried reader will not realise that it does not speak highly of a musician when the deaf have to be quoted in favour of his playing.

As hinted before, the status of some experts is difficult to assess. Lack of general interest in readily available information on academic customs and standards helps interested parties to confuse the majority. A few words on the academic assessment of the two sides in a debate on health may help the reader.

Not all experts worth listening to are university graduates. Michael Faraday did not study for a degree, nor did quite a few outstanding scientists of our days. On the contrary, some people with high degrees are known to be incompetent, muddle-headed and quite unreliable even on matters of their own profession. Although a degree does not make an expert, it indicates the probability of proficiency in a certain direction. The exact value of a degree varies with many factors. Universities can go through stages of efficiency and inefficiency. These fluctuations can affect the various university schools to different extents; e.g. it is possible that a graduate of a certain university had excellent teachers of chemistry but was left mathematically semi-literate, then staff changes reversed the situation when his younger brother obtained a similar degree.

First degrees of universities (Bachelor's degrees in the English-speaking countries) are not intended to license scientists. Holders of good first degrees must learn to become scientists during post-graduate studies largely devoted to research. Successful completion of such work is recognised by the award of Master's degrees or of the more senior degree of doctorate, the Ph.D. Although men of Michael Faraday's stamp still exist, some of his achievement would have to be manifest before a person without formal evidence of research training should be accepted as a potential expert in his field. In the professions of mathematics, physics, chemistry, the fundamental aspects of biology, engineering and so forth, this is the accepted practice, and difficulties of interpretation seldom arise.

Medicine presents an awkward problem. The course is long and expensive. Most of the graduates, Bachelors of Medicine and Surgery, have not the patience or the means to start learning about research. They go into public or private practice as soon as possible, and assume the courtesy title, sanctioned by custom, of 'doctor'. Now the courtesy doctor may have taken as many years to set up his brass plate as the research scientist to receive a genuine university doctorate, but there is a difference between the two. The medical practitioner studies the fundamental sciences for one year only; after two more years' study of some special science subjects at a level below that prescribed for science students of the same subjects, he finishes his studies with three or more years of largely practical work. This is all very useful, of course, but it leaves him with little more science than the minimum required to make use of some thumb-rules. He has not seen how scientific investigation, including medical research, is conducted from day to day. He does not understand that science is not so much a matter of discoveries but a long series of heart-breaks, disappointments and the will to fight against one's own pet ideas.

The Ph.D. may be less useful than the general practitioner in some comparable emergency but he has begun to know what science is about. In particular, he will not confuse a promising idea with 'proof' nor the lack of an unwanted observation with 'absolute safety'. The Ph.D. has also learnt to respect and consult specialists in other fields, also to make critical comparisons between their manual or intellectual methods and his own. To sum up, the degree of Ph.D. is usually evidence of scientific experience, the medical courtesy doctorate by itself is a claim of having avoided contact with creative and critical science.

There are, of course, many medical scientists with the degree of M.D. (the senior medical doctorate) or Ph.D.'s from non-medical departments; they are possibly the most versatile scientists with the broadest human vision. There are also holders of university Ph.D.'s who specialised in Tibetan grammar, economics or Puritan poetry; their knowledge of health, drugs and related matters is often very slight.

There are also persons who boost their sales of drugs or fluoride by conferring doctorates on themselves; e.g. a group of Tasmanian dentists, with rather less than the average medico's scientific training have decided to call themselves 'doctors'. Since university doctorates are awarded under rather strict conditions, usually on the advice of outside referees of high reputation, they offer some guarantee that the young Ph.D. will hold his own as a peer of established scientists. When a man promotes himself to the rank of a doctor there is no such guarantee of course. In the analogous military case, a decoration for bravery in battle means something, but a bronze plaque with the words 'I am brave' and used for one's own decoration is not very complimentary to the self-decorator.

Thus the layman is surrounded by a great variety of doctors, some scientists, others completely ignorant of science; some recognised by all scholars of the learned world, others ignored, others again abhorred for bringing a respected degree into disrepute. In Tasmania, a state noted for eccentricities, medical doctors are forbidden to show that they have earned genuine university doctorates but dentists are free to sport self-conferred degrees. In countries which respect learning there are strict rules as to the use of doctorates. Fines and gaol sentences may appear a little harsh to punish dunces hankering for the prestige of learning, but such severity helps both the layman in the street and the layman called to power and forced to rely on the evidence of degrees.

It is unnecessary to add that if courtesy doctorates and self-assumed doctorates are no evidence of scientific competence, associations which recruit 95% of their membership from such people, no matter how good, worthy or practical, are not 'expert' bodies unless there is some indication that it is the scientific 5% that govern the professional decisions of the rest.

Special bodies with high-sounding titles do not get over this difficulty. The World Health Organisation and the Australian National Health and Medical Research Council are often quoted as bodies expert enough to make reliable scientific prophecies. Both are political organisations; most of their members are appointed by political procedures irrespective of scientific standing. The majority of the nations which nominate members of the World Health Organisation are countries without scientific institutions, often with insufficient numbers of native scientists to staff a single mediocre little university. Many competent people serve the World Health Organisation and their personal view on controversial questions could be of great value. The World Health Organisation as a whole has no more standing in scientific disputes than the United Nations or a convention of Buffaloes to which many competent people, no doubt, belong.

The National Health and Medical Research Council consists of Australian Federal and State Directors of Health with some other medically trained civil servants, representatives of some medical and dental bodies, two lay persons and one representative of medical research. By accident or design, more than the one member may have research experience, but this still leaves the organisation a lay body as far as the assessment of scientific matters and future prediction of safety are concerned.

It is not denied that a body can fulfil many useful functions even if it is not competent to act as a court of appeal in scientific matters. Also one cannot blame an essentially lay body asked by other laymen to arbitrate on scientific matters if, sheltering behind the immunity of ethical anonymity, it turns on a little pontification for the good of the profession, together with some dignified abuse of critical scientists. In fact we are not so much concerned with rhetorical rights and wrongs as suspicions that must guide the responsible layman in a noisy crowd of real and imaginary experts. The suspicious part of the business is this: if a scientific issue is both obviously vital and controversial why is it not submitted to a body of people who are recognised as experts all over the world?

If a controversial matter like fluoridation were approved by a select committee of the Royal Society of London with representatives chosen so as to look into all the dental, medical, chemical, biochemical, engineering and other aspects of the matter, it would take an exceptionally brilliant team to query their verdict. Discussions at the highest possible level would take place, and if they did not settle the matter they would stimulate research on the points separating the two camps. The Pasteur Institute could render similar service. Some world-famous independent research institutes could second some of the brilliant scientists on their staffs to conduct a critical survey.

All this would take much time, of course. The method suggested is not equivalent to the smuggling of authority into science: the decision would not be accepted because Professor A is supposed to be infallible or because one must not contradict Dr Z. The people suggested would not be judges, but with skill, tested on the evidence of dozens of successful discoveries and many examples of powerful thinking, they could bring out the experimental and logical connexions between the claims and counter-claims. They would do it in the open, in a manner that allows checking by any science student or layman interested enough to follow up the technicalities of the argument. Instead of saying: '*Only fools can deny*' they may say '*There is no evidence either way*', and their arbitration is not likely to insist on compulsion in the summing up.

The nature of scientific evidence may be compared to a net woven from many strands: it is acceptable if it forms a fabric with few holes, not large ones at that. It is the fabric's state which constitutes the authority, not the weavers' skill. On the contrary, anybody—layman or expert—can add to the fabric, and if it is the layman's thread that makes the fabric fall apart, the pattern is rejected whether authorities like it or not.

Compare this view of authority based on a coherent pattern with that likened to a circular thread. Dr A makes a claim; his colleagues B, C, and D repeat it. F, an official in a Health Department, reads the claim and reports that B, C, and D have 'confirmed' it. G, the Minister of Health, announces the claim as a 'proved fact', whatever that may be. H, a young man wishing to please the Minister, conducts what he is pleased to call an experiment and announces his 'confirmation' of A and all his followers.

Drs I, J, and K are appointed as a committee of investigation and provided with travelling expenses to see Dr A, who after a good dinner repeats to them his claims. The committee returns and issues a report that 'confirms' A's claim. By now a number of papers have been written, newspaper reports have appeared, the report of I, J, and K has been placed before parliament. With so much written the evidence remains the same: *A said it.* If now the matter goes to a select committee, the judge may hear the 'independent evidence' of I, J, and K who have 'seen it all'. With a Minister and a judge to support A's claim, others rally too. As the ballyhoo is growing A's claim is still the only thread in the pattern, but it is protected by parliamentary, judicial and professional immunities and authorities, who all rely on A's authority.

Arbitration by a committee of personally identified leading experts on controversial matters is rare. Those interested in scientifically sounding half-truths prefer anonymous arbitrators with powers of coercion, but those who know the history of science appreciate the dangers of even competent, objective use of authority. The very act of helping agreement may also lead to the discontinuation of criticism which is the soul of scientific progress, a curious paradox to be noted.

From a practical point of view the usual requirement is not the most reliable assessment of a claim but guidance how to act in a hurry. When time is too short to think scientifically we must clutch at the straw of authority. This is unavoidable in many cases. The engineer about to design a bridge has not the time to develop or check all the mathematical techniques involved in his calculations. The chemist starts his synthesis from commercial materials with a 'guaranteed' or assumed purity, and follows methods described by other authors in the chemical literature. The surgeon often follows routine, established by surgical research work before his time. In such cases one relies on the authority of experts as quoted in books and journals.

The scientist writing for publication offers his services as an authority. If individual scientists, books and journals represent authority this is, or should be, incidental. The individual's activity is on record, and as a scientist he is not protected against criticism. On the contrary, he invites criticism by writing for publication. He is an authority while his views and claims survive free criticism, especially after his death when his friends of the press, in the government, on the executive of professional pressure groups or in the club that runs the country are also dead and powerless to prevent the publication of hostile claims or muzzle a criticism of sloppy thinking. Again, it is not the straw of personal or institutional authority, but stability of a much attacked but resistant pattern of claims and views that constitutes authority.

The same applies to books and journals. Not all printed matter is of the same value. There are first class books and journals, which have been edited so strictly that further criticism is not at all easy. There are also trade journals of wealthy professions which are edited carelessly enough to admit many articles that '*are not flawless examples of scientific literature*', to use the euphemism of the *Australian Dental Journal* concerning the papers of amateur scientists in the *American Journal of Dentistry*.[17] Such journals are not better than the daily press. The straws of their authority float unconnected or have to be secured by pressures which have no place in science.

Even weak authority may be accepted in grave emergency. In case of accident or a sudden and alarming attack of ill-health one bows to the authority of the first doctor on the scene. From what one knows about medical education and the average doctor, there is no reason to assume that a strange doctor has all the knowledge, skill and prophetic vision required to do all the right things and avoid all the wrong things in a dangerous situation. At the same time there is an overwhelming probability in favour of the assumption that even a mediocre doctor knows far more about some critical features of the situation than others who did not have his years of practical training in medical techniques. Thus, unless one harbours a paranoid mistrust of the medical profession, emergencies favour the authority of a physician when the more accurate but much slower methods of science cannot be used.

This then is a rational test for the acceptance or rejection of professional authority. If it is clear that only a quick intuitive answer can help at all, back medical or dental advice against that of scientists. If it is a question of a long-range project or one that in principle admits personal choice between comparable risks and benefits, the matter is best left to a critical decision by scientists. No action would be preferable to reliance on essentially unscientific medical or dental pressures in such a case because the reliability that a patient may expect from his personal doctor and dentist is far higher than the standards of medical or dental group-conscience towards the community as a whole. If the latter assertion is doubted, let one inquire how the business time of a medical or dental conference is divided between scientific topics on one hand and matters of fees or prestige policies on the other; then compare this with the way the average doctor divides his time between healing and charging his patients. Not only the contrast between the humanity of the soldier and the inhumanity of an army is involved; the critical point is personal responsibility.

The authority that a scientist commands flows from such responsibility. A profession acting as a pressure group loses the authority which would attach to personal responsibilities of individual members. Practical considerations may force professional bodies to some measure of responsibility, but the authority of government departments is completely worthless because civil servants can be forced to agree to or to keep silent on scientific matters for political reasons. The power of modern governments, even democratic ones, to hush up and disfigure awkward evidence makes governments and their bound servants the worst possible witnesses from a scientific point of view. In any dispute between the humblest scientist speaking as an individual and the most august government department, the intelligent layman should back the former until the matter can be settled in a satisfactory manner.

6 Safety

A decision for or against approval of mass-exposure to biological, chemical or physical treatment hinges largely on the issue of safety. Other considerations are not unimportant, but they either provide their own answer (e.g. economic feasibility of the scheme) or are decided on principles that favour individual or sectional interests. Given the support of the press or of the ruling party, it is easy to secure acceptance for almost any measure that offers health in the future and 'progress' at once. The true nature of progress, which could range from a useful line of electoral propaganda to the yearly sale of millions of pounds worth of otherwise unsaleable products, need not be made explicit, and it is not customary to spoil a good advertising line with warnings that the slightest imperfection of the scheme may spell tragedy to any one of the citizens anxious to be caught on the baited hook.

Tragedies caused by the unscientific application of scientific progress have made the general public suspicious at last. Consequently there is an increasing tendency to deny to laymen a vote on the action of politicians, aldermen, do-gooders in progress associations and a few moderately qualified doctors and dentists who spend more time on the soap-box than in their surgeries. It is now or never that responsible laymen must make a stand against pseudo-scientific totalitarianism.

There are three main groups of questions that must be asked to check the safety of a measure that is to be used on a large scale: Is the measure beneficial? How safe is it? Is it really necessary to compel its adoption?

The benefits to be derived are not directly concerned with safety, but practical reasoning is directed by estimated probabilities: a very substantial promise which is likely to be fulfilled may justify a risk which is either of little importance or unlikely to eventuate. This matter is easier to decide for the individual than for the community since judgment of the relative importance of risks and benefits is a personal matter. One of the dangers of compulsion is to minimise the value of personal judgments and thus frustrate the serious minority who take pains to arrive at reasoned views.

Here are a few questions for the layman to ask when he wishes to judge claims of benefits in a critical manner. Who is making the claims? Is the propagandist a practising or trained scientist or does he merely belong to a profession *some* members of which are scientists? What are the proponent's scientific achievements? Does his reputation rest entirely on his advocacy of the controversial measure or has he given unquestioned evidence of scientific ability? The same questions must be asked about the opponents in relation to their claims.

As to the subject of the benefit, one must know whether it has wider implications. If a chemical is being discussed, it is not enough to have a physician's recommendation for its merits. The chemist should also be consulted, since the origin, nature and stability of the substance may affect its practical value. Does it dissolve easily? How does it react with common metals, fabrics, paper, wood and other materials found in the household?—Such questions may be very important. How pure is the commercial product? Is it easy to analyse? How can it affect plants and animals? These are other important questions that few doctors could answer at all and fewer still with the authority of knowledge.

Why is the proponent sure of the benefits he claims? Has he conducted research on the matter, and if so, has he published his results in an independent, critically refereed scientific journal? Has he merely read the claim, and if so what steps did he take to convince himself of its trustworthiness? Has he checked the figures? Did he apply statistical tests as to their significance? Is he mathematically competent for such a task? Did he consult the leading mathematicians, physicists, chemists and biologists on aspects of the claim within the fields of such experts? What does he know about the training, qualifications and other achievements of people at the source of the claim?

Does the claim rest on experimental evidence? If so, was it designed to exclude bias? Did the experimenters use adequate controls? Was it possible to use adequate controls? Is all this known or merely assumed?

Similar questions must be asked from opponents of the measure if their opposition takes the form of claims. On the other hand, no special reason need be given for not believing an insufficiently proved story. The onus of proof is on the person who makes the claim. This may appear to give an unfair advantage to sceptics but the strength of real scientific work consists in overcoming scepticism. At the same time the sceptic must be questioned too. It is not sufficient to reject a claim, one must indicate the reason. The sceptic has the duty to declare what parts of the evidence displease him. Strictly speaking, he should also specify the criteria on which he would accept the controversial claim. 'More research work is needed' is a statement trivially true for any subject; the nature and extent of the required research work must be specified.

On the matter of safety itself, we have seen that it is nonsense to speak of 'absolute safety'. Let us look now at the positive side of the question. To appreciate the problem, assume that you have a drug which has been proved beneficial in the sense that sceptics asking the questions suggested in the preceding paragraphs have declared themselves satisfied with your answers. Now the benefit uppermost in your mind constitutes a rather narrow claim, e.g. the property of healing wounds. Much ill-health and many fatalities are due to slowly healing wounds; the benefit is important enough to put up with the risk of minor discomforts such as itching or temporary discoloration of the treated area.

The drug may have been tried on animals first. Many animals have been used without noting ill-effects. This is a promise of safety but not safety itself, as different species of animals (of which the human species is only one) do not have the same sensitivities. If the experimental animals were mice of a certain strain, even another strain of mice could be sensitive. It is better to stick to one kind of experimental animal at a time but at the conclusion of the experiments animals from a wider range, preferably from species closer to man, may be tried. Lack of ill-effects is still not a proof of safety but it strengthens belief that the substance is not very dangerous in moderate doses or short exposures.

If the drug is to be used widely, a number of screening tests are indicated. Using animals again, dozens of standardised tests are carried out to see what doses, if any, have effects, and then what are the effects on the heart, blood vessels, different portions of the nervous system, and so on. These tests often employ excised parts of animals, hence the question of safety does not arise as such. The answer is obtained in terms of effects. All this can be translated to suit human conditions and may be checked with the help of human volunteers. The effects achieved may be compared with those produced in a natural manner. For instance, the drug may increase the rate of respiration in much the same way as a run of 100 yards would. Now running 100 yards is 'safe' in a manner of speaking, although it could be unsafe for a person with a bad heart. The beneficial and generally safe drug too could have effects which are not noted in normals but can add to the strain of already existing pathological conditions.

Suppose the drug slightly increases blood pressure. It is given to a large number of normals and patients who are then given medical examinations at intervals. Let us assume that the majority of the tested persons are not affected and that only a few, already suffering from high blood pressure, show some slight deterioration in their condition. Such deterioration may be detectable as a matter of quantitative testing but it is impossible to ascribe it to the drug with certainty. After all, conditions of high blood pressure can deteriorate through a number of causes, and a bias in favour of the drug can lull one's suspicions. In any case, the best such tests do for the drug is to increase our faith in its safety further still.

A really thorough testing of a drug need not include too many physiological functions, since the interrelation of these and others is very likely to show up some untested ill-effect. On the other hand, it is unusual to test in comparable detail the effects of the drug on enzymes. This makes many statements on safety fictitious.

Enzymes are the engines which do the work of the cell: digestion of nutrients, synthesis of essential materials (including the assembly of the engines themselves), storage and mobilisation of cell constituents are all effected by enzymes. The hundreds or thousands of enzymes are interlinked in a complex manner like machines along a production line. The complexity of this network provides alternative routes for major processes as a safeguard against temporary blockage or other local weaknesses. An isolated enzyme may be very sensitive to poisons such as cyanide of fluoride, but the community of enzymes in an intact cell or organism is much more resistant. For example, fluoride in a concentration of 1 part per million significantly inhibits some vital enzymes, yet the whole organism can tolerate such a concentration without anything like the effects one would expect from the damage to individual enzymes.

To the practical man who knows little of enzymes, a concentration that does not result in a call for the ambulance is 'safe'. His confidence reminds one of a set of drawings by Wilhelm Busch: in the first picture the farmer is tackling a huge foaming mug of beer with gusto; his enthusiasm is increasing as the level of his beer is falling until the last gulp reveals a dead mouse at the bottom of the mug, which spoils all the fun. A strained enzyme system need not interfere with normal health in a readily detectable way, but the strain may result in damage not ascribed to it by the practical physician. Younger members of the profession are being trained now to think of biochemical causes of diseases and to refer their patients to clinical biochemists, but the majority of patients are still seen by doctors who are either completely ignorant of biochemistry, or mistrust the little they know, or who rely on a few biochemical thumb-rules in the manner of medicine-men consulting churinga stones. Evidence from the health professions as to safety seldom includes the safety of enzyme systems or the absence of a few odd damaged cells surviving as a potential danger to neighbouring normal cells.

A close analogy is presented by motor cars handled by expert and inexpert drivers. In the absence of accidents, at least when the cars are reasonably new, the effects of bad driving may remain undetected. Even later a casual inspection will not always reveal the relative cost of replacement and relative frequency of need for repairs. Two twins, one with well-treated and the other one with misused and overtaxed enzymes, may look the same in a two-guinea examination but they are not identically safe.

The main scientific difficulty of establishing safety is due to the theoretical impossibility of adequate controls since no two men are identical. Returning to the drug which slightly increases blood pressure, suppose we give it to Peter and use Paul as control. If Peter has a nagging wife, his blood pressure will be high (thanks to wife + drug) while Paul's low blood pressure could be due as much to a considerate wife as to the absence of the drug from his system. With differences of disposition, diet, age, sex, social duties, climate, political and economic events and so on, one cannot assume that minor, barely perceptible changes are due to the administration or denial of the drug.

Also human beings, unlike mice and test-tubes, are not always truthful, particularly on matters of health, thus experiments with humans are notoriously unreliable. This difficulty can be minimised through a statistical approach. However, statistical safety is not the same thing as personal safety, and its purely statistical features must be remembered as such during arguments.

Try to visualise yourself in the position of testing the safety of a drug the beneficial effects and low toxicity of which are beyond reasonable doubt. As usual in this kind of thinking, assume that satisfactory tests exist, also that you know how to carry out such tests and that you have the necessary materials and facilities. Let us imagine that you have tested the drug on 1,000 persons and that tests confirmed the usefulness of the drug without showing up actual or potential ill-effects. Your faith in the safety of the drug will have been strengthened to the point where you are tempted to regard it as a fact. If you are a scientist, the degree of elation will act as a red light, and you will ask yourself how much or how little do your successful experiments mean.

Do not wait for awkward questions from critics, anticipate them. Some obvious critical remarks spring to the eye. Suppose the drug is safe enough in general, but one person in 10,000 is allergic to it. There is a high probability that a survey of 1,000 cases will not reveal an incidence of 1:10,000. Such an incidence is very low, but if the drug is compulsorily used or if doctors can be persuaded that it is 'absolutely safe' hundreds of people would be affected in big cities. The drug may have several kinds of unrelated ill-effects, e.g. a second ill-effect endangering one person in 100,000 may also exist. To detect safety in this respect 1,000 tests are quite inadequate.

The drug is not ready for safe circulation even after tests have been carried out on human samples gradually increasing from 1,000 to 1,000,000: the ill-effects cannot be noted until the drug has reached a sufficient number of persons to include the affected minority. If the circulation is on a personal basis, by the experimental subject's choice or on the advice of the family doctor, the drug can be withdrawn where it is badly tolerated. If administration is compulsory, the onus is on the victims to prove that the drug has caused their condition. If the medical profession supports the drug, individual doctors of modest standing may avoid condemning the rashness of their highly placed colleagues. In any case even a team consisting of the general practitioner and the victim will find it difficult to provide proofs that hit at vested interests.

Assuming the utmost goodwill from individual doctors and medical associations, let us consider the case of a drug which affects one person in 100,000 and is used by 50,000,000 persons. The number of those affected will be 500 in a community enjoying the services of about 50,000 doctors. The 500 victims will be distributed at random between the medical population, with the result that one doctor in a hundred will have a chance to observe the ill-effects of the drug. Not all doctors have the time and ability to observe new ailments; many make errors of diagnosis even in relatively common cases. If then 10% of the actual cases of allergy are recognised as suspicious, the fifty doctors with a critical eye will be 'a fringe minority' of 'cranks' among 49,950 sane, practical, honest, community-loving, disease-hating physicians entitled to 'absolute confidence' when they pontificate on 'absolute safety'.

The criticism of claims to safety derived from a few thousand observations goes much further. If the group studied is not a well-randomised sample of the community, its risk in respect of the drug need not be the same as that of other groups. For example, tests on schoolchildren or old-age pensioners cannot determine the safety of pregnant women and new-born babies. This has been the trouble with thalidomide which is an adequate sedative as long as it is not given during pregnancy.

The health of people is not constant: biochemical and physiological features exploited in tests vary from time to time even during the day. If one examines as few as 1,000 subjects, they will become incomparable whether one strings out the tests over a year taking three to four cases a day or one finds a method that can test 1,000 people in one minute each. The summer-health of A is not comparable with the winter-health of B. A blood test taken at 3 a.m. (in order to get through 1,000 one-minute tests during the day) will differ from that taken at 10 a.m. from the same person, who at the later time will either have had breakfast or be getting hungry. Such problems may be approached through the mathematical technique of Markov chains but how many doctors or dentists talking of proofs and evidence have even heard of the term?

Long-range effects are the greatest enemy of assertions on safety. Survival at a moderate dose of the drug during the day of testing or during a longer but still restricted and special period (e.g. school years) does not prove how the subject of the test will cope with a regular intake after twenty, thirty or forty years. Quite a few pathological conditions are known which come to light years after their supposed single cause; other troubles reach a critical stage through accumulation of small effects. Spilling mercury from a broken thermometer does not present a great danger, but exposure to mercury spilt from hundreds of broken thermometers in the course of a few months can be very serious. A glass of beer with a somewhat high content of lead or arsenic need not lead to complaints, leave alone a correct diagnosis, but the drinking of such contaminated beer for a few weeks has been known to cause mass fatalities.

In a few cases there are arguments against the possibility of long-range effects; these concern materials present in natural food and drink which do not seem to have affected the health of communities which lived on such contaminated nutrients for decades or centuries. Such arguments have a *heuristic* value, that is they increase our confidence in the proposition under debate, but they do not place the seal of validity on claims to safety. For one thing a population can become accustomed to doses which are undoubtedly toxic to others. In a long-settled population this process of acclimatisation could have occurred generations ago, eliminating the sensitives and leaving the resistant human material to survive. A sudden introduction of arsenic into drinking water would exterminate most populations with the exception of a few Austrian arsenic-eaters.

Again, conditions which enable one to tolerate a certain dose of a drug may change. This is particularly true in an atomic age when food, drink and drugs could help or handicap one in coping with radiation and fall-out. It is quite irresponsible to claim anything safe without an expert knowledge how the drug or treatment in question would affect safety after an industrial or military nuclear disaster. A change of diet brought about by population pressure, new methods of agriculture or some catastrophe also affect the safety of a certain dose of a drug given at different times. For instance, a drug that reduces the effective vitamin content of a normal diet can appear safe when the diet is rich in vitamins but can kill when some vitamins are at a premium. The discovery of the vitamin biotin is an example. Normally a lack of biotin does not cause effects serious enough to be noted by the general practitioner, but biotin is inactivated by a constituent of raw egg white. It was the peculiar dermatitis of a person addicted to the consumption of raw eggs on a Gargantuan scale which led to the discovery of the deficiency caused by his eating habits, and showed the importance of biotin to health.

One hears many arguments for and against the virtue of 'natural' and 'synthetic' substances. The usual argument for 'natural' dietary articles wrongly holds that there is a difference between natural and synthetic vitamins, fluoride, etc. However, chemical identity of the pure products is not at all the same thing as identical safety of natural and factory-made materials; here the adherents of natural products score. The fluoride content of 1 p.p.m. of a river is constant unless contaminated by industrial effluents but the fluoride concentration of a municipal water supply is variable, subject to fluctuations of the equipment and mistakes made by personnel. A natural vitamin in, say, fruit is accompanied by many other factors, some of them not even suspected at present, while a pure synthetic vitamin taken religiously for good health may deprive the addict of essential nutrients. The difference between the safety of natural and synthetic materials is not chemical but human: the risk of artificial additives to food and drink stems from the high probability of human ignorance, sloth, irresponsibility and liability to make mistakes.

The technical aspects of safety, especially the last point, lead to an understanding of the nature of compulsion. A free choice enables one to discontinue a treatment against which one's instinct protests. The instinct may be wrong, but it is often right. It is free choice which safeguards human future. Without compulsion some people will accept a certain treatment, leaving others to reject it. In due time one or the other group will be proved right; almost certainly one of the groups will derive some evolutionary advantage. If all are coerced to fall into one pattern, the effects may be irreversible in twenty to forty years' time when more is known of the matter.

For example, it has been suggested, but not conclusively proved by Albert V. Szent-Györgyi that one component of thymus glands, *promin,* promotes, while a second component, *retin,* retards and inhibits cancer. This hypothesis may be disproved, but again it could be right. Before the proving or disproving, which will call for years of intensive work by scientists of exceptional skill, it is useless to ask whether any particular drug or treatment helps or hinders either promin or retin. Nobody knows. Without compulsion, some people may have taken food or drugs with the unintended result of favouring promin over retin; others may have helped retin to triumph. At a time when mortality of cancer is rapidly growing it is a foolish thing to compel the community to put all eggs in one basket, for this endangers not only individuals but whole cultural groups, including mankind.

There are emergencies which encourage authorities to urge compulsion; examples have been mentioned before. Such compulsion is justified when no alternative exists or when one person's action deprives others of some natural right. My right to be ill with a highly infectious disease affects the right of others to remain free of it. On the other hand, my need for a headache pill does not give me the right to demand that all my neighbours take it, preferably in the morning milk when the treatment is required, so as to save me the trouble of counting out pills and also to preserve me against the danger of inadvertently overdosing myself. In this case my neighbour's refusal to take my medicine does not prevent me from obtaining the treatment I seek.

It is immaterial that headache pills are as a rule synthetic. Friends of compulsion ridicule the nature-worshipper's distinction between natural and artificial products, but make the same distinction when in a corner. If spinach juice were revealed as a sensible treatment against, say, anaemia, it would be wrong to force a whole community to have spinach juice mixed with their morning milk so as to save anaemics from the danger of cutting their hands with tin-openers.

Data on Argentinian spinach-eaters would not justify compulsion in Brazil. Statistics showing that 500 Congolese spinach-eaters did not more often die violent deaths than their anti-spinach neighbours would also be pointless. The only argument to justify the compulsory distribution of spinach would be some emergency in which a prompt supply of supposedly life-giving spinach juice could not be channelled fast enough to the spinach-starved millions except by mass-distribution in a medium few can afford to avoid. The emergency in question must be vital. The measure would not become safe through the emergency; one would merely trade immediate clearly seen danger against the distant, but possibly more serious risks of the future.

7 How Safe is Food?

The preparation of food by methods known to prehistoric man relies on many physical, chemical and biological principles, most of which had remained unknown until this age of science. Our ancestors had accumulated much experience, and many of their short-range inferences were correct, but they lacked ideas enabling them to see beyond the wood the forest of food science. When uses and dangers of medicinal poisons were discovered, their preparation and application gradually became the right and duty of medicine-men, but food had to be prepared individually and its technology remained the people's science. The advent of more fundamental sciences and the socialist ideal of feeding the masses in communal kitchens are challenging the position of food science, but most readers can be credited with much sound knowledge based on long experience with food. Drink is included under the name of food, not only for the sake of brevity but for biochemical reasons.

The bulk of our solid food is supplied by plants and animals, tissues of which usually contain more water than all other constituents put together. The water content of liquid blood is of the same order as that of the apparently solid heart or kidney. In the course of digestion the main organic constituents of solid food are turned into liquids: they are converted by enzymes to substances which are readily dispersed in water.

The same applies to the whole human body, about two-thirds of which consists of water. To understand why so much liquid presents a solid aspect two analogies may be considered: a jelly in which a spoonful of gelatine forms a network of molecules to cage a pint of water, or milk carried as solid cargo in a number of containers, to which the cells of our body correspond.

Analogies play an important part in scientific thinking. When faced with a complex problem, the scientist tries to think of a related problem that is simple enough to solve. Once part of a problem is solved it becomes easier to provide somewhat more complex answers to increasingly complex part-questions. We use analogies when we think of an electric current as a fluid, thus reducing the strange nature of electricity to the readily intelligible and observable nature of a river. From this start one may predict, then verify, the behaviour of electricity in some respects in which a flow of water does not provide a correct analogy.

The danger of analogies is that lovers of simplicity stick to them rigidly. An argument is properly started by the picture evoked through some analogy, but then one must test how far the analogy is valid, where it breaks down and how it must be modified to provide another analogy that does not break down so easily.

The analogy between milk bottles and their content of milk on one hand and cells on the other is inadequate. The bottles do not exchange their contents with the rain and dust falling on the milk-van but cells have permeable walls that permit entry and exit. This suggests bottles with walls made of stout blotting paper or not quite water-proof canvas, which again are understood on the analogy of a sieve with extremely fine meshes. However, such extensions of our original analogy are still imperfect. A sieve-like barrier cannot distinguish between the nature of particles that pass through it or are retained on it: it selects by size and shape only. Cell-barriers are more selective; e.g. the functioning of nerve cells involves a phase when potassium ions are not allowed to leave and sodium ions are not allowed to enter, followed by a phase of counter-current flow of these ions through the cell-membrane.

The *model* (pp. 56-57) of a cell-barrier can be extended in this way further and further to explain an increasingly large and varied set of data. It is not for us here to follow the progress of analogies to the latest models of cell-membranes, but the preceding discussion leaves us with two important results.

One is the method of creative argument by analogy. More important to our present purpose is the view of the cell-membrane as an intricate mechanism which reacts with substances that seek inward or outward passage through it. The study of cells and their chemistry requires expensive facilities and time-consuming experimental work. Scientific medicine increasingly looks to the biochemistry of cells for hints on diagnosis, therapy and prevention, but the practical physician has seldom the time or training to go beyond judgments based on superficial observations, and those responsible for legislation on food often lack the practical physician's personal interest in individual cases, his experience as an observer and his intuition.

When it comes to professional testimonials of the safety of food products there is less reason still to take any claim on trust. Production and distribution of food means big business and the vote of farmers, which is an important political factor even in industrialised countries. Industries, parties wishing to remain in government, branches of civil service hoping to extend their power to control more and more phases of private lives, are not concerned with individuals, exceptions, minorities or variations around an average. They soothe their consciences and woo our confidence with statistics (of the non-mathematical kind).

The layman's chance to assess the safety of food lies in a disagreement between producers, governing party and civil service. Independent scientists able to speak on general aspects of the safety of food are few. There are many who can criticise the value or safety of certain food products but they can be brushed aside if the three main groups with vested interests in the matter stick together. The layman who has not the facilities to put his criticism in numerical terms will hardly get a hearing. The only defence short of becoming a recognised expert is to seek chinks in the armour of privileged power.

Man requires food for different purposes. The diet must supply considerably more energy than the amount used to keep warm, to perform mechanical and electrical work and to permit chemical syntheses. Next, it must provide building materials even to adults whose bodily growth appears to have come to an end, as they have to reconstruct enzymes, other cell constituents and whole cells which are regularly destroyed and must therefore be replaced regularly. Finally, the diet must include constituents essential to health which the body cannot synthesise but must take from organisms endowed with synthetic power.

At the cruder stage of scientific materialism, during the eighteenth and nineteenth centuries which witnessed the industrial revolutions brought about by steam engines and mechanical devices, the analogy between the human body and a locomotive appeared impressive. In the absence of chemical and electrical information on the nature of life, energy appeared to be the main requirement of food. This idea still survives in the form of commercial or departmental advertisements which sell the 'food value' of a product on calories, that is its value as fuel when burnt with oxygen in a vessel constructed to withstand high temperatures and explosive pressures. It is true that energy must be supplied by food, but the main question is how such energy can be utilised by the body at normal temperature and pressure. A pint of medicinal paraffin oil is a better fuel than a similar weight of cheese, but it is not food for humans. Even more obviously, a nuclear explosion is not equivalent to so many meals.

The calories of more or less comparable foodstuffs (e.g. meat and bread) may give some indication as to the choice between them within some scheme of rationing. There are tables that suggest optimum total calorie intakes for persons of specified age, sex, height, weight and occupation; unfortunately these tables differ from author to author. The same applies to the many systems of special diets suggested for the one purpose: to reduce weight. It is becoming clear that it is not so much the characteristics of individual dietary constituents but the diet as a whole that has to be considered. Claims made out in favour of single articles of food as being equivalent to so much of other items may increase sales but their scientific value can be ignored.

The idea of a balanced diet is commonly accepted. Proteins of plants and animals are needed to replenish our own proteins: enzymes, the working parts of muscles, the main constituents of blood, cell-membranes and genes all consist of or contain proteins. Proteins are also needed to supply nitrogen for the synthesis of other nitrogenous substances essential to life. Sugars and fats are needed to supply energy without drawing too heavily on proteins required for other purposes but depleted during starvation. The necessity of consuming varying amounts of certain minerals, vitamins or their precursors is also recognised. On a normal, liberal, natural diet these requirements raise few problems; these arise when grave shortages of food or the lazy habits induced by too much leisure result in unsatisfactory feeding.

One of the problems is shortage of essentials brought about either by over-processed foods or one-sided nourishment. Treatment of food intended to improve appearance and solubility or to cut down the effort of cooking in the kitchen may remove minerals and vitamins. Food selected for ease of eating (e.g. a diet of refined sugar, processed cereals, ice cream, flavoured carbonated drinks and sweets) can favour one constituent at the expense of others. The body makes a quick protest against hunger but the reaction to a bad diet of sufficient bulk and utilisable energy is delayed and often complex enough not to be related in one's mind to starvation in plenty.

In rich communities the supply of bulky constituents is seldom low enough to cause severe trouble, but the intake of minerals and vitamins is often deficient in populations with more money to spend than knowledge of how to spend it. Authorities in Britain, Canada, the United States, Australia and elsewhere recommend certain daily intakes of the more important dietary factors, but some of the substances known to be essential cannot be specified; for others the figures suggested by different authorities may differ by more than 100%; estimates vary within three to five years' intervals. Some authorities recommend the same average intake for all without considering that infants, pregnant women and young mothers need nourishment different from that best for adult males. Obviously age, weight, health and other circumstances vary the optimum from individual to individual.

It is a mistake to think that constituents of good food are necessarily good for one, and that all nutritional problems can be solved by doubling the highest recommended intake. The dangers of overeating in terms of bulk and calories are well understood. It is less well known that vitamins (especially vitamins A and D) can kill or cripple in overdoses.[*] Potassium, sodium and chloride are essential but excess of potassium or of ordinary salt can endanger health. Water is essential, but a condition of water poisoning is known to occur when thirsty miners ingest large volumes of water without salty food.[*] It is not always bulk of a particular product but its ratio to other dietary constituents that matters. Scientists would be less suspicious of claims made in favour of some ratio of dietary fluoride to magnesium and phosphate (which are known to modify its biological effects) than a hesitant advocacy oscillating between 1 milligram (1/65 of a grain, i.e. a *quantity*) per day (i.e. a *rate of intake*) and 1 part per million in water (that is a *concentration*)[*] irrespective of other dietary factors.

In some diseases the physician, possibly guided by clinical scientists, advises patients to abstain from normal, wholesome ingredients of diet or to reduce their intake far below the requirements of an average person. Thus the intake of fat, carbohydrates, protein, cooking salt and acid fruits may be restricted. Evidently, if a person tried to anticipate the doctor's orders and ceased to take all these foodstuffs he would starve to death or would have to be fed artificially with scientific aids at an expense that would deny such a diet to most of his fellow-citizens. Even the patient who on doctor's orders must watch certain dietary ingredients cannot altogether avoid them: a small risk of aggravating his condition must be accepted in order to avert the certainty of starvation.

Every material passed through the alimentary tract is potentially dangerous. The danger is not a property of materials, but a characteristic of the relation between the food and the eater. Normal people are sometimes allergic to certain kinds of food. In some cases the effects are psychological and do not appear if the person does not know that he has eaten 'something that does not agree with him'. In communities with religious dietary laws persons are known to become sick when told that, unwittingly, they have consumed forbidden food.

When food is considered unsafe, quantitative considerations are important. A person may be forbidden fat by his doctors but allowed to eat lean meat. However, lean meat contains 3-15% fat, possibly not enough to matter. An occasional canister of tinned food may add unwanted lead to the diet, but a considerable amount of such tinned food must be eaten before symptoms of lead poisoning become apparent. Such symptoms do not necessarily appear at the same time in different members of the family even if their shares of the food have been equal.

These few examples, and hundreds more could be quoted, show up the stupidity of the notion of 'absolute safety'. There is hardly a substance commonly occurring in human diet which is safe for all ages, in all conditions and irrespective of intake. Any one of these if distributed compulsorily will hurt a minority. The quantity ingested governs the extent of harm in those affected. Careful individual investigation could show that a certain person can safely tolerate a certain *quantity* of salt, fluoride, sugar, vitamin A, etc., but it is wrong to speak of safe *concentrations* without specifying the quantity of the diluting agent.

The danger of some dietary constituents is not easy to detect because often they are only one of the possible causes of trouble. Resistance or sensitivity are matters of genetic constitution modified by many factors. Also it is not unnatural to blame ill-health on the factor in which one does not possess a vested interest. Abortions and stillbirths could be due to (i) genetic deficiencies of either parent, but they are also linked with (ii) fathers who work with lead but do not show symptoms of lead poisoning; (iii) deficiency of vitamin E brought about by the treatment of bread flour with chlorine dioxide and excessive milling; and (iv) lack of essential fatty acids through the use of margarine and hardened fats. An unfortunate parent proud of his or her stock would prefer to blame the bread and the cooking fat. The miller will blame the parents or the margarine manufacturers.

Agene, nitrogen trichloride, was extensively used to 'improve' flour, that is to bleach and sterilise it. Neither doctors nor the great majority of laymen worried. Of the hundreds of millions of people who had used agenised flour not one was diagnosed as suffering from agene poisoning. Agene was far more 'absolutely safe' than the use of fluoride and diagnostic X-rays against which warnings of a scientific nature exist. In 1946 Mellanby showed that agene converts a minor constituent of flour into a toxic product which induces fits in animals. With this evidence beyond scientific doubt, vested interests succeeded in having agene regarded as 'safe' for ten years, when it was replaced by chlorine dioxide. Some dangers of chlorine dioxide have already emerged, but it will require years of hard scientific labour to prove conclusively some of its dangers; then it will take further years before authorities will be compelled by the rising tide of scientific evidence to force its replacement by something else inherently dangerous but 'absolutely safe' until investigated by a genius comparable with Mellanby.

The danger of a widely used poison may not become apparent until its discontinuation. Thus it was only after the ban on agene that experts began to suspect that it could have been responsible for short sight in children.

The use of agene was criticised years before Mellanby's work. Critics were called faddists, nature-cranks, inexpert meddlers with a milling problem that was best left to milling experts; they were accused of creating fear in the minds of the public and threatening confidence in the citizens' daily bread.

The role of dietary fats in the development of disease is receiving much attention these days. Disseminated sclerosis, a disease with an incidence of 500 in a million, is possibly connected with defective fats. In Norway the wartime loss of margarine factories was accompanied by a decreased incidence of the disease, followed by an increase after the restoration of margarine to the table. The majority of Norwegians did not contract the disease, hence margarine cannot be the only cause. Traces of lead are thought to be a contributory cause, possibly through suppressing the beneficial effects of copper required in very small amounts.

The increase of coronary disease in wealthier countries is beyond doubt. Constitution, habits, pressure of life and other causes difficult to estimate may be at work. Overeating without a physiological demand for excess food is an undoubted contributing factor. Those who cannot master their greed and are too lazy to exercise are looking for magic. Let the scientists find a guilty substance, we'll omit it from the diet and live happily ever after; or better still let them find a pill that will neutralise the cause of the trouble. Demand usually produces supply, in this case the cholesterol 'theories'.

Cholesterol is a natural constituent of all animal fats. Dissection of coronary vessels usually shows an increased concentration of cholesterol in the diseased area. From such undoubted data one could conclude either that cholesterol causes the cardiac lesions or that such cardiac lesions, once caused, attract cholesterol, possibly as a natural defence against some anterior damage. Evidence available at present does not allow a definite choice between these alternatives, but only the first one supplies a popular answer.

During the first stage of the cholesterol scare people were advised to avoid dietary sources of cholesterol, that is, animal fats. All animal flesh and eggs should have been banned too, but this would have made the magic too uncomfortable. Cholesterol is synthesised in the human body even if one abstains from food containing it. Thus the strict ritual of abstinence could be relaxed and some of the more comfortable forms of magic have been tried. The profits from drugs supposed to block cholesterol formation run into millions; a widely advertised one of these lowered cholesterol concentrations in the blood, did not prevent heart disease but was quite effective in inducing cataracts.

The troubles of cholesterol research conducted by dietitians begins with analysis. The many known analytical methods give widely differing results on the same sample. The investigator setting out to analyse cholesterol in the blood can choose methods that give low, medium or high results, depending what he wishes to 'prove'. Possibly he does not realise this and merely chooses a method that seems convenient. One of the reasons of analytical difficulties is that cholesterol, as found in the blood or in arterial deposits, is contaminated with a large range of similar sterols. Some of these are toxic to growing tissue and others harmless. If an accidental lesion of the blood vessel is exposed to a toxic sterol, the damage may become permanent and increase without permitting one to blame any particular substance.

However, local accumulation of cholesterol is undesirable. Unsaturated fatty acids (absent from hardened fats), vitamin B_6, methionine (the substance in flour destroyed by agene) and possibly many other factors help to keep the synthesis of cholesterol and kindred substances in safe bounds. Impaired thyroid function may lead to increased cholesterol production.

The thyroid function itself is impaired by lack of dietary iodide which can be controlled by iodide pills or iodised salt, but not iodide addition to the water supply as many people are sensitive to excess. There is an unsettled controversy on the effect of fluoride: some scientists assert that it inhibits the thyroid function, others deny this. The feeding of cows on kale, cabbage, turnips, etc. passes antithyroid substances into the milk; the resulting goitre does not respond to treatment. Astwood, one of the discoverers of natural antithyroid substances, drew attention to this matter during his visit to Tasmania where goitre is common and cannot be stamped out with the help of iodide pills. When he hinted that the milk might be at fault, the government lost interest in the matter. Press and authorities have kept the information from the people, presumably in order to protect the milk industry. Goitre and hydatids—both with known causes—are not tackled lest electors in the country be put to inconvenience; instead it is the scientifically unsettled issue of fluoridation that attracts the interest of health authorities.

This is just one incident of the many that are becoming a greater threat to mankind than nuclear warfare. The horror of war in an increasingly crowded little world may help the wise and patient to preserve peace, but the pressure of growing populations encourages production and preservation of food by chemical means without adequate testing. The consequence could be widespread damage to health, some of it capable of genetic transmission until butchery by euthanasia and eugenics on a colossal scale will appeal to some as the rational solution.

Penicillin used against infections of the udder enters into milk and can cause asthma, allergic rashes and shock. Other antibiotics, sulpha drugs and tranquillisers are used to improve the growing of poultry, pigs and calves. Eggs and meat transmit a host of drugs to man regardless of personal allergies. Oestrogenic sex-hormones, which are known to cause cancer in man, are used as a method of chemical castration of cattle, sheep and poultry. In the United States where the practice is widespread and much poultry is eaten, assay of the excreted sex-hormones, an important clinical test to assist the surgeon, cannot be reliably performed in many cases.

Vegetables, grain, fruits are made available in increasing quantities through the use of insecticides, other pesticides, weed killers and preparations against fungi and other micro-organisms. Many of these preparations are distributed by spraying, and the air is contaminated far beyond the fields and orchards. Not all such products can be washed before using; washing will not remove a fraction of the chemicals which have already penetrated into the skin.

DDT and related insecticides have been known to cause acute and chronic poisoning in man and animals. These poisons spare the foetus but accumulate in body fats and enter mother's milk; normally born puppies of dogs treated with DDT are killed by their mother's milk. Organophosphorus compounds (TEPP, parathion etc.) may accumulate in plant products (grain, tomatoes, olive oil, wine, cocoa) to concentrations higher than 1 p.p.m., and present a danger far greater than fluoridated water. Like fluoride, but to a much greater extent, they attack enzymes concerned with the transmission of nerve impulses to muscles and glands. Indeed, they have been developed originally as military poisons. In small doses toxic effects may appear with considerable delay, sometimes over a week; this makes the diagnosis and the lodging of protests and claims very difficult. Long-term exposure to small doses may result in severe disorders of the nerves.

Some insecticides and weed killers cause no immediate symptoms; a salesman of a department responsible for their distribution to farmers would call them 'safe'. However, on long exposure they can cause leukaemia or cancer without timely warning. Arsenical sprays are thought to be the cause of skin and lung cancers. Aminotriazole is another weed killer that has been known to cause cancer in animals but produces no other ill-effects. Other weed killers derived from dinitrophenol upset the co-ordination of respiration with the metabolism of phosphorus; one of the consequences of chronic poisoning is the development of cataracts in a small fraction of the victims.

The list of dangerous agricultural chemicals could be continued throughout the length of a whole book, restricting oneself to compounds the toxic effects of which are beyond doubt. The analysis of some of these substances is difficult; in many cases unspecified impurities are present, sometimes to the extent of 90% or so. Some of these impurities are unknown and thus remain uninvestigated. Safety is 'proved' by short tests in which acute toxicity does not become apparent. It is much easier to synthesise new compounds than to subject them to thorough biological testing. As a fortunate accident a compound passed as 'safe' may be found toxic by independent research workers at the last moment. One of the most dangerous cancer-producing substances, 2-acetylaminofluorene, was nearly released for general use.

Notwithstanding warnings and knowledge of the risks, the use of poisonous dusts and other murderous agricultural chemicals is practically unrestricted. Some countries control a few products, others ban a few more, but action taken by health authorities and the medical profession is negligible.

On a far less important matter the health authorities make some effort to protect the public. Acceptable food must not only contain certain quantities of nutrient, it must also appeal to the eye, nose and palate. The art of cooking aims not only at making food digestible, it is also concerned with its appearance. Health Acts in more advanced countries limit the range of artificial colours, flavours, sweeteners, dispersing and stabilising agents that may be added to food. Preservatives either added to the food directly or contained in wrappers in contact with food are similarly checked.

Unfortunately surprises will crop up. Coumarin from tonka beans or woodruff has been a popular 'safe' flavour of sweets for centuries until 1958 when its toxicity to liver and kidney and its haemorrhagic properties were established. Its use is banned in the United States but not everywhere else. Liquorice is still a popular sweet; one of its constituents has been suspected of being able to cause cancer. The more recent but widely spread use of silicones in the manufacture of food is known to be dangerous but ability to cause cancer is 'only suspected'.

In general, a test for safety should extend to over one lifetime of about seventy years to exclude long-range damage in the next generation. The occurrence of such transmitted damage has been repeatedly demonstrated with short-lived animals. In the case of man a quarantine of about a century should be necessary, as animal experiments do not permit an inference of safety for humans.

It has been well said that one can prove danger at times, but one can never prove safety. The layman cannot prove even danger, except at his own expense. In search of safety he can do two things: (i) insist on the strictest control of agricultural chemicals, including an automatic ban against them in case of the slightest doubt; (ii) keep the unchecked agricultural chemical racket in mind when health authorities assure him of the 'absolute and unquestionable safety' of any chemical foisted by one man on another.

8 How Safe is Smoking?

Disputes on safety often concern a choice between two evils with theatricals to deflect attention from the possibility of more satisfactory solutions. Arguments for and against the safety of smoking help us to forget the real question: why should smoking be a problem at all?

Unlike food, smoking is not essential: one can live and keep in good health without it. Top achievements in any field of endeavour are open to non-smokers. Happiness and wisdom can be attained without the help of tobacco. On the contrary, many smokers had to overcome a natural revulsion against tobacco. Smoking is an expensive habit and a cause of fires and accidents. The happy smoker, unless a sadist, must train himself to ignore the discomfort of non-smokers whose nose, palate, clothing, furniture and books he assaults with broadsides of sparks, nauseating fumes and hot ashes.

The main argument for smoking is the economic importance of the tobacco industry. Many non-smokers are prepared to put up with the obnoxious habits of smokers so as not to prejudice the livelihood of farmers, factory workers and shopkeepers.

Some new considerations came to the fore during the last two decades. With increased earning power and growing unconcern with parents' wishes, today's youth is more exposed to the dangers of drinking and smoking than ever before. The dangers of drinking are more obvious. The worst offenders are often dramatically eliminated, and their example helps the cause of moderation. In the case of smoking both the known and suspected dangers need many years to take recognisable shape. If the undoubted immediate risks of alcoholism do not deter all, it is easier still to disregard the possible consequences of smoking twenty to forty years ahead. Laws against selling tobacco to children are of little value when vending machines serve all who have a few coins to spare. Parents do not keep their supply of cigarettes in the safe. Shopkeepers who refuse to sell to a child of seven do not always ask a fourteen-year-old for his birth certificate, and children sent to fetch a packet of cigarettes from the corner shop add to the shopkeeper's difficulties.

If we can satisfy ourselves that smoking will harm those who have not the knowledge to realise the risk or the will-power to resist massive advertising campaigns, we must seek some way to defend the children. Although a complete ban on tobacco could be eluded by a few, it should be effective on a communal scale. It would return land to more essential food production and reduce the intake of agricultural poisons which are spread also by tobacco products. Admittedly, prohibition of tobacco could be exploited by criminals and hostile countries in much the same way as they exploit narcotics regulations. At this point the problem passes from scientists to politicians, soldiers, policemen and customs officers. Licensed houses and hours for smoking or rationing are not likely to satisfy tobacco addicts but would encourage lawlessness. Some suggest education as the most civilised and effective answer, but the lowering of primary and secondary school standards (which is the pragmatic definition of education) has failed to check alcoholism, promiscuity and violence among children, and even the relatively simple control of hepatitis and hydatids appears to be beyond the power of some much admired systems of education.

In other words, should we satisfy ourselves that smoking is harmful and a threat to the generation which will be in power in twenty to thirty years' time, a number of awkward, possibly insoluble problems would emerge. There is a temptation to avoid the problem: radio, TV, films, books and posters encourage us to relax with a smoke. Possibly we could relax with a conscience good enough to make the cigarette unnecessary if we could lay the ghost of the tobacco scare.

It is not denied that excessive smoking is harmful, but this is not an argument against tobacco, or else the same must hold against anything we breathe, eat or drink. The special sensitivity of a few individuals to tobacco dust or smoke is matched by exceptional sensitivities to milk, eggs, strawberries, etc., with the only significant difference that a normal person can drink a glass of milk without giving eczema to a sensitive child at the next table, while smokers compel their neighbours to share their fun or flee; the latter is not always possible in a moving train. Protection due to non-smokers is recognised in principle but seldom enforced except where danger to property from fire is involved. Where democracy is understood to mean that minorities may be ignored, the problem of hypersensitivity to tobacco does not exist.

Buerger's disease, characterised by inflammation of blood vessels which may lead to ulceration and gangrene requiring amputation, does not affect every heavy smoker; it is a rare ailment. Yet most of those afflicted are heavy smokers; abstinence from tobacco helps the treatment, and recurrence of symptoms often coincides with the resumption of smoking. However, it is not simply a smoker's disease as practically all who contract it are males. Some other ailments, not necessarily due to tobacco, are aggravated by smoking. In all these cases it is commonly held that it is in the patient's interest to control himself, and that the community is not bound to suppress the tobacco industry in order to lessen the effort of abstinence from smoking.

The foremost contemporary problem of safety in connexion with smoking is that of cancer. Smoking of pipes is associated with cancer of the lip. This condition is rare in European women except in Pustertal (Austria) where women are pipe-smokers. Pipe-smoking women used to be more often seen in the United States, especially among Negroes, and the incidence of cancer of the lip was accordingly higher than in Europe. However, all kinds of cancer have incidences varying with social groups, and the high incidence of cancer of the lip among Negro women in the United States may have been due to causes other than pipe-smoking. Regular exposure to mechanical or chemical irritation for ten to fifty years may precede the clinical manifestation of cancer. Pipes, cigars, and chewing tobacco can provide the chronic irritation which gradually leads to cancers of the lip, tongue and mouth. The allocation of blame to a single cause is not always easy; e.g. some cancers of fishermen could be caused not so much by the pipes most of them smoke but by exposure to tar, the earliest example of chemical carcinogens.

Cancer is not a single disease but a group of diseases. Even cancers attacking the same organ can be of different types. It is with such a qualification that we shall speak simply of lung cancer, the most worrying risk incurred by smokers today. The most common symptom of lung cancer is cough; loss of weight, pain in the chest, respiratory infections, discharge of blood, short breath, weakness, wheezing and a change of voice are other symptoms which could be due to different, mostly less serious, causes. It is not surprising therefore that many cancers of the lung are diagnosed too late. According to the records of a famous American surgeon, 668 of his 1,467 cases of lung cancer were inoperable, and of the 723 that were operated, 254 were too far advanced to have the growth removed; 89 of the 469 completed operations ended in death in the hospital; about 10% of those who returned home after operation were alive five years later. These figures are rather old; means of diagnosis and chances of survival have improved and keep on improving but the picture remains grim.

X-ray diagnosis should help to detect cases early enough to give the patient good chances of recovery, but I remember a friend (a non-smoker) who had been passed fit at his last attendance at a compulsory chest X-ray and died of widely spread lung cancer a few months later. His condition was recognised by a surgeon whom he consulted about a swelling in the groin. The diagnosis was confirmed by a second X-ray investigation undertaken with the competence and care one cannot expect from mass-medicine whether it aims to diagnose or to cure.

It is often stated that cancer of the lung is increasing. This statement would have a meaning if one knew what the incidence of lung cancer had been in the past. With less thought given to the matter and with more primitive methods of diagnosis many cases must have escaped detection at the beginning of the century. All we can say is that the numbers of recorded cases of lung cancer have grown. However, the increase of diagnosed cases has been very great. In the first fifty years of the century cases recorded in England and Wales have grown from 8 to 343 in a million. The increases vary from country to country but the incidence since 1930 appears to have increased up to eightfold in the United States and Western Europe. It is reasonable to assume that increases of such magnitude are not due to better methods of diagnosis only. If, as the example in the preceding paragraph shows, the personnel of a much-advertised state X-ray unit cannot detect lung cancer in its last stages with expensive modern apparatus, lack of such equipment need not make much difference.

Another possibility is that the shorter life-span of half a century ago gave prominence to diseases which killed their victims relatively young, and our conquest of such diseases must increase the importance of ailments of the elderly. This view has not been refuted but increases of lung cancer in all age groups argue against it.

One of the surprising findings was the shift of male:female death ratios from lung cancer. Earlier in the century the ratio was 1, today it is about 7. Diagnosis of lung cancer is just as easy or difficult in males as in females; a mere improvement of diagnostic facilities should not have affected the ratio.

These and other data suggest that something with a causal connexion to lung cancer has been and still is operating. The susceptibility to a given disease need not be the same for males as for females, and factors of equal intensity for both (e.g. exposure to industrially polluted air, water or food, cosmic radiation) may differentiate between women and men. Yet it is rational to search for possible causes present in men but not in women.

One such factor is cigarette smoking. Before 1900 the average tobacco consumption of English women was negligible. The English male above fifteen years consumed about 6 lb. of pipe tobacco yearly during the period 1881-1900, while the consumption of tobacco in the form of cigarettes rose from 0.006 to 0.4 lb. p.a. during that period; it rose rapidly to over 8 lb. p.a. in 1950, but the use of other forms of tobacco fell to 2.4 lb. p.a.

English women started smoking after World War I; their cigarette tobacco consumption rose from 0.2 to 2.4 lb. p.a. between 1921 and 1950. The incidence of lung cancer in women began to rise as their cigarette consumption increased, but the men had a great start on them, and the figures suggest a lag of not less than twenty years between cigarettes as cause and lung cancer as effect. The figures also indicate that cigarettes rather than total tobacco consumption are to blame.

It is premature to speak of *cause and effect* on such evidence although the figures are acceptable as trustworthy data: they come from independent investigators in many countries and from the published records of the tobacco industry and were made public years before a link between lung cancer and cigarette smoking was suspected. Unless we are prepared to consider some sinister plot to bring the tobacco industry into disrepute fifty years later, we must agree that the tobacco and lung cancer statistics until about 1950 are free from bias.

Assuming that cigarettes have the same effect on women as on men, one could regard women as non-smoking controls sharing climate, food and most other biological factors with men. Although the incidence of lung cancer in women appears to be rising, we cannot assume absence of a sex-determined factor, and in the absence of reliable controls we are not within sight of a convincing demonstration along these lines.

The hypothetical suspicion against cigarettes would carry more weight if we were unable to think of an alternative that does not put the blame on tobacco. But there is such an alternative: cigarette smoking is a response to growing strains and stresses of modern life; some of these could be the cause, with smoking nothing but an indication of or possibly a countermeasure to the real harm.

There could be something more fundamental than vague strains and stresses, e.g. one's physical make-up, possibly determined by heredity, and the patterns of irritability and activity that flow from it. The effects of heredity on human behaviour are difficult to prove because social pressures confuse the issue. One of the most powerful tools of investigation of human heredity is the study of identical (monozygous) and non-identical (dizygous) twins. Parental example, domestic discipline, advertisements reaching the home, etc. are the same for most twins whether they are identical or not. If smoking is largely a matter of social pressures, twins would be expected to have similar smoking habits. If hereditary features are involved, different smoking habits would be much rarer in identical than in non-identical twins. Mathematical analysis of statistics on the smoking habits of twins from England and Germany strongly suggest that a genetic effect is present. The evidence becomes even more impressive when identical twins are compared in two groups, those brought up together and those separated at birth: the ratio of pairs with similar to those with different smoking habits is not affected by separation.

By the time statistical comments were made by one of the founders of modern statistical methods, Sir Ronald Fisher, a powerful campaign against smoking had already been launched by the usual champions of public health. It is much easier to believe than prove a claim. Many would-be medical researchers can get a publication from hasty approval or condemnation of an insufficiently investigated matter. Others have the tactical sense to realise that a serious threat to a much-used product is bound to increase the flow of research subsidies both from the anxious authorities and the industry in danger. Finally, some officials cannot resist the temptation to ban something the people are using or to compel them to accept yet another instance of mass-feeding, mass-diagnosis or mass-treatment. Sir Ronald Fisher was answered by what he termed *'eloquence'*; the technique of argument by modern publicity is best described in his own words:[18]

'*. . . a simple assumption, which* might *have been true* (*though the first factual evidence at once showed it not to be*) *is progressively built up into confident assertions that both my method and my results were erroneous; and as it is built up, so it is progressively ornamented. The public should not think that publicity, even if supported by the Ministry of Health is always aimed at* improving *public knowledge.*'

The high probability of a genetic link does not exonerate smoking. The main evidence on which the fear of tobacco is based comes from the surveys of Hammond and Horn in the United States and Doll and Hill in Britain; the former team interviewed nearly 200,000 white men of fifty to sixty-nine years and followed up nearly all the cases. The latter sent circulars to 60,000 doctors of whom 40,000 replied. Both surveys presented the same kind of *prima facie* case: cigarette smokers provided more than their expected average share in deaths from lung cancer; the incidence increased with heavy smoking; the smoking of cigars and pipes did not seem to be associated with incidences high above expectation. Some minor features of these and similar surveys can be criticised but the data are generally accepted. They are properly regarded as a serious warning against possible risks, but there is no scientific justification for regarding good *evidence for association* as *proof of causation.*

Some support for the anti-tobacco hypothesis came from a careful Norwegian survey in which a distinction was made between two types of lung cancer, one 'avoidable', i.e. due to external causes, and another one 'unavoidable', in the sense of originating from latent defects in the patient's cells. The ratio of 'avoidable' to 'unavoidable' was about 1.5 for non-smokers suffering from lung cancer but rose to 10.4 through different degrees of heavy smoking. This is impressive enough until one realises that the categories 'avoidable' and 'unavoidable' beg the question. Any set of data can be sorted out and provided with suggestive names to prove anything. For instance, if the Norwegian workers had decided to oppose the anti-tobacco hypothesis, they could have switched the names round, thus lending strong support to the hypothesis that heavy smoking merely reflects some physical defect but does not cause it. All this would be clear if one really used transparent terms such as 'avoidable' and 'unavoidable'; the actual terms, 'exogenous' and 'endogenous' respectively, are less likely to be spotted by laymen except for the minority whose common sense is backed by classical training.

Data of the unquestioned surveys have been used to refute the anti-tobacco hypothesis. If it is true that cigarettes are to be blamed, this lets tobacco out since it appears relatively harmless on its own, as in cigars and pipes. To defend the hypothesis it was assumed that arsenic in Virginia tobacco or the light fermentation of this type is responsible for its carcinogenic effect. Such *ad hoc* assumptions usually do more harm than the honest admission that our knowledge is insufficient to pass a final verdict. In fact it turned out that Turkish tobacco is relatively free from arsenic (a poor nation cannot afford to save crops by poisoning customers) and well-fermented, but lung cancer is common among the heavy smokers in Turkey.

Research had to switch to a study of cigarette paper. Machines were constructed to chain-smoke hundreds of cigarettes and to collect the volatile matter for analysis. Substances known to induce cancer in mice have been found in the tar formed in burning cigarettes, but only in amounts which one normally inhales from the air of industrial cities. Furthermore, only 5% of these potentially dangerous substances were due to the cigarette paper. This puts the blame on tobacco again, but there is the uncomfortable witness of cigars and pipe for the accused!

It was suggested then that the hottest portion of the burning cigarette is much hotter than the comparable portions of cigars and lit pipes. Why this should cause cancer of the lung rather than cancer of the lip or tongue which are more directly exposed to the heat and to the products it may generate is unknown. Some excellent chemical research projects are devoted to this problem, but none of them is likely to be completed in the near future. Undeniable association between lung cancer and polluted industrial air, exposure to petroleum products, registration of cars, use of coal and other factors evidently related to tar production still require investigation.

Lung cancer is also associated with radiation, arsenic, the mining of haematite (an iron ore) or asbestos, industrial exposure to chromates and to some drugs that can inhibit other forms of cancer. The first of these has led to a study of the role of potassium present both in the ash and the smoke of cigarettes, since a small fraction of naturally occurring potassium is radioactive. It appears, however, that the extra radiation to which the heaviest smokers are exposed is a small fraction of the normal radiation which affects all.

The exact nature of the substance that causes cancer of the lung in many (but not all!) heavy smokers need not be known to make the danger of cigarette smoking very probable. But if we assume that cigarette smoking attacks the lung, we cannot easily avoid the conclusion that the agent will be more effective if inhaled than if only blown about on the lips. Unfortunately for the anti-tobacco hypothesis, smokers who inhale are significantly less affected. According to Sir Ronald Fisher's analysis of data which are supposed to 'prove' that cigarette smoking 'causes' lung cancer, the same data can be used to establish with a high probability that inhaling 'prevents' lung cancer. To quote Sir Ronald:[19]

'Those who refuse the jump from association to causation in the case of cigarette smoking will not be tempted to take it in the case of inhaling; but the Medical Research Council and its Statistical Research Unit think the argument is valid in the first case. Can they refuse to admit it in the second?'

Here the matter rests for the moment. One has every right to suspect the dangers of smoking, and it is rational to avoid an unessential risk. On the other hand, it is intellectually dishonest to speak of proofs where only suspicion exists, especially when the evidence in support of it is not altogether consistent. The danger of claiming proof on insufficient or unsound evidence is that we persuade ourselves and the community that looks to our profession for knowledge that we know enough. This untruth paralyses professional interest in detecting the unknown truths of the matter and encourages laymen to abdicate their right and duty of individual responsibility in favour of ignorant men who pretend to knowledge. If this helps scientific mountebanks and their publicity experts towards totalitarian authority, the threat to individual and public safety exceeds that of the further increase of lung cancer. On the other hand, the manifest failure of wrongly claimed knowledge brings into disrepute honest scientists and turns the community away from the sound fruits of valid knowledge.

The moral for the layman is not to rest satisfied with the claim that 'statistics have proved this or that'. Statistics never prove, only permit estimates of probabilities of certain guesses. Always ask what guarantees the reliability of data used for statistical purposes? Try to think of a rational implication (e.g. inhaling in the case of smoking), then ask the nearest 'expert' what work has been done to test the implication. If he has an answer, keep on asking who (name and qualifications) has done the work where and when. Take careful written notes of the reply. Most 'experts' admit at this stage that their enthusiastic positive assertions were inspired by unbounded faith and narrowly limited knowledge. Others will defer the argument until an opportunity to 'consult their files'. Leave your address with them and ignore their views until they remember to provide satisfactory information. The answer may not help directly but your action will pay dividends. Searching demands for specific answers will put some scientists-by-the-grace-of-publicity out of business, and will force rash potential scientists to read the claims they are publicising. Many a scientist has changed his views when he began to read and think about all the wisdom he had dispensed to unsuspecting laymen in the course of years. Every scientific swindler who discovers his intellectual conscience is a gain to a community longing for well-founded safety. Good foundations for houses, bridges and scientific procedures need their own time, which cannot be shortened to save individuals from the discomforts of impatience.

9 The Safety of Radiation

Man had millennia to learn of dangerous foods and centuries to get used to locally prevalent poisons. Radiation is a new threat to which human minds and bodies are not yet accustomed. Roentgen discovered X-rays in 1895. Becquerel's discovery of radioactivity came a year later, and that of the first highly radioactive elements, radium and polonium, by the Curie couple in 1898. Metallic radium was not isolated until 1910. Roentgen received the Nobel Prize in 1901; Becquerel and the Curies were similarly honoured in 1903, but their discoveries did not become important parts of medical curricula at once.

Doctors graduating at the time of these great discoveries started practice without any knowledge of radiation, and reached the zenith of their professional and social influence during the third decade of the century. Some uses and dangers of radiation became common knowledge during this period but others were not suspected even by leading authorities, whose lectures and text-books continued to influence medical thought years after the retirement or death of the masters. University lectures and text-books are means of transmitting knowledge, but when such knowledge is implanted in minds looking for dogma rather than living, dynamic truth, and when it is not supplemented by wide and systematic reading, the effect amounts to transmission of ignorance. Many doctors are too busy to read after graduation; this makes them as unsafe as a primitive man deposited among modern machines and allowed to operate them on 'familiar principles'.

The diagnostic value of X-rays was quickly realised but data on their dangers accumulated slowly. Hundreds of pioneers of radiology had been killed or crippled before the early twenties when standards of safety and methods of protection began to be studied.

Much has been written about the early medical victims of X-rays. Injuries to patients exposed by eager physicians to the latest scientific toy are less widely advertised, even though a number of cases are known of X-ray burns, often followed by amputations. One year after the discovery of X-rays an article in the *Lancet* advocated their use as a substitute for shaving, and the removal of hair by X-rays was practised by doctors and quacks alike. Treatment of cancer by X-rays was also attempted one year after Roentgen's discovery, but the first survey showing that cancer caused by exposure to X-rays may take four to fourteen years to become recognisable was published in 1911.

X-ray apparatus was easier to obtain than radium, not to mention less accessible radioactive elements. Thus most of the radiological experience of the first third of the century relates to X-rays. Pierre Curie suffered radium burns but was killed in a street accident well before the average time required to develop malignant disease. Madame Curie and her scientist daughter Irene died prematurely from leukaemia, one of the serious effects of over-exposure to radiation.

The dangers of radioactive emanation (now called radon) were recognised by Curie who saw experimental animals killed by short exposure to it. During the following decade some doctors in Europe and the United States assumed that radioactivity, a natural source of energy, would be beneficial. An American company exploiting this unfounded guess, made in blissful ignorance or contempt of Curie's data, claimed over 150,000 customers. A summary in the *Journal* of the American Medical Association published during 1913 reported results of medical treatment of over 1,000 patients with radon. The value of the treatment was claimed by a number of doctors to have been '*unquestionably established*' against arthritis, rheumatism, gout and many similar complaints. The improvements claimed were over 80%, quite a lot better than the 60% usually claimed by advocates of fluoridation.

Since the value of radium treatment had been thus 'established', an influential American doctor strongly recommended the method. Medical records show that thousands of patients were given large oral doses of radium salts, others (children included) were treated with intravenous injections.

A medical article in 1916 stated:[20] '*Radium has absolutely no toxic effects, it being accepted as harmoniously by the human system as is sunlight by the plant.*'

The use of radium spread to treatments of circulatory, nervous, endocrine and other disorders, also of venereal disease. Radium treatments were listed in 'New and Non-official Remedies' by the American Medical Association in 1932. The same association's Council on Pharmacy and Chemistry took a stand against intravenous injection of radioactive thorium oxide in 1932 but was not prepared to condemn it altogether. The substance is still in use under the name of thorotrast; it is being administered in doses corresponding to seventy to eighty times the allegedly safe limit.

As cases of death and mutilation through medically administered radioactive substances were accumulating, Dr Harrison S. Martland was one of the first to warn against radium therapy. Ridiculed in 1925, in 1931 he was ignored by 'research workers' at a state hospital in Illinois who injected thirty-nine psychiatric patients with large doses of radium in the hope that '*radioactivity in the living body might result in some benefit in certain psychoses*'. The difficulty of Dr Martland has been that even relatively large doses of radium can have long delayed effects.

Painters of luminous dials with paints containing radioactive substances took ten to twenty years to develop cancer. Similar delays were noted in victims of radioactive injections and tonics. Like every other pseudo-scientific fancy that captures the imagination of the medical profession, radium was 'safe' until there were too many victims dying horrible deaths from radium poisoning. The extent of the butchery by radium did not become generally known until after 1940.

A few years earlier the advocates of radioactive psychiatry could write:[21] '*Previous researches on the rate, manner and completeness of the elimination of radium from the body convinced us of the harmlessness of our dosages. We therefore were certain not to injure the health of patients.*'

This is an important passage to remember as the standard defence of any medically administered or tolerated poison that does not cause dramatic effects soon enough after application to land the physician or health authority in court.

'*Previous researches, etc.*' sounds good. Unfortunately researches of this nature are not always recorded in reputable journals. On the contrary, the retention of many radioactive poisons is well established. In general doctors are 'certain' that their treatment is to the advantage of the patient but their certitude about hitherto undetected consequences are no better than those of anyone else equally ignorant. It is interesting to speculate upon the effects of a municipal council, convinced by medical certitudes and the unspecified 'previous researches' of medically qualified investigators, deciding to add radioactive salts to the water supply. Everybody 'knew' that radioactivity was '*natural, safe and beneficial*'. It had the approval of '*eminent medical authorities*'. Only '*scare-mongers*', possibly with '*wrong thought processes*' (p. 19), would talk about future effects. The already known cases could be ignored in view of the much-quoted but little specified 'previous researches'.

It may discourage lovers of safety, but will give heart to advocates of progress by means of enthusiastic administration of insufficiently investigated remedies, that those who countenanced or practised delayed murder by radium escaped prosecution or censure. Some of them are still convinced of the safety of radioactive salts. It is said that the practice survives in the United States where radioactive contraceptive jellies were promoted a few years ago.

The use of diagnostic radiology needs some consideration because of the aspect of compulsion. Tuberculosis of the lungs, once a widespread disease, has become rare in the more advanced countries. However, it has retained its dreaded reputation, with the result that campaigns against tuberculosis attract more electoral votes and charitable donations than a serious attempt to tackle some more prevalent and less readily cured or controlled diseases. On the other hand, it can be said that there is some wisdom in trying to eradicate one disease before attacking the next. If the vote-catching aspects of present procedures could be disregarded and if Health Departments were advised not only by 'authorities' and 'experts' but also by some with, say, five years' training in the fundamental sciences, the fight against tuberculosis would start with a biochemical screening process. This would be safer than irradiation but would not definitely detect the disease. The small group of suspects could then be examined thoroughly to detect also tuberculosis of organs other than the lung.

Admittedly this would be a slow procedure compared with mass-radiology which is probably the best known means for the quick detection of sufferers and their prompt elimination from society. To most victims of tuberculosis, detection spells economic and professional ruin, often with the break-up of the family, but the destruction of the few for the safety of the many has been a fundamental principle of good government for centuries, and the only problem to be considered for the moment is whether the process whereby the new lepers are weeded out from those in blooming health is at all likely to inflict disease on the non-tubercular majority.

Radiation can be measured in different ways and in different units. For our purposes a commonly used unit abbreviated *r* (for Roentgen) will be satisfactory. In principle an exposure of 0.05 *r* should be sufficient for a chest X-ray. It is known that effects of radiation accumulate and that the proverbial straw that broke the camel's back has a radiological analogy. However a life-time's ideal chest X-rays will add up to 3 *r* only, when something like sixty years' combined experience in radiology has satisfied optimists that up to 25 *r* in one exposure and 200 *r* accumulated over sixty years are not likely to produce effects detectable by known means. This does not amount to 'absolute safety' but to the bargain of a small risk against a high probability of being saved from further contact with carriers of tubercular infection, which obviously cannot be declined because one must satisfy his neighbours that he is not a menace. Lack of similar action against sufferers from more common and more dangerous diseases is irrelevant to the argument this side of emotion.

The risk of a chest X-ray is not due to the dosage one is supposed to get but to the uncertainty of the one actually administered. Some X-ray units deliver twenty times the ideal dose. The time of exposure matters; in the absence of automatic timing devices the dose may depend on any matter entering the operator's mind and slowing up his reactions. If the operator is clumsy, the exposure may be spoiled and a repeated exposure becomes necessary. If the operator is untrained or, worse still, rendered unaware of his radiological incompetence by his thorough training in other branches of medicine or dentistry, the patient may receive a dose insufficient to induce radiation sickness but high enough to harm white blood cells. According to the American College of Radiology about one in thirty of the professional users of X-ray equipment have '*the comprehensive training of radiologists*'.

Since even gross incompetence in operating chest X-ray equipment is practically undetectable but may have serious consequences, and failure to attend chest X-rays is taking the place of the old offence of not attending church on Sundays, one wonders what rights to safety the layman may claim. Automatic devices would go a long way towards minimising serious harm. Another measure would be the insistence on high professional qualifications in attendants of X-ray apparatus. Such qualifications should be made public, and the person compelled to suffer irradiation at the hands of an unknown person should have the right to demand some proof of his qualifications. Laws do not offer much protection even to victims of rapidly developing heavy damage by X-rays, as the plaintiff would be expected to produce medical evidence, which would amount to one doctor testifying against another. This is possible in principle, but 'unethical' in practice unless good reasons exist for the profession wishing to get rid of the defendant. Claims for insurance may eventually involve doctors in the same manner. Perhaps a profession of radiological scientists without medical qualifications would help if and when courts came to accept their standing as equal to that of a medical graduate or licentiate without much scientific training.

In one respect compulsory chest X-rays represent a danger far greater than the remnants of tuberculosis. Radiation passing through cells is similar to a volley of shots fired in a street. A few bullets fired on odd occasions may not do much damage, many or frequent shots are more likely to cause irretrievable harm. At the same time a single shot may by an unlucky chance blow up a tank of petrol and thus destroy the town. Although the police may be given the right to shoot in an emergency, it is usual to discourage gunplay in the streets. The analogy with radiation is not perfect: the seriously injured cell does not react by an immediately recognisable catastrophe, and even the long-range effects need not produce a recognisable change in the body to which the affected cell belongs. However, the damage may be transmitted to the next generation. In the fully formed organism a single defective cell is surrounded by millions of normal ones. The new creature is conceived by union of two parental cells; if one of these is damaged, 50% of the foundation of a new human existence is faulty.

Apart from X-rays or industrially produced radioactive substances a person is exposed to cosmic rays and radioactive elements distributed all over the earth. This causes a certain amount of *mutation*: some children are born with new properties not found in their ancestors. It has been estimated that in the United States, where the average person accumulates 5 *r* from the natural background in thirty years, 16 million mutations occur in the 100 million children of the country; medical examinations contribute 10 *r* more but the much-dreaded nuclear fall-outs only 0.5 *r*. Not all mutations are objectionable but about 2% of the children born in America are deaf, blind, malformed or mentally deficient owing to some mutation preserved or brought to light by the processes of heredity. Not only would an increase of radiation increase the number of defectives in the first generation, but further breeding would add to the number.

The fight against tuberculosis in the United States aims to reduce the 16,000 deaths a year due to this disease. Compulsory chest X-rays would not detect, and thus prevent or delay, more than 90% of these cases, since 10% of tuberculosis lesions do not affect the lungs. The minimum radiation load in respect of these diagnostic X-rays would amount to 1.5 *r* over thirty years; this has been calculated to be equivalent to about 7,000 defective American children in the first generation, eventually contributing to major defects in 70,000.

These figures are low estimates. Chest X-rays account for 15-20% of medically produced radiation, only three times as much as nuclear explosions against which lovers of regimentation like to protest in a dramatic manner. The remaining types of medical radiation are not discussed because most of them are not generally compulsory for the time being and are justified by the reasonable choice between preserving a life now and avoiding the birth of a defective child in so many generations. There is, however, sufficient compulsion in some cases to make the layman aware of problems that have been solved only by the standards of professional complacency but not by 'previous research' of scientific quality.

Armed services or employers may order recruits or new employees to undergo a more thorough X-ray examination which could expose them to double of thirty years' combined natural, medical and nuclear radiation dose. Dental X-rays may expose the patient to anything between 5 *r* and 150 *r*. Few of those exposed to the highest dose would suffer radiation sickness but children are more sensitive to radiation than adults and the consequences of genetic damage are more serious when young people are irradiated. Dentists do not compel by law, but a hint that they cannot do their best without using the expensive

X-ray machine amounts to compulsion which is difficult to resist. Most dentists have X-ray equipment, but not all of them know the dose of radiation it produces. Not all dentists use filters; careless handling of X-ray apparatus could shorten their life-span by up to four years without producing notable symptoms. The daily dose robbing a highly trained man of something like 10% of his professional life can be as little as 1/15,000 of a lethal dose. This is to be kept in mind when safety of any health measure is proved by lack of symptoms and the smallness of the proposed dose in comparison with a lethal one. Radiation (unless administered in the form of radioactive substances) does not accumulate as such, but its effects do: a door does not accumulate the hammer that strikes at it, only the blows to which it may yield in time.

Radiation has many important medical uses and it would be a mistake to renounce its benefits. Scepticism of the layman should not be directed against radiation as such but against the men who use it. Well qualified men are relatively safe if one can check their qualifications and certitudes. But turn them into 'experts' or 'authorities', give them immunity from questioning, help them to evade the rigours of scientific evidence, and you will forfeit not only your own safety but that of untold generations to come.

10 The Safety of Fluoridation

Fluoridation is the treatment of communal water supplies so as to increase the concentration of soluble fluor*ide* to a certain level, e.g. 1 part in 1,000,000 parts of water (abbreviated to 1 p.p.m.). Fluor*ine* is a pale-green gas, difficult to handle and extremely dangerous: exposure to it is thought to have shortened the life of its brilliant discoverer, Henri Moissan. Fluorine reacts violently with water: nobody in his right senses could advocate its use for fluoridation. Fluor*ides* are compounds of fluor*ine,* and are relatively easy to handle. Hydrofluoric acid is a fluoride that corrodes glass and some metals. Its use for fluoridation is not practical because of the expense, difficulties of transport and appreciable health hazards, but it is present in very low concentrations when water is fluoridated by safer means, and is partly responsible for the high rate of corrosion in municipal pipelines that carry fluoridated water. Copper or nickel piping could overcome this difficulty as a matter of engineering technique, but the cost of such pipes could be afforded by oil sheiks only, not to mention health hazards accompanying their use.

The materials commonly used for fluoridation are sodium fluor*ide* and calcium or sodium *silicofluorides.* Condemnation of them with reference to the toxicity of fluor*ine* is sheer nonsense. After all, both sodium and chlor*ine* are dangerous elements but their compound sodium chlor*ide* is ordinary cooking salt. Potassium is a metal even more dangerous than sodium; corrosive, dark iod*ine* is known to many in the form of antiseptic solutions; but potassium iod*ide* is a white crystalline substance, distributed (greatly diluted) in pills to control endemic goitre. Sodium fluoride and silicofluoride are being used as poisons against insects and rodents; this is not sufficient reason to condemn their use in appropriate doses for medicinal purposes. Morphine, quinine, tubocurarine, etc. are dangerous poisons in certain doses but valued medicines in others.

When sodium fluoride is dissolved in water it separates into two parts: sodium *ions* and fluoride *ions*, electrically positive and negative particles respectively.

The sodium ions formed when sodium fluoride is dissolved in water are exactly the same as those formed when sodium chloride is dissolved. The fluoride of the metal calcium, calcium fluoride, a common natural source of fluoride, is hard to dissolve in water. When solution occurs, ions of calcium and fluoride are formed; the latter are the same as those formed from sodium fluoride. Sodium fluoride is usually obtained from industrial sources, but the fluoride it releases is no more toxic or beneficial than that released from a natural sample of calcium fluoride. Claims of differences of efficacy or safety between 'natural' and 'artificial' fluorides flow from ignorance of elementary chemistry.

The difference between natural and artificial fluorides is variability (p. 84). Fluoridating equipment can break down; automation intended to ensure that fluoride concentration remains at a set level responds also to constituents other than fluoride and does not reject, say, cyanide added by mistake. Where fluoridation to 1 p.p.m. is undertaken without a proper water-treatment plant the concentration may vary up to 10 p.p.m.

The safety of an artificially fluoridated water supply is dependent on the engineering standards of the community. It is a very different thing advocating fluoridation in Sweden, Germany or the Netherlands, where technical efficiency can be taken for granted, from introducing it in a colonial town where fluoridation is approved concurrently with break-downs of a pumping system and a 'baffling' defect of a suburban reservoir which threatens to flood the neighbouring homes. Whatever the merits and demerits of fluoride, fluoridation should not be undertaken by a community which cannot be trusted to pump or store ordinary water. Some large American industrial centres (Schenectady, N.Y., Acron, Ohio etc.) have discontinued fluoridation because of damage to pipes and boilers or breakdown of the fluoridating equipment.

The distinction between safe organic and unsafe inorganic fluoride does not rest on scientific evidence. Fluoroacetic acid, an organic fluoride present in a South African plant, is one of the most dangerous poisons, far more dangerous than any of the inorganic products used to fluoridate water. There are organic fluorides which are less toxic than the common inorganic fluorides (the freon charge of some refrigerators is of this nature), but lack of toxicity usually goes with lack of medicinal effectiveness.

Levels of toxicity and medicinal value vary from person to person. Against this objection to the same compulsory dose for all, it is asserted that fluoridation does not give a common dose: people regulate their own dose through drinking water according to their needs. But if it is true that children benefit most from fluoride, and taking for granted that toothless persons do not need fluoride at all, one would think that children need more fluoridated water than their elders. However, adults drink more water than children, so that fluoridation is a way to ensure that those who need little get much fluoride and vice versa. Administration of pills and drops *as required* is the only way to avoid doses inversely proportional to need.

Scientists not hostile to fluoridation admit that the essential nature of fluoride has not been proved. The layman can decide for himself: if fluoride were really essential one could not live without it. This is obviously false; people have lived in places now recommended for fluoridation since times immemorial. The perfect teeth of some communities deteriorate when progress catches up with them. Does progress diminish the fluoride content of natural waters or merely create a need for more fluoride in the diet? The former is unlikely; the latter is a possibility. Does every person living in a modern but unfluoridated place have bad teeth? Certainly not. On the contrary, the good teeth of the unfluoridated can be a great embarrassment to fluoridation.

Fluoridated Grand Rapids was provided with an unfluoridated control, Muskegon—in deference to scientific usage. When teeth in the control area were doing too well, Muskegon was fluoridated in 1951. The same happened in New Zealand where the control was fluoridated on the principle '*better a bad experiment than a good one that proves you wrong*' (p. 40).

From a scientific point of view, problems of the safety of food, drugs and artificial radiation are more important than that of fluoridation. They have attracted creative contributions from leading scientists on such a scale that the remaining controversies call for more detailed information rather than reassessment of the validity of existing knowledge. The safety of smoking has a much less distinguished literature but it also relies on unquestioned data. On the other hand of the thousands of publications devoted to fluoridation, few are fit for publication in first-class scientific journals. There is not one major paper or book setting out the whole evidence in favour of fluoridation written by a scientist whose standing has been established in other ways and who therefore need not defend fluoridation as his only claim to fame. On the other hand, the biological effects of small traces of fluoride figure in many outstanding publications by eminent scientists, some of whom oppose but none of whom support fluoridation. Opposition from Nobel Prize winning scientists does not appear in leading scientific journals either, but one cannot seriously criticise something that has not been put forward seriously. As soon as major work on fluoridation reaches a standard acceptable for publication by a scientific body, scientists will take over the dispute which has been envenomed, but not steered closer to agreement, by laymen with vested interests.

Magical powers claimed for fluoride against unrefuted principles of pharmacology, biochemistry, statistics or even ordinary arithmetic were publicised in a manner unusual in scientific circles. Still more unusual was the pressure put on American dentists (cf. p. 67). They did not have to support fluoridation, but it became unethical to condemn it in public, and dentists were deregistered for not accepting unscientific claims. The official excuse was that such men had criticised the dental society which supports fluoridation; such disloyalty rather than criticism of fluoridation justified their punishment. Galileo too was punished, not for his criticism of the Ptolemaean astronomy, but for his disloyalty to the Holy Office which at the time happened to support the Ptolemaean system. Whenever a Holy Office has to be called into action in defence of a proposition, one may safely assume that the matter does not rest on scientific evidence.

Agreement *after* criticism is the main authority in science (cf. p. 72). When criticism of a measure is suppressed by threats to one's livelihood, the alleged agreement of American dentists is just as good an argument for fluoridation as the 99.99% polls for Hitler and Stalin used to be for Nazism and Communism. Dictators, inquisitors and hatchetmen in white sometimes use terrorism to defend truth, but truth protected against criticism deprives men of knowledge, leaving them with the hypocritical variety of faith. This unscientific, authoritarian approach is the greatest threat of fluoridation.

Scientific publication is not the only method of proof in science; a practical demonstration is as good if not better. Unfortunately the benefits of fluoridation are very difficult to demonstrate. You can be shown children with good or bad teeth (pp. 59-60). You can be told that they had or did not have fluoride; the information will come from one who has been told that someone else had analysed a sample of water. In American cities you may, but in small provincial settlements of Australia, you cannot assume that the children have been drinking the water that had been allegedly analysed, or that the water they have drunk had the same fluoride content as an analytical sample drawn once daily or weekly from an imperfectly mixed solution. Since some children without fluoride but on a good diet have good teeth, and others with fluoride and bad genes or hygiene have bad teeth, the few children you have seen prove nothing either way. The population of children could be ascertained with sufficient accuracy, but it would be difficult or impossible to decide whether the children displayed to you had been properly sampled or picked to prove a point. The observations cannot be duplicated by independent investigators. To sum up: a few trivial facts + second-hand assertions + assumptions of dubious validity + a mathematically untrained dentist's idea of statistically significant sampling = evidence for the benefits of fluoride. This kind of sum has been tried on municipal councillors, politicians, journalists, TV stars, trade union leaders and judges; with them and everyone else professionally confident of being right it usually works.

It does not work with scientists. They are like the child in the retinue of the duke for whom the rascal, Till Eulenspiegel, was painting a picture which was to be visible to the good but invisible to the wicked. The courtiers were good and claimed to see the imaginary picture; thanks to them Till Eulenspiegel was richly rewarded. The child was soundly spanked because he could not pretend to see what fooled the others and thus proved himself wicked. The number of dentists acting as Till Eulenspiegel is very small, probably not more than a few hundreds. The gullible worthies number thousands, the sceptical wicked scientists likewise. The millions of laymen are still undecided whether they wish to be fooled or smacked.

A new actor appears in the modern version of the prank, the blind man who thinks he can see the invisible picture but dislikes its style; that is, the eccentric who disapproves of fluoridation to the accompaniment of few facts, second-hand assertions, assumptions of dubious validity and a scientifically untrained orator's idea of all the sciences, which together are taken to equal evidence against the benefits of fluoride.

In a fluoridated city the fluoridator counts good teeth, unbroken bones and survivals to three-score years and ten, crediting the lot to fluoride. His anti-fluoridating counterpart has his own 'statistics' of bad teeth, fractures and funerals, blaming them all on fluoride. Both sides have their photographs to encourage or to warn. The fluoridators of Beaconsfield (with 100 children odd on fluoridated water and similar numbers drinking from tanks and wells) have wizard's eyes which can see which child abstained from unfluoridated tank water, well water or bottled drinks from the shop. The anti-fluoridator has a pendulum that performs special swings over poisons, and thus fluoride is shown to be poisonous. A film (produced at the taxpayers' expense) shows good and bad teeth, municipal fathers raising their hands in a kind of attenuated totalitarian salute, marching girls (with one pair of legs per person) and some rough chemical apparatus: this proves that fluoridation is good for you. Pamphlets about a Communist Conspiracy aided and abetted by the Elders of Zion prove that fluoridation is bad.

One part of the technique of publicising fluoridation is to contrast a few selected civilised statements made by fluoridators with the many weird assertions of their fellow-clowns from the opposing camp. This suggests to the public that the argument about fluoridation is merely a tussle between dentists and faith healers or Douglas Creditors. The opposition of Nobel Prize winners to fluoridation is not allowed to confuse the journalistic picture (pp. 16, 19).

The discovery of fluoridation started with a chemical comedy and a demonstration of the dangers of fluoride. Throughout the first three decades of the century American dental scientists, notably F. S. McKay, investigated the cause of discoloured, pitted teeth known as Colorado Stain, Texas Teeth or Mottled Enamel. The same kind of trouble occurred with sheep and cattle in parts of Queensland, but the men in charge of stock preferred more interesting drinks than bore water, and do not seem to have come to harm. Talks, dental meetings, investigations went on for about thirty years. Chemical analyses were fruitless, probably because most analysts are useful for routine work only, and really good ones are much rarer than more advertised varieties of chemists. Bad staining near bauxite mines of the Aluminum Company of America and lack of staining five miles away should have given an unmistakable clue to chemists connected with the aluminium industry. Indeed, in less than three years' time fluoride was detected in the offending waters and concentrations between 2 and 13 p.p.m. appeared to be associated with mottling, which was renamed *dental fluorosis*. The discovery was well publicised at the time, but any graduate in chemistry should have made it in one day any time after 1905 when J. Casares showed how to modify an unsatisfactory detail of analysis owing to which the fluoride content of waters had often been overlooked.

Five years earlier E. V. McCallum, the great American physiological chemist, already knew that fluoride alters the structure of teeth. This was elaborated later by H. V. Smith and his wife who produced good evidence to show that fluoride was responsible for mottling. Many years later the Smith couple first opposed hasty fluoridation, then gave qualified approval but remained 'lukewarm'.

A number of precursors had suggested the use of fluoride against dental decay, but it was H. Trendley Dean's claims in 1938 that caught the imagination of powerful Americans. Dean noted that in some small settlements fluorosis ruined the teeth but the incidence of dental caries was low. He proposed that there might exist a concentration of fluoride which reduces dental decay without causing serious mottling. The hypothesis was reasonable but not easy to test (p. 29). Animal experiments remained inconclusive because workers for and against fluoridation tried direct comparisons that were clearly inapplicable. Modern investigators seem to have forgotten the centuries-old story of antimony which found its way into the pigs' food. The pigs grew fat, and it was decided to try the stuff on excessively lean monks; unfortunately the monks died.

In 1939 a biochemist called Cox suggested fluoridation as a mass-treatment, well before any evidence as to the efficacy and safety of the measure. During the next few years 7,000 children were 'selected' from twenty-one cities with fluoride contents allegedly between 0.1 and 2.5 p.p.m. In 1943 Dean called for investigations to exclude the danger of harm from slowly accumulating fluoride, but a year earlier the U.S. Public Health Service had already *assumed* that 1 p.p.m. fluoride was 'safe', and plans were made to commence mass-fluoridation. In 1944 toxicity tests were regarded as 'negative'. Grand Rapids was fluoridated in the same year, Newburgh a year later. Five years later efficacy and safety and all were regarded as 'proved'. Let us think of the forty years odd required to show up dangers of cigarette smoking or twenty years odd to settle the safety of radium injections with crippled corpses. Artificial fluoridation is not quite nineteen years old at the time of writing but it was 'safe' before it was tried!

Anti-fluoridators make much of the report that Dean, the father of fluoridation, admitted in a Chicago court that some data in his early report were fictitious. If fluoridation had anything to do with science, all the work linked with fictitious data would be rejected. On the other hand, so little attention has been given to details of fluoride analyses in surveyed areas that the fundamental variable in the famous fluoride surveys is quite unreliable and the data are no more valid than if they were frankly fictitious.

The value of older analytical data on the fluoride content in human and animal tissues or even in river water is open to doubt. Even today it is possible to pick analytical methods to give low or high figures. Dental statistics compiled by people who are not aware of this problem are of little value. After all a 'proof' of the virtues of fluoridated water is meaningless if the fluoride is not present or if the 1.0 p.p.m. analysis in the fluoridated area actually corresponds to a concentration of 0.2 p.p.m. in an unfluoridated city tested by a different analytical method. I have been informed by a very competent chemist that in analysing the fluoridated water of Beaconsfield the results do not come out right if one uses distilled water for blank instead of the local product. Now a dental survey has to be taken on the dentist's word, but a chemical analysis must be such as to satisfy every doubting Thomas. One need not be a professor of scientific method to see the nonsense of compulsion on the strength of results resting on analyses which rely on the use of a special brand of water with the help of which the results justifying compulsion are obtained.

Worse mistakes were made when testing the benefits of fluoridation. Instead of a properly designed, controlled, bias-free experiment (pp. 38-40), a number of tests were carried out on the Barnum-Hollywood scale by amateur scientists in Canada and America. To those used to proof by logic, mathematical statistics and experiments capable of duplication, two things only have been proved by these much-quoted experiments: the investigators (i) wished to demonstrate the value of fluoride and (ii) did not believe in its value.

Controls (p. 41 ff.) were chosen so as to guarantee results able to favour fluoridation. Fluoride was invariably administered to the healthier of the two centres, the one with better mineral supply or better standards of dental hygiene, leaving the obviously less favoured community as 'control'. In Evanston (p. 51) test and control subjects had to be reshuffled after the start when the 'investigators' realised that they had left people with better teeth as controls. Had scientists been in charge they would have deliberately chosen a distinctly worse area for fluoridation against a control with superior dental health, especially if they expected fluoride to win (pp. 43-44). The juggled and fiddled surveys leave us in doubt how much of the claimed benefits was due to fluoride, how much to lack of calcium and magnesium in the 'control' area, how much to racial and economic differences and how much to dental care. As an instance of the latter, in fluoridated Philadelphia children's teeth are treated by dentists anxious to show the world what fluoride can do. Prophylactic minor operations are performed, the children's diet at school is supervised, and, of course, they drink fluoride and bathe in it. Assuming the teeth are good, what is the reason? Dentistry, diet or fluoride? An investigator who honestly expects a certain result need not spoil his case by too obvious a bias.

Nothing anti-fluoridators or scientific sceptics could hold against fluoridation compares with the fluoridators' description of their march to victory by Donald R. McNeil.[22] His book must be read by those interested in the subject to get the picture of haste, intrigue and the slick outmanoeuvring of the few who tried to approach the problems of fluoride in a scientific fashion.

Before accepting the usefulness of fluoridation, one would like to know how it helps children of different ages and how the results shape towards the end of childhood. An honest answer would require not less than seventeen to eighteen years, a scientifically significant answer possibly twice as long. But our enthusiastic investigators—'*when they were able to chart a lower decay rate within five years, they believed they had the neces-*

sary facts to proceed with mass fluoridation'.[23]. Note '*facts*'. Also that this kind of science was good enough to get the approval of the U.S. Public Health Service a year later. A little intrigue neutralised Dean and other cautious fluoridators and earned the approval of the American Dental Association. A year and a half after this event, still decades before one could speak of scientific evidence, Dr Allen O. Gruebbel, the A.D.A.'s secretary of the council on dental health, '*summed up the A.D.A.'s attitude toward Frank Bull and his hard working colleagues in Wisconsin. Though they urged fluoridation "long before the results of the trial projects were known", and though some scientists have said that it would have been "tragic" if they had been wrong, Gruebbel said, "the evidence now shows that Dr Bull and his colleagues in Wisconsin were right".*'[24] What were they right about? '*They knew the value and the methods of political procedure and stubbornly maintained a steady pressure on their professional enemies.*'[25] No wonder politicians favour fluoridators against the common variety of scientists.

Fluoridators themselves do not know how or why fluoride works its magic. They have a number of 'theories', meaning guesses, which biochemists working together with dental scientists may prove or disprove one day, unless laws are passed to protect fluoridation from all criticism. Compulsion at present is like being forced to move into a house just when the contractors are about to discharge the bricks from which it will be built. The few respectable results from fluoridating surveys suggest that concentrations of fluoride which cause moderate incidence of mild mottling delay dental caries due to too much sugar and white flour or to lack of oral hygiene. The delay is about two to three years, at the age of seventeen to eighteen the difference between fluoridated and unfluoridated teeth largely disappears. This has been claimed by Dr Weaver in England (in one of the few papers on the subject to appear in a reputable scientific journal). Results from Newburgh in the U.S.A. and Hastings in New Zealand lead to the same conclusion.

This benefit is not to be underestimated. A dentist friend of mine, an enthusiastic fluoridator, remarks with justice that deferment of dental caries to the age of seventeen to eighteen relieves the family man and shifts the financial burden of dental bills on the adolescent who is being overpaid these days. Also, at the age when vanity is a strong motive, young people are likely to seek prompt dental aid.

Apart from such considerations, it is possible that a genuine 10-20% inhibition of dental caries by fluoride could be demonstrated by scientific methods. The often quoted 60% reduction cannot be achieved just through picking children by biassed investigators; certain age groups must be picked too. The double-picked figure presented as 'average' has a good psychological effect, but outside the realm of fluoridating fancies, human beings are more variable in their reactions to medication.

What were the reasons that moved a number of professional persons in high positions to accept the unscientific claims in favour of fluoridation? Admittedly the cigarette scare had not broken and the radium scandal had not sufficiently sunk in, but there were many known examples of dangers detected decades too late. The Aluminum Company of America (ALCOA) must have been interested in selling industrial fluoride wastes to municipalities instead of dumping them expensively at sea or, at the risk of lawsuits, in rivers. If ALCOA had no such interest it was an unfortunate coincidence that its former legal adviser O. Ewing became one of the chief promoters of fluoridation through the Federal Security Agency in control of the U.S. Public Health Service. Research subsidies offered by industry on condition that results unfavourable to fluoridation are not to be published without reference to the donors could also be misunderstood. The magnitude of fluoride wastes in relation to population is less important in Central Europe and Soviet Russia, and fluoridation is a problem in the American sphere of influence only. However, it is unlikely that the possibility of sales of £35 million p.a. would have been sufficient for more than the creation of a favourable press and some satisfied key-men.

Pressure on dentists did not come until the majority of the profession was satisfied with premature claims. Mass-hysteria and the thirst for a gospel in a pagan age do not explain the attitude of fluoridators who ridiculed religiously based objections to coercion in the matter of food and drink.

Two explanations may be offered; if they are not more rational, they are at least more charitable than some others. One is the undoubted prevalence of dental decay in countries too rich for their own good. Dentists are aware of the extent of dental decay and of its effect on children. Even if one agrees that the cause of it all is too much sugar, ice-cream, chocolates, carbonated waters etc., one cannot shrug off the suffering of children with a 'serve their parents right', and one could plead emotionally: *'Let us save the children while they are children, never mind the consequences to adults.'*

The second argument for haste is the pragmatic attitude common in the English-speaking countries: right is what works or at least appears to work. Absolute safety may be spoken of in the course of political speech-making but we know it does not exist. Safety is what looks safe in terms of ambulances, funerals, court cases and insurance claims. Now it is little doubted (except by those who have seen the tricky ins and outs of public analysis) that many Americans live in large communities that use water containing rather more than the proposed 1 p.p.m. of fluoride. Whether they have better or worse teeth will be inferred when somebody has the courage to check the matter without biassed investigators. But there is little doubt that the general health and mortality rates from main causes (especially heart disease and cancer) are not significantly different in communities with or without a little fluoride. There is every reason to believe that fluoridation of a city will not justify lynching parties organised by bereaved survivors.

The problem of fluoridation is unique in the history of science. Never before has the need to justify administrative decisions affected the design and trustworthiness of supposedly scientific work; never before has compulsion anticipated scientific evidence and never before have political authorities rejected the advice of so many distinguished scientists in favour of amateurish claims. Irradiation, immunisation, chlorination of water etc. are compulsory measures in some countries, and opponents of fluoridation are often likened to those who oppose such compulsion. However, it is beyond doubt that X-rays can detect some cases of tuberculosis, that immunisation protects against certain diseases and that chlorine reduces the number of dangerous organisms in water. Such lack of doubt is the reward of scientific work, conducted without bias and exposed to rather than protected against criticism. Immunological reactions, the bactericidal action of chlorine and the use of X-rays can be demonstrated to any intelligent layman. On the other hand, the evidence for the efficacy of fluoridation is simply that a few people made claims that cannot be checked, and evidence of its safety rests on silence or prevarication. The Royal Society's motto (*Nullius in verba,* nobody's word is good enough) is accepted by critical scientists. Fluoridation rests on faith in the words of people little known or completely unknown. Lack of scientific status makes fluoridation comparable with the theological systems that used to be foisted by theologically untrained rulers on subjects who had no say in the matter.

States that insist on compulsory immunisation or irradiation will make exceptions for reasons of health. On the other hand, fluoridation makes the ingestion of fluoride, 100-500% above the present level of intake, practically unavoidable short of being forced into exile. Effective defluoridating apparatus is beyond the means of most people and cannot be operated without some technical knowledge. If the water is fluoridated without adequate purification it can cause the growth of algae or dangerous micro-organisms in the defluoridating equipment.

Installation of rain-water tanks is not a satisfactory solution. During droughts (common in Australian cities) the tanks will have to be filled with fluoridated water after all. Metal dissolved by water stagnating in tanks made from galvanised iron is more objectionable than fluoride. The owner of a tank must still avoid beer, cordials, bread, jam and other local products made with fluoridated water. He must also refuse to eat out or to accept hospitality. Many of the horrible consequences of anti-Semitism originated from social isolation through ritual diet. Fluoridation will create a ghetto for people who must restrict their dietary fluoride intake for reasons of health.

Similar remarks apply to the use of distilled water which will also deprive people of essential minerals. Private stills are unlawful even if only water is to be distilled. Commercial distilled water will force old age pensioners to ration a dietary necessity almost as essential as air.

However, the number of persons who will acutely suffer because they object to fluoridation is not expected to be large. With an 'I'm right, Jack, the devil take the hindmost', the credo of *Homo hygienicus,* we may turn to problems of fluoridation that affect the majority.

In a pragmatic sense, water containing 1 p.p.m. fluoride is safe in America. Fluoridation is quite another matter: its safety involves not only that of fluoride but also the skill, industry, care and technical competence of fluoridators. This concept of safety is crude; let us consider it from a more sophisticated angle.

The number of American fluoride-drinkers has been estimated as between 30 and 50 million; let us take the higher figure which is more favourable to the fluoridators' case. The uncertainty of findings on a sample of 50 million is its square root, 7,000 in round figures. In other words, when we think that 50 million fluoridated Americans are safe we are likely to be in error of about 7,000. Now 7,000 in 50 million is about the same as 1.4 in 10,000. Let us recall the discussion in the chapter on safety about the implications of an incidence of 1:100,000 observable by not more than 1% of the doctors at the best, or by a much smaller fraction on normal expectations (p. 82). If fluoride has been found pragmatically safe in a population of 50 million, it could have harmed 7,000 without having been observed by more than a small minority of critical doctors opposed to fluoridation. Clearly, safety has to be established more carefully.

The most useful way would be to survey the incidence of every possible minor and major ailment in fluoridated and fluoride-free America. Taking a modest thousand for the number of common ailments and keeping in mind that the damage could be slow to develop, there would be enough research projects to occupy tens of thousands of American doctors. In the absence of such surveys one may realise by accident only (as in the case of agene, (p. 92) that fluoride affects eyes, ears etc. in a way that is not obvious at present. As a matter of science, the onus is on fluoridators to show that nothing is affected by continued ingestion of fluoride, not even in a small minority of 0.01% or 0.001% (1 in 10,000 or 100,000 respectively). The dentists can answer by comparing the visible ravages of dental decay with unknown, possibly non-existent chronic damage, placing the onus on laymen to give examples of harm twenty years before any of the few current experiments can be completed.

A possible way to avoid the impasse is to study whether dietary fluoride is accumulating at all. Investigations of this nature are contradictory. Some investigators maintain that fluoride is stored at all levels of intake, even if it is as low as 0.4-0.8 milligrams daily; others claim that 95% of the ingested fluoride is excreted if the daily intake does not exceed 5 milligrams. These extreme figures (with many intermediate data from other authors) apply to 'normals'; aged people and those suffering from kidney diseases are said to excrete fluoride with less ease, that is to store it more readily. Proponents of fluoridation usually admit that an intake of 5 milligrams a day is excessive;

in fact dental fluorosis is very common at that level. Let us defer to fluoridators again and accept 5 milligrams as a daily dose which may be expected to be harmful after so many years' ingestion. If the municipal water is fluoridated to a level of 1 p.p.m. an adult on a little less than 3 pints of water will ingest about 1.3 milligram fluoride. Add to this figure 20-30% to allow for fluctuations in the main, the highest estimate still remains about one-third of the level of potential harm. These data suggest that fluoridation at the proposed 1 p.p.m. level is not likely to cause chronic damage—to normal persons in America.

Even in America the position of old people and kidney patients has not been settled: young fluoridated normals have been favourably compared with unfluoridated inmates of an old age home (!), and fluoridated children's urine pooled in batches of fifteen '*did not show abnormalities*'. The first piece of sharp practice is an example of biassed controls; the second is worse: even extreme anomalies of one sample can be hidden by dilution with fourteen parts of normal urine. Dodges of this kind do not disprove fluoridation but underline the suspicion that all is not safe in the safety racket. Inconclusive tests have their place in science as orienting experiments, but they are not a safe foundation for compulsion.

What is to be done with people who drink too much water (this can happen everywhere) or whose diet differs from the American average and already contains much fluoride? This is the case in England, Australia and New Zealand where the normal domestic drink is tea. The Americans' coffee is practically free from fluoride, but a cup of tea contains about 0.2 milligram, occasionally more. Twenty-five cups of tea are drunk by some, but let us consider the fairly normal consumer of twelve cups a day, equal to 2.4 milligrams of fluoride. A generous helping of cake made with self-raising flour may contain up to 1 milligram of fluoride, a tin of sardines 0.8-3.5 milligrams, a bowl of stock made with meat on bones up to 1 milligram. A dietary intake of over 5 milligrams of fluoride is quite likely in the case of some unfluoridated Britons. If now their tea and stock are made with fluoridated water, and more fluoride is taken through bread, jam and vegetables cooked in water, not to mention locally produced cordials, beer and boiled sweets, few adults will ingest less than 5 milligrams a day in a fluoridated British city. Accordingly the British Ministry of Health recommends the discarding of meat and vegetable stock (together with vitamins and minerals) in fluoridated areas.[25] Any measure of safety claimed in respect of alleged observations on Americans with their fluoride-free diet is utterly irrelevant where much fluoride is consumed and where children will lose essential vitamins and minerals in order to make the administration of unessential fluoride easier.

Heavy drinkers (some people drink up to thirty pints of water) could ingest up to 25 milligrams daily, that is about twice the amount consumed in the form of natural water with the highest known concentrations of fluoride.

It is all very well to be sorry for kiddies with teeth sacrificed to the interests of manufacturers of sweets, but those who require much water have also a right to live. Furthermore, pills or drops of fluoride or suitable food with high fluoride content could help the child prone to caries, but a man who needs a certain amount of water cannot help himself if his water becomes too dangerous to drink.

If the teeth of children come first, one could consider legislation against negligent parents rather than action against excessive consumers of drinking water. Alternatively, Food and Health Regulations should protect the adults by banning the sale of foodstuffs normal consumption of which could raise the fluoride intake to a dangerous level. In practice this would oblige bakeries, breweries, cordial factories, makers of jams and conserves and sweets (especially boiled sweets) to install defluoridating equipment; the sale of wine and sea food would have to be restricted; tea would have to be banned or severely rationed. The implications to health, employment, prices and so forth can be left to the reader.

If we accept that fluoride is the same whatever its origin, we must also admit that fluoride placed in the jug by mother is not less effective than fluoride stirred into the reservoir by a municipal employee. The possibility of parental negligence raises two issues. The danger of overdosage is slight, especially if the fluoride is dispensed in drops: a few years' supply for the whole family would be required to administer one fatal dose. Other mistakes of dosage (e.g. confusion of relatively harmless fluoride drops with some more potent medicine kept in the same chest) could occur in the fluoridation plant as well.

Those who have faith in fluoride are afraid that without universal compulsion some children will miss their regular supply of fluoride. Some parents do not provide their children with minerals, vitamins and proteins required for normal growth and health. Shall we therefore iodinate, add calcium, magnesium, vitamins and beef extract[26] to the water supply? If sympathy for stunted children comes before any other consideration: yes.

A compromise between human variability and the need of neglected children is offered by banning eating outside communal refectories conducted by dietary experts trained to provide the children with fluoride drops but leaving the adults to drink water to their hearts' delight; a reduction in the intake of luxury foods would probably make the use of fluoride unnecessary. On the other hand, socialism in Russia and China appears to have claimed many more victims than fluoride, and excessive haste towards the rainbow of safety may be dangerous in this instance too.

Still another approach to the assessment of safety is through the study of enzymes. Several thousand enzymes are involved in health and disease; of these a few hundred are reasonably well known. New enzymes are being discovered all the time. One of the rare scientific books written in defence of fluoridation devotes a chapter to the effect of fluoride on enzymes[27]: eleven enzymes have been studied by fluoridators; two of these have been inhibited and one very slightly inhibited by concentrations eight to ten times higher than those proposed for fluoridation. From this the safety of fluoridation does not follow, only that the eleven enzymes selected from the possible thousands are not much affected by fluoride. On the other hand, Euler, Warburg and Theorell, three Nobel Prize winners working independently (the first two many years before fluoridation had been suggested) showed that a number of enzymes of great importance are appreciably inhibited by fluoride concentrations between 0.2 and 1 p.p.m. (pp. 79-80).

A vast volume of modern research work is devoted to the group of enzymes called *cholinesterases*. The function of such enzymes in relation to the activities of nerves and muscles is partially understood, but far too little is known of the significance of cholinesterases found in blood serum. The concentration of serum cholinesterases is diminished in old age, malnutrition, diseases of the liver and kidneys and especially in cancer. This undoubted association of weakness and disease with low cholinesterase activity must not be understood to mean that deficiencies of cholinesterases in the serum are necessarily dangerous. There is no compelling evidence to suggest that inhibition of serum cholinesterases will harm the otherwise normal adult. Yet observations on rats (not necessarily applicable to man) indicate that reduced cholinesterase levels decrease the animals' resistance to cold and that parents deficient in serum cholinesterase produce stunted offspring with a relatively high mortality. These very recent experiments should be continued for several generations to produce significant results. Experiments on humans have not started, but one may agree that inhibitors of serum cholinesterases cannot be regarded as safe for another generation or two.

Now fluoride is a powerful inhibitor of serum cholinesterases, which it inhibits to the average extent of 50% at the allegedly safe concentration of 1 p.p.m. In 1961 Harris and Whittaker[28] used the inhibition of cholinesterases in different human sera by 1 p.p.m. fluoride to demonstrate three main genetic groups of humans with *fluoride numbers* (i.e. per cent inhibition of serum cholinesterases by 1 p.p.m. fluoride) of 61, 48 and 23 respectively. Correlation with other similar techniques establishes five, possibly six, groups, one of which is possibly linked with mental disease. Such investigations do not prove 1 p.p.m. fluoride good or bad, but establish that it has not the same effect for all. Hence biochemically untrained municipal councillors should not have the right to decree that irrespective of personal differences each citizen must be treated with the same dose. A recent report[29] from the Radiobiology Laboratory of Churchill Hospital, Oxford claims that '*the growth of two types of mammalian cells in vitro has been shown to be inhibited by extremely minute quantities of sodium fluoride in the growth medium—quantities equivalent to those recommended for use in drinking water*'. The article is temperate in tone, but brief and far from conclusive. Two Australian State Governments which were ready to force fluoridation on their electors without a referendum have deferred further action until more experimental evidence comes to hand. The National Health and Medical Research Council contemptuously dismissed the report on authoritarian grounds. In one Australian State committed to the welfare of fluoride producers the Minister in charge of health and disease was quite shocked at the idea that actual research work could upset policies based on departmental guesswork.

It is little short of folly to insist on compulsion just when research work begins to produce *prima facie* evidence of possible dangers. If people who had not had personal research experience with the effects of fluoride at 1 p.p.m. or lower concentrations on enzymes ceased to be regarded as experts on fluoridation, compulsory mass-medication by fluoride would be deferred for another thirty to sixty years or more.

At the mercy of biochemically untrained fluoride salesmen one's personal future is unpredictable and one's safety is at the mercy of decisions made in dark ignorance. The concluding passages of C. P. Snow's famous essay, 'Science and Government', are haunted by a phrase from the Icelandic saga about the '*wisest men who had not the gift of foresight*'; that is why he wants '*some scientists mixed up in our affairs*'. Politically enforced mass-fluoridation in the West without scientific method and after muzzling critical scientists could have far-reaching consequences, not excluding a '*last scene of all that ends this strange eventful history . . . sans teeth, sans eyes, sans taste, sans everything*'.

CONCLUSION

In the realm of experimental sciences no proofs are final. A person determined to be awkward is certain to win his argument. Prove to him that a claim is 90% probable, he has the right to insist that you adduce further evidence that will make it probable to the extent of 99%, 99.9% or 99.999%. The sceptic is right in knowing that there is no absolute safety, but he is wrong to insist on the impossible. It is impossible to avoid risks altogether and one can never be completely certain that a particular choice between foreseen hazards will prove best in the long run. An act of choice distinguished by both courage and reason is more fruitful than dithering with superstitious fears.

Before a new idea becomes a useful reality, somebody must have the intellect to conceive it and courage to try it. Blood transfusion, immunisation, chemotherapy and other powerful weapons against disease presented terrible risks at the start and are far from safe even in our days. It would be irrational and cowardly to avoid such therapeutic aids, but it is equally irrational and cowardly to anticipate fears by assurances of absolute safety. It is worse when imaginary facts and unacceptable arguments are used to create or to dispel fear. The worst is when compulsion, suppression of criticism and victimisation of critics are used as a bridge between the low attainable probability and the unattainable certainty of a claim.

Much of the intellectual opposition to the use of fluoride would disappear if people were asked to look for possible, almost certainly minor, symptoms of hypersensitivity instead of threatening doctors and patients who have such symptoms to report with the straitjacket. Again, it would be much easier to accept or condone the principle of *democratic dosage*—the same amount of calories, vitamins, irradiation, fluoride, injections, etc. to man, woman and child, if clear, businesslike arrangements were made to provide alternative services for hypersensitives and compensation for those damaged.

Guarantees of health are nonsense. The grocer can replace rancid bacon, the tailor can cut a new pair of trousers if he spoils the first pair, but it is impossible to compensate a medically or dentally harmed person for loss of health and limbs or for the birth of defective children. The offer of free hospital services to those who can prove ill-health from compulsory mass-medication is a little more honest but still unsatisfactory.

Errors committed with intelligent courage can be serious but may enable one to learn and then apply the truth. Errors committed in wilful ignorance, in an atmosphere of deceit, political intrigue and coercion are unsafe far beyond the immediate harm they cause because they tend to substitute goose-stepping hygienic stormtroopers for responsible individual scientists. Scientists are human, and few of them can avoid corruption in a world which substitutes *pseudo-events* concocted by publicity experts and the whims of uneducated politicians for scientific methods of evidence.

Having offered so much to mankind, genuine scientists are frustrated by the growing threat of anti-rational faceless men, the anonymous 'authorities' and 'experts' who—without experiments, logic, publication or tangible record—are gaining the ear of politicians in power. Yet scientists must endure frustration. As Lord Kelvin, one of the most successful scientists of all time, has put it: '*One word characterises the most strenuous of the efforts for the advancement of science that I have made perseveringly during fifty-five years: that word is failure.*'

There is less to be seen of scientists than of enthusiasts; Sir Arthur Amies, one of the leading Australian dentists, has a word of wisdom to say of them: '*The passion to regulate the lives of others is deep seated in many individuals. When this is based on political expedience it is bad, and when it is inspired by an idealism which wishes to inflict benefits on others, it can become dangerous.*'

We are being overrun by suburban do-gooders, their prehistoric logic, classical contempt for experiment, mediaeval miracle-mongering and modern totalitarian hatred of individuality. It is probably too late to warn the reader against this vanguard of a Brave New World, but let us part both warned and cheered by that grim realist and calm optimist, Machiavelli:[30] '*Those who have been present in any deliberative assemblies of men will have observed how erroneous their opinions often are; and in fact, unless they are directed by superior men, they are apt to be contrary to all reason. But as superior men in corrupt* *republics (especially in periods of peace and quiet) are generally hated, either from jealousy or the ambition of others, it follows that the preference is given to what common error approves, or to what is suggested by men who are more desirous of pleasing the masses than of promoting the general good. When, however, adversity comes, then the error is discovered, and then the people fly to safety to those whom in prosperity they had neglected.'*

NOTES

Works recommended for reading in a wider context are listed under References. If quoted in these notes, the names of authors are given followed by page numbers. The Roman numerals in brackets refer to the chapter to which the work is assigned for purposes of reference.

[1] Aztec Feathered Serpent and God of Learning.

[2] Pencil, paper and ruler can be used to check these statements by those who have forgotten their geometry.

[3] *Hobart Mercury,* 27 November 1962.

[4] H. Theorell, 'Communication to Royal Medical Board, Stockholm, Sweden, 1 March 1958'. *Proceedings of Third Medical-Dental Conference on Evaluation of Fluoridation,* edited by Dr A. Allen (London, August 1959) pp. 21-2.

[5] *Hobart Mercury,* 24 September 1962.

[6] *Sydney Sunday Telegraph,* 11 August 1963, p. 15.

[7] '. . . and every man is a liar' (*Romans,* **3** : 4).

[8] E. B. Wilson (III) pp. 26-7.

[9] *Hobart Mercury,* 28 September 1962.

[10] Gideon asked for a sign and suggested the use of a fleece of wool on the threshing floor. If dew settled on the fleece but left the floor dry, he would know that miracles could occur in his favour. When the miracle occurred, Gideon insisted on a second sign. This time he wanted the fleece dry but dew on the ground. Success of the second test completed the proof (*Judges,* **6** : 36-40).

[11] 'Why your State Health Department recommends Fluoridation', written by anonymous authors for the Department of Health Services, Tasmania, 1961-2, p. 8.

[12] J. R. Blayney and W. H. Tucker, *J. dent. Res.,* 1948, **27**, 279-86; I. N. Hill, J. R. Blayney and W. Wolf, *ibid.,* 1950, **29**, 534-40.

[13] I. N. Hill *et al., ibid.,* 1951, **30**, 670-5; 1952, **31**, 346-53, 597; 1955, **34**, 77-88; *J. Amer. dent. Ass.,* 1956, **53**, 327-33; *J. dent. Res.,* 1957, **36**, 208-19; *J. Amer. dent. Ass.,* 1958, **56**, 688-91.

[14] I. N. Hill *et al., ibid.,* 1957, **55**, 473-82.

[12, 13, 14] See also P. R. Sutton (X) pp. 35-6, 84-94. Dr Sutton prints the replies of Drs. Blayney and Hill to his criticism, an unusual courtesy that cannot be afforded by those who are not too happy with their own argument.

[15] Cf. (11) p. 12.

[16] I. Rapaport, *Bull. Acad. Med. France*, 1956, 529-31; 1959, 367-70.

[17] Editorial, *Austr. dent. J.*, 1960, **5**, 41.

[18] R. A. Fisher (VIII) pp. 43-4.

[19] *ibid.*, p. 47.

[20] J. Schubert and R. E. Lapp (IX) p. 112.

[21] *ibid.*, p. 116.

[22] Donald R. McNeil, *The Fight for Fluoridation* (Oxford University Press, New York, 1957).

[23] *ibid.*, p. 80.

[24] *ibid.*, p. 84.

[25] Margaret Brady, *New Statesman*, 1963, **65**, 334 (8 March).

[26] In anticipation of the rejoinder that fluoride is a natural constituent of all waters, merely enriched by fluoridation, let it be pointed out that so are calcium and magnesium. Vitamins and meat extract are natural constituents of the impure water which supplies a certain city.

[27] J. C. Muhler and M. K. Hine, *Fluorine and Dental Health*, (Staples Press, London, 1960) esp. Dr W. J. Frajola, pp. 60-9. The monumental report, *Fluoride Drinking Waters* (U.S. Dept. of Health, Education and Welfare, Bethesda, Maryland, 1962) containing the most famous pro-fluoride articles published between 1901 and 1962, ignores opponents' views and does not treat fluoride effects on enzymes except in a relatively short passage of an outdated review from 1933. Between the almost total ignorance on this subject in 1933 and the still undispersed darkness in 1960, the Public Health Service declared fluoride 'safe'.

[28] H. Harris and Mary Whittaker, *Nature*, 1961, **191**, 4787.

[29] R. J. Berry and W. Trillwood, *Br. med. J.*, 1963, 1064.

[30] *The Discourses*, 2nd Book (XXII). (*The Prince* and *The Discourses* Modern Library, New York, 1950). Translation by C. E. Detmold.

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The works listed here have influenced the writing of this book but they are not cited to defend it with their authority. On the contrary, some of the references advocate views and claims unacceptable to the author.

The main purpose of the reading list is to provide the critical reader with a range of controversies, claims and counter-claims to be assessed by the methods illustrated in this book. Having been told that these methods are elementary, often nothing more than useful samples illustrating a greater number of more sophisticated intellectual devices, the more adventurous reader will seek to explore some of the many compartments of scientific method beyond the front door which this book may have opened for him.

There are many excellent books on the subject, and those recommended are mostly economical paper-backs or works readily available in public libraries; most of them are popular in the sense that interest makes them intelligible even in the absence of technical knowledge. A few references marked with an asterisk are more advanced; they may appeal to readers with some mathematical or scientific training and will offer to others a glimpse of the complexities of formal sciences.

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