A Course in

Basic Scientific English

J. R. Ewer Department of English, University of Chile

and

G. Latorre School of Engineering, University of Chile

Unit 6 to 12

课文由曹运洪同学根据他保留了四十多年的课本提供，特此致谢。

6. Science and International Co-operation
7. Underdevelopment and the Sciences
8. Sources of Error in Scientific Investigation
9. Straight and Crooked Thinking
10. Science and the Future
11. The Role of Chance in Scientific Discovery
12. The Scientist and Government

Unit 6

SCIENCE AND INTERNATIONAL CO-OPERATION

One of the most striking characteristics of modern science has been the increasing trend towards closer co-operation between scientists and scientific institutions all over the world.

What have been the reasons for this? One of the factors has already been discussed in Unit 5, i.e. the growing complexity and widening scope of present-day research, which has resulted in the creation of large organizations employing great numbers of scientists and technologists in programmes of directed research. This has inevitably led to the extension of many items of research beyond national boundaries.

The most important factor, however, has been the magnitude of the problems to be solved. In fact, it is becoming more and more evident that many of the problems affecting the world today cannot be solved except by the pooling of scientific effort and material resources on a world-wide scale. The exploration of space, world finance and the development of new sources of power, such as atomic energy—these are examples of areas of scientific research which are so costly and complicated that no single country or organization, working by itself, can hope to tackle them efficiently.

A third powerful reason has been the increasing political and economic interdependence of nations, both rich and poor. This has had a direct effect on large areas of scientific and technological investigation, such as those connected with armaments, communications, health, agriculture, economic planning and sociological research.

As a result of the conditions outlined above, international co-operation has been greatly intensified during the last 20 years, largely owing to the initiative of the United Nations Organization (U.N.O.) and its specialized agencies, in particular the United Nations Educational, Scientific and Cultural Organization (UNESCO). Thus the most urgent problem for many parts of the world, i.e. food production, is being dealt with by the Food and Agriculture Organization (F.A.O.). The World Health Organization (W.H.O.), another U.N. agency, not only co-ordinates many research projects on medicine all over the world, but supplies advice and aid in the control of diseases in underdeveloped areas. Technical and economic assistance is provided by other U.N. bodies such as the Economic and Social Council (ECOSOC) or the Economic Commission for Latin America (ECLA) and similar agencies for other regions of the world.

Apart from the international agencies controlled by the U.N., many scientific and technological organizations, both governmental and privately owned, are pooling their resources and incorporating themselves into supra-national bodies: a good example is the Organization for Economic Co-operation and Development, with over 20 member-countries throughout the world. Universities, too, are tending to develop joint research

projects with their counterparts in other parts of the world, and finally, many scientific disciplines have had, for a long time past, their own international unions and associations whose main functions are the dissemination of information, the co-ordination of research and the standardization of measurements and nomenclature.

Science, then, seems to be playing a major role in the creation of the 'One World' of the statesmen's dreams.

UNDERDEVELOPMENT AND THE SCIENCES

In this unit we are merely going to present some of the problems of underdevelopment, and then leave it to the reader to discuss how modern science can help to solve them.

To begin with, it is hardly necessary to point out that we live in a world of increasing industrialization. Whilst this process enables us to raise our standards of living at an ever-accelerating rate, it also leads to a corresponding growth of interdependence between the different regions of the world. Given (In view of) these conditions, it is easy to see that any permanent economic or political instability in one area is bound to have an increasingly serious effect upon the rest of the world. Since the main source of such instability is underdevelopment, it is clear that this now constitutes a problem of international proportions (dimensions).

What, then, is to be done? Although it is difficult to know where to begin to deal with such a large subject, the first step is perhaps to consider the main economic difficulties an under-developed or emerging region has to face, e.g.

(a) The economies of such countries are orientated primarily towards the production of raw materials, i.e. agricultural and mineral products; these are then exported to the industrialized countries. A number of quite common occurrences are therefore sufficient to cause immediate and serious interference with this export production: unfavourable weather conditions, plant or animal epidemics, the exhaustion of soil fertility or mineral deposits, the development of substitute products in the industrialized regions, etc. The sensitivity of the economy is greatly intensified in cases where exports are confined to only one or two products—'monocultures', as they are sometimes called.

(b) Being under-industrialized, these countries are largely dependent on imports to supply the equipment needed to produce the raw materials they export. This also applies to the manufactured goods required to provide their populations with the 'necessities of life'—a concept which is continually being enlarged through the mass media of communication such as newspapers, films, the radio and advertising. This economic structure makes it difficult for them to avoid being politically dependent on the countries which absorb their exports and provide their essential imports.

(c) Since, under modern conditions, a rapid rise in population is a phenomenon closely associated with underdevelopment (Why?), this cause alone can subject the whole (entire) economy to severe and continuous stress.

(d) Although it is obvious that industrialization is the key to development, it is usually very difficult for emerging countries to carry out plans of this nature. In the first place, to set up modern industries necessitates (requires) capital on a large scale, which only industrialized regions are able to provide; secondly, they lack the necessary trained manpower; thirdly, their industries—when established—are usually not efficient enough to compete with foreign imports, and any restriction on

these imports is likely to lead to counter-action against their own exports.

From another point of view, it is necessary to bear in mind that there are invariably political, educational, social and psychological obstacles which tend to interfere seriously with any measures taken to deal with the economic difficulties outlined above. To consider only one point: it is obviously useless to devote great efforts and expense to education, technical training and planning if, for psychological reasons, the population as a whole fails to turn theory into effective action.

To conclude, it seems clear that if we are to succeed in solving the many inter-related problems of underdevelopment, only the fullest and most intelligent use of the resources of all branches of science will enable us to do so. How is this to be done? Do *you* have any suggestions to make?

Unit 8

SOURCES OF ERROR IN SCIENTIFIC INVESTIGATION

In Unit 3 we examined briefly the sequence of procedures which make up the so-called scientific method. We are now going to consider a few of the many ways in which a scientist may fall into error while following these procedures.

In formulating hypotheses, for example, a common error is the uncritical acceptance of apparently common-sense, but untested, assumptions. Thus in the field of psychology it was for many years automatically assumed that the main cause of forgetfulness was the interval of time elapsing between successive exposures to a learning stimulus. Experimentation, however, was subsequently undertaken, and several other factors, such as motivation and the strength or effectiveness of the stimulus, turned out to have an even more important bearing on the problem. A somewhat similar error arises from neglect of multiple causes. Thus two events may be found to be associated, e.g. when the incidence of a disease in a smoky industrial sector of a city is significantly higher than in the smoke-free zones. A research worker might infer that the existence of the disease is due to the smokiness of the area when in fact it might equally well be found in other reasons, such as the under-nourishment of the inhabitants or over-crowding.

Both in collecting the original evidence and in carrying out subsequent experiments, a frequent cause of error is the fact that observations are not continued for a long enough time. This may lead not only to a failure to discover positive items (e.g. Le Monnier's failure to recognize that Uranus was a new planet, not a fixed star, etc.), but may also result in important negative aspects of the investigation remaining undiscovered. In applied science, this latter error may have disastrous consequences, as in the case of the thalidomide drugs, cancer-inducing industrial chemicals, etc.

Another well-known error in experimentation is lack of adequate controls (see Unit 3, ll. 39–43). Thus a few years ago it was widely believed that a certain vaccine could prevent the common cold, since in the experiments the vaccinated subjects reported a decrease in the incidence of colds compared with the previous year. Yet later, more strictly-controlled experiments failed to support this conclusion, which could have been due to a misinterpretation of chance results. This error is often caused by a failure to test a sufficient number of subjects (inadequate sampling), a disadvantage which affects medical and psychological research in particular.

Errors in measurement, particularly where complicated instruments are used, are common: they may arise through lack of skill in the operator or may be introduced through defects in the apparatus itself. Furthermore, it should be borne in mind that apparently minor changes in laboratory conditions, such as variations in the electric current, or failure to maintain atmospheric conditions constant, may disturb the accuracy of various

items of equipment and hence have an adverse influence on the experiment or series of experiments as a whole. In addition, such errors tend to be cumulative.

Finally, emotion in the observer can be one of the most dangerous sources of error. This may cause the researcher to over-stress or attach too much importance to irrelevant details because of their usefulness in supporting a theory to which he is personally inclined. Conversely, evidence disproving the view held may be ignored for similar reasons. Even routine matters such as the recording of data may be subject to emotional interference, and should be carefully checked.

To sum up (summarize), the multiple possibilities of error are present at every stage of a scientific investigation, and constant vigilance (care) and the greatest foresight must be exercised in order to minimize or eliminate them. Additional errors are, of course, connected with faulty reasoning; but so widespread and serious are the consequences that may arise from this source that they deserve separate treatment in the following unit.

Unit 9

STRAIGHT AND CROOKED THINKING

If we observe the actions of men, whether as individuals or as groups, and whether scientists or non-scientists, we find that they frequently fall into avoidable error because of a failure to reason correctly. There are many reasons for this, though only a few can be dealt with here.

The first difficulty is bound up with (related to) the use of words. It frequently happens that what one person means when he uses a certain word is different from what others mean. Consider, for example, the words *intelligence*, *oxygen*, *accurate* and *average*. In *intelligence* we face the problem that a word may not mean only one thing, but many—in this instance a very complicated set of aptitudes and abilities whose number and characteristics are not agreed upon by the specialists who study the phenomenon, and are even less understood by the layman (non-specialist). In *oxygen* we have a different problem, for although both a research chemist and a chemical manufacturer identify the word theoretically with the element O, in practice they have different concepts about it. Thus if the researcher performed a delicate experiment, using the manufacturer's *oxygen*, it might easily be a failure since the so-called O, whether used as a solid, liquid or gas, would almost certainly contain other substances. Hence another difficulty about words is that they often do not differentiate clearly enough between several varieties of the 'same' thing.

Another common error connected with words consists in confusing a word or a name with a fact. The course of scientific progress has been frequently slowed down by (1) assuming the existence of *something* to account for a certain phenomenon, (2) giving the assumed substance a name, e.g. *phlogiston*, *aether*, etc., and (3) implying that the phenomenon has been satisfactorily accounted for (explained).

Apart from the misuse of words, mistakes in logic can occur. Thus an example is recorded of a young sociologist, investigating literacy in a certain community, who discovered from the official records that over (more than) 50 per cent of the population were females. He subsequently found that approximately 70 per cent of the population were literate. When he had obtained this data he summed it up and drew conclusions as follow:

Most of the population are females;
Most of the population are literate;
∴ most females are literate.

This was, of course, an unreasonable inference, as the investigator himself realized as soon as he had re-examined his chain of reasoning more carefully.

Another mistake is to confuse cause and effect. This may easily occur at the beginning of an investigation, but if it remains uncorrected it can be considered as primarily a by-product of insufficient experimentation. To illustrate this, the following case can be quoted. The inhabitants of a certain community had

noted over the ages that whenever an individual became ill with a fever, the body parasites left him. They therefore made the correlation that the parasites kept them healthy. Later, however, properly-controlled scientific investigation showed that the reverse was true: in fact the parasites transmitted several kinds of fever, and then left the sick persons when the latter's bodies became too hot to live on.

Some other factors which may influence reasoning are (a) faulty analogizing, (b) the inhibiting effect on further research of concepts which have been widely accepted as satisfactory, (c) the role of authority as a bar to the re-consideration of a problem. As regards the first of these, it should be emphasized that the process of tackling one problem by analogizing from another has frequently yielded valuable results, as in the case of air-pressure (see Unit 3). On the other hand, it may lead to the adoption of a totally false hypothesis, as when the idea of the atom as an infinitely small piece of solid matter was obtained by analogizing from the world of visible appearances. This erroneous viewpoint blocked progress in this field for many decades. Similarly, the comparison of the movement of light to a wave—an analogy which had actually provided a satisfactory explanation of the observed phenomena during most of the nineteenth century—tended subsequently to interfere with the development of the equally valid concept of light as a stream of particles. This example also illustrates the second factor enumerated above. As far as the third factor is concerned, the history of science shows many instances in which the force of authority has operated in such a manner as to build up an exceedingly powerful resistance to further investigation; in some cases centuries elapsed before this resistance was eventually broken down, as happened in cosmology, for example.

Thus in addition to the chances of going astray outlined in the previous Unit, the scientific investigator shares with the ordinary citizen the possibilities of falling into errors of reasoning in the ways we have just indicated, and many others as well (in addition). The more he knows of this important subject, therefore, the better equipped he will be to attain success in his work; and the straighter he thinks, the more successfully he will be able to perform his functions as a citizen.

Unit 10

Revision of material appearing in Units 6–9

SCIENCE AND THE FUTURE

In preceding (previous) units, we have examined briefly some of the characteristics, methods, effects and problems of present-day science. At this stage it may be worth considering a few of the ways in which it may develop in the near future, i.e. the next decade or so.

To begin with, we can expect applied science to produce a vast (huge, enormous) increase in entirely new synthetic products of all kinds. These will range from light-weight, high-strength materials for use in the many specialized branches of engineering, to drugs and chemicals with a greatly-increased selectivity which can be used in medicine and agriculture. However, in this latter case in particular, it may be predicted that the wide-spread application and combination of new and more complex products will give rise to unexpected inter-reactions or side-effects. For this reason, greatly intensified programmes of research will be required in order to discover and eliminate the harmful results of such combinations.

Another point is that the rapid expansion of industrialization throughout the world must inevitably lead to a progressive exhaustion of natural resources. If we wish to counter-balance these losses to some extent, we shall have to follow two main courses of action: (a) much greater efforts will have to be applied (devoted) to conservation, particularly of such items as soil, water, fuels and minerals; (b) more efficient methods of exploitation and utilization will have to be developed.

In the more developed countries, the automatization of industry (automation) will lead to a high degree of efficiency in the production of manufactured goods, and is likely to have far-reaching social effects. For instance, workers will need to be more highly trained and more flexible—they will probably have to be capable of changing (shifting) from one skilled job to another—and they will also have more free time, as they will work fewer hours per day. This in turn will necessitate a considerable expansion and re-orientation of education. Another result of automation should be to accelerate (speed up) the accumulation of surplus capital, which could then be made available for the purpose of assisting the emerging countries to solve some of the problems of underdevelopment. It should, however, be borne in mind that this process itself might involve a chain of difficulties, in this case of a political nature.

In general, the application—or misapplication—of science and technology in all fields is certain to affect the structure of society as a whole. This will remain true whether we are dealing with the application of psychology to advertising and political propaganda, or engineering to the mass media of communication, or of medical science to the problems of overpopulation or old age. This could lead to the development of a special discipline, whose job would be to estimate (evaluate) the social consequences of all major research and development (R and D) projects before they are put into large-scale operation. It should

here be pointed out that one of the most powerful trends in present-day science is for separate branches to converge and form inter-related groups of studies. If this trend continues, it may in fact lead to the emergence of an entirely new type of scientist, i.e. the multi-disciplinary co-ordinator.

As we have previously seen, international co-operation has become greatly intensified in recent years, and this tendency will doubtless become even more strongly marked in the future. It is therefore likely that the scientific efforts of individual countries will tend to be unified and co-ordinated by supra-national entities, and the more this is done, the greater the probability that supra-national governments will eventually be set up.

National governments, also, will be brought into closer and closer contact with science. To quote only one reason, the State will have to provide an increasingly large proportion of the money spent on scientific investigation: it can therefore be expected to play an increasingly important role (part) in the planning of R and D programmes. It will also tend to determine one of the fundamental questions affecting science in the future, viz. the percentage of the funds which are made available for basic research, and the percentage allotted to development projects. From another point of view, the cumulative use of science in government must have the overall effect of greatly extending the control of the State over the ordinary citizen. All these factors, and many other related considerations, should stimulate a great deal of re-thinking on this subject, the results of which could bring about (cause) a scientific revolution in politics, or a political revolution in science—or both.

Unit 11

(General Revision Unit)

THE ROLE OF CHANCE IN SCIENTIFIC DISCOVERY

Nearly a century and a half ago, a Danish physicist, Oersted, was demonstrating current electricity to a class, using a copper wire which was joined to a Voltaic cell. Amongst the miscellaneous apparatus on his demonstration bench there happened to be a magnetic needle, and Oersted noticed that when the hand holding the wire moved near the needle, the latter was occasionally deflected. He immediately investigated the phenomenon systematically and found that the strongest deflection (deviation) occurred when he held the wire horizontally and parallel to the needle. With a quick jump of imagination[1] he then disconnected the ends of the wire and reconnected them to the opposite poles of the cell—thus reversing the current—and found that the needle was deflected in the opposite direction. This chance discovery of the relationship between electricity and magnetism not only led quickly to the invention of the electric dynamo and hence to the large-scale utilization of electric energy, but forms the basis for modern electro-magnetic field theory, which is now an extremely valuable tool in both macro- and micro-physics.

The above story illustrates the part played in scientific discovery by chance (accident). Again, about 20 years ago a group of British bacteriologists and biochemists working in agricultural research were carrying out investigations into substances of organic origin which could be used to stimulate plant growth. One of the approaches they used consisted in studying the nodules (small round lumps) found on the root-hairs of certain plants, and which contain colonies of nitrogen-forming bacteria. Working on the hypothesis that these bacteria manufactured a substance which stimulated the nodule-forming tissue, the investigators eventually succeeded in isolating this substance. However, when they then tested it on various other plants, they found—quite contrary (opposite) to their expectations—that it actually prevented (inhibited) growth. Further systematic investigation showed that this toxic (poisonous) effect was selective, being much greater against dicotyledon[2] plants, which happen to include the majority of weeds, than against the monocotyledons[2], which include the grain crops and grasses. The researchers thus realized that they had discovered a powerful selective weed-killer: they continued their research, using inorganic compounds of related chemical composition, and in this way laid the foundations of a technology which is of the greatest value in present-day agriculture.

Another well-known instance of the role of chance is connected with the discovery of penicillin by Fleming. This medical researcher had been investigating some pathogenic (disease-causing) bacteria, and after being absent from his laboratory for

[1] Or *intuition*, as it is often called when it produces successful results.
[2] Usually *dicots* and *monocots* respectively in U.S.A.

some days found on his return that one of the culture dishes in which colonies of the bacteria were growing had been contaminated by a colony of another organism, a mould of penicillium *spp*. He was going to throw the dish away when he noticed that the penicillium colony was surrounded by an area completely clear of the pathogenic bacteria. He immediately realized that the penicillium must have manufactured a substance which had broken down (disintegrated) the pathogenes. He then isolated this substance, which turned out to be the most powerful agent yet discovered against bacteria causing a number of dangerous and widely-spread diseases.

Apart from demonstrating the way in which chance may lead to scientific discoveries of primary importance, an analysis of the three cases outlined above may be useful in showing *how* a successful worker utilizes these accidental opportunities. The first point to notice is that although in all cases the key phenomenon produced results which were both unexpected and—in the last two cases—even apparently disadvantageous, the scientists invariably reacted in an extremely positive manner. The refusal to be disturbed or disorganized by unexpected or apparently adverse occurrences, but, on the contrary, to be stimulated by them, has in fact been a marked (strong) characteristic of successful investigators.

Secondly, we note that in the first and third cases the phenomena were very slight and might easily have escaped notice, whilst in the second case they produced a negative result. From this we might deduce that a superior capacity for observation is also a property of outstanding researchers. On this point, however, a psychologist would probably tend to disagree. He would point out that observation or perception is a concept which refers not so much to acuteness of sight, hearing, etc., or to the care with which they are applied, as to the ability to relate phenomena to a complex network of previous experiences and theories, i.e. to a meaningful frame of reference. In other words, an observer who lacks such a frame of reference will be unable to realize the significance of certain phenomena even though his senses may 'experience' them, and so he may fail to observe them. This can be illustrated by the following example:

At the end of last century, an American chemist, Hillebrand, was using a recently-developed instrument, the spectroscope, to analyse the gas given off by a certain mineral when treated with acid. This instrument works on the principle that each individual substance emits a characteristic spectrum of light when its molecules are caused to vibrate by the application of heat, electricity, etc; and after studying the spectrum which he had obtained on this occasion, Hillebrand reported the gas to be nitrogen. At this same time, another scientist, Rayleigh, happened to be investigating the anomalous fact that nitrogen obtained from the air appeared to be heavier than that obtained from other sources, e.g. ammonia (NH_3). Rayleigh repeated Hillebrand's experiment and, immediately noticing that the spectrum showed several bright lines which were additional to those typical of nitrogen, went on to discover the rare gases argon (A) and helium (He). Why had Rayleigh observed these extra lines whereas (while) Hillebrand apparently had not? Part of the answer seems to be that the former already possessed a frame of reference which included the possibility that a different sort of N might exist; he was therefore extremely sensitive to any apparent anomaly in the behaviour of this element. Hillebrand lacked this concept, and was therefore unable to see the slight deviant reaction of the gas he assumed he was dealing with.

This dual (double) quality of being sensitive to, and curious about, small accidental occurrences, and of possessing a frame of reference capable of suggesting their true significance, is probably what Pasteur meant when he said 'Chance benefits only the prepared mind.' Nevertheless, it is clear (plain, obvious) that these qualities alone, even when joined to those mentioned previously, are not necessarily sufficient to ensure success: an indispensable factor in all the discoveries quoted above was careful and systematic experimentation. We may therefore conclude that it is the capacity to plan and undertake such experimentation which finally allows the investigator to make the most of his luck —if it comes.

Unit 12

(General Revision Unit)

THE SCIENTIST AND GOVERNMENT

We have already seen that science, besides affecting our whole environment—and hence the community as a whole—is becoming connected to an increasing extent with government itself (see Unit 10, last paragraph). As this is now beginning to modify the status (position in society) of the scientist himself, it may be worth while considering the subject in more detail at this stage.

To begin with, we may notice a number of additional factors which are accelerating this process. These are:

(a) *Defence Requirements:* The governments of most of the developed countries have always applied a large proportion of their total resources to the development of destructive apparatus and nowadays many of the newly-independent countries are doing the same. This apparatus and its use has now become exceedingly complex and requires the participation of large numbers of scientists and technologists. Moreover, many types of industry, including the largest, e.g. the aerospace industry, are strongly linked to defence requirements and again depend increasingly on scientific and technical personnel.

(b) *Economic Requirements:* Governments throughout the world act on the assumption that the welfare of their people depends largely on the economic strength and wealth of the community. Under modern conditions, this requires varying measures (degrees) of centralized control and hence the help of specialized scientists such as economists and operational research (O.R.) experts. Furthermore, it is obvious that the strength of a country's economy is directly bound up with the efficiency of its agriculture and industry, and that this in turn rests upon the efforts of scientists and technologists of all kinds. It also means that governments are increasingly compelled to interfere in these sectors in order to step up (increase) production and ensure that it is utilized to the best advantage: for example, they may encourage research in various ways, including the setting up of their own research centres; they may alter the structure of education, or interfere in order to reduce the wastage of natural resources or tap resources hitherto unexploited; or they may co-operate directly in the growing number of international projects related to science, economics and industry, such as the International Atomic Energy Agency, the European Iron and Steel Community or the various Common Markets. In any case, all such interventions are heavily dependent on scientific advice and also scientific and technological manpower of all kinds.

(c) *Social Requirements*: Owing to the remarkable development in mass-communications, people everywhere are feeling new wants and are being exposed to new customs and ideas (Unit 7, ll. 33–35), whilst governments are often forced to introduce still further innovations (things which are new) for the reasons given in paragraph (b) above. At the same time, the normal rate of social change throughout the world is taking place at a vastly accelerated speed compared with the past: for example, in the early industrialized countries of Europe the process of industrialization—with all the far-reaching changes in social patterns that followed—was spread over nearly a century, whereas nowadays a developing nation may undergo the same process in a decade or so. All this has the effect of building up unusual pressures and tensions within the community and consequently presents serious problems for the governments concerned. Additional social stresses may also occur because of the population explosion or problems arising from mass migration movements—themselves made relatively easy nowadays by modern means of transport. As a result of all these factors, governments are becoming increasingly dependent on biologists and social scientists for planning the appropriate programmes and putting them into effect.

(d) *Political Requirements:* Since defence, economics and social welfare constitute a very large proportion of the subject-matter of politics, it can easily be seen that science is already playing a major role in the political process. Not only this, but even in the field of action commonly considered to be purely political—e.g. the process whereby (through which) the politician obtains and retains the support of the people, or that of making rapid decisions after weighing the evidence from many different sources—it is again evident that he relies heavily on the scientist; in the first case, on the psephologist, social psychologist and mass-communications expert, and in the second, on the mathematician and computer scientist.

It follows from the above considerations that scientists, whether they like it or not, are becoming involved in government, and hence in politics itself, to a far greater extent than ever before. This fact raises several important questions:

First, how do these new circumstances affect the position in the community of the politician? For whereas in past ages, and even until recent times, the politician could act as a leader because he could reasonably claim to be an 'expert' on economics, war, human relations and the various other sciences that fall within the scope of government, he is now not only a non-expert, but has in almost every case been educated and trained in a non-scientific or even anti-scientific tradition. Yet when dealing with both long-term planning and short-term, day-to-day problems and arrangements he is, as we have just seen, forced to rely to a great extent on the advice and services of scientists. Thus it seems that a rapid change is occurring in the relative effectiveness—and hence of the relative positions in society—of politicians and scientists, and that the latter are moving more into the centre of the political process, possibly at the expense of the former. Second, how far is the scientist equipped to handle political and governmental affairs, apart from his specialized knowledge? Various general characteristics developed by his professional activities are certainly favourable, and some of these have already been mentioned in

Unit 1. Others are his use of the practical and experimental approach to problems rather than the dogmatic one, his preference for the long-term solution rather than the temporary and partial one, and—not least—his training in interdisciplinary and international co-operation. To offset these advantages, scientists have so far (up to now) been on the whole unwilling to accept their new status and responsibilities in government. This rejection may be due to a mixture of reasons, e.g. because they are unaware of the situation or on the grounds that political involvement would interfere too much with their professional work. Another objection arises from the marked difference commonly found between the type of education followed in the scientific disciplines and that of the humanistic branches of study. For if the education of the politician usually unfits him to understand science, the scientist too often lacks training in the humane and social values of art, philosophy and human relationships. Although there are signs that this gap between the 'two cultures' is being bridged, much remains to be done.

Lastly, what are the special responsibilities, if any, of the scientists towards the community? It seems to us that on the one hand he must make intensive efforts to give the ordinary citizen —and the politician—the means of evaluating the role of science in the modern world, since in the long run it is only the existence of a large body of well-informed and energetic citizens which can control abuses of governmental power; on the other hand, he must take more trouble to prepare himself for his own growing role as decision-maker and administrator. Progress is being made on both these points, though mainly by the developed countries so far. As educators, increasing numbers of scientists are making an understanding of science more accessible to the layman by means of simply-written books and radio talks, whilst in many countries the scientists are also the main force behind efforts to improve and expand the teaching of science and scientific method in schools and adult education courses. As far as the second requisite is concerned, progress has been slower, for the reasons given above; nevertheless, one significant indicator for the future may be the widening scope and influence of the Pugwash Conferences, which are informal meetings held once or twice a year by leading scientists from all countries, in which science and its relationship to world affairs is discussed. Another significant fact is that the necessity for establishing co-ordinated national science policies—now being put into effect in various countries—is bringing comparatively large numbers of scientists directly into government administration; this in turn is bringing about (causing) the evolution of a new type of scientist, the scientist-administrator.

To conclude, it is clear that the whole world is passing through a social revolution in which a central part must be taken by scientists and technologists. But whether their efforts can be more effective than those of the traditional politician may depend not so much on the present-day working scientists, but on the scientists now being trained, i.e.—you.