for weights and measures—"they are the older country, the mother country, more advanced in the arts and sciences, possessing more wealth and leisure for their improvement, and animated by a pride more than laudable . . . The subject should therefore be opened to them with infinite tenderness and respect, and in some way which might give them due place" His approach reminds one of the techniques and tendernesses necessary at the present time in advocating international fellowship.

Jefferson makes an interesting commentary ("Writings", 13, 105) on the English gentleman as an amateur man of science. "We (in Virginia) are all occupied in industrious pursuits. They abound with persons living on the industry of their fathers, on the earnings of their fellow-citizens, given away by their rulers as pensions. Some of these, desirous of laudable distinction, devote their time and means to the pursuits of science, and become profitable members of society by industry of a higher order."

Returning to his consideration of units of weights and measures, Jefferson proposed, in one crystal clear sentence, unmatched in my experience for simplicity and completeness, the following:

"That our unit of measure then be a pendulum of such length as in the latitude of 45°, in the level of the ocean, and in a given temperature, shall perform its vibrations, in small and equal arcs, in one second of time."

His uncommon gift for clear writing could not be better illustrated. But his proposal was not accepted. His arguments against the unit of the one ten-millionth part of the distance from the pole to the equator were to the point. But it takes more than clarity and logic to simplify the deeply rooted system of weights and measures.

Jefferson's "Notes on Virginia" were among his most noteworthy writings. To me they demonstrate more clearly than anything else that if he had been free from his national political life he could have readily developed into one of the leading men of science of his time and country. His "Notes" touched all phases of the natural history of the region, and dealt with its people and its government. There were many editions, many translations. But he viewed his accomplishments with modesty. On September 25, 1785, he wrote to Francis Hopkinson: "I have sometimes thought of sending a copy of my Notes to the Philosophical Society as a tribute to them, but this would seem as if I considered them as worth something, which I'm conscious they are not. I will not ask you for your advice on this occasion, because it is one of those on which no man is authorized to ask a sincere opinion. I shall therefore refer it to further thought."

How many an editor has wished that his scientific contributors would refer their compositions to further thought!

The "Notes" were written in the war years, 1781 and 1782, and therefore we should make some allowance for Jefferson's rather stinging comparison of *little America* with Great Britain and great France, so far as the production of genius is concerned. His war-time comments on Britain: "The present war so long having cut off communication with Great Britain, we are not able to make a fair estimate of the state of science in that country. The spirit with which she wages war, is the only sample before our eyes, and that does not seem the legitimate offspring either of science or of civilization. The

sun of her glory is fast descending to the horizon. Her philosophy has crossed the Channel, her freedom the Atlantic, and herself seems passing to that awful dissolution whose issue is not given human foresight to scan." For four hundred years worried men have predicted the impending dissolution of Britain. She has always been in a state of rapid decline!

One could continue at length with quotations that show the sensitiveness, the vast learning, the curiosity, and the originality of this astonishing Virginia farmer. He had, as they say, pretty nearly everything. In the field of natural philosophy he had caution and daringness, inquisitiveness and a willingness to change his mind in the light of new facts or as a result of further thought. What we would now call proper scientific methods and attitudes appeared to be instinctive with him.

His scientific creed is illustrated in his response to the Abbé Raynal's taunt, that America had produced no poet, no mathematician, or man of genius in any art or any science. In his "Notes on Virginia", Jefferson asked for time with regard to the poet; but pointed to Washington and Franklin (as well he might) as leaders in the soldier's craft, and the craft of physics; and concerning the Philadelphia astronomer he wrote, "We had supposed Mr. Rittenhouse second to no astronomer living; but in genius he must be the first, because he is self-taught. As an artist he has exhibited as great a proof of mechanical genius as the world has ever produced. [A famous orrery is referred to.] He has not indeed made a world; but he has by imitation approached nearer its Maker than any man who has lived from the Creation to this day." In a footnote he points out that the European nations traverse the globe with the aid of Hadley's quadrant, which was actually invented by the American Godfrey.

But to return to the scientific creed. The Abbé Raynal later withdrew his taunt with regard to the North Americans; but still disparaged the South Americans. In a footnote Jefferson questions the sufficiency of the Frenchman's knowledge, and the depth of his research on the subject concerning which he was writing. He indicated how the nationality and conditions of the interpreter might well affect the interpretation, and concluded with the unforgettable statement:

"A patient pursuit of facts, and a cautious combination and comparison of them, is a drudgery to which man is subjected by his Maker if he wishes to obtain sure knowledge."

THE WAY AND SPIRIT OF SCIENCE*

By GENERALISSIMO CHIANG KAI-SHEK

Chairman of the Military Affairs Commission of the Republic of China and Supreme Commander of the Chinese Armies

The Scientific Approach

PROCEED from the immediate to the distant, from the low to the high; attain the great through the small, the difficult through the simple. To

* Abridgment of an address by Generalissimo Chiang Kai-shek, given in 1942; translated by Huang Hsing-Tsung and Dr. Joseph Needham, F.R.S. Note that the word "Way" has a special significance in Chinese philosophy. The address is posted in all Chinese Government laboratories and workshops.

accomplish great and important things, it is necessary to start from the nearest, simplest, and most minute matters, enlarging and expanding gradually in systematic order.

Competence in small things precedes competence for big affairs; first know how to do commonplace things well; afterwards talk of doing work of special importance. Know how to solve small and easy problems; afterwards you may be successful in rare accomplishments. Never run after speculations and far-reaching conclusions, missing out immediate stages and hoping for lucky shots. Your work will only be superficial; short cuts will not lead to the desired aim, and nothing solid will be accomplished.

The Scientific Spirit

In order to investigate thoroughly all the phenomena of man and Nature, our attitude towards anything should be, not only to attempt understanding of what is not understood, and to make experiments where the previous experiments have not been satisfactory; but also to understand further what is commonly supposed to be already understood, and to improve further those experiments which have already been commonly considered satisfactory. The more knowledge grows, the more the lack of it is felt. The greater one's accomplishment, the more intensely the smallness of one's ability is realized. But it is through this very feeling of inadequacy and insignificance that knowledge and achievements can continually progress.

Never be satisfied with obtaining one result or even a small success. Whatever be the department of knowledge one is investigating or whatever kind of work one is to do, it is necessary before starting to consider properly the facts of the case, avoid all vagueness in defining the aim and be sure about the method to be employed. Once started, be determined to carry the project through, working unceasingly and meeting every obstacle with undaunted resource.

Many young men of to-day have no understanding of this principle. They will start to study a subject or work on a project, but when they meet the slightest obstacle or disappointment, instead of holding on doggedly and industriously, they will merely skip the difficulty and turn over to some other easier problem. This mental unsteadiness, chopping and changing time after time, will never bring any result.

There are also many who have as their main object in life the attainment of wealth or high official position, and if they find themselves engaged in work where these aims seem to have little or no hope of realization, they will discard it without any consideration, however important it may be, and creep into some new path. Such opportunists, consulting only their own selfish interests, have no responsibility to the country and the people.

The Scientific System

Limitations. In doing anything we must first know the limitations of the question; in other words, one must be quite clear about one's object and aim. This is of prime necessity, for one can then concentrate time and energy upon possibilities within the frame of reference. Thus one can avoid all distractions from other sources; and one will not try to do several things at once. If we think of attacking one problem to-day, another to-morrow, and still another the day after to-morrow, finally nothing will be accomplished. In investigations and affairs it is

essential to define the central idea. Only if this is done can we distinguish between the roots and branches of things, avoiding confusion between the first and the last. A clear idea of the order of things, which stands the test of practice, is required for the success of any research.

Management. All reasonable scientific organization must satisfy the following requirements: (a) a vertical definite dendritic order; (b) a horizontal intimate co-ordination. The vertical order embodies the relation between the upper and the lower, the deriving to the derived, levels of organization. Such relation must be well understood before the organization can be effectively controlled and steered with ease. The horizontal co-ordination embodies the relation between each small part of the organization to every other part, so as to give harmony in operation. Such relations must be intimate before the different portions can achieve complete co-ordination, and the organization run with maximum efficiency.

Recording and Preparation. Before beginning work on any subject, collect every type of material available, examine it carefully, and presuppose all possible situations which may be encountered at different later stages, using all possible intelligence and resourcefulness. Consider the preparation of different types of formulae to meet different situations so that at any stage of the work the most satisfactory formula can be produced. Only those who are thoroughly industrious and persevering in thought, only those who have different solutions and formulae prepared beforehand, can meet every situation with calmness and ease. However difficult the matter in hand may be, in the end they find the solution which carries them through.

Division of Labour and Co-operation. The advance of human civilization has been entirely due to division of labour and co-operation. Whether it be knowledge or practical affairs, division of labour is necessary for specialization, and co-operation is necessary for success. For the intelligence and ability of one single man are limited; hence each man has to select a particular branch of knowledge for investigation or a special type of practical work to do; only then is the highest efficiency attained. Then the results of different investigations have to be unified and co-ordinated, and the entire whole of knowledge and achievements makes real progress. We Chinese suffer from a great lack of co-operation in knowledge and affairs. In our scholarly researches there is not enough discussion and mutual understanding; and in our affairs there is little sympathetic and helpful co-ordination; thus the research spirit is low and few things are done well and effectively.

Research. The progress of science and the improvement of the lot of man have been due to the efforts of research. These were not accomplished by people who are content to work to strict office hours. In the West, work is carried on not only in the normal working hours, but even free time is not wasted. For example, Sundays have been found just the right time for intellectual investigations. If we are to save our country, we must break through the present lethargic and pessimistic psychology, and cultivate an industrious and persevering spirit, dedicating oneself to research with all one's heart and mind.

Experimentation. Many of the results of investigation and observation are only theories which have to stand the test of experiment before it can be shown whether they are correct and suitable for

practical purposes. If experimentation shows flaws in the theory, then it is necessary (according to the facts of the case) to study more carefully, trying various improvements until as satisfactory a hypothesis is obtained as possible. If one still fails, the reasons for failure must be further inquired into, and corrections made accordingly. The ideal type of research worker is one who stands firmly by the scientific attitude (the objective outlook), observes facts and circumstances objectively and with humility, and draws his conclusions therefrom. Then only will there be any hope of knowing the truth.

Analysis and Statistics. When any plan or project of work shows development at the experimental stage, whether good or bad, one must collect and analyse the mass of material on hand, find out where the defects or good points are, decide whether the plan is workable and how far progress has been made, and in which direction and along what lines future developments are to take place. This statistical and analytical ability and the power for precise decision are fundamental in the success or failure of our research or practical work. Without the analytical and decisive mind it will not be possible to see clearly and objectively the relevant facts, and one falls into a mental state of chaos and disorder, failing to discover any likely approach to a successful conclusion.

Improvements and Inventions. To be conscious of mistakes is the most important factor in making progress. So in all our analytical examinations it is imperative to find the causes of these mistakes; only in this way shall we be able to find the required improvements. We must also persevere to discover those new principles, new methods, and new factors which are essential for general progress.

Conclusions. We live in an era of difficulty, suffering and danger. To be able to shoulder the heavy responsibility of reviving our nation and completing our revolution, we must have at all costs a clear idea of the content and meaning of science; we must propagate the spirit of science; and we must utilize the methods of science; so that one man will be as efficient as ten, and in one day ten days work will be done. While we are fighting intensely at the front for the mode of life we want, we cannot remain stationary at home; if we do not progress we shall degenerate; if we cannot achieve success we shall be ruined; if we do not prosper we shall be crushed; if we still refuse to gather our full strength our very existence will become impossible. From this day onwards, whatever it is we have to do, and whoever is doing it, there should be no more inefficient half-heartedness and no more spirit of fatalistic resignation.

OBITUARIES

Prof. David Hilbert, For.Mem.R.S.

News has reached Great Britain that Prof. David Hilbert, of Göttingen, died recently. He was born on January 23, 1862, and was a mathematician of tremendous power who ranged over a wide field and had an unusual influence on present-day mathematics. An indication of the breadth of Hilbert's influence is the number of mathematical topics which are associated with his name. For example, we have Hilbert space, Hilbert inequality, Hilbert transform, Hilbert invariant integral, Hilbert irre-

ducibility theorem, Hilbert base theorem, Hilbert axiom, Hilbert sub-groups, Hilbert class field. Again we recall his contributions to the "Yellow-Backs": "Methoden der Mathematischen Physik" (with Courant), "Grundlagen der Mathematik" (with Bernays), "Anschauliche Geometrie" (with Cohn-Vossen), "Theoretische Logik" (with Ackermann).

The fact that Hilbert was able to produce outstanding original results in a large number of different branches of mathematics and mathematical physics is most remarkable in our times. It was made possible by his ability to concentrate completely on one subject for a time; when he had finished, he rarely returned to it or even cared to hear about it, not even recognizing his own results. However, when Hilbert did become interested in a subject, he was able to indicate so many possible lines of development that mathematicians were kept busy for decades afterwards on new problems.

There can be few mathematicians nowadays whose work does not in some way derive from Hilbert. His personality and naïve enthusiasm attracted to Göttingen many pupils and followers who will always delight in recalling their experiences there and in passing on some of the Hilbert anecdotes. Hilbert's devotion to mathematics was complete: he allowed no prejudices, racial or otherwise, to interfere. For example, despite violent opposition from his colleagues, during the War of 1914-18 he insisted on delivering a eulogy on Darboux and on Emmy Noether receiving the *venia legendi* at Göttingen.

While it is not possible to give here an account of Hilbert's work, it is worth while recording some of the main topics on which he concentrated at various periods: invariant theory, algebraic number theory, diophantine equations, integral equations, foundations of geometry, mathematical physics, calculus of variations, foundations of mathematics. A detailed study of his papers reveals the continuous development of his thought from "theology" back to "theology". In honour of his seventieth birthday a three-volume edition of his papers was published. Reviews of the volumes by Prof. L. J. Mordell, to which those who wish for a more detailed account of his work should refer, appeared in the *Mathematical Gazette* in 1932, 1934 and 1936. I had the privilege of being closely associated with Hilbert in the preparation of this edition. In conversation, Hilbert often affirmed that, much as he admired every branch of mathematics, number theory was for him the most attractive. By number theory he meant algebraic number theory rather than the number theory typified by Waring's theorem, for which he nevertheless found the first proof and by which he is perhaps best known in Great Britain to-day. His work on Waring's problem was totally unconnected in content and time from his main work on number theory. It is interesting to recall that, in connexion with a lecture by Prof. R. Fueter at the 1932 Zurich Congress, Hilbert asserted that the theory of complex multiplication (of elliptic modular functions) which forms a powerful link between number theory and analysis, is not only the most beautiful part of mathematics but also of all science.

Among Hilbert's papers, I will mention only a lecture in Paris in 1900, in which he stated his famous series of twenty-three problems. These were the problems which he considered most significant in mathematics at that time; not isolated questions but problems of such a general character that their