EXPERIMENTS, FACTS, HYPOTHESES AND THEORIES

One frequently hears it stated that "An ounce of fact is worth a ton of theory," the observer generally not understanding that the men who postulate the theory are necessarily aware of the facts. When a lot of experimental evidence has been collected with regard to certain events, we may become so convinced of the correctness of our observation of the effect of certain causes operating that a law is formulated, or the results may be stated as a "principle." Take, for instance, Boyle's law: The volume of a given mass of gas is inversely proportional to its pressure, provided that the temperature be constant. We know that this is not perfectly correct for all conditions of pressure and temperature, and that later experiments have shown us modifications even at customary temperatures and pressures. But within the usual order of accuracy with which we are concerned, if we double the pressure on a gas without changing its temperature or letting any escape, its volume is halved; and so on. This does *not* happen in obedience to Boyle's law, as one frequently sees stated—but Boyle's law is a statement of the fact that these pressure and volume changes occur in a material which we call a gas. An hypothesis is an attempted explanation of a law, or set of laws; it is not a statement made merely for the sake of philosophical argument, and not based on experiment, but is designed to lead to fresh experiments. There may be several different explanations suggested to us to account for some experimental facts—we test these by fresh types of experiment, and discard hypotheses that do not fit in with the results. The big advantage of that tentative explanation, the hypothesis, is to suggest fresh experiments. An hypothesis is a stage ahead of a conjecture. A theory is that explanation of a set of experiments which is accepted at the time as being the most probable—although, like the hypothesis, it may require to be discarded or modified as fresh experiments are performed. The philosopher, J. S. Mill, sums it up in book III of his "System of Logic," when he says that "Nearly everything which is now theory was once hypothesis." We do not believe that our present theories to correlate experimental laws are final. But we are also cautious in accepting the results of an experiment as final. Renewed experimentation, to the limit of the accuracy permitted by modern methods and instruments, discloses modification of experimental results which though slight may be of the greatest importance.

Many people talk about subjects of which they know very little; and we frequently find that the less they know about them, the more certain and assertive they are in their statements. Suppose, for instance, some boy to declare that the Sydney University athlete, Metcalfe, has just cleared seven feet in a high jump; it is quite possible that you will politely doube his statement, because you think that rather high.* You might say that you do not believe him. That is quite in order—it is a statement of the fact that you do not believe him, and you are on safe ground, though perhaps discourteous. There are, we know, certain school expressions implying disbelief which are less courteous.

When you make a statement yourself that "Metcalfe has never cleared seven feet in a high jump," you are making a statement with which I am in agreement, but with which our first friend is apparently in opposition. If we ask him how he knows that the seven feet have been cleared, he may reply, "I know; that's all," which used, when we were schoolboys, to be regarded as a crushing reply: but what if he asks us how *we* know that Metcalfe has never cleared seven feet? Are we going to make the same reply?

Somewhere at some time someone must have measured the vertical height to the top of the centre of a light bar, which Metcalfe has just cleared, and found it to be seven feet above level ground, if our friend is correct. People have been carrying out experiments as to how high he can jump, although they may call it an athletic meeting rather than "experimental athletics," or a section of "applied experimental physics."

What we are really demanding is the authority for the statement that the height cleared has been as much as seven feet. We may be told, "I read it in a newspaper." Knowing something about newspapers, we might not regard that as final, or knowing something about our friend, we might continue in our disbelief. We do not require actually to have seen the jump ourselves, much less to have made the actual measurements; if it comes to that, it would not be reasonable for you to hold one

* His actual record is 6 feet 5¼ inches.

end of the tape on the ground whilst reading the height at the bar—you have to depend on the observations of someone else.

We are prepared, then, to accept the results of observations made by others, provided the experiments have been performed under satisfactory conditions and by people qualified by training to make them; and we require the measurements to be made several times by independent observers before we accept them, noting the order of accuracy of the work.

If you jumped over a bar six feet nine inches above the ground in your back garden and wrote into the Athletic Association and claimed a record, it would not be admitted, although you probably have a reputation for truthfulness. In your case, of course, it would be a most astounding claim, and the more astounding a statement the more evidence we want before we accept it. Even if Metcalfe himself did it to amuse the youngsters some afternoon, it would not be admitted; he would be asked to come along and do it again under the standard conditions and before the trained observers.

The life of human beings is controlled by measurements. Because we are daily paying more and more attention to measurements, our lives are becoming longer, and we are more comfortable and suffer less sickness during those longer lives. (Whether we are any happier is a subject on which I cannot state authorities I am prepared to ask you to accept, so I am careful not to make that statement here.) The fact remains that educated, rational people put everything to the test of experiment when possible before being prepared to make definite statements about them.

Even the fact that experiments have previously been carried out by others does not mean that old experimental results are blindly to be accepted; the conditions of an experiment may be modified, fresh apparatus and methods of attack may give different results (even though the difference be slight), and the conditions may, in some known or unknown ways, have changed since the performance of the earlier experiments.

We have never learnt, we are always learning. Observation is very important. Our observations may be qualitative or quantitative. You may pick a daisy and note that it is, say, a pretty little white flower with a tinge of yellow in towards the centre. That it has petals, and so on. Or you may count the number of petals, and by doing that to a number of daisies find out whether daisies usually have the same number of petals or not.

As a further example: You are going to buy eggs for human consumption. The eggs are graded in Sydney as hen eggs, medium eggs, pullets' eggs and small pullets' eggs. You go into the shop and make the qualitative observation that the hen eggs appear small, the medium eggs appear smaller, the pullets' eggs still smaller, and the small pullets' eggs smallest. And you can make all sorts of exciting qualitative observations as to their shapes and colours. Which are you going to buy? Qualitatively, you like a large egg. You probably like two eggs. What about having two medium eggs or three pullets' eggs? We now come on to quantitative measurements. The object is to get a given amount—volume or mass as you like—of egg. Not of egg shell, but of white and yolk. We want to measure the amount of matter in these different kinds of eggs. Another quantitative question arises: Undoubtedly qualitatively the hen eggs are dearest, and the medium and pullets' eggs cheaper in that order—but by how much?

Yesterday's prices for a dozen eggs were 9d. for hen eggs, 7d. for medium, 5d. for pullet, and 4d. for small pullet. We could, of course, go on to second grade eggs, but the risk is great enough on first grade. Two pullets' eggs cost just about the same as one hen egg. Do the hen eggs contain nearly twice the material that is in the pullets' eggs? If I were personally concerned with the buying of eggs to make cakes and puddings and things, or for breakfast consumption, I should certainly want to know that; and it would be no good guessing at it. (I admit that I do not know, though it is quite probable that the experiment has been carried out, and even that the results have been published and are available.)

It would not be sufficient to take *one* of each egg and weigh them. For one thing, we are not interested in the shell, but in the contents; and also we might happen to get a large egg of one class and a small egg of the other class.

There have always been people prepared to guess rather than to experiment, even when the experiment would have been so simple. Take, for instance, the well-known case of the Greek scientist, Aristotle, who was quite an important person some 300 years before Christ. He was born in Macedonia in 385 B.C. Because he was a very clever person it was considered respectful by his followers and his successors to accept his statements without question. That is a very foolish attitude to adopt towards anything which is capable of experimental verification; there are many things that we have to accept on faith if told to us by persons whom we are prepared to trust, because they are not things which we can verify experimentally. Even in matters purely scientific there are a lot of things one teaches, and which are used in connection with the solutions of other problems, which one has never checked oneself. The experiments have been performed, and the results have been presented by people whom we believe to be competent and trustworthy. Even these people, however, make mistakes, and we are not surprised if we find them in later papers producing modified results of earlier experiments.

One of Aristotle's teachings was that all bodies fell towards the earth with speeds proportional to their masses. For instance, he said that a one-pound lump of iron would take twice as long to reach the ground from a given height as would a two-pound lump of iron dropped from the same height. You know that is quite wrong, because competent authorities tell you that experiments carried out show that one pound and the two-pound lumps take precisely the same time to fall through the same height in a vacuum, where the effects of the fluid through which they ordinarily fall, the air, are not present; and that when falling in air the time is so nearly the same that you have to have some special means, like a slow motion picture, to show the slight lag. There is an illustration of that as the frontispiece of your elementary text book in Physics. The experiment was recently performed with this apparatus, made at the Sydney University, for one of the "talkie" companies, and the film is being shown in Australia at present.* A heavy iron ball of mass about 2,000 grammes and a cork ball of the same size (4·1 cms. diameter) but weighing about 50 grammes, are let fall at the same instant. They initially are held up by electro-magnets in front of a vertical screen marked off in feet, the cork ball having a tiny tack in it so that it will be held by the magnet. The electric currents through the wires round the magnets is stopped by pulling out a switch, and the two bodies

* Fox-Movietone.

are thus released at the same instant. The big iron ball falls through ten feet in 79 hundredths of a second; the big cork ball takes 82 hundredths of a second, the difference of three hundredths of a second being quite noticeable when multiplied by the "slow motion" factor. This little difference in time of falling, amounting to less than four per cent., is due to the fact that they are falling through a fluid, the air. We know that if we put them in water the cork will not fall at all, but will float, and the iron will take much longer than before to fall through ten feet.

According to Aristotle's teaching, which was generally accepted right through to the end of the sixteenth century, the cork ball being only 50 grammes to the iron ball's 2,000 grammes, should have taken forty times as long to fall—if the iron ball fell through ten feet in 79 hundredths of a second, which is a little over three-quarters of a second, then the cork ball should have taken 32 seconds, or over half a minute. It would almost appear as if Aristotle and his followers were very careful people, and had never dropped anything—the discrepancy between less than a second and over half a minute being so great. But we must remember that we are likely to make errors to-day which will appear just as astounding to our descendants unless we put everything possible to the test of precise measurement.

When we have a big accumulation of experimental evidence with regard to some particular occurrence or set of occurrences, we may formulate a law, which is a statement of the result of that evidence. Aristotle made a statement with regard to falling bodies, apparently without having the experimental evidence which is the fundamental necessity. It was, therefore, *not* a law.

Not only is *all* modern scientific work in all spheres based on a knowledge and acceptance of the fundamental laws of physics, and all applied work such as Medicine, Radio, Agriculture and all manufacturing processes dependent on an understanding of the elements of scientific observation, but such a big percentage of the educated populations of the world are familiar with the elementary ideas, definitions and terms that we are out of touch with our modern surroundings if we ourselves are still ignorant.

We ask, "What happens if we do this?" and first of all inquire of someone who is likely to know what experiments have already been performed. Even if other people have already tried, it may be helpful to repeat the experiment, as practical experience is worth more than hearsay. We must be sure, of course, that we are not endangering apparatus, ourselves or others in repeating the experiment. Large numbers of boys have carried out the experiment of ramming an old gaspipe full of gunpowder, putting in a fuse through a plug in the end, and of lighting the fuse. Large numbers of boys have been killed, or more or less seriously damaged, by the experiment. It has been done so much better by other people, in strong explosion chambers fitted with gauges and recording drums for measuring the internal pressure and temperature instant by instant, that the value of the experiment with the gas pipe, without any quantitative measurements, is negligible. It is really only done because it is going to make a loud explosion and is exciting. We teachers may admit to an unquenchable liking ourselves for explosions; but we are old enough now to like safety more, and so keep in touch with what other people are doing—the improvements they make and the mistakes they make. (The author himself first experimented with explosives when he was quite young. Chemistry was his first love—in the scientific field, that is, because this is really a paper on science—but he did not have the necessary fundamental knowledge of physics apart from what he got in his introductory chemistry, and passed to a specialisation in explosives too soon. There was a loud bang, and he had three months' holiday from school, after just failing to acquire a lot more knowledge by leaving this world altogether. He had personal experimental evidence of the danger of doing dangerous things with insufficient preliminary knowledge, which was a salutary lesson.)

Science nowadays publishes the results of its investigations. We can profit by the experiences of others and avoid the pitfalls into which they have tumbled. If we happen to have the nature which makes us do silly things to see what happens, then we should not repeat the silly things that other people have done.

When a boy climbs on to an iron roof and catches hold of a wire, it may help merely to steady him, or it may provide an electric current to kill him. It is probably not necessary to climb on to the roof at all, but if he does he at least takes with him the knowledge that bodies tend to fall towards the earth, and that his is no exception to the general law. Also, that the greater the height through which he falls the greater the work done in stopping him when he arrives at the lower level. Not only does he know that it is dangerous to prowl round on high, sloping roofs, but he knows *why* it is dangerous. We cannot overemphasize the over-importance of knowing "why," and we cannot tell people "why" unless they can speak even haltingly the modern language, which includes scientific words. (They should take it that all wires are dangerous, as a first step. That all metal objects which are liable to come into contact with a wire are dangerous. Then they can work from that basis as to how improbable it is that a particular wire is dangerous.)

An elementary knowledge of certain experimental facts and the laws stating them in connection with electricity will not make anyone an electrician, but will help to bring him more into touch with modern conditions.

Culture is not limited to the small group who have the ability to repeat lengthy extracts from the works of Roman and Greek authors who lived between 500 B.C. and 500 A.D. We should call no man or woman cultured who has not a *familiarity* with modern English, and who is not in touch with the economic and scientific developments of his day. Students should learn to read and reason for themselves, using their teachers as guides rather than drivers. They must always try to express themselves in English, and to use their text books and dictionaries to add to their vocabularies. We cannot speak to them, and they cannot reply to us, so that we understand one another, unless they appreciate the fact that to the scientist the use of the correct word is as important as the use of the correct instrument.

Even if they enter some sphere of life in which they appear to make no direct use of their earlier training in physics, they should have learnt the invaluable habit of orderly thought and expression.

Reverting to the opening paragraph, we see that a theory is not a guess or a speculation made by people unfamiliar with facts. Actually, an "ounce" of theory may be forged as a connecting link between tons of facts; the experimental observations, which provide the information which we believe to be correct, are made first. The glib use of the old expression merely shows an ignorance of the meaning of the word "theory."