When all the β's are equal and all Z's are equal, we have an equation obtained by Goldman (*14*) in another way:

$$V = \frac{RT}{ZV\ 23060} \ln \frac{\sum_i |Z_i|\ a_{io} p_i}{\sum_j |Z_j|\ a_{jo} p_j} \qquad (20)$$

Planck (*15*) derived a useful form of some of these equations. The more general equation (Eq. 18) is required when we have ions carrying current with different valences and different asymmetric barriers, as is sometimes the case. Active transport occurs whenever the ion current in one direction is not balanced by its reverse current. This happens in corrosion, for example, and it is always associated with a decrease in the free energy of the system. For example, if sodium forms a complex with some agent (or agents) which has much higher permeability than ordinary sodium ions, there will be active transport of this complexed species down its gradient, although the gradient of ordinary sodium is opposite. If the chelating material for sodium is formed at higher concentration inside the cell and if this material is modified outside the cell to chelate with potassium, making potassium highly permeable for the return journey, we have a shuttle system which will build up the potassium concentration inside the cell and the sodium concentration outside. The chelating material can be part of the membrane, provided it is able to make the journey with the ions through the impermeable part of the membrane. The energy for modifying the chelating material comes from adenosine triphosphate, but what this chelating material is, is much less clear. Since it has not been possible to isolate the chelating material, the conclusion is that it must be used very efficiently and with little loss. If acetylcholine and phosphoric acid chelated with sodium for the outward journey, and acetic acid and the choline ester of phosphoric acid chelated with potassium for the backward journey, we would have a neat fitting together of a number of the facts concerning active transport. Something like this must happen. Skou (*16*) has recently made some very interesting observations concerning active transport.

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The Art of Talking about Science

Lawrence Bragg

I propose to analyze "Talking about Science." How is it best done? Why is it that a subject presented by A is a thrilling account which leaves a deep impression, whereas the very same material presented by B is dull and boring and produces no impression whatever? How should we present our branch of science to fellow scientists who work in quite another field? How can we present science to those who have little or no scientific background, as is often the case with men of high ability who are important in affairs of state? How can we make the nonscientist understand why its study means so much to us, a passion they sometimes find very difficult to understand? The gap between C. P. Snow's two cultures is not so much due to a lack of understanding as to a lack of desire to understand. There are philistines as regards science as well as regards the arts.

These problems have been brought vividly home to me in a number of ways. I was for many years president of the Physics Solvay Conference. It must be one of the most exclusive of international science gatherings, because only some 20 participants are invited to discuss the subject chosen for the meetings which are held every 3 years. I have listened for 12 years to all the Friday evening discourses at the Royal Institution, where a broad review of some branch of science is given, and the speakers are both well known in their fields and artists in framing their talks. I talk to many thousands of school pupils every year, and find the nature of their response to be a fascinating study. Recently we have been framing courses for men and women who are new entrants to the Civil Service, and who have had no scientific training. I cannot help but be interested in the basic principles which apply to all talks of this kind.

What is the basic character of a "talk"? I think it can be expressed by saying that its primary object is to create a state of mind, or point of view, not to convey information. I can perhaps illustrate what I mean by dwelling on the vast difference between the spoken and written account. Under the heading "talk," I am not including a course of lectures where students take notes and the lectures follow each other

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as a composite whole. Nor do I include the "get together" of two or three experts in the same line of research, for which no rules are necessary. I am considering the hour's talk to an audience whose attention one has to retain and whose interest one has to arouse. The written account can also aim at creating a viewpoint, but its main function is to be a storehouse of information. The argument can be meaty and condensed. It can be packed with tables, graphs, and mathematical equations. This is possible because the reader can always pause and digest it at his leisure, going back over parts which he finds to be difficult. The written account has a quality also which I find hard to define. It is as if the writer were giving evidence on oath, and had to justify the accuracy of every word. He must be careful to give references and all due acknowledgements. I do not mean to imply that one can be irresponsible in a talk, but one need not cross all the "t's" and dot all the "i's." In fact, the talk would be spoiled by an attempt to do so.

A talk is therefore different altogether from a "paper." To my mind the governing factor which determines its art form is this: The success of the way in which the subject has been presented is measured by the extent to which the average member of the audience remembers it next day.

This may seem an obvious statement, but if we use this principle as a yardstick to assess a lecture we have listened to, or in planning a lecture of our own, it creates a very significant viewpoint. The value of a lecture is not to be measured by how much one manages to cram into an hour, how much important information has been referred to, or how completely it covers the ground. It is to be measured by how much a listener can tell his wife about it at breakfast next morning, or, if she is not interested, a friend in the morning train. If we honestly put this question to ourselves and think how little we can remember of talks we have heard, it gives us a sense of proportion and of values in planning a lecture and makes us realize that what we say will go over the heads of the audience if we set our sights too high. I would like now to list what I believe to be some of the considerations which apply in planning a talk.

For instance, suppose we ask how many main points can we hope to "get over" in an hour? I think the answer should be "one." If the average member of the audience can remember with interest and enthusiasm one main theme, the lecture has been a great success. I like to compare the composition of a lecture to that of a picture. Of course this is dangerous ground on which to venture, because art experts differ so much among themselves. But in simple terms, is it not held that a picture should have one main centre of interest? It may have numerous subsidiary features, but the composition is so cunningly arranged that when the eye falls on these and follows their placing it is subtly led back to the main centre of interest and does not fall out of the picture frame. A lecture should be like that. There should be one main theme, and all the subsidiary interesting points, experiments, or demonstrations should be such that they remind the hearer of the theme. As in a picture, so in a lecture, the force of the impression depends upon a ruthless sacrifice of unnecessary detail. I do not mean that a lecture should be like some modern pictures, consisting of an otherwise blank canvas with one button or other object sewn on it at a place which I suppose has enormous aesthetic significance. It can, on the other hand, be richly endowed with exciting details, but they must be of such a kind that the recollection of them inevitably brings the main theme back to mind. In other words, the lecture must "compose" in the sense of having a pattern because it is this pattern which helps so much to impress it on one's memory.

Reading

I feel so strongly about the wrongness of reading a lecture that my language may seem immoderate. I think it is a dreadful thing to do, something quite out of keeping with all that a lecture should mean. The spoken word and the written word are quite different arts. Though the reader can pause and go back to a passage he has found difficult, the listener cannot do so and may lose the thread of the argument. It is boring in a written account to be repetitious; it is right in a spoken account to put a key idea in several ways to make sure the audience has grasped the point. When a man writes out his lecture he inevitably writes it as if it were to be read, not heard. The ideas follow each other too fast. It is, of course, far easier for the lecturer to read than for him to "think on his feet" by constructing his sentences on the spot, because he can frame his sentences at his leisure. I realize that many lecturers read their material from a feeling of modesty, thinking they will give a poor rendering if they have no script. While appreciating their reluctance, I am sure they are wrong. I feel that to collect an audience and then read one's material is like inviting a friend to go for a walk and asking him not to mind if you go alongside him in your car. It is easy for the lecturer to deliver well-considered rounded phrases, but the audience has to follow and to think. If someone says, "I dare not talk. I must write it out," I am tempted to ask, "Then why lecture? Why not send a written account to your friends and let them read it comfortably at home, instead of dragging them all out to a lecture hall to listen to your reading the very same thing?"

We come back, it seems to me, to the essential feature of a lecture which justifies bringing the lecturer and his audience together. It is the emotional contact between lecturer and audience. If a lecturer has to find his words as he speaks, he will be automatically restrained from going too fast because he is thinking along with his audience. Every lecturer knows the trick of watching a few sympathetic faces in the audience and of judging (by noting their response) whether he has been successful in making his points or whether he must put things another way. A lecturer who reads is earthbound to his script, but the lecturer who talks can enjoy a wonderful feeling of being airborne and in complete accord with his audience. It is the greatest reward of lecturing.

Just as the troops used to say "The worst billet is better than the best bivouac," so one is tempted to say in a similarly approximate way "The worst spoken lecture is better than the best read one." But there are exceptions to all rules. Some very fine lecturers read their lectures, and I have tried to analyze the peculiar quality which makes their performance possible. I think they are the people who so refine and weigh every word and sentence that their beautiful prose almost becomes poetry—it is like a poet reading his verse. Eddington read his lectures marvelously, and on the arts side I have heard most moving read lectures delivered with great dramatic effect. But I think one ought not to venture to read a lecture unless one has these considerable poetic gifts.

The First Ten Minutes

A lecture is made or marred in the first 10 minutes. This is the time to establish the foundations, to remind the audience of things they half know already, and to define terms that will be used. Again this seems obvious, but I have listened to so much splendid material lost to the audience because the lecturer failed to realize that it did not know what he was talking about, whereas, if the precious first 10 minutes had been spent on preparation, he would have carried his listeners with him for the rest of the talk.

Slides

Lecturers love slides, and in a game of associations the word "lecture" would almost always evoke the reply "slide." But I think we ought to apply to slides the same test, "What will the audience remember?" Some information can only be conveyed as slides, photographs, or records of actual events, such as the movement of a recording instrument, for instance, a seismograph. But slides of graphs or tables of figures are in general out of place in a lecture, or, at any rate, should be used most sparingly, just because the audience has not time to absorb them. If the lecturer wishes to illustrate a point with a graph, it is much better to draw it, or perhaps clamp the component parts on a magnetic board or employ some device of that kind. I remember well the first time I was impressed by this latter device, during a lecture on airflow through turbine blades. The lecturer altered the angle of incidence and the air arrows by shifting the parts on the board. It was far better than a series of slides. It is again a question of tempo—the audience can follow at about the rate one can draw; one is forced to be simple, and the slight expertise of the drawing holds attention. One must constantly think of what will be retained in the audience's memory, not of what can be crammed into the lecture.

Experiments

Faraday had much to say about experiments that was very wise. The best experiments are simple and on a large scale, and their workings are obvious to the audience. The worst experiment is the one in which something happens inside a box, and the audience is told that if a pointer moves the lecturer has very cleverly produced a marvelous effect. Audiences love simple experiments and, strangely enough, it is often the advanced scientist who is most delighted by them. There are tricks too about demonstration. The wrong way is to do the experiment, ask the audience if they noticed this or that, and then explain what this or that meant. The right way is to start by explaining the significance of the effect you are aiming at producing, tell the audience what to look for, and then, after a pause to make sure you have their attention, to bring it off. These tricks are important because they are all part of fixing your message in the minds of the audience; they have the humble but necessary function of the hypo in fixing a photographic exposure.

The Arousing of Interest

Here a most important principle comes in which I think of as the "detective story" principle. It is a matter of order. How dull a detective story would be if the writer told you who did it in the first chapter and then gave you the clues. Yet how many lectures do exactly this. One wishes to give the audience the esthetic pleasure of seeing how puzzling phenomena become crystal clear when one has the clue and thinks about them in the right way. So make sure the audience is first puzzled. A friend of mine, a barrister, told me that, when presenting a case to a judge, if he could appear to be fumbling toward a solution and could entice the judge to say "But, Mr. X, isn't the point you are trying to make this or that?" he had as good as won the case. One wants to get the audience into this frame of mind, when they are coaxed to guess for themselves what the answer is. Again I fear I am saying the trite and obvious, but I can assure you I have often sat and groaned at hearing a lecturer murder the most exciting story just by putting things in the wrong order.

We all know the tendency to go to sleep in lectures; how often have I felt ashamed at doing so myself. Though the best lecturer can never entirely escape from producing this effect, there is much that can be done to minimize it. A continuous even delivery is fatal. There is something hypnotic about it which induces sleep (this is another reason why it is so bad to read). Pauses and changes of tempo are essential. Above all, jokes have a marked and enduring effect. The science lecturer is of course greatly helped by his experiments and demonstrations which make useful breaks.

Timing

Some try to get the timing of a lecture right by, as they say, "running over it beforehand" and seeing how long it takes. I am doubtful of the usefulness of this exercise when applied to the lecture as a whole. I prefer to divide it into some half dozen portions, and allocate about 10 minutes to each, marking this timing in the margin of my rough notes. One can sometimes fall into a dreadful trap with a subject in which one is a specialist. One thinks "that point will only take a minute or so to explain" and realizes to one's horror in the actual lecture that, having to start from scratch, it takes ten times as long. Of course the way in which each 10-minute section is to be put has to be carefully thought out and its timing roughly estimated. The advantage of dividing the time up in this way is that the pace can be adjusted during the lecture when it is clear that it is going to be too long or (rarely) too short. If time is running short, the part to shorten is the middle where it will be little noticed. The beginning or the end must not be hurried. It is rather like fitting a patterned carpet in a room which is too small for it. If this heroic measure must be adopted, it is much better to cut a strip from the middle of the pattern rather than to cut off an edge. An hour is as much as an audience can stand, and it is most unfortunate when a lecturer has to race through his material at the end and even then runs over the hour.

Kindness to Lecturers

A lecture is a tour de force and a good and conscientious lecturer is both nervous beforehand and prostrate afterwards. I think there is a great deal to be said for the tradition at the Royal Institution that the lecturer should be immured in a small private room termed "The Lecturer's Room" for at least half an hour before the lecture starts. Tradition has it that this was originally laid down because once a lecturer (actually Wheatstone of Bridge fame) ran away from nervousness just before the lecture started, and so a guard has been

placed over the room ever since. In fact, the guard is there not to keep the lecturer in but to keep intruders out. Most if not all lecturers value this quiet time to have a last run over their material and get their minds into the right mood. In particular, if members of the press realized the state of mind of one about to give a lecture, which is much like that of an athlete about to run a race, I am sure they would refrain from tackling him just before the lecture starts, to get, for instance, his views on the atomic bomb. After the lecture he should be at their service and oblige them in any way he can, because he is free to switch his mind off his lecture.

I have emphasized the difference between the spoken and written word. To prepare a talk, and to write an account of it, are two separate tasks and the latter may be much the heavier. I think, therefore, that, when a man is invited to speak, it should be made clear at the same time whether he is to write as well. I know to my cost what a difficult position one is placed in if one discovers, after agreeing to talk, that the heavy labor of writing up the material is also expected. I am sure the task is often imposed unwittingly, under the idea that if a man is talking he will have written what he wants to say, but you will have realized from my remarks about reading that I feel this ought not to be assumed. The most embarrassing thing is to be told that a tape recording will be made, and asked if one would please correct it. It is embarrassing to see a verbatim report with all the remarks recorded literally, and it is generally far less trouble to write it from the beginning than to try to patch the record.

In conclusion, I hope you will realize that the last thing I want is to seem to lay down the law about lecturing. I have spoken so feelingly about the pitfalls because I have so often fallen into them myself. One has to be constantly watchful if they are to be avoided, and even then one does not escape. It is most dangerous to be complacent about a lecture, to think that it will be all right because one knows the stuff and has given a similar talk elsewhere. Every lecture must be approached as if it were a new problem. No pains are too great in the attempt to make a talk a success, and I believe that, given the right treatment, any subject can be made fascinating to any audience.

Kinetic Isotope Effects and Organic Reaction Mechanisms

A fruitful application of quantum theory to organic chemistry has now been strengthened.

M. J. Goldstein

The replacement of any atom in a molecule by one of its isotopes is surely the smallest and most trivial of all the possible structural perturbations in chemistry. Yet the addition of one judiciously placed neutron can often depress the rate of chemical reaction tenfold. This kinetic isotope effect has long been better understood than almost any other rate phenomenon. It has provided the organic chemist with a unique and often indispensable tool with which to pry open the secrets of reaction mechanisms.

In part because the technique proved to be so very useful, a curious development has ensued. The theoretical foundations were slowly refashioned, through the achievements based on them, into simpler guides, which soon became working rules. More recently, the limitations of such rules have become apparent, and the need for their revision has become increasingly obvious. Here I am concerned with the development of this problem and of its resolution, and also with the stimulus which both provided toward a newer, perhaps more fruitful, application of a phenomenon that was well understood long ago.

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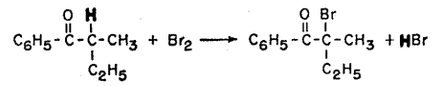
Elucidation of Reaction Mechanisms

To illustrate how a technique can be distorted by its application, I have chosen to describe the reactions of molecular bromine with four different organic molecules. The first of these reactions, that of molecular bromine with the ketone, **1**



1

will serve to demonstrate the kinds of questions that were asked, and often quite adequately answered, without the use of kinetic isotope effects at all (*1*).

This reaction is strongly catalyzed, for example by acetate ions, and so it must in fact represent the sum of several simpler reactions or steps. In the first of these, acetate is consumed as it reacts with **1**. In some later step acetate will have to be regenerated in order that it cancel out when all the steps are added together. Every molecule encounters these steps in a fixed sequence. Each step is limited by the availability of some precursor which it alone must consume. The first step is here also the rate-limiting one, the bottleneck that controls the velocity of those that follow. These things are known from kinetic experiments. If the concentration of either **1** or of acetate is changed, the reaction rate changes proportionately. Doubling the concentration of either doubles the rate; doubling the concentration of both quadruples the rate. But a change in bromine concentration has no effect whatever! Since it is surely a reactant, bromine must be kinetically impotent only