Science for Its Own Sake[1]

Presidential Address to the British Association for the Advancement of Science

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IN EXPRESSING MY WARM APPRECIATION of the signal honour of being elected the Association's President, I would like to add how particularly agreeable the occasion is made for me by the fact that our Meeting this year takes place in Liverpool. In my younger days all my journeys by sea began at Liverpool which thereby came to represent for me a gateway to adventure; and something of the old magic still remains.

Now, although our Association met four times in Liverpool before the University was founded, in the two succeeding Liverpool Meetings the University has joined with the City in welcoming our members and organising much of our week's activity. Our reception by Town and Gown has been, on this present occasion, notably graceful and gracious, and I would like to tell both the Lord Mayor and the Vice-Chancellor how touched we have been by the cordial expression of their greetings and good wishes.

There is, I think, something very appropriate in our meeting here in Liverpool, a city whose interests and history have been so long and so closely bound up with the advancement of science. This happy conjunction has been remarked on by several of my predecessors and has been a fruitful source of inspiration to them. I have noticed, on looking through their Addresses, how often their thoughts have turned towards the practical achievements of science and how often they have been able to cite their instances from Liverpool itself. It is interesting to note, too, how the city has served, through successive meetings, to point the direction which science was to take. The great developments that were noticed here by the Earl of Burlington at the first Liverpool Meeting in 1837 were an indication of many things to come in other parts of the country before the turn of the century. Indeed, one might say that what was true of Liverpool at one British Association Meeting was true of the rest of Britain at the next, and of most of the world by the one after that.

I confess that I stand somewhat in awe of my distinguished predecessors, who were inspired by this setting to range so widely over the fields of scientific progress in their own day. To succeed to an office which has been held here in Liverpool by such men as Rutherford and Lister and Huxley can be no easy task. It is not only the abilities of these men which now appear so outstanding. What has particularly struck me, on reading their words, is the story of solid achievement each had to relate in speaking of recent scientific progress. "The heroic age of physical science" Rutherford appropriately calls the period that saw the first investigations of the radioactive elements, the discovery of x-rays and the development of wireless telegraphy. And, again speaking of the period between the two Liverpool Meetings of 1896 and 1923, he remarks "the epoch has been an age of experiment when the experimenter has been the pioneer in the attack on new problems. At the same time, it has also been an age of bold ideas in theory, as the Quantum Theory or the Theory of Relativity so well illustrate." Joseph Lister, at an earlier meeting, dwelt in his Address on the same conjunction of experiment and theory, and how their application in the field of medicine had led, in his own time, to the ever-memorable discoveries of anesthetics and antiseptic surgery. A similar sense of substantial achievement is conveyed in the words of T. H. Huxley. Devoting himself to a theoretical account of the genesis of bacteria, he nevertheless pauses in it to estimate that the practical application of the theory, in the French silk-worm industry and wine trade alone, had—to quote his own words—"repaired the money losses caused by the frightful and calamitous war of this autumn"—he was speaking in 1870. In Huxley's remarks, indeed, I seem to detect a certain diffidence about entering the realm of pure theory at all, for, after apologising to his audience for the dreariness of the theoretical approach to his subject, he continues: "Nevertheless you will have observed that before we had traveled very far upon our road, there appeared, on the right hand and on the left, fields laden with a harvest of golden grain, immediately convertible into those things which the most sordidly practical of men will admit to have value—namely, money and life."

What my predecessors had to tell was indeed a story of outstanding achievement. And yet what those great men had to say about the benefits of science can surely be equalled, if not surpassed, in our own day. It is true that nowadays we are more sharply aware of the debit, as well as the credit, side of our accounts with science, as my predecessor, Professor A. V. Hill, reminded us last year. But no one could doubt that the material benefits of science are there, and, indeed, are

[1] Reprinted with permission from *The Advancement of Science,* No. 38, Sept. 1953.

with us in our daily lives to an extent which even the 19th century could scarcely have expected.

Now the subject of my address, "Science for its own Sake," is already known to you. It was chosen to emphasise something that, at times, is in danger of being overlooked, namely, that science has interest as well as utility—that science is illuminating as well as fruitful. Having spent ten years of my own life in seeking to further the applications of science in the practical life of our country, I do not think I can be accused of under-estimating the vital importance of science as an instrument of material utility. I have long held the belief that the cost of scientific research is the price we must pay for our industrial progress. But we should be misleading the public, as well as ourselves, if we based our case for the general support of the pursuit of science on its utilitarian aspects alone. I know that we can claim that many discoveries in pure science, which in their time had no obviously practical import, have later proved to be the foundations of major improvements in our material civilisation. But even that is an argument of profit and loss, and, to my mind, does not bring us entirely to the heart of the matter. I should like to go back beyond the achievements, to the example of the scientist—be he amateur or professional—who is impelled solely by a passionate desire to explore and understand. That is what I mean by science for its own sake—when knowledge and insight are sufficient reward in themselves. Can the pursuit of a scientific vocation of this kind be a way of living worthily? Can it, in Dr. Johnson's phrase, help to advance us in the dignity of thinking beings? What values for us as individuals does it propound? As well as theoretical knowledge, as well as material benefit, is there some deeper, if more intangible, thing, even wisdom itself, to be found in our vocation?

I certainly make no claim to be able to provide the right, or the only, answers to such questions. At the most I simply hope to indicate to you where I think *some* of the value of a scientific vocation lies. After the extravagant claims that have sometimes been made on behalf of science—claims which have had the disagreeable consequence of putting the scientist on a pedestal—it is well that we should walk humbly. And yet, all the same, in a time of uncertainty of values and lowering of ideals, it is important that we should own to what we believe.

Now I begin by attempting to get the setting right, by pointing out that we scientists do not really inhabit the kind of universe which has sometimes been attributed to us. Science has so often been accused of having reduced the beauty and mystery of the universe to something cold and mechanical. When science enters the door, enchantment, it has been said, flies out of the window. You will remember the lines of the poet Keats:

> There was an awful rainbow once in heaven:
> We know her woof, her texture; she is given
> In the dull catalogue of common things.

Now it is fairly easy to see how this attitude came about. The world of what is now called classical physics, as it was mapped out for us from the time of Newton onwards, had the advantage of appearing comfortably solid and tangibly final. Anyone, it seemed, who could understand why an apple falls from a tree could also understand the stars in their courses. In this light the universe might well seem to a poet to fail to come up to his expectations. We now know how misleading it was to regard this account of the matter as final. Perhaps the most striking fact about modern science, in its explorations ranging from the heart of the atom to the frontiers of the universe, is that, like poetry, like philosophy, it reveals depths and mysteries beyond—and, this is important, quite different from—the ordinary matter-of-fact world we are used to. Science has given back to the universe, one might say, that quality of inexhaustible richness and unexpectedness and wonder which at one time it seemed to have taken away from it. "The world will never starve for want of wonders," says G. K. Chesterton, "but only for want of wonder."

I hope to try to illustrate all this in a moment from the fields of cosmical research which have been my own interest for many years. But just now one general point I want to emphasise is that the scientific approach to things is a far more personal and imaginative activity than is sometimes realised. I am ready to admit that deliberate application to discovery can often take us some distance; also that important progress can result from the operation of a team of workers, as distinct from an individual, though this is mostly the case when the follow-up or consolidation of a basic discovery is in question. But the big jumps ahead are usually the adventures and intuitions of a single mind.

I need hardly remind such an audience as this that scientific activities are twofold. We can make observations and experiments—that is to say, gather facts. And we can also seek to understand how the facts fit together. We express any order we can discern among the welter of facts in the form of a hypothesis or a theory. A theory, by the way, is only a hypothesis that has become, so to speak, respectable. But even then there is nothing final about it. As J. J. Thomson once said, a theory is a policy rather than a creed.

Now, even in this question of making observations, the scientific process is one which requires the fullest and subtlest employment of all our faculties. It demands, for example, that we should not only see things, but should notice them; and not only notice, but perceive them. Many a vital discovery has been nothing else than recognising the unexpected. To encounter nature in this necessary state of awareness is inevitably to find all its forms and movements, from the infinitely small to the infinitely large, full of inexhaustible significance and relevance. But even in experimental work it is the primacy of an imaginative idea or intuition that often starts it all off. In simple words, I might say that the important thing in experimenting is to ask nature the right question and in its most direct form. Only then is the answer clear and unmistakable. But so often one has failed to ask the right question and the terms of it have to be recast. In this complex process it is as if knowledge were playing a game of chess with the mind, and one has to be constantly on the alert with fresh tactics or even a changed strategy.

Many of our questions turn out to be wrong because they are unanswerable, but it is only by asking them at all that we eventually find we have asked the right one. And one knows how oddly, how unreasonably I might almost say, the right question has often flashed into men's minds. It was recorded by the German physicist Helmholtz that his best ideas only came to him when he was walking up a slowly ascending street —and significantly enough he was one of the founders of the principle of the conservation of energy! What I do know, from my own experience, is the fruitlessness of pondering over a scientific problem too long. The mind gets polarised and thought becomes captive to a groove. How often the best way of solving a scientific difficulty is to leave it alone! Also, speaking as a professional scientist, who has only recently turned amateur, I would like to acknowledge the immeasurable debt which science owes to members of the latter category. My own subject of radio-physics has, on many occasions, been advanced by the observations of the gifted and enthusiastic amateur who was able to recognise the unexpected, even if his professional skill was insufficient to enable him to reveal its full meaning and implication.

Asking nature the right question in the right way— or recognising a theoretical pattern in a tangled skein of experimental data—often has the effect of introducing an element of beauty and elegance into the scientist's work. Do we not, on occasion, refer to a "beautiful theory" and an "elegant experiment"? It is perhaps a little difficult to say what precisely we mean by this. Not, I think, that the theory or the experiment is necessarily conclusive or irrefutable, or even particularly fertile in its consequences—that would be virtue of another kind. The quality I have in mind is that of inevitability—and yet, paradoxically enough, an inevitability which can cause surprise! A great experiment seems to us, somehow, something which could not have been done differently. Or, if it had, something essential would have been lost. We are surprised that someone thought of doing it that way but we can see now that that way is really the only way to do it. Taking away something, or adding something, only detracts from it. In this respect a beautiful experiment can surely be classed with a great work of art.

Now I have spoken in general terms of the scientist's approach to nature and of the kinds of mental quality and awareness that science requires in its followers. And I have tried to suggest that the exercise of these skills has a value in itself which is ample justification of a scientific vocation. To go further might be claiming too much. And yet, I wonder. If we think of the great figures of science and, to be fair, restrict ourselves only to those we have known intimately, can we not go further and say that the scientific vocation, by its very nature, calls for personal qualities that deserve to be recognised and honoured? I might point, for instance, to that tolerance and openmindedness to new ideas which shine even from the printed page of Rutherford's Address to this Association when he was President here thirty years ago— that freedom from prejudice, muddle, hypocrisy and darkening of counsel which characterised the man many of us were so privileged to know.

And yet, in less serious vein—a vein to which Rutherford was as much addicted as anyone else—ought we not, as scientists, to try to see ourselves as others see us? Joseph Addison once declared that there was this at least to be said for natural philosophy, that it occupied the attentions of men, who, if they had pursued public affairs and politics with equal zeal and vigour, would have set the whole country aflame. While Dr. Hartley in his *Observations on Man* declares that "Nothing can easily exceed the vain-glory, self-conceit, arrogance, emulation, and envy that are to be found in eminent Professors of the Sciences, Mathematics, Natural Philosophy, and even Divinity itself. Temperance in these studies is, therefore, evidently required, both in order to check the rise of such ill passions, and to give room for the cultivation of other essential parts of our natures." And yet Adam Smith, in his *Theory of Moral Sentiments,* finds far more to say in our favour. "Mathematicians and Natural Philosophers," he says, "from their independency upon the public opinion, have little temptation to form themselves into factions and cabals, either for the support of their own reputation, or for the depression of that of their rivals. They are almost always men of the most amiable simplicity of manners, who live in good harmony with one another, are the friends of one another's reputation, enter into no intrigue in order to secure the public applause, but are pleased when their works are approved of, without being either much vexed or very angry when they are neglected. It is not always the same case with poets, or with those who value themselves upon what is called fine writing." I only hope we scientists can see ourselves in that mirror.

For specific examples of what I have called the pursuit of science for its own sake there is, of course, no shortage of material on which to draw. I have, however, decided to tell you the story of only one field of development tonight—a long short story if you like—instead of a number of short stories in brief outline. My story has been selected because it bears on what men think about the world rather than what they do about it, for it concerns the nature of certain objects in outer space whose nature has only been revealed in recent months. If I required a more homely title for my story it would be "Finding things out about places we can't visit."

From time immemorial men have examined the sky with their eyes, and found it to be populated with luminous bodies, the stars shining with their own, and the planets with borrowed, light. As time went on, telescopes were used to assist the naked eye, and in this way it was possible to see more feeble and more distant stars. Generally we may say that the bigger the telescope the more powerful it is in helping us to plumb further into the depths of space. The 200-inch telescope at Mount Palomar can detect stars so far away that it takes the light from them 1000 million years of travel to reach us. In such cases the human eye is supplemented by the photographic plate which, through prolonged exposure, permits the photography of faint objects which can never be detected by the eye alone. In addition to the telescope the astronomer has also looked at stars with a spectroscope, by which the light from the stars is analysed into its constituent colours. In this way it has been possible to identify the kinds of atoms which exist in stars; since we know, from experiments carried out on the earth, how to recognise particular atoms by the particular colours—or wave-lengths—of the light they give out. We can call all observations of this kind optical astronomy since, in making them, we examine the optical light which comes from the stars.

Now it is of great interest to us here in Liverpool tonight to recall that it was Sir Oliver Lodge, one of the first professors in Liverpool University, who first thought of looking at the heavens with a "radio eye" instead of with an "optical eye." The year was 1900, in the earliest days of radio, and Sir Oliver tried to discover whether he could detect radio waves from our own particular star, the sun itself. The experiment failed because of the insensibility of the wireless receiver used—it was the day of the coherer. Yet it would be no misnomer to call Sir Oliver the first radio-astronomer, for the experiment was surely conceived on right lines and, with modern valve equipment, would have commanded success.

However, it fell to an American radio-engineer, the late K. G. Jansky, of the Bell Telephone Laboratories, to discover that radio waves, as well as light waves, could be received from the heavens. One interesting feature of this discovery was that Jansky found all this out when he was looking for something else. But with impressive scientific awareness he was ready to recognise the unexpected. Jansky was primarily studying the direction of arrival of atmospherics, but he noticed a persisting hiss in his ear-phones when his directional aerial was aligned to receive from a particular direction, which he later showed was the direction of the stars in the Milky Way. The year was 1931.

Jansky, appropriately enough, was the first person to speculate on the origin of this radio noise from outer space. He pointed out that the most obvious explanation was that the radio waves came from the stars themselves and that we get the radio noise in strength from the Milky Way because a great population of stars is concentrated there. But when he came to test his hypothesis by looking for radio waves from our nearest star, the sun, he obtained a discouraging result. For, even with the equipment available in his day, he found, like Sir Oliver Lodge, that no radio waves were detectable.

Now it is one of the remarkable features of the history of this subject that Jansky's researches incited only a few sporadic observations in the way of repetition. During the Second World War, however, radar operators, using their sensitive equipment operating on wave-lengths of 5 to 10 metres, so to speak re-discovered the phenomenon. But that was a period when one had to distinguish sharply between the scientific things that were only interesting as distinct from the things that were really useful. Quite a number of other matters of purely scientific interest arose in the same way, but all one could do was to note them and shelve them till the war was over.

I can well remember how these various topics cropped up, during the War, in the discussions of a panel of young scientific workers of which I had the good fortune to serve as Chairman. This panel was really a small sub-committee, though it had a long name[2] and a distinguished parentage. It used to claim that, unlike most other war-time committees, its membership was confined to scientific workers and did not include officials. That I might have been classed in the latter category was generously overlooked. The task of the Ultra Short Wave Panel was to examine and interpret all the manifold vagaries of radar transmissions which were reported to it from operational experience and from *ad hoc* experiments. The Panel had to concern itself with many things including, for example, the profound influence of the weather on radio wave travel in the lower atmosphere. The foundation of a new subject, that of radio-meteorology, was one result of its labours. That was a matter of practical moment. But the odd bits of information on radio-astronomy, though choice delicacies for a scientific appetite, had to be renounced. I have in mind here, in addition to the detection of radio noise from the Milky Way already mentioned, such subjects as the radar detection of meteors or "shooting stars" and the detection—for the first time—of radio waves of violent intensity coming out of sunspot regions on the face of the sun.

Soon after the War, however, these matters became the objects of further enquiry and it is of much interest to note that radar equipment, developed in the first instance for the detection of aircraft and ships, proved extremely useful for this purpose, requiring only minor adaptations. Dr. J. S. Hey and his colleagues, S. J. Parsons and J. W. Phillips, for instance, made the first really detailed investigation of the amount of radio noise coming from different parts of the sky. For this purpose they converted a war-time radar receiver, which had been used in conjunction with anti-aircraft batteries, into a directional radio-telescope. Their work at once confirmed Jansky's original findings and showed that there was a close agreement between the intensity of the radio emission and the distribution of visible stars in the Milky Way.

Now I must digress from my main theme for a moment to remind you of a little of what is known

[2] The Ultra Short Wave Panel of the R.D.F. Applications Committee of the Advisory Council for Scientific Research and Technical Development of the Ministry of Supply.

about the distribution of stars in the universe as a whole. Our own solar system is really part of the Milky Way which is, itself, a colony or island of stars in space. This island colony has a structure like a magnifying glass, so that it is circular in shape but thicker at the centre than at the edges. You would not be far wrong if you thought of it as a Yorkshire tea-cake, the currants of which represent the stars. We inhabitants of one of the planets in the solar system do not occupy, however, a particularly privileged position in it, for we are situated nearer to the edge of the island colony than to its centre.

Space is, however, populated with far more stars than are to be found in our own Milky Way. But they are not distributed uniformly. They are grouped in island colonies exactly like our own. The astronomer calls these star colonies extragalactic nebulae, and, with our big modern telescopes, it is possible to detect between 100 and 1000 million of them. The average distance between any one of these star colonies or nebulae and its nearest neighbour is about ten to a hundred times the size of either.

But I must resume my detective story about the radio noise from the Milky Way, for I think you will agree that it sounds much like a detective story as one clue after another is followed up. It was natural to assume at first that the radio noise coming from the sky represented the integrated radio effect of the stars in our own galaxy, since such stars are nearest to us. Our war-time experience concerning radio noise from the sun helped with the necessary calculations, for one could assume, as a first aproximation, that all the stars would act like the sun. However, it turned out that there did not appear to be enough stars in the Milky Way to account for the high intensity of the radio noice. So then, as an alternative hypothesis, it was thought that possibly the noise came from the flying atoms and electrons which we know must populate the space between the stars. This was the inter-stellar matter theory. Unfortunately, here again, there were found to be difficulties. To account for the high intensity of galactic radio noise, when observed on the longer radio wave-lengths, required the ionised gas in inter-stellar space to be at a temperature of 100,000 degrees absolute, a value much too high to be reasonable. Also, we already knew that the inter-stellar material in question is concentrated in a narrow band near the galactic equator quite unlike the wide dispersal of both the stars in the Milky Way and the radio noise. So another theory had to be abandoned.

We had therefore arrived at this position, that the cosmic radio noise could not be accounted for as coming from the visible stars in the Milky Way or from the tenuous material existing in the spaces between the stars. However, this unpromising situation was soon relieved by an experimental discovery which, in its turn, led to others. Dr. J. S. Hey, observing the intensity of radiation from different parts of the sky, noticed that the strength of the radio noise from one particular direction—from a region in the constellation of Cygnus—occasionally showed rapid variations in a period of about a minute. At first it was thought that these fluctuations indicated variations in the emission from the source itself, but we now know that the variations are brought about by irregularities in the ionosphere, through which, of course, the radio waves must pass before they reach us on the surface of the earth. We can, in fact, look upon these variations as a kind of "twinkling" introduced by irregularities in the atmosphere. But the most startling conclusion which could be drawn from these observations was that the source of this variable radio noise must be a very small one. In the case of visual light we all know that we can have a "twinkling" star—because the star is a small source—but not a "twinkling" moon.

Attempts were therefore immediately made to find out, by even more refined radio experiments, how big —or how small—in size this radio source in the direction of Cygnus actually was. There is no time to describe to you tonight the apparatus which was used, in Australia and in Cambridge, to test this matter but I can assure you that both experiments qualify for my adjectives "beautiful" and "elegant." Both sets of investigators announced the same result, that the source in Cygnus was too small to have its size assessed with the equipment used—that is, that it occupied less than a tenth of a degree in the sky. However, in the course of the same experiments, the position of this powerful radio source was fixed pretty accurately. And maps of known stars were eagerly consulted to see if the Cgynus radio star, as we may now call it, coincided with any special visual emitter. The result of this examination was most significant for it was found quite impossible to identify the radio source with any particular star. Within the region which contained the radio star there were many faint visual stars to be found, but none of them seemed to exhibit any special peculiarities likely to associate it with the very powerful intensity of the radio emission.

Then, other parts of the sky were examined with the same apparatus and a further number of "point" sources of radio waves were identified. One was found in the constellation of Cassiopeia, which was even more powerful than that in Cygnus. It also could be located with good accuracy. But, here again, there was no remarkable visible object apparent on the star map to connect it with.

It is important to pause here a moment to consider the effect of these observations on our outlook at the time. It was natural to ask a whole series of questions. Could it be that a radio star is always a dark star—and so a new type of object in the universe? If so, could it be that there was a duplicate universe—only to be seen with a radio-telescope as distinct from a visual telescope? And, as regards the overall phenomenon itself, could it be that the total emission of radio waves from the galaxy might be really the integrated effect of these dark stars, just as the diffuse band of light of the Milky Way arises from the unresolved radiation from distant optical stars? You will see that the tendency of the time was still to think of the radio emitters as being neighbouring bodies and inhabitants of our own galaxy rather than of other, more distant, island colonies or nebulae. However, a little reflection will show that we must not rule out the possibility of radio nebulae, as distinct from individual radio stars, even if we suppose that the greater part of our own radio noise comes from our own galaxy, the Milky Way. Any observer well outside the Milky Way should be able to detect the radio emission just as we, who are situated inside it, can do. Such an argument received strong experimental support when a group of radio astronomers in Manchester noted a relatively faint, but quite detectable emission, from the Andromeda nebula, which is a neighbouring stellar island colony of our own. Further work, at Manchester and Cambridge, has revealed appreciable radio emission from other nebulae not far from our own galaxy. It is clear that, in such cases, we are probably detecting their internally generated radio noise from the outside.

But the problem of the much more powerful sources remained. Where were they, why were they so powerful, and were they, basically, radio stars or radio nebulae? Again it was a case for more refined experiments which would enable their positions to be found with greater precision and give some notion of their sizes. I might mention here, in passing, that workers in Sydney, Australia, under the lead of J. G. Bolton, had already tentatively identified one radio star with the Crab nebula, a diffuse, expanding, cloud of gas which represents the remains of a stellar explosion, visible news of which reached the earth, according to Chinese records, on July 4, 1054 A.D. So this was another radio source identifiable with a visible object, but it was of abnormal type, the ancient relic of a supernova eruption.

The real attack on the identification of the two major radio sources, those in Cassiopeia and Cygnus, depended on the more accurate identification of their positions. In 1951 some new determinations were made by F. G. Smith at Cambridge and the results were communicated to the optical astronomers with an invitation to search afresh the parts of the sky in question. In the spring of 1952, a new and intensive optical search was therefore undertaken by Baade and Minkowski, at Mount Palomar, using the 200-inch Hale telescope and the 48-inch Schmidt telescope. As a result of this meticulous search, two entirely unknown objects were discovered in the universe. The Cassiopeia radio source was found to be associated with a diffuse cloud of luminous gas, situated within our own galaxy, and possessed of unique characteristics. The tenuous matter of which it is composed is concentrated in a number of fine filaments which are in the most violent motion. From a study of the colour of the light emitted by different parts of the same filament it is concluded that the velocities of such movement are of the order of several thousand kilometres per second. The origin of this gaseous cloud is unknown for it seems impossible to regard it as yet another supernova explosion.

The source in Cygnus, which you will remember was the one which first gave the clue to the possibility of radio stars, was found to be an entirely different type of object. Here the source of the radio waves was identified with another exceptional object which is considered to be two island colonies—two extragalactic nebulae—in collision. Moreover, the distance away of this compound group of stars is estimated as being such that it requires 100 million years for the light and the radio waves generated in it to travel to us here on the earth. It is rather a humbling thought that it is only during the last sixty years of that travel that human beings have managed to learn how to produce radio waves and receive them. Now when a collision of two nebulae takes place it is considered that the stars of one island colony will pass freely between those of the other. On the other hand, the more extensive inter-stellar materials of the two island colonies will meet in collision, which will result in high excitation of the gaseous atoms of which this material is composed. One must suppose that, in both the radio source in Cassiopeia and the colliding nebulae in Cygnus, the high gaseous velocities give rise to this intense radio emission, although the detailed mechanism by which it all comes about is not understood. These identifications were finally confirmed by observations in Manchester, Sydney and Cambridge using still more refined methods of finding the sizes of these radio sources. The results of all three radio-observatories were gratifyingly consistent and were published simultaneously last December. In all cases it was found that the radio sources examined were definitely much bigger than simple stars and therefore corresponded to the sizes of the objects observed optically.

The accurate location of these radio sources in the universe—we must now, I think, drop the term "radio stars"—has therefore led to new discoveries of great astronomical interest. Two unknown objects of unique character have been identified in the heavens, as a result of clues from the radio side; and it is to be expected that future accurate measurements of the positions of these cosmic radio emitters will lead, in turn, to the discovery of other visual objects of uncommon types. I should explain that the discovery of these rare objects by direct visual search with large optical telescopes would require quite prohibitive effort. The radio-telescope has therefore shown itself to be an important adjunct to the world's greatest optical telescope. But, in addition, there is a further and far-reaching possibility. It is the astronomer's ideal to reach, with optical ranging, the hypothetical limit of the expanding universe, the distance where the extra-galactic nebulae are receding from us with the velocity of light. So far he has reached very approximately half-way. But the fact that, already, the second most intense radio source can be detected without difficulty at a distance equal to one-tenth of the maximum distance plumbed by the 200-inch telescope suggests that it may, in time, be possible to detect sources at greater distances by radio than by optical means.

But, in any case, the more detailed radio mapping of the radio sources in the heavens must go on; for, as you will have gathered, we are still without an explicit solution of the original problem which started it all off, namely the rough overall correlation of the distribution of radio noise with the general structure of the Milky Way. Much progress in these matters can, I am sure, be expected from the operation of two large British radio-telescopes. Professor A. C. B. Lovell's group is constructing a large steerable paraboloid of 250 feet diameter at Jodrell Bank, a station of the University of Manchester, which will be the largest single radio-telescope in the world and available for a great variety of investigations; while the large interferometric radio-telescope, recently completed at Cambridge, for work by M. Ryle and his associates, is already yielding entirely new results in the detailed mapping of radio sources.

The radio-astronomical story is therefore far from being fully told, but even already one can record achievements in these three centres of Cambridge, Sydney and Manchester—partly in competition and partly in collaboration—worthy to be ranked with the greatest feats in the art of experiment.

I have only a few words to add by way of postscript. I have tried to show how science, pursued for its own sake, can enlarge men's horizons and invest the world with deeper significance. As an exercise we can claim it to be one of the most complex and far-ranging of our mental experiences. But we must not forget that there are other values and other experiences. At the opposite pole from our scientific endeavour there are the ways of thought which do not change, whose concern is with what is *not* new, with the things that will not be superseded; and today we stand in need of these enduring and sustaining values of the spirit more than ever. We well know that, in the field of science, our work will in due course be probably outdated and certainly surpassed. At any one moment we may have only a precarious hold on a temporary truth and our consciousness of this ever urges us to seek fresh truths and new understandings. I fear that, in doing so, we may lose sight of other aspects of life which have their values too. For, you know, there is a virtue in contentment, in being satisfied with what we already have, which we shall not learn from science. Our vocation, in other words, cannot be the whole of life for it cannot satisfy all our needs. Nevertheless, I hope I have represented it fairly as no unimportant or unworthy part of it. For we scientists are specially fortunate in this, that our vocation can never be simply an occupation; it is, by its very nature, more than that—a dedication to an end. It often seems to me that what we lack in the world today is not so much the impulse to dedication as the opportunity for it. This, at least, the scientist need never lack; the opportunity is open to him everywhere "to strive, to seek, to find and not to yield." To those words of Tennyson's Ulysses I would add the words which Dante, long before, put into the mouth of the same Ulysses, when he encourages his crew to venture with him, beyond the furthest point of the known world:

> "O, brothers," he said, "who through a hundred thousand dangers have reached the West, deny not, to this brief vigil of your senses that remains, experience of the unpeopled world behind the sun. Consider your origin: you were not formed to live like brutes, but to follow virtue and knowledge."

To Ulysses and to Dante "experience of the unpeopled world behind the sun" meant, of course, the adventure of voyaging out into the Atlantic, where the sun set and the world came to an end. Tonight, as I have tried to show, the scientist has commissioned the words to take on a different—and, indeed, a quite literal—meaning.

But we must still ask ourselves what it is that urges men to do these things and our answer must surely be that it is the challenge of it all. Why should anyone want to climb Mount Everest? Simply, I suggest, because it is there—as a challenge of the unknown and the unaccomplished—a challenge to spirit and body, now so gloriously met by Hillary and Tensing. In its different setting, the pursuit of science also presents to the human mind an enduring challenge on an endless frontier, quite apart from the material enrichment of mankind to which it may incidentally give rise. "The work may be hard, the discipline severe," as Lord Rayleigh said on an occasion similar to this, nearly seventy years ago, "but the interest never fails and great is the privilege of achievement."