



*"Reflections on Science
and Culture"*

... a public lecture by ...

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FOREWORD

In these days no university is complete without a Department of Physics and no Department of Physics is complete without one or more theoretical physicists. In this respect, as in others, the University of Alberta has been especially fortunate; not only has its Department of Physics had a strong group of theoretical physicists, but its Department of Mathematics includes several men who are doing distinguished research in this field.

Such a flourishing interdepartmental group deserves regular support. For their work they need little space and little equipment beyond pencils, paper, calculating machines, and a computer; but more even than other scientists they benefit from opportunities for discussion with one another and with others of similar interests—young men rich in promise, older men rich in scientific accomplishment.

In order to give its theoretical physicists this kind of support and encouragement, the University in 1960 established an Institute of Theoretical Physics, to which would be appointed brilliant young men as research fellows and which would attract to the campus, for periods of a few days to a year, prominent theoretical physicists and mathematicians.

In April 1961 the Institute invited the distinguished physicist Dr. J. Robert Oppenheimer, Director of the Institute for Advanced Studies, internationally known as an outstanding theoretician, an inspiring leader of scientists, and a wise and experienced administrator. Members of the Institute were grateful for his counsel and enthusiastic about his contributions in seminars and lectures.

But Dr. Oppenheimer is more than an outstanding scientist and administrator. He is a man of unusual breadth of interests and depth of culture, and a gifted public speaker. (His Reith Lectures on "Science and the Common Understanding", which he gave on the BBC in 1953, won a very large audience and in their published form have been widely read). Under the joint sponsorship of the Institute of Theoretical Physics and the University's Department of Extension he delivered a public address in the Northern Alberta Jubilee Auditorium to an audience of over 2,000 people—an audience that was deeply impressed with his eloquent address on "REFLECTIONS ON SCIENCE AND CULTURE". In response to

many requests from those who heard him and from those who wished they had, his address is now being made available in printed form. I am confident that it will be warmly welcomed—as Dr. Oppenheimer will be any time he cares to return to the University of Alberta.

L. H. Cragg

October 6th, 1961.

Reflections on Science and Culture

Thank you for those very kind words of introduction. Thank you all for your warm reception. I am indeed happy to be here in this super-alive city and community, where every building I enter seems to have been finished just the day before. I am very glad to be able to visit at its inception the new Institute for Theoretical Physics. I am confident that it will fulfill the high hopes of the young men who founded it; and confident that we shall have many fruitful patterns of cooperation and collaboration in the years to come.

Just before I left Princeton Institute, a meeting adjourned of some two score of the world's astrophysicists and astronomers. They had come to study new evidence, largely from radio signals, about the nature of galaxies. We know that there are something more than a hundred billion of these—we do not know how many. We cannot see far enough with our telescopes yet, and cannot interpret well enough the radio signals. We do not even know if they stretch out on the analogue of an infinite flat plane, or whether they stretch out on a closed surface like that of a sphere. But we know a great deal about them, much more than ever before. The typical one, ours for instance, has about one hundred billion stars; sometimes they have a thousand billion stars; sometimes they are much smaller. They vary a good deal. Some are rather inactive, contain stars, but contain neither new stars that are just forming nor stars that are bursting apart and exploding. And these have a rather orderly quiet structure, and seem to be dominated by the gravitational attraction of the stars for each other. But there are others, the spirals, of which our own galaxy is one, which are a madhouse. They have, in addition to stars mostly compressed in an incredibly thin plane, on the scale of the galaxy, and with a great deal of structure, discs, whorls, spiral arms, also vast spaces in which stars are rare, but in which there is a lot of gas, in which there are magnetic fields and which are full of cosmic rays. This group of men have spent ten hard-working and rather thoroughly unsuccessful days in trying to figure out, of our galaxy and those like it, how they work, why they work the way they do, and what one might do in the way of observation to find out a little more.

Six centuries ago our forebears looking at the heavens would not have seen anything like this—beyond the sun, be-

yond the moon, beyond the planets—they would have seen the fixed firmament of the fixed stars sealing off a finite world. In the disturbances of the centuries that followed, we lost forever the central and meaningful character of our habitation in the universe; even in our galaxy, which is one of a hundred or a thousand or more billion other galaxies, we are merely one of a hundred billion stars, very average, not at all near the center of the galaxy, not even very near the edge, in a very average position. Whatever virtue we have does not derive from where we are in the world. And this was disturbing enough so that centuries later John Donne could write of the havoc that had been created by Copernicus, by Kepler, by Newton—"Tis all in pieces, all coherence gone".

A few centuries ago it was the duty of a good Christian in Europe who was an officer of the law, a judge, to condemn to death for witchcraft those unfortunate women who, on the most implausible of evidence, were accused and proved guilty of it. Only four decades ago in my own country, a very pretty part of it, there was a great trial testing whether it were within the law to teach that man had an evolutionary relationship to other forms of life. Today, in dozens of laboratories, people are studying in minute detail those features of the great molecules whose overall structure is known, which tell whether the product of procreation will, in fact, be a rabbit or a lion or a man, and a great deal else besides.

It is hard to over-estimate the manifold and profound ways in which the growth of science has altered what we believe, what we think, what we value, and what we see. And as for today, we live in a world of which the most overwhelming and outstanding characteristic, and I need hardly say this to my friends in Edmonton or to any one who reads a daily paper, is an incredibly accelerated rate of change, a rate of change in what people are doing and thinking, in how they live, in how their lives are ordered, in what they know, in their ability to manage to do new things, in their tastes, in their style.

Indeed, it seems to me that in traditional societies—you may think of Japan a century ago or Europe in the Middle Ages—the role of tradition was almost homeostatic. It was so to assimilate the new to the old, tomorrow to yesterday, as to create a great sense of the likeness and sameness and harmony of things. It was in the proper and noble sense of the word a conservative tradition. That is still of course true; but we have gone very far from the primitive societies where essentially the only purpose of tradition was to cope with the unexpected by relating it to what had already been expected.

Today, in ways that will, I suppose, get clearer as I continue, a very essential part of our traditions is that they provide us with the knowledge, the techniques, the instruments, the ideas, and the power—intellectual and material—to find out new

things, to try new things, to alter the world both in the way we see it and in the way we make it. It is this new role of tradition which is expressed in the work of the sciences that has brought the world to this changing, fluid, wonderfully exciting, very unfamiliar situation. I do not mean to oversimplify. The world is not only science, and many things go with this altered situation. I will come back to that also. But clearly the accumulation of wealth is not a direct consequence of technology—it is made possible by technology. It is not exhausted by it. Clearly, a belief in the equality of man and of opportunity is not a direct consequence of science. It has been coupled with the great western developments which have led us to the present time. The real point is that unlike what has happened in the arts, unlike what has happened in politics, unlike what has happened in morals, unlike what has happened in the great religions, the development of the sciences has had a character which is quite its own. On the one hand it is cumulative in the sense that everything new is built on a relatively solid foundation of what has gone before. It is cumulative in the sense that although one may have over-estimated how widely what one found out to be true was true, thought that because it was true in a room it was also true in a universe, although one has indeed made such mistakes, with proper attention to the limits of what one has experienced, the things that have been found out about nature, and in a much more limited sense about ourselves, remain true and remain as valid floors on which to erect new enterprises, enterprises of experiment and exploration, enterprises of the mind, of understanding and of synthesis. The analogy that so many people use about the sciences, that they are like houses and that everybody, even if he is not very good, can bring a brick or two, is a valid analogy. It suggests something a little too symmetrical and square; otherwise it is a valid analogy.

Quite apart from the acquisition of techniques, in the acquisition of knowledge, of insight, there is in the growth of the various sciences an irreversible character. As I say, you may have been a little too cocky in thinking you knew more than you did; but by and large you know what you know and you hope that you can get by; and then experience slaps you down and it shows you that you have something new to learn but nothing has to get unlearned. In science you have a long history in which nothing is lost. This is, of course, quite unlike the practices of politics, in which a change of political style and political philosophy will essentially not have been able fully to have absorbed the lessons and the merits of what it replaces.

This irreversible character is important to bear in mind, and I give you two quite disparate examples. One is from technology. We hear that many of my colleagues spend the

better part of their days now studying means for reducing and eliminating the new atomic weapons; they are a great danger; and no one can be indifferent to the extreme, unprecedented peril in which their presence puts us. But whatever is done on this score, which I hope will be much and think will be rather little, we need to remember that putting the bombs away will not reverse the processes by which they were first understood and then improvised and made—because this is a matter of knowledge and technique which simply cannot be erased as long as there are men. And the world is irreversibly altered by this in practical ways, so that to go back to the days of twenty years ago is quite an impossibility.

Let me take the other example to which I have already referred, which has nothing to do with technology. It is not possible now, no matter what we find out, even if we find, as people hope and fear, some signs of intelligent organic arrangements on other planets and in other parts of the world, it is not possible to go back to the notion of the centrality of man's habitat and the closed comfortable ordered world in which the medieval man lived. These things have been changed, and cannot be changed back.

I have already indicated that I speak very broadly when I use the word 'science'. It is, on the one hand, a matter of invention and application of knowledge, what one may call technology; it is the technique of doing things. On the other, it is the using of simple or complex inventions to find out about the world, to gain knowledge, and typically to gain understanding, to see what makes it tick, to see what hangs together and what is orderly about it and what accidental, to get it sorted out. These two, the practical desire to make something, and the theoretical or contemplative desire to understand something, go hand in hand. They do not always go without a fight; but by and large they re-inforce and feed each other. Without the immense activism of technology, science today would not look at all as it does. The great telescopes would not exist; the radio telescope would not exist. Most of what we are talking about would not exist. Without the continued earnest usually rather visionary effort to get to the bottom of things, and to understand the law, the harmony and the order in them, one would never have a basis for the inventiveness of today, which is very different from the simple inventiveness of even a century ago.

I have in mind, in what I talk about tonight, not primarily the immense technological, economic, and political changes that technology has brought, but rather the immense changes in what we understand of the world which the development of the scientific age has brought with it. I do not want to be too simple. This is not the scientific age. There are countless sciences that are not yet born or if born, hardly known and

hardly named. I believe—as Jefferson said of Condorcet—I believe with Jefferson that man's mind is infinitely perfectable, and that a great deal is to come that is not in our present scene. I also emphasize again that if this is a scientific age it is also many other things which go with the scientific age, partly by nature and partly by historical accident. I shall, nevertheless, talk about this scientific time, because of its qualitative differences from any earlier time. I shall not talk to you with the conviction that science is an adequate basis for man's life, for his art and love and play and politics and morality and worship. It manifestly is not. I am not even going to pretend that it is an adequate basis for his rational life, for the life of human reason. I am not in this sense a believer in scientism; but I am even less or just as little a believer that what we have learned is trivial or irrelevant or uninteresting, or that there can be in today's world a healthy culture which deprecates and pays no attention to and cannot understand the revelations about nature and man which lie all about us, which have presented us with an unparalleled intellectual and cultural situation as well as an unparalleled economic, technical, and political situation.

There is no doubt, it seems to me, that the hypertrophic development of the sciences has had a certain disproportion in bringing to certain uses of man's reason a far greater success, a far greater speed and rate of change and development than to any other aspect of his spirit. And this, I think, has given us as a people a kind of indigestion, a kind of indigestion for which there are to my view no very simple pills. What I shall do is to enumerate—recount—a few of the characteristics of the growth of science and its character. It seems to me to throw light on the difficulties in which we are, and perhaps in the end to suggest some of the more specific directions in which effort would be helpful, some attitudes which may let us live in a time, I will not say more difficult than others—all times are more difficult than others—but which has difficulties which are not the same as those any culture has even confronted, and which are plenty difficult in their own right.

I will mention what these points are and then go to them. The first has to do with a question to which I do not know the answer but will volunteer one. Why is this the scientific age? The second is: What do we know about the growth of science as a human activity? And the third is: What do we know about its structure? And the fourth is: To what extent are things discovered in the sciences that make any difference to man's view of himself or to man's view of his destiny, his duty, his mission? And the fifth is: What elements of freedom and what elements of necessity, to use two often-used words, are there in the growth of the sciences? And the last of this list is: What have we learned in the sciences about the notion of objectivity,

the notion of being able to talk without too much concern about just who we are and about our history, our prejudices, our passions? At the end I would make a few concluding remarks.

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If you ask why this is the scientific age you may start with noticing that no high culture, neither the Buddhist nor the Confucian, neither the Chinese nor the Indian, certainly not the Greek, was free of a passionate curiosity about the nature of things, and of a belief in the virtue of contemplation and of understanding. I do not want to get too complicated; there are, for instance, traits in Indian culture in which this is not very prominent, but other traits in which it is very prominent.

When you come to the Greeks you find that they developed on the basis of the experience of the Mediterranean peoples not only a very sophisticated sense of number and of form, but something far more general and important, a sense of rigor, of proof, the sense that not everything can simultaneously be true. And this is an indispensable thing for the development of science, because science is the discovery of mistakes. That is the only way you will ever find out anything new, the only way you make progress; and if there is no necessary connection between things, if every event and if every proposition is loosely related or not related in a necessary way to every other, you will never learn anything from error because you will have to try everything out one by one. The notion of rigor and proof is a necessary part, and this is only partially and poorly present in Oriental cultures.

But the Greeks had that; they had also a very very lively enquiring tradition, and they had the art of experiment. One of the things which has from time immemorial been said about the Greeks is that they had no technology; they were full of slaves; and therefore they could not have science. Well, it is not true. About fifty years ago a diver off the southern tip of Greece, by an island called Antikythera where a ship sank a long time ago, brought up some bronze, quite beautiful things, and also a flat plate about a foot long which lay around for almost half a century. People supposed it might have had something to do with navigation, because it looked like an instrument. It was analyzed a couple of years ago. It is an astronomical computer. One can identify the date on which the computer was made by the position of the planets as 81 B.C. and one can identify the wreck of the ship by archaeological evidence as 80 B.C. This little computer is an incredibly sophisticated thing technologically, with eccentric gears, epicyclic gears, a very large number of interlocking gears and set with such precision that one can two millennia later tell for what constellation of the planets it was designed, tell when it was made, and why. Maybe in the Hellenistic world, the Greek

world, there were not enough people interested; maybe there was not enough communication; but it seems to us in retrospect extremely good.

And I do not believe that this is the only point. I think that one came to have a rapid, progressive, cumulative, and accelerating growth of science in Western Europe with the Reformation and the rediscovery of antiquity precisely because in this land the ancient idea of progress, which you find in the Old Testament more even than in the New, the idea of the meaningfulness of man's history and the idea of the progressive betterment of man's condition for the first time took root, and for the first time animated and determined the mood of a civilization. I think, therefore, that what one sees in the enlightenment, the notion of brotherhood, of equality, and of progress, and the belief in the value of science and its application, and the rapid growth of science itself are a family of related things. When we now encounter new civilizations newly stirring, newly interested in the sciences, we need to remember the concomitance, perhaps not necessary but historically important in our own history, in this great human change.

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There is a remarkable simplicity about the record of the growth of the sciences in the last two centuries. This is almost comic. Of course, if you talk of growth in terms of excellence I think there is no such thing. I do not expect that we or any generation that succeeds us will ever see a better scientist than the young Newton or the young Einstein. I do not think that in that respect science is different than scripture or literature; it is as stupid to talk of growth in terms of quality as to ask who is better than Sophocles. But if you take a much more quantitative and contemporary view of growth, not in terms of quality but in terms of quantity, then there are a depressingly large number of ways in which we can measure it. You can measure it by how many people work at it, you can measure it by how much is published, you can measure it even by identifying new measurements or new theories, and this has been done. In almost all ways of estimating you would give the same answer. The growth is exponential, that is, in every decade, or maybe twelve years, maybe ten, in every rather short period the volume of this business doubles, the volume of what is published, the number of people working at it, the number of new things that are found out. This is quite something, when you think that it has been going on for two centuries. There are a lot of ways of making it vivid, all of them corny. One—I think it must be mine because the man I thought said it did not—is that today 93% of all scientists in the whole history of man are still living. The second is that if you take one journal that is published in the United States—that is very much a Can-

adian journal too— which is one of about twenty-five journals on the restricted subject of physics, which is only one of the rather smaller sciences in today's world, and if you take its rate of growth since 1945, then early in the next century it will weigh more than the earth. This will not happen. The examples go on and on. In five years the volume of chemical abstracts has multiplied by four, and this is not even a science of which most people are aware that it is a very active science.

This is true; but there are a few qualifying things to say about it. This vast increase in bulk means that none of us will ever stop having to learn, if he is interested in learning. It also means that there is a very strong tendency to learn about less and less, because one simply cannot cope with the vast volume that is published about a broader field, the traffic, the flow of ideas. You could say that all of this is trivial, but it is not. I cannot offer you that comfort. No sane scientist would put himself in a position of having to read so much and having to study so much if he could get along without it. You could say, and here you would be right, that much that is new makes what is old a little obsolete, that you can, if not forget it, at least half forget it. And this is true.

It is just that in the countervailing spread and enrichment of the sciences one has a much stronger movement than in the ordering of past experience, which enables you to remember a few general facts and forget many particular ones. It is also true, of course, that the Physical Review will not weigh more than the earth and that this growth will not be maintained at quite this rate forever. How it will go no one knows; but if we have a reasonable measure of peace and a reasonable measure of liberty, I think that the level of scientific activity will be far higher than it is today; the demands made on any living man who wants to find out either about a special subject or in a different way, a broader way, about a field, will be life-long and very great indeed.

This seems to me inevitable. Of course, this raises a question because to the alternative 'do you want to know a little about a lot or a lot about a little', the answer *both* is right; but it is hard. And my impression is that this is one of the troubles of our times. The easy way is to say 'know a little about a lot' by reading summaries, popularizations, even magazines; and there is a role for that (and I do not deprecate it) and there is a role for every form of teaching from the highest to the lowest. But I also believe there is a great role for knowing a lot about a little, because it is in this intimate, active, completely engaged form of knowing that really new things, the really deep things, come to you. It is in this part that the human character of the doing of science, and the analogy between science and the arts is most easily felt and seen.

Now this wonderfully inventive, beautiful activity which grows so fast, grows so fast that a man's years do not know his youth, has a structure which I believe is a little different than is ordinarily thought of. I suppose if we had asked ourselves some time ago how the sciences are related we would have been tempted to say: Mathematics is the most abstract, it is really just an exercise in logic, although very high-flown, in indicating what follows from what and what things cannot be compatible. And we know that whatever we find out about nature will somehow accommodate itself to the fact that if something cannot be compatible to something else, both will not be there. Therefore, mathematics will control the content of physics, biology, chemistry, psychology, geology, what have you. In the same way, we do not know the laws of matter, but we know almost everything, everything, I think, about the laws of matter that is relevant for chemistry and biology. The things that are unknown have no perceptible effect in the ordinary life of ordinary materials. They are interesting to us in a morbid sort of way, because they have to do with the nature of matter and the basic order of its ingredients. And I hope we will live to see the answer.

We know the laws of atomic matter, and you could say that from that we could deduce how chemicals will behave and from that how living organisms behave and from that you should be able to deduce how the earth will behave and from that how the stars should behave, and the galaxies, and then even go on to try to get into the question of why we behave as we do. Well I think this is completely wrong. I think it is true that the laws of mathematics will not be contravened by any of the sciences. I think it is true that the laws of atoms will not be contravened by chemistry or biology or astronomy, and in this sense there is a kind of boundary condition in these more abstract disciplines they call more fundamental which prohibits a certain kind of arbitrary proliferation of behavior in the other sciences. But that is purely a negative thing, because no physicist could ever sit down and imagine a living thing, and no mathematician could imagine the world of nature. These are not deducible from each other. They are different orders of science, autonomous in their own right, and each requiring its own means of investigation, its own instruments, its own insights, its own concepts, its own words. It is not a hierarchical affair; it is much more like a tree, everything growing out of common sense and then branching into increasingly specialized enquiries. This means that it is not much use, if you want to understand what a biologist is worrying about, to tell him either that two and two are four, or the equation that determines the behavior of atoms. It means that the unity of science is something very much more subtle and very much less robust than one might suppose. It means, in fact, that the unity consists in an absence of contradiction. In two sciences one will

never find incompatibility: one may find incompatible vocabularies; but one will not find incompatible predictions, even when the two overlap and come close to the same subject. And it consists of something else, this unity of science, which is a very frequent, pervasive sense of analogy or mutual relevance between them, so that one is not deducible from another, one is not equivalent to the other, but they are not strangers to one another.

What we have in intellectual terms is a vast family of guilds, of syndicates, in which the specialists in one field and the specialists in another each have their own preserve, their own expertise, but know that they have something to tell each other. No one can tell the other's business, but each may be able to learn from the other and sometimes even to teach. This reticulated and very loose structure seems to be a very important aspect of the sciences, because it means that in all essential respects, except one, the scientist and the laymen, the scientist and the statesman, the scientist and the artist are in the same fix. The scientist is just as ignorant as the artist, the statesman, and the layman, except for his own field, and that is a very small part. That has, I think, one good quality—it teaches him the difference between knowledge and ignorance, and makes a rather deep impression.

This, of course, means that just to keep ourselves a human society, to know what can be known, to be sure we are not missing things that we need to know professionally or should know as men, there is a formidable, never ending job of teaching, teaching in every sense of the word. By that I mean the simple classroom, the professional with a disciple, the man who tries to see why the subject is hard and writes a good textbook or a good curriculum, the popularizer who says 'I will study this as well as I can and see what I can make of it'—teaching in all its manifold and time-consuming aspects; it is time-consuming to be taught as well as to teach.

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I should turn quite briefly to another point, because it is quite relevant to the question of teaching, and that is, is it really true that what gets found out about nature can be known, and should be known, by man? I am not now talking about the practical consequences. It is clear that the existence of automobiles and rockets and bombs and automation and telecommunication and so on are things that people need to know about. There is no question. But do they need to know about new discoveries, in the sense of new things about nature itself, not about what we are doing with it? And does this make any difference? Does it affect the way they think? I opened with some examples. I think it is clear. I think that if you look at the history of our knowledge of disease you will

see that it makes quite a big difference that we know something about some rough things about the nature of life and the nature of our bodies. I think that if you look at the extent to which superstition in its blackest form has tended to abate in our societies you will recognize that it has been a healthy thing that something has been found out about the world, in a way that has carried a certain conviction with it. I do not take a fanatical view; yet it seems to me that sometimes a great discovery in science will change the way men think. For that, there is one condition that is desirable, and that is the discovery be intelligible. That was by and large true of Newton's discoveries, and very true of Darwin's. It is not true of contemporary physics without much more schooling than we have. We hear of things like relativity and uncertainty. They make us think of how we feel when we get up in the morning. They do not suggest at all what they stand for in the sciences; they are a kind of pun. This means that the more developed a science is, the more unlikely it is, and the more difficult, to make its discoveries meaningful to non-professionals. In addition to this, there is also something, I think, quite subtle and contingent, about whether the discovery happens to fit in with the mood of the time. As all of us say, Newton did not make a Newtonian of himself, but he made Newtonians of the men of the next century, because they were ready for a mechanical view of the world, ready for an essentially secular view of the world, ready for a view of the world in which the power of the human intellect had played a dazzling part. Newton was not ready for any of these things.

I think there has to be between the mood of a culture, and what is found in the sciences some kind of harmony to make this impact very great. I would not look primarily to the physical sciences for this kind of change in man's view of himself, and where he stood, and what his duties were in this our 20th century. I think those changes may come rather more from the biological sciences, and if and when they exist, the many different psychological sciences. I am not a very good predictor. They may come quite unexpectedly, if we should find some form of companionship, which will certainly not stay our loneliness, not as well as human companionship (and that never does the trick wholly either), somewhere in this world of ours. We may, if we find that, have some shocks and some puzzlements and learn, what we ought to know, how enormously different things can be and still be intelligent and still be alive.

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There are two things about the sciences that I find quite hopeful. They are rather general, and, I think, maybe not fully appreciated. Einstein used to say that a theory in physics is a free creation of the human mind. It certainly is not a neat

summary of a lot of numbers on a piece of paper. There is a great deal of freedom in it. And one has the sense in the whole history of the sciences that they are human enterprises and are touched with that aspect of freedom which is never very far from man. They could have been different. I mean by this that we could have asked entirely different questions. I do not mean by it that with the same questions we could have evolved different answers. It seems to me that we have the great freedom as to what to turn to, to what to direct our attention, what questions to ask of nature, where to put our emphasis, where to see our puzzles and paradoxes as intolerable and where as trivial. Most of what goes on, of course, nobody can understand. It is too complicated. We do not bother about that. We look at the things which are not too complicated to be understood. Could a society, could a race of men do otherwise? I do not know. We have this great freedom, not as individuals, of course, because we are conditioned and limited by our tradition, but still some as individuals; and the great men of science are those who use that freedom more fully than others; for the tradition itself is man-made.

The answers are not man-made. The answers are man-discovered, and there is no fiddling with them. We can fail to invent the idea of an electric charge, but once having invented it we cannot fail to note that the elementary particles of which matter is made have either no charge, or the charge of the electron, or its opposite, the charge of the proton; there are no others. This statement may not be true; but this is an example of what we will know, of what might be true, what we think is true, what we will find wrong shortly if it is to be wrong. We are, in other words, enormously free to direct the growth of science: free as men and, in the measure in which we are worth our salt, even free as an individual man, although the individual man is the product of his schooling, his training, and he can break with it, but break only with a very small part of it at a time. We are free to choose what we ask and how we ask it and, in fact, it is how we ask it that determines what it is we ask. We are not free to dictate the answers that nature gives to these questions. Because of this, there is an open and infinite character to the relations between knowledge, as in the sciences, and the world of which we know. We could have learned quite different things. We could have a very different knowledge of the world; and no choice that we ever make is exhaustive or complete. And this is because, as one knows from the simplest study of perception to the most subtle points of the atomic theory, in order to learn we have to act, and in order to act we have to choose, and when we choose we lose something. We lose the possibility of the other choice. There are many examples. You are listening to me, and if, as I hope, I am doing what I am supposed to be doing, you are hearing my words. But the price of that is you

are not hearing all the noise I make. You could not then hear my words. This is the kind of very elementary choice which we make most unconsciously; but in the growth of a science, of course, often quite deliberately, which opens some evidence of the world of nature to us at the cost of losing some other evidence which we happen not to want so much, or did not expect to see.

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This open and partial and voluntary and free character is guided by taste, our tradition, our sense of beauty and style and interest, and humanizes, it seems to me, the experience of science. Apart from this, there is another, almost equally abstract point. In the philosophy books it says that something is objective if it is there and does not depend in any way on who it is that is taking cognizance of it. Something is objective if it is there without your seeing it, if it is there without your touching it. Something is objective if it is just plain there. This is a nice ontological definition, which of course cannot in any possible way be applied, because if you cannot get any evidence of its being there, then you do not know whether it is there or not and you do not know whether it is objective. But we always say "objectively" and we mean "it is really there."

But in the sciences, of course, we have had to think about this. The word reality does not occur very much, but we are concerned as to the extent to which what we are talking about makes sense. We start with a completely common experience. Do not worry about whether the other physicist in the laboratory is real or not. We start with chairs and do not in general worry about whether they are real or not. And in terms of these, we tell each other of what to do in order to find what we have found, we tell another man how we have gone about an experiment or what we have done to verify a theory or what we have done to extend a theory. The words we use, of course, in a late science like mathematics, are quite unintelligible except to our brethren, but they all rest on very simple starting points. They can all be expressed in terms of things which all of us experience daily and which we talk about in the humdrum business of living, the humdrum, sometimes wonderful, business of living; and instead of regarding objectivity as a characteristic inherent in something—is the Washington Monument objectively there? is an atom objectively there?—we tend to regard it as characterizing the nature of our communication.

When we talk about ordinary things, our lives together, our loves, when someone writes a poem, if it is any good, he inevitably and rightly uses words so that they have more than one meaning. It is one of the ways of harmonizing conflict and of pointing to unity and relevance to use the am-

biguity of language; I believe that a language with no ambiguity would not be a possible medium for poetry, and not much for any form of literature. Of course, physicists do the same thing and so do biologists. But when they are in a clinch on a problem, they do not; they make sure that what they are saying is clear, as clear and plain as in ordinary plain English or whatever it derives from. And they reduce to the maximum extent possible, correct if they find they have not done enough, the ambiguity of what they say to each other.

So if two scientists talk to each other about a scientific problem each knows what the other means as to what he has done, what conditions he has established for studying something, and each knows what the other has found, and they can compare notes, and if they did not find the same thing, they can see where that gets them, and if they did find the same thing they can write a joint paper.

Of course, this is also something which has come out very much in the development of atomic theory in this century, where certain aspects of the small things on atomic scales about which in large objects we talk as though they were there, simply cannot be given a logically meaningful existence unless we talk about the means by which we study them. And there are not practical experiments but experiments which you devise on paper to show what your theory means, in which there are no things you can say about an atomic system at all until you next decide how to look at it. And then suddenly if you say how you look at it, you can begin to say these properties, these properties are real. I can measure then, perhaps, but I know they are there. You can say that they have been realized, but by that you mean only that you have been able to explain quite unambiguously exactly how you are going to bring about this state of affairs. And this, of course, again by indicating that the distinction between the things we talk about is not for us fruitfully an ontological distinction, but has to do with the very nature of our talk and our action, brings an open and human element into the nature of science, very largely absent from the picture of the great machine once wound up that was the Newtonian legacy, not Newton's view, but the Newtonian legacy to our times until so very recently. It seems to me to make for a more plural and more tolerant notion of the role of science in human life, not only as not being co-extensive with human life, but as not being co-extensive with the rational aspects of human life. And this is to me really quite important because with all the growth of science—the necessarily partial, occasionally deep, occasionally superficial knowledge which we have of it, we, as a group of people, and as a community; the existence of many things in the world of which only very few people know, and of the brilliant technical success of the enterprise of science which is an intel-

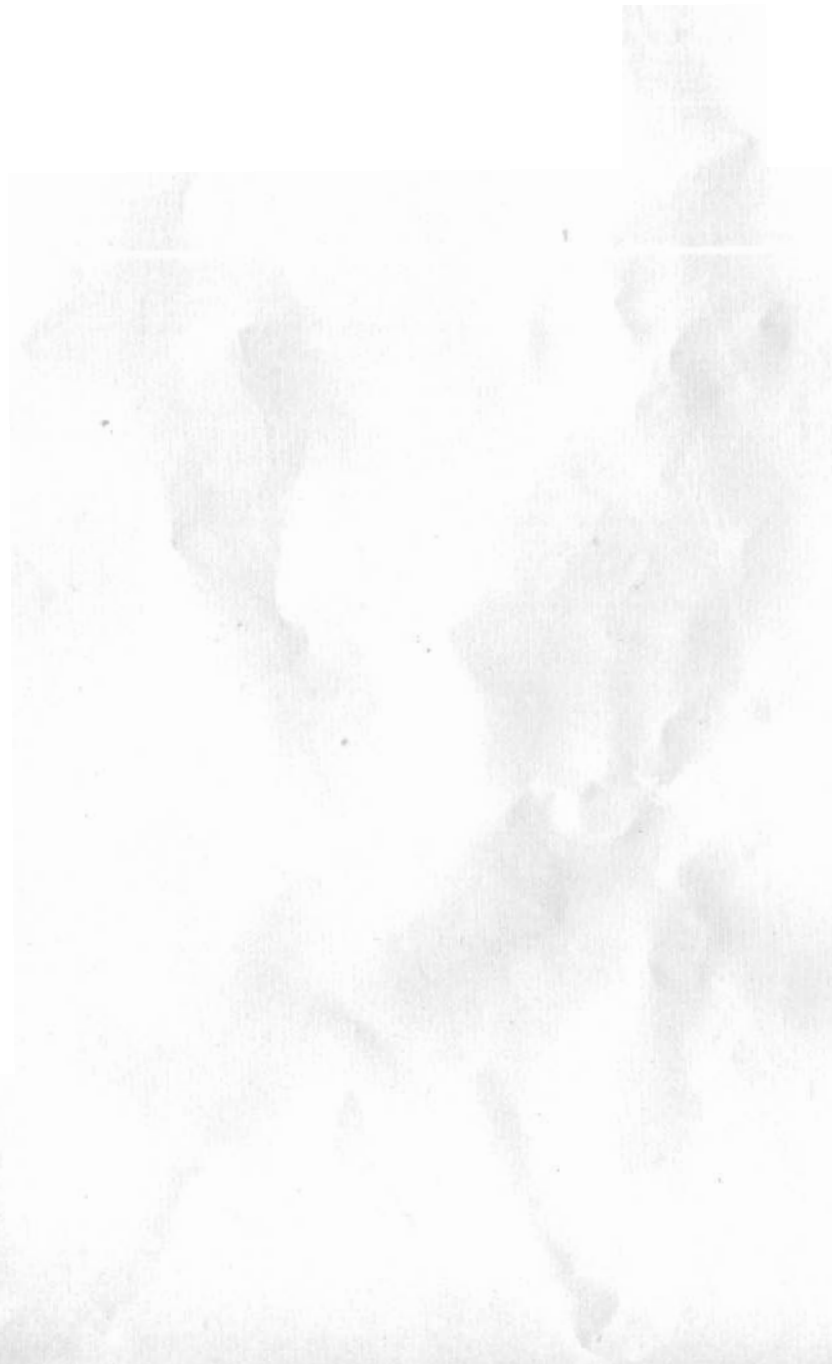
lectual enterprise par excellence and a rational enterprise par excellence—there has been a sort of inhibiting effect on a very large part of human intercourse and human life. This is the part of human intercourse and human life that is rational discussion of things which are not verifiable, in the sense that the sciences are.

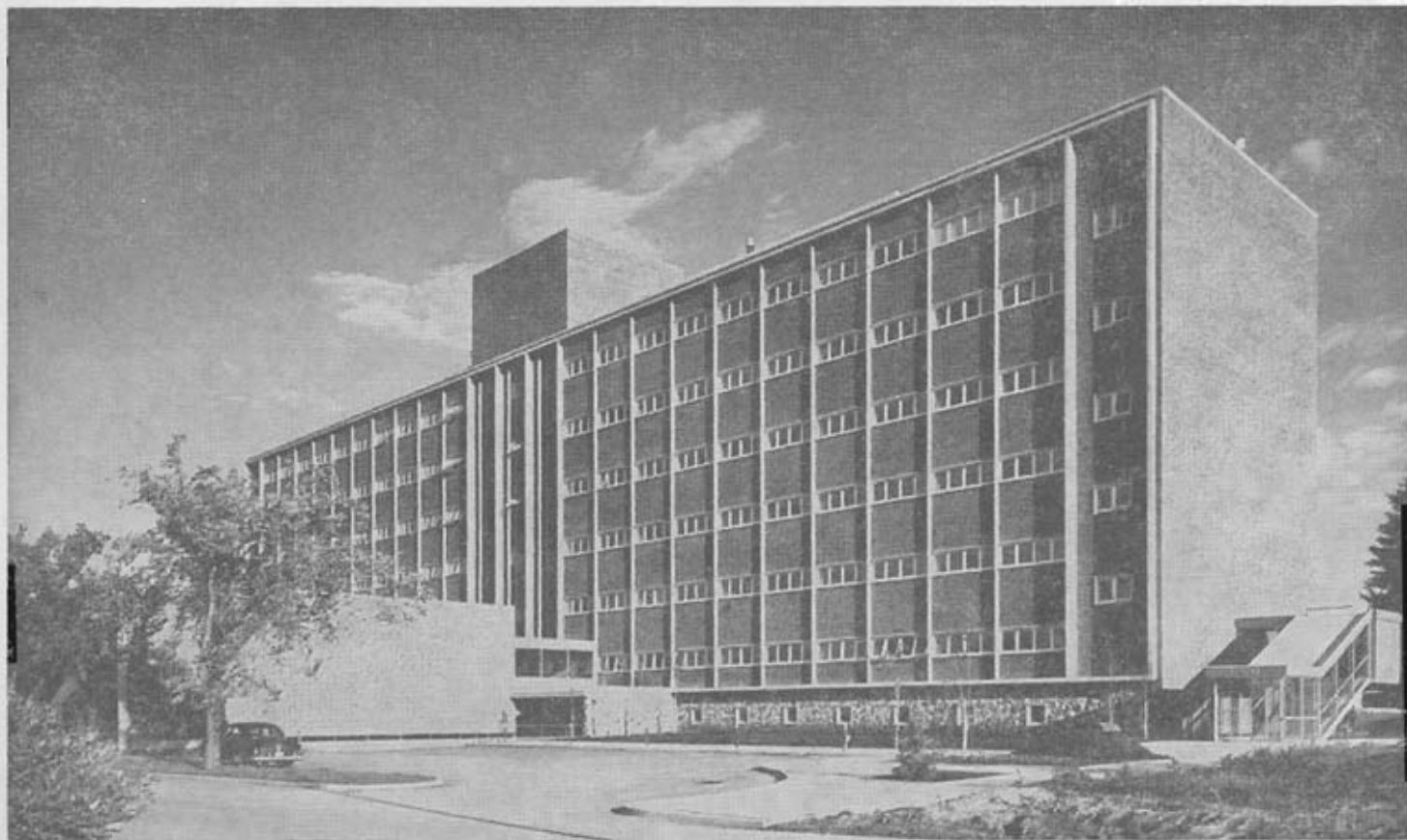
There are a lot of things we have to talk about that are like this, questions of committing ourselves, questions of valuing things, questions of regarding things as related and united, questions of priority, questions of all sorts that are normative, that express our commitment, our evaluation, our love, our dedication. These are not unimportant parts of life, and it is not unimportant that we be able to discuss them, and it is not unimportant that this be done in the light of reason; but on this it seems to me the general effect of the immense growth of the sciences has been very much less than salutary. I have been much concerned that in this world we have so largely lost the ability in this full sense to talk with one another. In the great succession of deep discoveries, new discoveries, we have become removed from one another in our tradition and even in language. We have had neither the time, nor the ruggedness, nor the skill to tell one another what we have learned, nor to listen properly. Here I am not talking about the professional communities. I am talking about the community of man, things which are not parts of the scientific life. For any true community, for any scientific community, for any society worthy of the name, there must be an element of being common, of being public, of being relevant and meaningful to man and not to specialists, in our talk about normative things. For the lack of this, because we have not had the ruggedness to talk and to listen to each other, and to see what there was that would increase and enrich our common culture and understanding, the public sector of our lives, what we have and hold in common, has suffered. And so I think have the illumination of the arts, and the deepening of justice and virtue, and the ennobling of power itself, and certainly of our common talk and discourse with each other. We are less men for this, for never in man's long history have the specialized traditions flourished more than today. We have our great, deep, private beauties; but there are high undertakings where man derives strength and insight from public excellence; and in these we have tended to be impoverished; we hunger now for nobility, the rare words and acts that somehow harmonize simplicity and truth.

I think that looking ahead we can see that without a new conception of the effort involved this will not quite be fixed up. Too much is going on, there is too much to be learned, and the intimidation of total ignorance is too devastating to man's

reason. Let us dedicate ourselves (perhaps not everybody, but enough people) to a continued effort to study as long as we are alive, to teach, to learn, and to regain for man that right to talk about his destiny without which he is not properly human. Certainly for specialists, and I think for artists, (and I think that most men are either one or the other and many are both) we have in this a most difficult and subtle balance. It is one which I touched on earlier. We have, on the one hand, to keep with utmost reverence and devotion and dedication our specialty, our own way, our own life, our own loves. If we do not do that we have no anchor at all in honesty; this is where we are really responsible, in the full sense of the word, for what we do; but we have also, with an equal importance but in a wholly different style, to be responsive to what others have to tell us, to be open to novelty and otherness, to have a sympathy which makes the understanding between men possible. I know that this is a matter of effort, but I can think of no greater ideal for the generations whom we in our schools and institutes and universities hope to encourage than to set them an example of people who are trying again to talk to one another, and who are trying again really to listen.

Robert Oppenheimer
University of Alberta
25 April 1961





MATHEMATICS-PHYSICS BUILDING
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