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## "Is Human Understanding Finite?"

Peter Brian Medawar

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Sir Peter Brian Medawar, "Is Human Understanding Finite?"  
Portland State University  
October 23, 1978

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JOSEPH C. BLUMEL: Good evening, ladies and gentlemen. It's my very great pleasure to welcome you to the second annual Morden Lectures at Portland State University. These lectures are made possible by the generosity of R. Burke and Alice Ann Morden, distinguished citizens of this community, whose commitment to the furtherance of international education and thereby to international understanding is well-known to many of you here this evening. The Morden lectureships make it possible to bring to this university and this community internationally known scholars from other countries, in order to increase international understanding among students and faculty of this university, and hopefully to other colleges and universities with whom we are closely associated.

I believe it would be safe to say that in no area—no other area—are international boundaries more irrelevant and less inhibiting than in scholarship and scientific research. The community of scholars is truly an international community. The value of these lectureships, therefore, extends well beyond their contribution to our faculty and students, great as these may be. Most importantly, they provide a visible and vivid example of the possibilities and values of international communication.

On a somewhat different level, I think it appropriate to comment on one example of the tangible and direct benefits to the university community of the presence on our campus of a distinguished international scientist. The visit here of Sir Peter Medawar was instrumental in the decision of the Oregon Committee for the Humanities to award the University Scholars Program a grant to conduct a series of colloquia on medicine in the humanities, which is described in your program this evening. I want to take this opportunity to thank, on behalf of

Portland State University, Burke and Alice Ann Morden for the opportunities they have provided to us.

[applause]

I should like now to call on Dr. Leon Richelle, Vice President for Academic Affairs, to introduce Professor Sir Peter Medawar. Leon.

LEON J. RICHELLE: It's indeed a unique privilege to be able to present and introduce to you Professor Sir Peter Medawar, who's a fellow of the Royal Society, a philosopher, an author, a Nobel Prize winning scientist who has accepted to come to Portland and deliver the second Morden lectures. Educated at Oxford, Sir Peter holds more than a dozen honorary degrees from universities in Europe and in the United States. He is currently Professor of Experimental Medicine at England's Royal Institution. And he's on the staff of the clinical research center of Northwick Park Hospital in Middlesex. Elected a fellow of the Royal Society at the age of 34, Sir Peter was awarded the Nobel Prize in 1960 for his basic research in acquired immunological tolerance. When I wrote to Sir Peter to ask if he would agree to come to Portland and deliver the Morden lectures, he answered to me a very nice letter.

As a way of introduction I used two names; one was Sir Ernst Gombrich, the Morden lecturer of 1977, and the other one was the name of an old friend and colleague of mine, Dr. Eugene Lance, with whom I worked in New York for many years and then who went and worked with Sir Peter. And his answer was "Hello," he said, "I was delighted to get your letter of September 28<sup>th</sup> with its reminder of two close friends: Sir Ernst Gombrich, the wisest and most learned man I have ever known, and Dr. Eugene Lance, a faithful drinking companion." [audience laughter] I immediately conveyed to Dr. Lance the high standing in which he rests with the British intellectuals.

Sir Peter has written many books: *The Uniqueness Of The Individual; Induction and Intuition in Scientific Thought*, and many others. And most recently, *The Life Sciences* in 1977, which he co-authored with his wife Lady Jean Medawar. Sir Peter has said that after the conference is over, the lecture is over, he would be most willing to answer questions, or even better, to visit with any member of the audience. And if you so wish, please do come down and join us on the stage, using the right side of the auditorium and the stairs there, and Sir Peter will be most delighted to talk with you and discuss matters with you. It is a great pleasure indeed to introduce Sir Peter who today will give a lecture titled "Is Human Understanding Finite?" Sir Peter.

[applause]

SIR PETER BRIAN MEDAWAR: Mr. President, Mr. Dean, and Mr. and Mrs. Morden, ladies and gentlemen. I want first of all to thank you, Mr. President and Mr. Dean, for your very friendly and heartwarming welcome. And I also want to say how immensely grateful I am to our patrons, Mr. and Mrs. Morden and the Morden foundation generally, for making it possible for my wife and myself to visit and make friends in a beautiful part of America which we have never visited before. I want to begin the lecture having said that, with a slight correction, the title of the lecture was given to you as "Is Human Understanding Finite?" and that is now the title of the lecture, but it began with the following title: "Limits of Size and Growth with Special Reference to Human Understanding." But mindful as we all are in England of President Carter's exhortations to save energy, to save paper, and generally speaking pull ourselves together and smarten up, we have streamlined the title of the lecture to "Is Human Understanding Finite?" [audience laughter]

I should like you to think of this lecture as an attempt to answer the first of the four questions which the great philosopher Immanuel Kant said defined the subject matter of philosophy. You have to imagine at some time a student, a rather impertinent student, asked the great sage of Königsberg what was this philosophy that he kept going on about, and we know from posthumous publications prepared by one of his pupils that Kant gave the answer that the subject matter of philosophy comprised the answers to four questions: "What can I know?" "What ought I to do?" "What may I hope?" And "What is man?" To these four questions, our son Alexander, adds a fifth, "Whom should I ask?" [laughter] Not less important than the other four.

I think Kant put "What can I know?" first because of the terrific upheaval in European thought caused by David Hume's skepticism, and in effect destruction of empiricism. David Hume pointed out, mercilessly and remorselessly, that there is no logical, no rational foundation for the law of causality or for the principle of uniformity of nature. There is no rational foundation for belief in either. We expect the sun to rise tomorrow morning, but there's no rational foundation for this belief. It is based on a mere habit of expectation, Hume pointed out, which might easily be mistaken.

A sort of awed respect for the opinions of David Hume is still prevalent in the 20th century. Bertrand Russell said, overstating it I think, "The growth of unreason throughout the 19th century and [what is] part of the 20th century is a natural sequel to Hume's destruction of empiricism." That is a little bit overstated, I think, but now Professor Karl Popper, who is the nearest modern equivalent to Immanuel Kant, said, "Our so-called knowledge is unmasked by Hume as being not only of the nature of belief, but of a rationally indefensible belief of an

irrational faith." It's hardly any wonder with the kind of turmoil caused in European intellectual circles by Hume's philosophy, that Kant should have made it his life's work to discover and propound *a priori* knowledge, knowledge that we say is independent of all experience, knowledge which we can be certain of independent of the evidence of the senses. Knowledge, therefore, which would escape the destructive effects of Hume's skepticism, and the discovery of *a priori* knowledge was the program of Kant's greatest work, one of the greatest works in the history of philosophy, *The Critique of Pure Reason*.

My plan in this lecture, ladies and gentlemen, is to break down the question in the title, "Is human understanding finite?" into two parts. Firstly, is human knowledge self-limiting? Is human understanding self-limiting? Are there any constraints upon the growth of knowledge or understanding that are the consequence of growth itself? That's one question. The second is, are there any built-in limitations to our capacity to know and learn? These are two different questions which I shall consider and try to answer separately.

The idea of a self-limitation, self-imposed limitation, limitation of growth that is a consequence of growth itself, is already very familiar to us from the growth of populations, the growth of individual animals, and even inorganic objects like skyscrapers or aircraft. All of these are self-limiting, as I shall explain. Populations, for example, to begin with: all natural populations, and this includes human populations, are restricted in growth by the operation of density-dependent factors, by factors which become more and more effective as the size of population increases. This of course applies to human population as well as populations of animals. It is an illusion that the growth rate of human peoples is so great that one day people will be too deep over the surface of the earth, that is an illusion. Now these simple truths are not in doubt. The human population will not grow to such enormous proportions. The great fear is, the fear that plagues us all, is that the density-dependent factors that control the human population will be famine and disease of unimaginable proportions. That is all I have to say about populations.

I want now to turn for a moment since it's more immediately familiar—the ideas involved are more immediately familiar—to the growth of individual animals and the factors that limit that. The most general constraint that operates in limiting the growth of animals, setting both an upper and a lower size incidentally, is that which is embodied often called Spencer's Law, after Herbert Spencer the famous evolutionist. Spencer's law states... I have no visual aid, so will you please imagine, and I'm going to use your imagination as a visual aid, imagine an object increasing in size without changing in shape. Now what Spencer's Law states is that the surface area of such an object which is increasing in size, imagine if you like a sphere getting larger and larger, and remaining a sphere or square. What Spencer's Law says is that the surface area of such a growing object increases as the square of the linear dimension, as the length or breadth

or height for example, whereas the volume increases as the cube of the linear dimension, as you know it does in the case of spheres or squares.

Now this is a mathematical truism or identity. It is not an empirical law. Nobody ever sat down and measured growing cubes and squares. It is a mathematical truism, and you may wonder what turns upon it. Well, a great many factors which effect the size of animals turn upon it. The weight of an animal, for example, varies as its volume and therefore as the cube of the linear dimension, but the part to support that weight varies only as the square, the cross-sectional area of the limbs, for example. And this sets a limit to the size of animals living on land. The elephant and the giant reptiles that we see today are about as large as land animals can be. If an elephant was very much larger than it is, one would be very lucky to see daylight between its legs, because its legs would have to be the size of the pillars of Baalbek. King Kong has already exceeded this critical size [audience laughter]; no such animal as King Kong could actually live without crumpling up underneath its own weight.

These constraints don't apply to animals in the sea. Whales, for example, are the largest animals that have ever lived because they are exempted from the exigencies of Spencer's Law. They are being supported by a medium of approximately the same specific gravities as themselves.

With land mammals, which have to maintain a constant body temperature, the problems of heat regulation set upper and lower limits of a more subtle kind. There is a little shrew-like animal called *Sorex minutus minutus*, which as you will shrewdly discern is not one of your great hulking animals, it an animal which is only 5 grams in weight as an adult. It has a terrible problem to generate enough heat to make good the loss of heat through the surface. It has to eat twice its own body weight, which isn't very much, of food in 24 hours in order not to die of starvation. The problem with large land animals is to excrete heat, not to conserve heat. Especially if they are dark in color. An elephant, for example, being very dark in color and very bulky has tremendous problems in excreting heat. Will you take my word for it, as a former professor of zoology at two famous English universities, that the way to ingratiate yourself with an elephant on a hot day is to hose it down with a cold hose pipe. It will be unforgettably indebted to you if you do that. [audience laughter]

Now this applies *a fortiori* to a hippopotamus. The hippopotamus, although Aristotle has conned us into believing that it was a river horse, *hippos potamós*, don't you know, it is in fact a river pig. [audience laughter] And therefore, if you'll forgive the non sequitur, disgustingly fat. It has what would be an insoluble problem in excreting the heat it generates through all those thick layers of fat, were it not that it lived, in effect, underwater. You have all seen pictures of

hippos at peace, they are in a river almost totally submerged, with their two huge noses just above the water. So they are on their way to becoming whales, [audience laughter] which are in effect, sea pigs.

With other animals, animals of other kind, special considerations apply. Insects for example. There is no more familiar figure in science fiction than the absolutely enormous insect, vast insect with strongly right-wing opinions, [audience laughter] which may sound as high as I do and look pretty menacing. Now in fact, there is a limit to the size of insects which is imposed by several factors. One of them is the fact that insects have to molt. They have to shed their hard outer casing in order to make growth possible at all. And during the period when an insect has shed its outer casing, any other insect could creep up behind it with a piece of lead piping and do it in. [audience laughter] And so the special vulnerability of insects during the molting period sets a limit to their size.

But still more, more exigencies that limit it, is set by the fact that insects breathe by means of breathing pipes which run from the outside air into the insides, as we anatomists call them. [audience laughter] Now, tracheae work by diffusion, a very, very slow process, and this in itself sets a limit for size of insects. So the great fascist insect that threatens us all is out. [audience laughter]

Now these considerations apply not only to living things, though living things are much more interesting than inanimate objects. It applies also to such objects as skyscrapers. Everybody who visits America, particularly for the first time, realizes how higher proportion of civic pride resides in having a higher building than any other city in the United States has got. I don't know if Portland is in the running for this idiotic stake, [audience laughter] I should think not. But the question arises, why should not skyscrapers be two or three miles high, even? What is the limit to their size? The reason is that as the height of a skyscraper increases, so the proportion of floor space, particularly on the lower floors occupied by elevators, reaches comically uneconomic proportions. If you look at a cross-sectional appearance of the lower floor of a big skyscraper, you'd be amazed at the amount of floor space that is occupied merely by elevators. That's to say, if there is to be any communication between the outside world and the people that live in the higher stories. [audience laughter]

A great prize of civic pride, et cetera, awaits the first person who builds a skyscraper that is uninhabited [audience laughter] except of course by a cat, and by a janitor to keep the cat company. [audience laughter] Then there is no such limit. Aircraft: why... there are both economic and aerodynamic reasons, I understand, why aircraft should be as big as possible. Why, what is the limit to their size? The limit, I'm told, by those aeronautical experts, is the

landing gear; to make the landing gear bulky enough and strong enough to withstand the terrific crump, with which large airplanes land on the ground nowadays.

Now these are all examples of self-limitations of growth. These are limitations of growth imposed by the act of growing itself. They are automatically imposed by the process of growing. May not the same considerations apply to human understanding? It has been thought to do so. That human understanding and knowledge is also self-limited in the same kind of way for one or other of the following reasons: First, the volume of knowledge is already so overwhelming that no one can know what is already known, and what still remains to be found out. Secondly, it is said that with the growth of knowledge, knowledge becomes so specialized, so finely fragmented, that we scientists could no longer communicate with each other. And this minute fragmentation of knowledge will inevitably impede the future advance of science. Moreover, at its frontiers, modern science is so difficult and so complicated, that instead of the modern three or four or five years of training to become competent in the frontline of the search for truth and all that, people have to study for ten years or more before they become qualified.

Another possibility, which I have heard darkly hinted at, is that the human beings will be destroyed by a Promethean fire of their own making. Or we will be damned in some huge Faustian payoff for the sheer impiety of probing into the unknown and seeking our own answers to the problems raised by the advancement of learning.

Now I don't believe any of these arguments carry any conviction at all, for reasons I should try briefly to explain. First of all, the volume of knowledge that is so overwhelming that we can no longer grapple with it; we can no longer encompass it with our minds. Now, it is true that the volume of knowledge is a pain, it is absolutely enormous. As any scientist knows when he is trying to master the literature of the field in which he is trying to make new advances. But this is really only, it's a nuisance, it is a technological problem for which technological solutions can be and are being devised. Information storage and retrieval is now an important branch of computer technology. And the problems raised by storage and particularly fast access retrieval are being solved quite rapidly.

I remember I once needed to find out what was known about a medication called anti-lymphocyte globulin, which is used in the transplantation of organs. I consulted the huge computer in Amsterdam, which is responsible for the printouts of *Excerpta Medica*, the best abstracting journal, the best medical abstracting journal in the world. And the most learned one too. Those acolytes of this huge machine programmed it to spit out the information it had in store about anti-lymphocyte globulin. They started the machine, or rather instructed me how to start it, without telling me unfortunately how to stop it. It went on and on, on, on; it was a



scene rather like “The Sorcerer's Apprentice.” [audience laughter] it was giving me so much more information than I wanted to know. Cubic yard after cubic yard of information poured out of this machine, until eventually I had to beg them to stop it. [audience laughter] Because I had only traveled to Amsterdam on economy class fare, [audience laughter] and my overweight probably would've been extremely embarrassing.

So I don't think that, I don't reckon much that the problem of the multiplication of knowledge as such. That can be coped with, and somehow we all do cope with it, however difficult it may be. Now as to increasing specialization leading to a fragmentation of knowledge, which makes it impossible for us to draw on each other's resources of knowledge and skill, I simply don't believe that this is true. If it were true, it would have hardly been possible for one of the great movements in modern biology to have occurred. That is, the recruitment into biology of numbers of extremely abled physicists, who have enriched biology amazingly. Now if it were true that it was so specialized they didn't even know what other physicists were doing, how could they have entered microbiology and immunology and many other fields of biology—and of course molecular biology—and enrich them enormously. It is not true that people are becoming more and more specialized. Somehow, I don't know how, we are becoming more and more broad-minded and liberally based in our scientific education.

So, I don't think much of that objection either. The next point I mentioned was, human knowledge and research is becoming so difficult and so complicated that it passes human comprehension... that the advances of science will rapidly pass human comprehension. But they have really done so already. No one man can master and understand all the hundred technologies going to making, for example, a cathode-ray oscillograph, but we don't work by single minds anymore. We haven't done so for years; we work by consortia of intelligences. Not only today—division of labor—but also drawing upon the intelligences of the past. And these act together synergistically, that's to say that working together produces a result greater than the sum of each individual contribution to it.

Now as to the extension of learning period for years and years and years, this happens anyway. Every scientist who graduates and undertakes research knows that he is at the beginning of a long hall. He's not going to stop learning at any time. We all go on learning all the time, thank goodness. There's never a time in the life of a scientist where he says, “Well, that's it then. I'm equipped now. I know it all. I will move on from where I have got to now.” Of course this still happens; we go on learning all the time.

We really are trained for much more than the ten years I held out as a sort of threat or bogey. Now, how about our being destroyed like Faust, or destroyed in a fire of our own making? This

is not an example of self-limitation of understanding or growth of knowledge, because it isn't the necessary consequence of the increase in human knowledge. It is theoretically possible, it is conceivable that some inmate of an institution in genetical engineering may devise a virus with a highly virulent DNA core, and a non-antigenic protein capsule, so this would be a virus against which we have no defense whatsoever, since it won't arouse any protective reaction. Now this is conceivably possible in one of these institutions, as I say, but it isn't necessitated by the growth of knowledge. Nobody has to do that. Adding, in the main I can say they don't; they don't do it, their consciences prevent them from doing it. So one cannot say it is an inevitable consequence of the growth of knowledge that we would blow ourselves up or otherwise do ourselves a mischief. We will now pause for breath, one moment. For me to have breath, I mean.

I've been asking if scientific understanding is self-limited in that nano-technical sense, again. Is it limited as a consequence of the process of growing itself? And the answer I gave you is no. In my opinion, no. I want to turn now to the question of whether there may now be an intrinsic limitation of scientific understanding. A limit set by some basic cognitive failure of human minds. There's a suspicion that such a limit, such a limitation exists, because of the manifest inability of science to answer elementary questions, the kind that children ask, and that science is manifestly unable to answer, "How did everything begin?" "What is the point of living?" "What are we all here for?" These are questions which we know perfectly well, to which no scientific answers can be given.

The answer given by positivism, that huge branch of philosophy known as positivistic philosophy, is all such questions are non-questions or pseudo-questions. That is an exceedingly feeble answer. [audience laughter] These questions have a meaning to those who ask them; they can imagine the answers; they would like to know what the answers are very, very much indeed. But they perfectly well know, that the answers to these questions cannot be scientific, and cannot even imagine scientific answers to questions like "What are we all here for?" The answers belong to some other domain of discourse that has not to do with the natural world. But although it... the answers have not to do with science, they have a great deal to do with human understanding and therefore I can't... I cannot neglect them. They point to some intrinsic inadequacy of rational understanding. Is it possible that such a thought barrier exists? That we can think so far in science but no further? This is the possibility that I'd like to examine and think about for a few minutes. I want to give you a couple of examples of what I mean by an intrinsic barrier. Please take these examples merely as examples, as illustrations or parallels or parables. They are not to be taken literally.

I want to consider first of all, the case of the Victorian microscopists, the 19th-century microscopists. The whole of pathology and bacteriology was founded upon the use of what we nowadays call the ordinary light microscope, with glass lenses and people peering through them. Wonderful feats of anatomic resolution were performed with the use of the ordinary light microscope. But the light microscope always fell short of revealing the internal structure of bacteria or the internal structure of the little organelles in a cell. Improvements are constantly being made; notably by the great optical physicist Ernst Abbe of Jena, upon whose endeavors so much of the success of the Zeiss... Carl Zeiss Optical Works was founded. He invented a condenser, he invented the achromatic lens, which prevented what you looked at under a microscope from looking like a rainbow of chromatic aberration. He invented the achromatic lens and these were great improvements, they led to considerable advances. But still the micro world remained shut to Victorian 19th century microscopists. There was, unknown to them, an intrinsic limitation in the ability of the microscope to see things very small. And this illustrates exactly what I mean by an intrinsic limitation.

No matter what refinements you introduce into an ordinary light microscope you cannot see anything that is smaller than the wavelength of visible light. Now this is an absolute intrinsic barrier to the resolving power of an ordinary light microscope, and this is the kind of thing, please take this only as a parallel, I mean by an intrinsic limitation of power of discrimination. One doesn't have to do repeated experiments or make repeated attempts to see things smaller than the wave length of visible light. It is a physical principle that you cannot do so. If you are using... if you are trying to look at objects which are smaller than the wave length of visible light. A cognitive... a similar example is the parallel of the fisherman's net. A fisherman cannot catch in his net fish smaller than the holes in his net. Now every fisherman knows this; he knows this almost *a priori*. He doesn't have to go indulge in the terms of fishing to satisfy himself that he's not going to catch tiny little tiddlers if the holes in the net are two to three inches wide.

So those are two examples of an intrinsic limitation. Now I want to introduce you, I will be introducing many of you, not all of you, all those who haven't studied logic in any shape or form, another kind of limitation upon understanding. It is that which arises when we are... when, for example, we are trying to study the workings of the brain by using the brain. Whenever the subject of our investigation is also the means by which that subject is investigated, this limitation which uses our inability to stand outside ourselves, was discovered in logic by a famous Austrian logician called Kurt Gödel. I call him Austrian but he is now, like so many great people, he's now American. Gödel showed that, for example, if one tries deductively to prove that a deductive logical system is free from contradictions, you come to an absolute barrier beyond which you cannot go. Consider for example the great logical deductive

system like Bertrand Russell's *Principia Mathematica*. If one tries to prove that this system of logic is free from contradictions, you find that it cannot be proved to be free from contradictions, so the logical system cannot be wholly completed within its own limits. It's because one cannot stand outside it. As Wittgenstein said and many others have said, to understand, to encompass a thing completely, one must stand outside it.

Karl Popper, a name I have mentioned so often and which I shall mention again, gives a very good, very good illustration of this. He points out that a painting... supposing a painter is sitting in a room, painting a picture of the room with the painter himself in it and the easel in front of him in which the picture appears. This is an example of limitation caused by inability to stand outside oneself. If you imagine that there is a painter sitting in a room, a canvas in front of him, and he's painting the room in which he is sitting with himself in the picture and a canvas in front of him, with the picture on that canvas of the room he is trying to paint, now this is incompletable. If you just allow about 15 seconds to pass while you satisfy yourselves intuitively [audience laughter] that this picture is incompletable, while that goes on, I shall mop my brow.

Another brief pause for breath, which will just give me time for a brief commercial. I hope many of you will read *The Self and Its Brain* by Karl Popper and a famous physiologist, John Eccles. *The Self and Its Brain*. It's no good writing the name down as the book is much too expensive for anybody to buy. [audience laughter] I have to borrow or steal it or something. They take the view that we shall never understand the nature of the interaction between the mind and the performances of the brain, I mean the electrical goings-on in the brain, and essentially the same reason as that which gives rise to Gödel's famous theorem of the incompleteness of logical systems. We can't... we must use the brain to study the brain, the mind to study the mind, and we cannot fight against a barrier beyond which we cannot perceive.

Let me summarize as far as I've got. I've said that the growth of human understanding is not self-limiting, but I do exhort you to take seriously the view that there may be some intrinsic shortcoming in cognition that withholds from us the answers to those elementary questions that children ask, and to which we should very much like to know the answers. But a more important practical problem is this. Is there any limit to the power of science to answer questions of the kind that science can answer? I want to get... to answer this question, I want to go back to Hume, David Hume and the tremendous upheaval caused by his showing in Popper's words that "No number of observation statements could justify the claim that any explanatory universal theory is true."

That was the great lesson of Hume, the epistemological question, element in Hume's teaching. That no number of empirical observation statements could justify the claim that any

explanatory general theory is true, no matter how much you multiply them. Now Kant's solution to this terrible challenge thrown out by Hume was, as I've already said, to seek *a priori* knowledge, to seek knowledge that was independent of experience and therefore not subject to the Hume limitation. Now Karl Popper's solution... he is a man, by his strength of mind and width of knowledge, a sort of modern Immanuel Kant. Popper's solution is on totally different lines. He doesn't look for *a priori* knowledge. What he does instead is to abandon altogether the idea of apodictic knowledge. Apodictic knowledge is knowledge which is demonstrably true beyond the reach of criticism. For Karl Popper—and many of you will know the essence of his philosophy—all scientific knowledge is conjectural. Science is a system of hypotheses about the nature of the natural world in which apodictic certainty is never achieved. No theory of any kind is ever established beyond the reach... beyond the possibility of criticism.

This is a lesson that Popper learned from the supersession of Newton's celestial mechanics by Einstein's celestial mechanics. Newton's system, Newton's celestial mechanics did at one time appear to have apodictic, an essential inner rightness, an apodictic certainty. Kant thought it even had *a priori* standing. It was of the nature of the universe that objects would behave in accordance with Newtonian principles. But these principles have been superseded. A leading theoretical physicist, a Dr. Hermann Bondi, has said of Newton's theory, "We can certainly now speak of disproof." Well, the question is, if you can't get apodictic certainty, how does the advancement of learning occur? Karl Popper says that all truths, all would-be truths, all putative truths, start life as imaginative preconceptions of what the truth might be. We invent the world as we go along. We have to imagine what the world might be like and then test our conjecture, our hypothesis against real life, to see if what we have imagined might be true, does stand up to observational and experimental criticism. So the day-to-day business sounds consistent in having ideas, dreaming up hypotheses, and testing their consequences against real life. The initiative comes always from the creative imagination.

The actual process of science is a testing of hypotheses, as I say, against real life. So science in the end becomes a dialogue, a dialogue between the possible and the actual: what could be true, and what is in fact the case. It is a dialogue between fantasy, our imagination, and fact. These notions were first found in the writings of a former Master of Trinity College, Cambridge, William Whewell, and also in the writings of your great American philosopher C.S. Peirce. They greatly alarmed John Stuart Mill, that great empiricist. He said, with a shudder of distaste, "An hypothesis being a mere supposition, there are no limits to hypotheses," said Mill, "other than those of human imagination." What scared and dismayed Mill, that there's no limit to scientific knowledge except human imagination, is of course one of the great glories of science. That is our principle assurance that there is no limit to the power of science to answer questions of the kind that science can answer.

For as Shelley, strangely enough, quite clearly foresaw, scientific invention, the dreaming up of hypotheses or having what Whewell called “happy guesses,” until he pulled himself together and talked about felicitous strokes of inventive talent, [audience laughter] is cognate with literary and artistic creativity to which there is no conceivable limit. Shelley was kind enough to say in one of his great defenses of poetry, “Poetry comprehends all signs.” He was using poetry in a wide sense. Poesis, creation, making, comprehends all of science. He clearly foresaw the incident that Coleridge also foresaw, that the initiative in scientific discovery and invention comes from the imagination.

If this is so, it’s reasonable to ask what distinguishes scientific truth, so what we accept for the time being as truth, from whimsical fancies or fairytales, or tales told by an idiot or by idiots? What is the line of demarcation that separates the merely fanciful, or the metaphysical if you like, from the world of science and common sense? There’s no difference between these two worlds; science and common sense belong to one domain of discourse. Philosophers of the Viennese Circle, people we now call logical positivists, believed the answer to this criteria of demarcation lay in the principle of verifiability. If a statement was either verifiable or verifiable in principle, then the statement belonged to the world of science and of common sense. If a statement of which this could not be said, which did not answer this criteria of being verifiable in fact or in principle, it was nonsense; they were quite clear about that. The logical positivists were a pretty rancorous lot. Metaphysics, religion: nonsense, that’s easy isn’t it?

Now for various technical reasons which it is far too late and quite unnecessary for me to go into, Karl Popper substitutes for verifiability in principle: falsifiability in principle. There are technical reasons for that, which are entirely valid. Now for Popper, statements which are not falsifiable in principle, which one cannot see anyway to test and decide whether they might be wrong, are not scientific statements. They belong to some other world of discourse, a world of metaphysical or religious discourse maybe, but he’s most insistent that such statements are not nonsense, that it is a mere vulgarism to describe such statements as nonsense. They are just different statements; they belong to a different world of discourse. The demarcation lies not between sense and nonsense, but as Popper insists, between two worlds of discourse: the world of science and common sense, and another world of metaphysics and religious belief or declaration. And such beliefs are not nonsensical. Popper repeatedly calls attention to the way in which purely metaphysical notions have promoted the advance of science. They could hardly be regarded as nonsensical.

And he also points out, as Frances Yates, one of the greatest scholars in England, has also pointed out, that magical notions had a profound influence on the founding fathers of modern

science, Francis Bacon and Jan Comenius, who were deeply affected by Rosicrucian and hermetic influences. As Shakespeare was too. Frances Yates has done the most brilliant study on Shakespeare's play "The Tempest." "The Tempest" is ostensibly, of course, the mighty storm which opens the play, and from which the principle characters manage to save themselves and arrive on dry land. But the real Tempest, according to Frances Yates, in "The Tempest," is the tempest in Prospero's heart: the ranging conflict between the world of magic on the one hand and the world of the new philosophy, the rational world, on the other. If one reads "The Tempest" in light of what she says, it is really quite illuminating; it becomes a new play of a kind one didn't expect to read at all.

It is to metaphysics and to religion that we have to look for the answers to those elementary questions I was speaking of, the ones that science can't answer. And we should evaluate metaphysical and religious answers not by the criteria of correspondence with reality, which we scientists all cling to, but by the degree to which they satisfy our hunger for understanding and by the degree by which they may improve human behavior. And these are both nonscientific criteria.

Now, ladies and gentlemen, my purpose has been to show that though there is no self-limitation upon the growth of scientific understanding, there may be, I say there may be some intrinsic cognitive incapacity. Shall I say that again? There may be some intrinsic cognitive incapacity which withholds from us the answers to questions which we all ask, or have asked, and to which we would all like to know the answers. No scientist should ever be so arrogant or so foolish as to say that science knows or soon will know the answers to all questions worth asking, because science is manifestly unable to answer the most elementary questions about the nature and purpose of life. What is much more important is: is there any limit of the power of science to answer the kind of questions that science can answer? Now, I hope I have convinced you that there is no limit to the power of science to reveal to us and increase our understanding of the material world. It can be said today as confidently as it was said by the founding fathers of modern science, by Jan Amos Comenius and Francis Bacon, that in science there is always *plus ultra*, there is always more beyond. Thank you.

[applause]

RICHELLE: As Sir Peter indicated, anybody who would be willing to come and talk with him and visit, please, there are stairs there; come and say hello. Thank you very much.

[program ends]