

Jagdish Merha: Ladies and gentlemen, I am very happy to welcome you to tonight's lecture of the humanities series of SMTI [Southeastern Massachusetts Technological Institute, now University of Massachusetts, Dartmouth] . May I first of all say a few words of thanks. We are delighted that this series of lectures and artistic events has made some positive and pleasant contribution to SMTI and the community which it seeks to serve. I want to thank Dr. Joseph Driscoll, the president of SMTI, for his interest and encouragement. We welcome his continued support. Thanks are due Mr. Augustus Silva, Chairman of the Cultural Enrichment Committee of SMTI, for his constant readiness and friendly availability to help the disarrangement and that in connection with this series. Mr. Lawrence Buell has worked hard for the publicity of our programs and I wish to thank him for it. In the final analysis, it is the audience and our distinguished speakers who have determined the success of our programs. The visits of personalities such as Oscar Handlin, Margaret Mead, and Gerald Holton, have set for us a very high standard of events in our lecture series, a standard that we shall try hard to maintain. Some of the future visitors to SMTI will be on October 14th, 1966, the famous Pulitzer Prize winning poet Archibald MacLeish. October 28th, 1966 Jerome Wiesner, Dean of Science MIT and former Science advisor to President Kennedy. December 2nd, 1966, theoretical physicist and cosmologist, Phillip Morrison, professor of physics at MIT. Also among these speakers, during the next academic year will be the author of "The Affluent Society" and President Kennedy's ambassador to India, John Kenneth Galbraith. And the chaplain who looks after God and man at Yale, Rev. William Sloane Coffin. Among the other programs we expect to have will be the visit of the Chamber Orchestra of Philadelphia on Nov. 16th, 1966 and the Harvard Redcliff Chorus in April, 1967.

It gives me special pleasure, however, to welcome tonight's speaker. He is Gerald Holton, professor of physics at Harvard University. To me and to many others, who value a humanistic tradition in the sciences, Professor Holton is a brilliant and inspiring leader for whom we have unbounded admiration. Gerald Holton was brought up in Austria, he attended the Classical High School in Vienna and the School of Technology at Oxford [now Oxford Brookes University School of Technology] . He graduated from Wesleyan University in Connecticut and received his M.A. and Ph.D. degrees from Harvard University. As a physicist, Dr. Holton's field of research is the properties of matter under high pressures. As a historian and philosopher of science, he has illuminated the character and concepts of scientific discovery. His concern for teaching helped organize Harvard Project Physics, of which he is a co-director. Dr. Holton is the

author and editor of several books, and the author of numerous articles in physics, and history and philosophy of science. As teacher, he has been a member of the Harvard faculty since 1945. He has lectured widely as a visiting professor. Berkley, Paris, and Leningrad are among the many places where he has taught. As a member of the Institute for Advanced Study in Princeton, as advisor on the History and Philosophy of Science to the National Science Foundation, as editor-in-chief of the American Academy of Arts and Sciences, as a founding editor of the journal, "Daedalus," as George Sarkin memorial lecturer, and through so many of his diverse professional activities, Gerald Holton has brought joy, wisdom, and reasonableness to the affairs of man and minds. Even at Harvard, which has more than its share of clever and distinguished people, Gerald Holton is someone very special. According to Archibald MacLeish, he is a unique and inspiring personality. Professor Holton is one of the prime movers in the discussion of the public responsibility of scientists, in times when scientists often tend to be uneducated beyond their specialties, when the indulgence and power with pride, and glory without grace is their gift to a technological society, when non-scientists often surrender their disturbed questioning to the mystique of scientific expertise, a man like Gerald Holton seeks to educate his associates in the essential humility and humanity of the scientific approach, and the heritage of philosophical wisdom. Ladies and gentlemen, to speak on "Science, Cause or Cure of Crisis," it is with enormous pleasure I present an eminently civilized man, Gerald Holton.

[applause]

Gerald Holton: Mr. Mehra, Mr. and Mrs. Driscoll, ladies and gentlemen, coming to your very lovely looking campus, and the imposing symbol of a building in the middle of it, I had that sudden, strong feeling of what Harvard must have been like some time ago, when there was only one building in a large meadow, on which cows were to graze for a long time after. May I express the admiration for the courage that both the landscape and the building and this excellent start represent, and may I wish you all the possible luck to avoid the many mistakes which have been made around Harvard Square, such as building immediately ramshackle things all around which hide the place and secondly, perhaps becoming so parochial that it takes a special invitation to see this nice place. That was my fault.

When I speak of "Science Cause or Cure of Catastrophe or Crisis," I speak here about a subject

in which there is a strong division of feeling. On the one hand, there are those who are very optimistic about where science and technology is taking us, and they show their optimism in many ways. One of them is to pay for it, at the rate of 22 billion dollars a year for research and development, of which only about 2 billion are really for anything that sounds like basic research, however. They show it secondly, they show their optimism secondly, in their hopes which really go back to the eighteenth century, to the great academies which were then set up which were motivated by the feeling that you could have capitalization and yet enrich your soul, as it were. That you could, through science and technology, find a road to riches and civilize this continent. And on the other hand, through a platonic argument through mathematical science in particular get close to being inzicht, free of the change that is all around us and transcend it in this way. And that hence, science and technologies are cures for whatever may ill us, whatever ills may beset us. And that feeling is still with us.

There are those who dispute it, and who are full of fears, perhaps misconceptions, who believe, that on the other hand, through science and technology, running wild, particularly the technological aspect running wildly after profits, including war profits, that we lose sight of our national destiny as well as the place for the person, for the individual, itself. And that secondly, through pragmatic scientific philosophy we are losing our sense of absolutes and the sense of the sacred, so that we lose our capital and our soul in the long run. My proposal tonight is that we look at science, as least as a heuristic model as if it were, as I believe it to be, neither quite the cause nor quite the cure, but that science itself is today, as it has always been in earlier periods, a byproduct of the general intellectual activities of the time. That it shares and helps us to share somehow in the thought and the problems and triumphs of our time just as does art and philosophy, and our home life and our behavior to our children and to each other.

I want to draw attention, in other words, to the interaction between the prevailing styles of thought in all fields on the one hand, and the functions and the state of affairs in the sciences in the other. And before turning to the contemporary period it is well to remind ourselves that such interactions have always existed. They are more easily discerned in the past because we are less involved. Let us remember our Plato again, it is commonly acknowledged that a proposal of Plato set the style for one of the main traditions of classic scientific thought. As has been pointed out over and over again in all our classes, Plato set his pupils at the academy the task of working out a system of geometrical hypotheses, which by substituting uniform and circular

movements, for the apparently irregular motion of the planets, would explain these irregular motions of the heavenly bodies to save the phenomena. Simplicius writes in his commentary on Aristotle's "De Caelo," "For Plato set this problem for students of astronomy, by the assumption of what uniform and orderly motions, can the apparent motions of the planets be accounted for?" Now this famous problem kept natural philosophers agitated for over two thousand years and was immensely influential in shaping science as we know it today. We look at this and we recognize that it is an immensely good problem. It is very lively. We still ask questions of just this kind. But built into it are a number of pre-suppositions which are quite characteristic and which in fact have buried in them the style of thought of the time as a whole.

Why look only at certain facts of experience and not the luminosity and apparent brightness of the planets, but their positions. Not the milky way, but the planets. Why not allow for irregular motions to explain other irregular motions, but call upon orderly motions in order to explain irregular motions? The analogon, which is built in to the answer yet to be given is quite rich, quite structured, not at all accidental. The Babylonians understood science in another way. To them, their style of thought would have been to catalogue the observations and to look among these orderly observations for something to remember, or worth writing down, or worth handing down. And that would have been their style of explanation. The issue raises itself forcibly, what are the criteria which guided Plato and which guide us in the pre-selection of the facts, the hypothesis, the explanatory methods that inform our science before we sit down to do it? On the answer to this question far more than on the facts of nature, themselves, depends what kind of science we have, whether such a science is possible, whether it's physics or biology, for example.

And this is where the style of the thought of the time enters. For in the Laws, Book Twelve, the Athenian gives the game away when asks Clinias and Megillus some questions. He speaks, "May we say then that we know of two motives in our belief in the divinity, one of them is our theory of the soul, the other of our doctrine of the orderliness of the motion and behavior of planets? No man who has once turned a careful and practiced gaze on this spectacle has been so ungodly in his heart that its effect have not been the very reverse of that currently expected, namely, atheism. The very reverse. They awaken wonder and arouse in the breast of close students the suspicion which has now been converted into accepted doctrine that were these without souls, these planets, and by consequence without intelligence, they never would have conformed to precise computation and orderly motion. "Anyone therefore aspiring to be a

sufficient magistrate to the whole community", Plato continues, "must possess the requisite preliminary sciences and apply his knowledge neatly to his moral and legal behavior. The proper study of man, of which the preliminary sciences are only a stage, is ultimately the soul", as always in Plato. And astronomy, we now see, is used as an illustration, as is often in Plato's work, to make this point. Plato tells us that astronomy is not pursued properly if one studies only minute processions of the equinox, for example or other measurable detail of calendars. All this becomes only later highly regarded. Man must pursue his studies aright with his mind fixed on the single end; the single end is the recognition of the divine in him. Astronomy, then, is an adjunct to moral philosophy. And now we have no difficulty to reconstruct the criteria of pre-selection in this kind of astronomy. They are precisely the criteria which assure that the subject matter and the persuasiveness of the science shall contribute to moral education. To let scientist look for their own subject of study, to fashion their own criteria for selecting facts, all this would be as absurd as giving the name true musicians, in "The Republic, Book 3" to those who would invent their own instruments, and who want to play on them any disharmonious tune for reasons that pleases them, who have not studied the forms of soberness and courage, liberality and high-mindedness.

You see that one of my conclusions, will be we are now at a time when it seems anyone may invent his own instruments and play on it any tune, but even that has built into it criteria of style which come from outside the sciences. In our time, the situation is not entirely different, then. An example will be helpful here. It is commonplace that the predilection for seeing problems in terms of a harmoniously ordered world was still characteristic even in the very language of scientific imagination in the classical periods of the seventeenth and eighteenth centuries. How far we have come from that time, not only in science is perhaps expressed most directly and simply in a passage that seems to our ears as strange now as it must have been congenial in 1681, when Thomas Burnet published "The Sacred Theory of the Earth" speaking of the annoying disorderliness of the distribution of the stars. He said this, "They lie carelessly scattered as if they had been sown in the heavens like seed by handfuls, and not by a skillful hand, either. What a beautiful hemisphere they would have made if they had been placed in rank and order, if they had all been disposed into regular figures, the little one set with due regard to the greater, and then all finished and made into a fair piece, a great composition according to rules of art and symmetry."

The heavens did not please him any longer. We have not of course lost this concept of hierarchy, continuity, order in our contemporary work. They stay in science, but mainly as inherited elements. They are not the new theme, the themes that correspond to the characteristic, powerful style of our own age. Of which one of the most powerful and significant is the very antithetical theme, the theme of disintegration, of violence, of derangement. In the language of physics, in the last 50 or so years, we have found a new language arising, a new terminology arising, if you look at the index of a recent physics book and compare it with one printed before 1900, and just look at the words which are new, you'll discover a quite interesting rhythm about the new words: radioactive decay, displacement law, degenerate state, fission, nuclear disintegration, discontinuity of energy levels, dislocation, indeterminacy, uncertainty, probabilistic rather than classically deterministic causality, time reversal, strangeness quantum number, negative states, forbidden lines, forbidden transitions, particle annihilation. I once wrote that it is not too farfetched to imagine that some physicists will propose to name a new particle the schizoid particle, and shortly thereafter discovered the term schizon in fact was being introduced into the technical literature of particle physics. It is as if after a successful search for the simplicities and harmonies in science from Plato, through the eighteenth century, in our time the search has turned into a more direct confrontation of complexity, of derangement, I think the French word *derangement*, is closer to what I mean, of sophisticated and astonishing relationships among strangely juxtaposed parts.

And if one is interested in the parallels between style in science and style outside science, it is not surprising to discover this same theme, this theme in the physical science, having its counterpart in modern themes outside, for example the analogous preoccupation with the theme of apparent derangement in contemporary art. Let me select an example among very many. Consider the work of the French artist Arman, who has called some of his works "Colères" or "Coupe." In the words of Peter Jones, a critic who made a study of his work, "The aim of the "Colères" is to quote, "hold fast, in one instant, the explosive instant, in which objects are violently disintegrated into a mass of pieces". This is action sculpture in the highly recalcitrant medium of objects that break the way the artist wants, only with much flare and practice on his part. Arman is fascinated by the coordinated mastery of all of the factors involved brought to bear at one decisive point in space and time. He describes one of his works, "Allegro Furioso" and let us have a look at it. And douse the lights for a few minutes. The "Colères" looks

spontaneous, perhaps we can turn this upside down. Turn the slide upside down. Well, rotate it so that the writing comes at the bottom. There are three axis...

"The Allegro Furioso" 1962. Jones gives this description, "The " Colères" looks spontaneous, but its construction was deliberate all the way through. Here is what Arman did. Having laid a black panel, that serves as the base flat on the floor, having built up temporary planks on the sides, he began by smashing a cello. This came first because it was to be the determining factor of the composition. Arman broke it diagonally, to divide the surface in two. Then he took the viola, an old, dry, hand-made instrument, which he knew would spread itself more broadly on impact, a newer one would have broken more compactly, he broke the viola to the left of center in order to leave a "V" in the middle of the panel. Next he broke the two violins, in such a way as to have them going in the same direction as the viola, not to have them too widely dispersed, he did not swing them through the air, and smashed them on the boards, as he had done with the other instrument, but he held them by the neck, and stamped on them with his foot, and dropped the necks nearby. Thus he achieved a compact mass on the left side, and finally to counterbalance fully the mass of the cello, he threw down the bows on the left." Let us have the lights.

The work of Arman and that of his colleagues in action painting and action sculpture may not turn out to be good art, but despite our initial impulse to object and even to scream out in horror, perhaps, I believe we must take the intention very seriously. It is through dismemberment of material, that one may hope one method among many, to discover certain clues to the original simple symmetry that is hidden in the wholeness of the object. Vesalius, who introduced dissection of human corpses into medicine, knew this very well of course. And I might point out that a physicist who is interested in the orderly structure of the nucleus or a subnuclear particle, very often has to induce that structure, to submit it to an Arman-like process. He prepares the nucleus by first stripping away the atom's electrons which shield it; he then lets the nucleus at the end of a violent journey crash into a target. There, if the energy is high enough, the projectile and perhaps the target will disintegrate, the fragments will go off, with momentum and energy and spins that are full of fascination and meaning to those who achieve a quote, "coordinated mastery of all of the factors involved," to cite Jones. But meanwhile, to the uninitiated this whole process looks like a ridiculous and dangerous destruction, and he is moved to object. And perhaps even to scream out in horror. If this analogy is valid, maybe the attention to the theme

of derangement in science, as well as in art, is at bottom an indication of the return to its anti-theme of order, in a more sophisticated guise. The simple harmonies, the simple symmetries, most of them, they have been found out. How much more satisfying will it be if we can detect harmonies and simplicities directly through a highly trained vision, trained both in the sciences and the arts, in complex apparently broken and apparently still deranged configurations. It may be that we are really now, just now beginning to train new sensibilities which will come to terms with this new style.

And in the mean time, the careful attention and sensitivity to chaos, to disorderliness, has yielded surprising new simplifications. It is a very telling fact that the carelessly scattered appearance of the stars, which seemed so disorderly, so irregular in the seventeenth century, that all this has since then slowly provided data for an entirely different view of the earth, of the sun, of the solar system, indeed of our whole universe. First, it turned out that we are located in one of the outer arms of a huge, lens shaped gathering of stars, many of which seem themselves now to be the centers of their own solar system-like planetary distribution and therefore, looking from our earth into different directions, we see of course, different densities, large numbers of stars in directions toward the center of the galaxies, a few stars at right angles. The hand that scattered these stars, was in fact, skillful. But to recognize this, we first had to get used to the idea that the hand did not also put us at the center of things, and that it did not place a higher value on simple lattice arrangements than on stochastic distributions. And secondly, looking beyond the stars to the nebulae, we again find them to be placed essentially at random as far as the telescopic eye can see. So after all, it seems to be that we are in a more or less isotropic and homogeneous, that is to say in the most simple and symmetric world possible. Or at least the style of thought of our time has made it easier to entertain this model.

Let me turn to another sense in which I might have used the word style. Thinking about the work of scientists, many of us who are in it and many of those who are outside it, see it as a threat to the person, in the depersonalization that seems to go on in scientific teamwork. Like that, indeed of all of contemporary life, many of us might be saying. Let us speak about this at least briefly. In 1902, when the Curies were at the height of their fame, Paul Apell, the dean of science approached Pierre Curie, and asked him, "Would you mind very much if I propose you for the Legion de Honuer?" To this Pierre Curie answered in a weary sort of way, "I have no need of honors but I have a need of a laboratory". Indeed at that point he still had only one

rented room, and that wooden shack off the Rue la Monde, in which they had done their original work together, with hardly an assistant. This is of course, impossible for people of creativity, ingenuity, and stature today. What has happened, on the contrary, is an almost overwhelming swinging of the pendulum in the other direction. It is not realized perhaps, to what degree teamwork has become, really, the rule in many fields, though not in all, there are still more individual papers being published, papers by individuals published, numerically than papers were ever published by individuals. The fraction, of course, has dropped. But a usual paper in a lively research subject looks more like the following, and here let me go to the next slide, in which I show you only, not the paper, it looks long enough, but just the title and the cast of characters which were responsible for this short paper. Indeed, it is a letter to the editor, a short one. In the Physical review letters, "The elicity of the proton from lambda decay," decay again, by a group numbering of the ordering of twenty or so. Reporting some very nice work, of the kind which indeed is being carried on right at your physics department here. What strikes our eye, in this by no means unusual title, letter, there are other articles with many more participants, indeed one has been published recently with only the institutions listed instead of any names at all, and with credit at the end being given to yet another institution, instead of a person, in this list what strikes our eye is the complexity of the team. From Syracuse, to Duke, to Oakridge National Laboratory, Johns Hopkins University, the University of Bologna, in Italy. These people have never met face to face as a group, probably, if they had, they probably couldn't talk to each other, not only because of language problems, because the language in all these cases probably is the international language of science, which is broken English, but rather because there are among them mathematicians, and engineers, and people who are really almost machinists, and electronic specialists, and real physicists, a few, and one or two who know how to get grants, but who also have a Ph.D. in physics. This new team, this new research animal, this research society is doing work which could not have been done by the sum total of these people working separately in neighboring laboratories without consultation. They are working on greater and grander problems, but also on far more complex problems. They are analogous to a very beautiful hi-fi set, rather than a crystal set, as it were. And the components are matched to each other so that while Lightner may not be able to speak to Poopy, he can talk to Gray, and Gray can talk to Cohen, and Cohen can talk to Mier, and Mier to Schlein, because they do have some overlap, and so there is an impedance matching between some parts of the team.

There's an amusing thing about the slide, I made it for myself in 1961 when this letter was published. It struck my fancy, and afterwards, I discovered that a young man who married my wife's sister, was this very Peter Schlein, in '62, so now I am related to one of them, and this indicates another aspect of my tale, namely, there are now 27,000 physicist in this country. The number around the turn of the century was about a hundred, and the line has gone up exponentially and shows no real sign of slacking off, so that in any random sample of large enough size you are likely to find a relative among physicist. That means that exciting things are going on there, which Curie would envy to have lived to see, if that many interesting people are drawn into it. Thank you. Let me have the lights, please.

What do we conclude from that? Would can go to ways, and say here individuals have been deprived of their liberties and now must work in harness with each other, and their souls have been sold to teams, and to universities, and national laboratories, and the military that foots the bill, and the other answer could be this: the Curies are still working more or less alone, the fact that they list other names just means that they are available for consultation and tell them what to do, and that has always happened, although the credit was not given for it, but now there is a chance through this mechanism of teamwork, for people to fulfill their potential at a level below the Curies, if I may permitted an in joke, at the milli-Curie level, to do some useful work, of a kind which by themselves, would really make no sense to do at all. That is to say, a physicist who really cannot by himself do anything enormously creative can do something much more creative when he is working on a team of this sort. He becomes more of a human being, rather than less. Many of us have seen that in our students, that by themselves they would be rather doomed to a rather pedestrian set of thoughts, but when they get into the atmosphere where they stimulate each other, that very much better ideas can be worked on. This, I think, is a human use of human beings. And the same model, applied outside in the chemical industry, applied in the hospital, where it has been done before the physicist came along, apply I even hope to think, in the humanities and the social sciences, where it is appropriate someday, a little is being done already, gives us, I think a model to look at this depersonalization of work as really a false characterization, but what is happening here is that a limited potential is being amplified. I want to stress this, particularly in an audience where there are some students. Because it is particularly the young that have this fear that science necessarily submerges now individual talent, and also that it necessarily submerges the emotion of the individual. And here

we speak about a fear which really comes from other aspects of contemporary life as well.

Let me turn to that aspect. There is a step basic to all scientific work, which is rarely discussed, it is the process of removing the discourse from this personal level, the level on which the problem really becomes interesting and exciting, a private level where aesthetic considerations are allowed, quietly, as long as you don't publish them, to a second level, one of public science where it ends up in articles or letters to the editor, where the discourse is unambiguously understandable, it's predominantly about phenomena and analytical schemes. This is a process which every scientist unquestionably accepts, learns very early, or he doesn't make it. It's a process which I might term externalization or projection. Scientist almost are defined as people who can project outward some of their dreams, some of their aspirations, many of their emotions, and make them appear on a public level to be so free of them that others who have very different motivations can project it back into their own reference system. Anybody who knows a little about relativity realizes this process of looking for an invariant formulation, is one which scientific processes depend on for their public usefulness. Now what interests us here is that on occasions, on certain occasions during this transformation of concepts from the personal level, where it's exciting to do them, to the public level where it's permissible to publish them, the scientist perhaps unknowingly smuggles in the style, the motivation, the commitment of his individual system, that of his whole society, into that supposedly neutral and value-indifferent luggage which is permitted. There is an element which scientist are not fond of talking about at all, which is really sheer anthropomorphic thinking which does get occasionally get projected along with one's own calculation. Let me be quite specific here, once more taking refuge into antiquity will help us match into the present day. It is not longer difficult for us to see that the hierarchical universe of an Aristotelian school-man was also abstracted from, it's a reflection of, the hierarchical class organization of society in which these thinkers lived. The same thing happens in our day. The chemist, the physicist, the astronomer, looks out, beholds a new world, it's one fitting his time. It is no longer a hierarchical universe, it's a profoundly egalitarian one, so much so that a whole theory of relativity, that of Milne has been built around a so-called cosmological principal, the principal that any observer anywhere in the universe interprets data in exactly the same way as any other observer anywhere else, making equivalent correlations between data and instance at which data are taken. The physicist sees a restless world in which the parts are always in interaction. It is as it were, a class unbounded world, in which many old questions are meaningless and none are impious, in which each of a few laws, presumed to have the widest possible scope, and in which the man standing before the puzzle of nature, is

the master. There is an impious little story about Einstein which I hesitate to tell because it can be easily misunderstood. But it makes the point so beautifully that I also cannot resist telling it. And it goes like that.

In 1919, Einstein was sitting with one of his favorite students, Ilse Rosenthal-Schneider, in his study. They were studying a book, one of the many objecting to relativity theory. They were having great fun with it. In the middle, Einstein said, "Turn to the window sill. There is a telegram there which will amuse you." The telegram, signed by Eddington, said, "The eclipse expedition has just brought in the result. The prediction of general relativity has been fulfilled.

Congratulations." The student was very excited, and said, "Well at last here is that long awaited prediction." The eclipse expedition had previously been attempted in 1914 but that expedition failed because they were [interred?] by the Russians. War broke out before they got to the site. And here was a second chance. But Einstein was quite unmoved, curiously unmoved, and Rosenthal-Schneider asked him, "Well, aren't you excited about it?" "No," said Einstein, "I knew it had to be so." But Rosenthal-Schneider thought there is something else to be said about this and she said, "What, Herr Professor, would have happened if it had come out the other way? If the experiment had disproved your theory?" "Ah then," said Einstein quite seriously, "The dear Lord would have...I would very much have pitied the dear Lord. [German? phrase] Because the theory is right." Now Einstein was not an impious man, on the contrary. He was as pious a scientist as I know, short of Kepler. What he was saying, I think, was that it would have been very much of a bother to the Lord to so arrange this on that occasion to produce that kind of a result, it shouldn't have been necessary because the Lord and Einstein both knew this was a correct theory. Just as Kepler said, "As to mathematics, we know it's true ourselves as clearly as God knows it." Insofar as we can know anything in this modern life.

This return to a feeling that between us and nature there stands nothing, and when we speak to nature, nature speaks to us, we are in touch with the divine, insofar as in this modern life you can check on it at all. This is another thing that scientists never want to talk about, very embarrassed, will try to laugh it off, they do not believe it, they will tell you. And yet, this exhilaration at being at the root of things when you are right. Maybe not heuristically, the way you might put it into your papers, but this is it. That experience is one which I believe is very existential. Facing of the facts on their own, without any intermediary. This is a theme of our time, in which it comes out in science as clearly as in any other field. And this gives one the

courage to say something, even in the literature which might project some of our own emotions into it. Martin Deutsch, a nuclear physicist at MIT, confessed in an article on evidence and inference in nuclear research, "In my own work I've been puzzled by the striking degree to which an experiment, this preconceived image of the process which he is investigating determines the outcome of his observations. The image to which I refer is the symbolic, anthropomorphic representation of a basically inconceivable atomic process."

"I have never met a physicist, at least not an experimental physicist, who doesn't think of the hydrogen atom," says Martin Deutsch, "by evoking a visual image of what he would see if the particular atomic model on which he's working existed literally on a large scale, accessible to sense impression." At the same time, the physicist realized very well that in fact, the so called internal structure of the hydrogen atom is in principal inaccessible to direct sensory perception. The more sophisticated science becomes, the more striking is this paradox. Even the simplest observation in any advanced science involves a formidable array of operators and of theory. What you are looking at is practically swamped. The two years of work, the millions of dollars that may be spent, the huge amount of noise that has gone on and is going on finally yields a wiggle on an oscilloscope, too short to see but there is a photographic trace perhaps. That is the moment of success. Everything else is noise and this is signal. How could we ever detect it? We could only detect it if we had a [mazor?] as it were built in, a preloaded equipment which was sensitive to this, to this very [transient?] moment. If we as you do in the problem of detecting any weak noise in the presence of, weak signal in the presence of large noise, if we did not know what it is that is going to happen, down to many of the little details, that in a word, we really have built this together in order to see something which we have built into it. It is far from the conventional idea that the scientist keeps a completely open mind. The more carefully we peer at the faces of our meters, the more we see a reflection of our own faces and our blackboards. Even in the most up to date physical concepts, this anthropomorphic burden is very large. Particles still attract or repel one another, just as people do. They experience forces, they are captured, they escape, they live, they decay, circuits reject some signals, they accept others, and so forth. We are not forced by direct sense perception to use these images. We have developed this because it allows us to reason from one experiment to the next, by an analogy which has in fact worked out again and again, even though or rather because it has such an anthropomorphic content.

Let me give you a concrete example. I want to give this example because I believe that here we

have here a reason why [Kuerstler?] and others are so very wrong in thinking of modern science as depersonalized, cold, abstract, neutral, devoid of all personal concerns. I do this because I think that the young often are misled into thinking science is that cold, de-personal, computer-directed activity. If that were so, scientist wouldn't find their work full of that secret source of excitement which can be analyzed but only a little, but it can be shared. I believe that this is why we can understand the success, just as we can understand the success of Babylonian or Greek astronomy, to some extent because they projected family relationships even to the naming of their stars and their constellations. Let us look at what a physicist is likely to look at and see what I mean when I speak of anthropomorphic projection to make it possible to see anything. The next slide, please. At first looking at this slide, which is obtained by bubble chamber being photographed, a liquid at very low temperature, liquid hydrogen is being bombarded with a stream of pi minus particles, mesons coming in from the bottom of the picture, and a few of them go out at the top. One of them in particular come to a stop, you see. Just a little below the bottom. And then there is nothing except there is a "v" on one side rather broad like that cello, then there is another "v" higher up, a little narrower, like the violin, and in between there is nothing. Between here and there, and there. There are various ways of looking at such a picture. Which is what people look at or send to their computers to look at. Or hire graduate students to look at. And when a physicist describes in the language of physics what this is he will say the following. He will say, "a pion, an elementary particle, whose [track?] is pi minus is marked by bubbles set up as it plows through the liquid, comes at a certain point to a stop." And if you'll look at the next slide, we'll see how this now fades into a more abstract scenario in his mind. The pi minus that was selected has come to a stop and then it give rise, it decays into a couple of other particles, strange particles because they live unexpectedly long, their trace is long, it would have take 10 to the minues 10 seconds, a very long time by nuclear standards to get from the end of the [pi minart?] to the vertex of the two other "V"s, of the two "V"s. These are labeled "k zero" and "lambda zero" on the slide, these are the strange particles. They are neutral; they don't leave a track, until they decay. Then they decay and the product of each of these strange particles decays into one positive and one negative particle, and they thereby produce in our view field again these bubbles, a third generation of particles, each having its own characteristic lifetime, and each perhaps decaying in turn.

What is this story? Out of the physical review of letters? This is the lifecycle story of happenings in a village, perhaps up in the hills of Albania, and told by old and wise women, of life and death, of decay and regeneration, of strangers coming in and identifying themselves by curious long

range habits, but ultimately becoming civilized and giving rise to more normal offspring. Its a primordial type of grammar, of folk tale, acted out in space and time. It isn't forced on us by the data. Let's look again at the data on the previous slide. We could have told a very different story about it. We could have chosen to look at this as a whole, as a calligraphic design, the way a Chinese artist might have, the way our mom might have, without any space-time development at all. We could have looked for the meaning of the slide in terms of the structure of our perception. Rather than a story of an evolution and devolution, a story about birth and adventure and death. The physicist objects immediately and says, "That alternative is barren." Because you could not use conservation laws to tell you what these particles are doing. But that's just restating the problem. These conservation laws themselves have a time element in them. They always say, "Once upon a time this was the state, and it looked this way, and after a while, a long time later perhaps,  $10^{10}$  to the minus 10 seconds later, there was another state, and it looked different. But the two had something in common." Our conservation laws by and large have that folkloric element already built in, which is why we use it to analyze slides of this sort. We have here imported the anthropomorphic projection taken from the world folklore and from the human grammar, and that is what has made our slide here understandable, and that to some degree, I would conclude, is really why it remains of interest to us.

Let me turn off this slide machine, I'll just turn off this slide machine for a moment. I'll turn now at the end to a general remark that I hope that has come out of the speculative considerations of the way in which the state of affairs, the contemporary folklore, the belief external to science, the humanity with which we approach our problems, because they are still problems that [traced?] us before we became scientists, how these interact with the imagination of the scientist himself. That science is neither the prime mover, nor is it merely being moved by surroundings, but that it participates in the general intellectual climate. Perhaps these thoughts are of some use to those who have been struggling with this old question. From where do we get our explanatory principles in the first place, since they can't be found in logic alone? There is another even more important reason, I think, for recognizing the existence of general stylistic commitments built into scientific work. In this way, I think, we may hope to contribute a little to the understanding of a puzzling fact, that science for so long has been so successful and has remained so interesting. Without some support for the imagination coming from beyond the boundaries of science, without the help of all that is best and most human, that has been thought and felt before, including folklore, how could we hope that the brief attention which we can give to our scientific problems during this short life would ever yield anything worthwhile? If

at every turn, we had to construct science anew out of science alone, without the guidance of style and knowledge in the wider sense, how could we hope to capture as complex, this infinitely fascinating world, with our minds at all? Thank you.

[applause]

Jagdish Mehra: If there are any questions, Professor Holton will entertain them at this time.

[inaudible question]

Gerald Holton: Yes, alright. The most interesting things of course were right cleaned out? Neglected. The very thing which is most important, perhaps, on first glance. First there is in chemistry all these explosions and smoke and noise and smell. And danger. [inaudible] when you look at the equation. These are first simple electrons which are caught in a magnetic field and make their little spiral. [inaudible] nobody would even have mentioned them. In some ways, they are the prettiest things. The Chinese calligraphically working, would have paid a great deal of attention to them.

Jagdish Mehra: Any other questions? Yes.

audience member: Do you really want to do science without scientists?

Gerald Holton: Well if I knew how to [inaudible] I think I would have the philosopher's stone, wouldn't I. Then I could do science without them. And the president would be very happy, and scientists, I think, would be very happy, too, because then they could go back to something else that haunts them even more. But what I'm saying is that I don't know of an operational distinction between these two. Perhaps the reason why the anthropomorphic element is at the moment such an interest to me, it's precisely because science so often gets defined as though it weren't being done by scientists, and if computers are going to do it all themselves, which even rarer is an error, often, because somebody has certainly programmed them, or at least built

them or built the first generation that then kept on building other generations by itself and has in it still those human touches, those legs of lions that carry the heavy piano because at one time it was thought to be unsafe to make them non [anamythic?] and just a [tube?]. Those great heads of people that were fastened to the tops of locomotives in the early days for the [echtorp?] because if so much has to be exhausted it has to be done by a mouth of some sort. Well, we still do this in our theories. That's what makes science and scientists indistinguishable to me.

[inaudible question]

Gerald Holton: Many scientist would rise up in arms, immediately, at least in our department. In the eighteenth century would have done so. In the seventeenth century, they would have welcomed your invitation. It's the styles of the time. There may come a time when what you say would be completely commonplace. At the moment it is rather challenging and perhaps when I say I feel as you do to a large degree, many scientists in this world have a [inaudible]. What is involved [inaudible] in my feeling. The word religious is a very complex word in that sentence, which already has set up a dichotomy, which I think one can't get away from when one looks at people who are religious do, when one compares a priest, say with a chemist. I think the two are not working on essentially different things, but they are both working on a deeply humanly felt problem. And the distinction which are put in, they are often to keep the administration clean, so we know how to categorize one set of people compared to another set of people. But this does a disservice when we look at a creative person. That does not mean I believe religion and chemistry are the same thing, but rather that the reason why the religionist are so good when they're good, and why the chemist are so good when they're good is that they both work in different ways with their best in their human potential. And not just different types of potentials. They both use the same type of imagination. The reason for that is, on one hand we are so utterly unimaginative. I think we have about 50 ideas a piece, and that they are successful in doing so much with these few.

[inaudible question]

Gerald Holton: People want me to address myself a question of what you call bridging the gap

between scientists and the humanities, which is felt setting up such a gap and then trying to bridge it. Well, I won't set it up, I'll let you set it up and then when you have done so I shall try very hard to let you see that the fundamental themes which invade the scientists, conservation for example, conservation laws, are very close to themes which are the important thing in understanding other things outside science. In other words my game will be to prove that there is such a gap. I will certainly agree that there are different kinds of people, that some people are more likely to enjoy the theater than the Cambridge electronic accelerator. But I would also want to have you buy, these be the gap, the gap between on physicist and the next, which is almost as large or perhaps larger. When Lightman on one hand meets [inaudible] at the other, and reflect each other, they will have an entirely different view of what the world is about. They will have some experiences in common, enough that the intermediaries can negotiate between them. But when you really ask them, are you doing style or are you doing research in elementary particle physics, if you look for gaps, you'll find huge chasms there.

Jagdish Mehra: Thank you very much, Professor Holton. There will be a reception and some opportunity for discussion [inaudible]. I will request your presence, Dr. Driscoll, to make a few comments and close tonight's program.

Joseph Driscoll: Very few things will I say. Professor Holton's lecture this evening, a very excellent lecture it was, complete our [inaudible] at the end of our humanities series at SMTI for this year. Certainly, acknowledgements are due, first of all to the hard-working committee of the faculty and administration which has built this series over a couple of years, and is continuing to build it. Men such as, certainly I'm going to forget some of the names, but Dean Silva which has been with it from the beginning, Professor Dias, Dean Meed, Professor [inaudible], Mr. [inaudible], many others, in particular I think a vote of thanks is I think in order for Dr. Mehra who has worked very hard and very successfully in developing this series, and has developed [inaudible]. I want to thank also all the other members of the faculty, of the administration, [inaudible], the students who have contributed so much, the faculty activity committee, who has been so gracious and so kind, so rich in it's hospitality related to these [inaudible]. Particular thanks, I think, must go to [inaudible] to the principal of Dartmouth High School, and all of [inaudible], for their very fine role of host that they have played for SMTI [inaudible]. They have been good to us. And we hope that as opportunities develop and as our intellectual capacities

grow, we'll be able to return that hospitality [inaudible]. The years program has been very stimulating and I think by those of us who followed them, lecture by such [inaudible] persons as Oscar Handling, Margaret Mead, other activities [inaudible]. Looking ahead to a season next year will bring us people such as Jerome Weisner, Archibald MacLeish, [inaudible] the music of the Philadelphia Chamber [inaudible]. This series and activities like are going to gradually develop a strong, rich, fulfilling, rewarding cultural center here, in the town of Dartmouth, and specifically here at SMTI's campus. We do believe sincerely, honestly, humbly, that we will develop, in this area that is so rich in its history, a cultural renaissance which will make indeed at one time an intellectual and cultural [inaudible] in Massachusetts. Thank you all for your cooperation and congratulations to the members of the committee, and we look forward to next year's programs.