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NIELS BOHR AND THE INTEGRITY OF SCIENCE

by

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It is an honor to address this distinguished gathering on the topic "Niels Bohr and the Integrity of Science." Each half of this title identifies a large and timely subject in its own right. Each deserves to be the subject of a serious colloquium. But at this time, in the autumn of 1985, these two topics are strangely and fatefully being brought together by the forces of history. This will become clear by and by in what follows.

Let us first make at least the briefest sketch of Bohr's scientific work. It is commonly agreed that it may be divided roughly into four periods. During the first decade of his professional life, his main concern was with spectra, the absorption and emission of light, the structure of the periodic table, and the chemical properties of matter. During the second period, from the early twenties for about a decade, he was the leader of his Institute in Copenhagen, devoting himself to the increasingly full understanding of quantum mechanics, working with furious energy and surrounded by a remarkable group of young scientists from all over the world. This was the time of concern with the wave-particle puzzle, the uncertainty relation, complementarity, the discovery of the loss of visualizable physics, and the clarification of problems ranging from the structure of crystals and the metallic state to the chemical bond. By the late '20s, it seemed that in principle all properties of atoms and molecules were now calcuable, and understandable by the single force of electromagnetism.

In the third period, from the early '30s until the occupation by the Germans of Denmark in April 1940, Bohr and his collaborators worked on what came to be known as field quantization, elementary particle physics, and the structure of the atomic nucleus. After Niels Bohr's narrow escape from Denmark to Sweden, followed by his trip to England and then to the United States, his career entered a fourth phase, as he worked with the British scientists, and later at Los Alamos, in the huge effort to preempt the German attempt to make a nuclear weapon, on which the Germans had in fact embarked first. But at the same time Bohr also became more and more concerned with planning for the postwar world, including his tragically unsuccessful efforts to open the eyes of Roosevelt, of Churchill, and later of the United Nations' leadership to opportunities that may well have averted the nuclear arms race.

In his last twenty years, Bohr was chiefly occupied with applying the lessons of his science, not only to further research in physics but to all spheres of life, ranging from philosophy to international politics. He also devoted himself to the internationalization of scientific cooperation, as in the founding of Nordita and Cern, and in encouraging scientists in third world countries.

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It is almost too easy to let the mind jump from the image of Niels Bohr to the idea of the Integrity of Science. He is one of the few whose life and work we can hold up as a standard or model, alongside such 20th-century scientists as Einstein, James Franck, Max von Laue, P. W. Bridgman, Hans Bethe, and a few others. They all devoted themselves to the twin goals that give operational meaning to the phrase integrity of science, one being the obstinate search for truths that will lead us to a more coherent scientific picture of the world, and the other being the application of their God-given reason and intuitions to the job of making the world a saner place.

I see four principles of integrity of science that possessed Niels Bohr from the beginning of his career to the end, four principles that shade into each other, but can well be emulated in our time.

1. The first of these is simply this: Try to get it right, at all costs, sparing no effort. You may have to seek help and advice where possible; but then proceed with the courage of your conviction to prove to others that your scientific idea is correct. This principle of integrity of science in the narrowest interpretation of the phrase can nevertheless be very hard, and may even drive one to the edge of despair if one has selected a really worthy problem. I have been surprised how often the word "despair" comes up in the autobiographies and letters of some of our best scientists. Heisenberg once recalled his collaboration with Bohr in 1926 and '27, saying "We couldn't doubt that quantum mechanics was the correct scheme, but even then we didn't know how to talk about it. [These discussions left us] in a state of almost complete despair."

As those of us who had the fortune to meet and talk with Niels Bohr know very well, he was always in the middle of a struggle to understand and to communicate his understanding. I once asked him why he expressed himself in such a complex way when he spoke, complex even compared to his writings, and he answered, "I do not choose to speak more clearly than I think." Another time I asked Bohr to tell me why he had not remained with J. J. Thomson when Bohr came to Trinity College, Cambridge as a young man to work with Thomson--why he left after a few months, going on to Manchester where Rutherford was. And Bohr replied, "I had really little knowledge of English, and therefore when Thomson talked to me about his theories I could always only say, 'This is wrong.'"

Now think of this episode in its historic context. Bohr was then an unknown 26-year-old postdoctoral fellow; but he already knew that Thomson's ideas, based on classical 19th-century physics, did not work in what we would now call solid-state problems that had interested Bohr during his dissertation work. But there he was, a new arrival from Denmark, the guest of Sir John, that discoverer of the electron itself, a man more than twice his age, head of the Cavendish Laboratory, Nobel Prize 1906, knighted in 1908, and working on positive rays that would lead soon to the discovery of isotopes. Much later, in his last interviews shortly before his death, Bohr said that he regretted he had seemed so abrupt at that time, but he also quite properly added a point which showed where the real problem was: that Thomson was not really interested in hearing how some young man could make his electron theory "a little better." In this encounter it was Bohr who did, and Thomson who did not, obey the first principle, the imperative to try to get it right at all costs.

I said also that obedience to this norm can force one to take risks on behalf of a hard-won scientific idea before it is fashionable or safe. Again, Bohr's life and work contain many powerful illustrations. On arriving in Manchester, he soon saw that Rutherford's idea of a nuclear atom was right, and moreover that the atom "seemed to be regulated from the inner part to the outer by the quantum," as he put it in one of his last interviews. This became immediately the basis of Bohr's first great work. But think what it entailed at the time. We are speaking about early 1912. Rutherford's publication of his theory had come only half a year earlier. It was not being taken seriously at all at the time. Although Rutherford himself was at the first Solvay Congress, nobody mentioned his nucleus during that summit meeting of the major physicists of the day. It took a few more years, including Bohr's and Moseley's work, for scientists to catch on generally. But Bohr had staked everything on it at once, and on the quantum ideas of Planck and Einstein that also were only beginning to be accepted by physicists. The result was Bohr's paper of 1913. It has long ago made its way into all the school books, but the reception at the time was quite different. Otto Stern is reported to have said, "If this nonsense is correct, I will give up being a physicist." Bohr said later, "There was even a general consensus that it was a very sad thing that the literature about spectra should be contaminated by a paper of that kind." The risk young Bohr took in his 1913 paper could well have endangered his career. It was a physics very different from that of Newton, Maxwell, Planck, Thomson, and even Rutherford.

I have said that part of the first principle of integrity is that you must submit yourself to the dialogue with others to find out whether indeed you are right. New science starts in the head of an individual, but it does not survive if it does not become part of the consensus of the community. How well Bohr knew this! When his mentor Rutherford received Bohr's paper in manuscript, he agreed to send it on to be published despite Rutherford's own objections; but Rutherford added, "I suppose you have no objection to my using my judgment to cut out any matter I may consider unnecessary in your paper?"

Poor Rutherford! A considerably extended version of the earlier manuscript was already on its way to him, and soon thereafter appeared Niels Bohr himself, on a visit from Denmark where he had gone to establish himself. For many long evenings they discussed every point. Bohr reported that at the end, Rutherford declared he had not realized Bohr would prove so obstinate, but "he consented to leave all the old and new points in the final paper." Then Bohr went on to Göttingen and Munich, and succeeded in bringing the older, skeptical physicists around.

That Einstein never gave in was to Bohr a source of real unhappiness. Indeed, very few others escaped Bohr's persuasiveness. Bohr's collaborators such as Leon Rosenfeld were overawed by Bohr's unrelenting effort to attain clarity of fundamentals. But Bohr's favorite quotation was from Friedrich Schiller: "Only fullness leads to clarity/And truth lies in the abyss." To gain the real treasures one must be ready to descend into the abyss, that dangerous place at the bottom where two huge slopes push against each other. Imposing such heroic work on oneself, and emerging victorious--that is truly honor in science.

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I have already begun to move into the second of the principles. It concerns the difference between choosing the narrowly specialized problems, relatively safe but at the cost of the fragmenting and disintegrating tendency for the subject, versus choosing the more difficult problem that has some promise to bring coherence to the field, and with it integrity in the second sense of that word. To put it succinctly, the second principle might run as follows: Try to be a scientist first, a specialist second. If you have it in you to make more than individual bricks that others might use, throw your life's energies into work on what Einstein called the great temple of science.

Again, Niels Bohr can give us all the examples we need, even in his 1913 paper where he introduced the correspondence principle in its early form precisely in order to connect quantum physics with classical physics in the limit of large orbits. It is a powerful bridge which Bohr used to great advantage for years, for example for the theory of stopping fast-moving particles in matter, in his 1948 survey. Similarly, he dealt with the puzzle of light and matter for over two decades, trying ways of reconciling in each of these the discontinuity shown by quantum effects with the continuity shown in classical experimentation.

Dealing with science in a coherent way also led him to think about scientific fields far beyond physics, in a manner that few had dared to do since the days of Helmholtz and Ernst Mach. He struggled constantly with "the epistemological lesson which the modern development of atomic physics has given us, and its relevance for [the other] fields of human knowledge." One chief lesson of quantum mechanics was that atomic processes did not have to be described in fragmentary ways, with different theories for different effects, but that through quantum mechanics we could see the wholeness of the processes in atoms.

Could this lesson not be applied to wider fields? Bohr thought Yes, it could. Therefore his essays dealt often with"biological and anthropological problems," stressing the features of wholeness presented by living organisims and human cultures--at least insofar as such "problems present themselves against the background of the general lesson of atomic physics."

To some extent, Bohr's pursuit of the second principle was part of the old hope of the "unity of all sciences," a phrase he often used. But it is not merely a phrase, or an empty dream. That science is one organic, interlocked picture of the world shows up in almost any substantial scientific research today. A modern paper on cosmology is really a jigsaw puzzle of which the pieces might well carry such labels as "elementary particle physics," "general relativity," "applied mathematics," and "observational astronomy." An experiment in neurophysiology brings together physics, chemistry. biology, computer technology and engineering, all at once. Such examples are becoming the rule. As Bronowski wrote, "Science is not a set of facts, but a way of giving order and therefore giving unity and intelligibility to the facts of nature."

If Bohr himself did not work directly in fields outside the physical sciences, he did persuade some of his younger collaborators. A major example of course is Max Delbruck, who gladly confessed that the prime motivation for his own early work in biology was "Niels Bohr's suggestion of the complementarity principle in biology as a counterpart to the complementarity principle in physics."

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As we come to the third principle exemplified in Bohr's life and work, the area of action, opportunity, and obligation for the responsible scientist widens still further, and so does the challenge to follow Bohr's example. Both the findings of modern science, and its "habit of truth to experience" have penetrated deeply into the world of culture as a whole. The third principle of integrity in science might go like this: "Science is, and must be, part of the total world view of our time. This is a vision you should imaginatively explore, defend, and contribute to."

There are various ways of implementing such a vision, and Niels Bohr was active in each of them. There is of course the task of pedagogy, the need to bring scientific understanding to all parts of society, not least because persons living in this modern world who do not know the basic facts that determine their very existence, functioning and surroundings are living in a dream world. Such persons are, in a very real sense, not sane.

Then there is the link of science and policy. If that link is not understood, if the technical implications for good and ill are not made clear, democracy is at risk because the leadership can be caught up in fantasies--whether technocratic or Luddite--and the citizenry cannot participate in the basic decisions that have technical components.

But for Bohr, the third principle asserted itself also in an almost compulsive pursuit, during the last 20 years of his life, to find bridges between scientific knowledge and such nonscientific fields as ethics, the arts, and philosophy. We know that Niels Bohr was interested in philosophy from early youth on. A biographer of Bohr records that "As a young student, fired with the ideas his philosophy professor Høffding was opening to him, Bohr had dreamt of 'great interrelationships' between all areas of knowledge. He had even considered writing a book on the theory of knowledge." This ambition eventually took a different and grander form, based chiefly on the complementarity principle of 1927. There are various statements of it. Niels Bohr's own briefest formulation goes like this: "Any given application of classical concepts precludes the simultaneous use of other classical concepts which, in a different connection, are equally necessary for the elucidation of the phenomena." The issue behind all this, as Oppenheimer and many others have stressed, concerns the three great overlapping questions: What is objectivity? What is reality? Is the world deterministic or not? For classical physics, it was possible to say that the world was deterministic in the sense that if the position and momenta of all objects were measured, the future course of all history would be known. But, Bohr asked, would this be true on the atomic scale? Could <u>that</u> world be known more and more certainly, independent of our own predelections, our decisions, our laboratory arrangements? As we know, about 60 years ago Bohr and Heisenberg and others of that circle gave a resounding "No" to that question. Objective knowledge of a phenomenon, in Bohr's terms, is what you learn from the full reports of the experimental arrangements that probe into the phenomenon--arrangements, be it noted, of apparatus on the scale of everyday life, and describable in ordinary human language (with mathematics merely a compact and refined extension of it). There is no firm boundary between that which is observed and the observing machinery, but a movable one, and the different descriptions that result from different placements of the boundary are complementary. Together they give an exhaustive account of whatever one means by reality. Objectivity, according to the Copenhagen School, is therefore, as Robert Oppenheimer pointed out, not an "ontological attribute," i.e., a description of the property of being, but becomes a problem of communication.

I have written elsewhere on the roots of the Bohr Complementarity Principle, and on his hope to extend complementarity beyond physics, in dealing with such opposing concepts or mutually exclusive experiences as thought and introspection, justice and charity, the processes in the living cell and the biophysical, biochemical analysis of organisms. By holding up his ambitious attempt for examination, I am of course not proposing that Niels Bohr's own solution to meet the obligation of the third principle of integrity be universally adopted. Rather, I am illustrating the challenge which genius sets for itself. We, in our more humble ways, should also do what we can, or we shall be pushed out of the common culture. The lab remains our workplace, but it must not become our hiding place.

We all know that the full grandeur of Bohr's ambition was to apply the complementarity point of view also to the understanding and toleration of differences between traditional cultural systems. What gave it all such urgency for him was of course his perception that the traditional method of conflict between societies was the attempt by one to annihilate the other, and that in the atomic age this method was a guarantee for universal catastrophy, for mutual suicide. As Bohr put it, the main obstacle to a peaceful relation between various human societies is "...the deep-rooted differences of the traditional backgrounds...which exclude any simple comparison [or accommodation] between such cultures. It is above all in this connection that the viewpoint of complementarity offers itself as a means of copingwith the situation."

He never gave up the hope that this could be achieved, though he knew it would not be done soon. On the day before his death, in his last interview, he said, "There is no philosopher who really understands what one means by the complementarity description. It has to go [into] the schools." The Copernican system was, for a long time, not accepted by the philosophers. But eventually "the school children didn't think it was so bad. [This is how it got into] common knowledge. I think it will be exactly the same with the complementarity description."

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With this I have come to the fourth, the last and most demanding of the principles of integrity, the special obligation scientists have to exercise sound citizenship, each in his or her own way. There are many reasons why the obligation is special. The most obvious one is simply this: Having been helped to become scientists and to live as scientists in this suffering world, we are the beneficiary of unusual privilege, of scarce resources, and of the painful labors of our scientific parents. The mechanics we learned in school came to birth in the anguish of Galileo, dictating his book in his old age, blind and under house arrest. Kepler died on a highway like a dog on one of his futile journeys to find the money to pay for printing the books from which we later learned about his laws. Indeed, many of the formulas we rely on every day were distilled from the blood and sweat of our distant forbears, most of them now forgotten. We stand not only on the shoulders of a few giants, but also on the graves of thousands.

Science by its very nature is a cumulative, consensual activity, a social activity across space and time. In addition, any new scientific finding has the potential of changing, sooner or later, some part of the life of mankind, and not in every case for the better. Under these circumstances, one must conclude that science has a just claim to moral authority when and only when it is widely seen to honor both truth and the public interest. By this I do not mean that each and every individual scientist must be active beyond science as were Bohr and Einstein; nor do I mean that the necessary funds should not be spent on the next big colliders and other instruments on which the future development of the sciences will depend. But I do mean that when we look over the profession as a whole, we must be able to say that our group, through the activities of enough of its members, is responding to its special responsibilities--special for all the reasons I have given, but also because on certain issues our scientific knowledge does give us an opportunity to make essential policy suggestions. And special too, some may wish to add, simply because the flow of so much good brain power into science and technology today may have caused a deficit or opportunity cost in the rest of the polity.

Here, again Niels Bohr is an exemplar of the good citizen within the republic of science. This came through in so many ways, earliest perhaps by his openness to and encouragement of new young talent, no matter from where it came. But among the many illustrations we must finally select the example he gave us through his dedication to oppose and control the arms race.

More than most others, Bohr thought of the atomic bomb not only as decisive in countering any such German effort. But as his memoranda to President Roosevelt, and later his letter to the United Nations show, Bohr also thought of such weapons as ending at last the <u>tolerability</u> of war. Thus he wrote, "The expectations for a future harmonious international cooperation...remarkably correspond to the unique opportunities which...have been created by the advancement of science." For this to happen, as he saw very clearly one had to preempt a nuclear arms race after World War II. To achieve that, in turn, meant capturing the energies of all the world's scientists as well as of the atom itself, for peaceful purposes. And that inevitably meant we would need an "open world," for the verification of arms control agreements, for sharing technical information for peaceful uses, and also for sharing more in one another's cultures.

The main stumbling block, he knew well, would be dealing properly with the Soviet Union. Often invaded, and again deeply ravaged by the war, its citizens viewed themselves as a great nation, beleaguered but not to be coerced. To avoid a fatal increase in hostility and suspiciousness on their part, Niels Bohr argued again and again in 1944 and early 1945 that one would have to bring them in before the end of the war, while they were still allies, to reach an understanding of the world's common interests, including the industrial uses of atomic energy, based on concessions on each side. Bohr saw a unique opportunity <u>before</u> the full development and deployment of a new weapons system, an opportunity in which historically-based rivalries and contrary traditions could be submerged and their negative potential diffused. He urged also that scientists of different countries, used to international collaboration and having bonds across national frontiers, could prove especially helpful with the deliberations of the respective governments. Finally, he hoped that the world's political leadership would contain sufficiently many statesmen to whom scientists could speak on such matters and who would understand them.

We know of course how very differently it all came out. In early 1944 Churchill and, at his urging, Roosevelt agreed that the Soviet leadership be faced with a fait accompli of the atomic bomb development. Thereby they were betting that secrecy was really working, and that any Soviet buildup of a similar system later on would be slow. Neither turned out to be true. Incidentally, they also agreed that Bohr should be carefully watched. If it had been up to Churchill alone, Bohr would probably have been interned.

Scholars will debate for years whether a break through the fears on both sides, and particularly a break through the alienation of Stalin and his circle, could have resulted from the vision of a harmonious and progressive world which Niels Bohr urged. With his usual eloquence, Robert Oppenheimer summed up the hopeful view on it in his Pegram Lectures in 1963, in these words: "I think that if we had acted wisely and clearly and discreetly, in accordance with Bohr's views we might have been freed of our rather sleezy sense of omnipotence, and our delusions about the effectiveness of secrecy, and turned our society toward a healthier vision of a future worth living for."

These words should remind us how strangely and fatefully the world has come around again this season to a moment in history that has many analogies between the situations then and now. And once more, as Niels Bohr and others have shown at analogous points, the moral authority of scientists as citizens will be tested by the seriousness, courage, and eloquence with which they inform the debate.

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With these four principles in mind, when our students and colleagues inquire about integrity in science, let us tell them of Bohr. Let us tell them that integrity is not achieved merely through fear of sanctions against dishonor, but must be earned through positive acts, acts motivated by some understanding of the grand history of our science, and of our privileged place in it: motivated by the scope and beauty and seriousness of our quest as scientists: motivated by the growing hope that science will lead to a coherent world picture; and not least motivated by our responsibilities, as scientist-citizens, to the larger society that has nourished us, the society in which we must live, or with which we shall perish.