Séminaire Poincaré

# Keeping Things Open

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**Abstract.** This year we are celebrating the 100th anniversary of the papers by Niels Bohr introducing the atomic model that dominated 20th century physics. Niels Bohr himself remained an influential participant in the development for almost 50 years and his institute became a magnet for young researchers and an important center for the development of modern physics. From both a personal and a scientific perspective - being both a grandson of Niels Bohr and a physicist - I shall try to assess some of the characteristics of Bohr's personality and his approach to science that made this possible.

Figure 1: Painting by Bolatta Silis-Høegh, comissioned by the "Experimentarium" in Copenhagen for Niels Bohr's 125th birthday in 2010.

## 1 Introduction

What was it that made Niels Bohr such a fascinating personality, one that could attract a whole generation of the most original young scientists and create a nerve center for the development of the physics, which revolutionized the 20th century? In that same period, there were physicists with greater mathematical skills or with greater experimental flair, but something singled him out as someone quite unique, who fascinated and attracted a great many people from pupils and colleagues to politicians - all the way up to president Roosevelt himself.

As Niels Bohrs grandchild, I myself have naturally experienced this fascination, the pleasure and the joy of being with him. It was inspiring to experience him, to be caught up by his warm and embracing personality and his wealth of paradoxical puzzles and stories, both fun and subtle. The mystical symbols that he and my father wrote and discussed on the blackboard were strangely captivating, as coming from a secret and safe world, to which one might some day gain entrance.

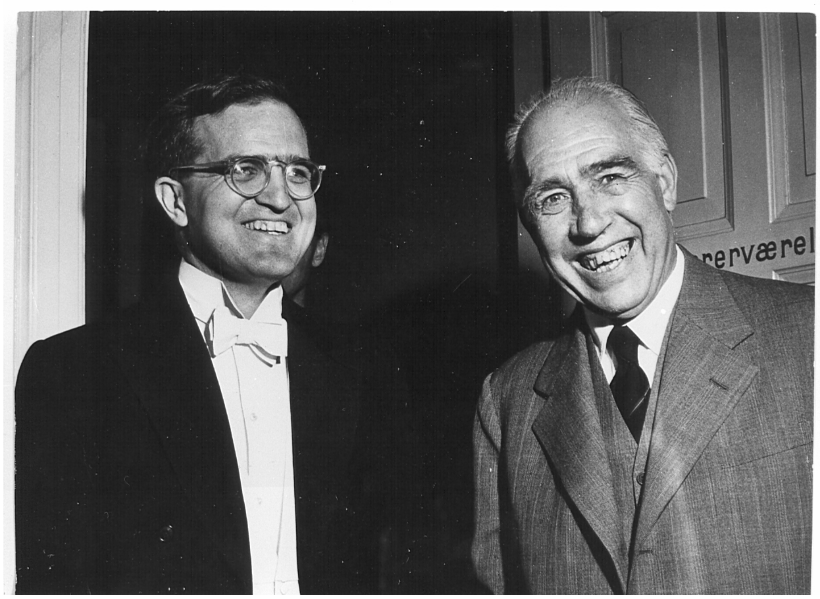
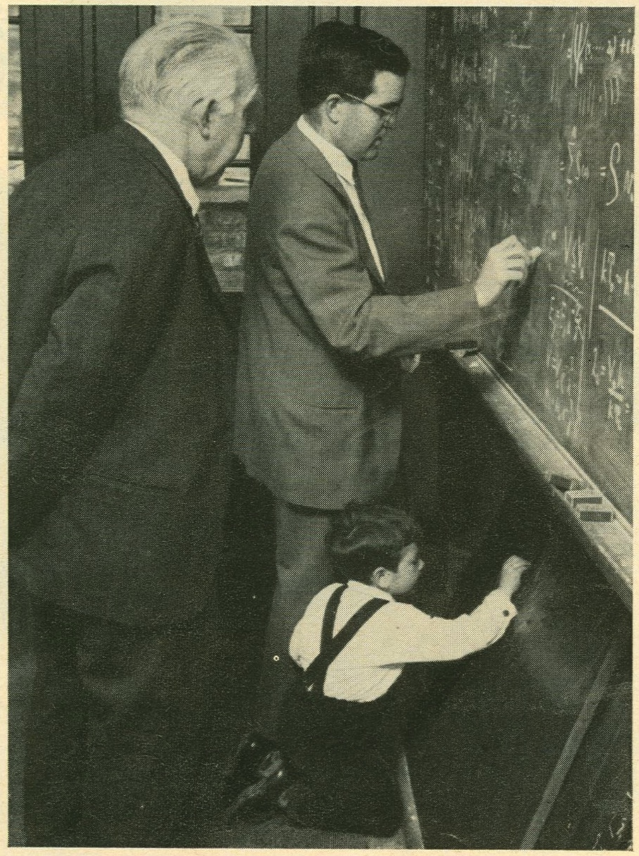



Figure 2: My father and my grandfather.

In later years, I have thought a good deal about what it was that made him so special. I have tried to collect some of these thoughts below. In this regard it has naturally been a great inspiration to discuss with my father, Aage Bohr, with my siblings Paula and Vilhelm, with my cousins, and many others, especially Jørgen Kalckar, Bram Pais and Finn Aaserud.

## 2 Courage

Niels Bohr had the courage and the abilities needed to throw himself into the most burning issues of physics of the time. He was good at identifying these problems and to confront them with a suitable mixture of, on one hand, fundamental principles, and on the other hand more pragmatic, intuitive ideas. He describes this mixture



In a blackboard-lined study at home, Bohr watches son Aage write out a calculation while grandson Tomas creeps in unnoticed.

Figure 3: With my father and my grandfather. From Life Magazine around 1958.

very beautifully in his speech at the banquet after the reception of the Nobel prize in 1922 [1]: *When the great experimental discoveries around the turn of the century, in which investigators from many countries took such a prominent part, gave us an unsuspected insight into the constitution of atoms, we owe this above all to the great researchers of the English school, Sir Joseph Thomson and Sir Ernest Rutherford, who have inscribed their names in the history of science as shining examples of how imagination and acute insight are capable of looking through the multiplicity of experiences and laying bare to our eyes the simplicity of nature. On the other hand, abstract thought, which has always been one of mankinds most powerful aids in lifting the veil that conceals the laws of nature to the immediate observer, has been of decisive significance for applying the insight gained into atomic structure to explain the properties of the elements directly accessible to our senses. Also in this work, men of many nations have made important contributions; but it was the great German scientists, Planck and Einstein, who, through their abstract and systematic studies, first taught us that the laws holding for the motion of atomic particles, which govern the properties of the elements, are of an essentially different nature than the laws by which science hitherto had attempted to order our observations of the phenomena of nature. That it has been my undeserved good fortune to be a connecting link at a stage* *in this development is only one piece of evidence among many of the fruitfulness, in the world of science, of the closest possible intercommunication of research work developing under different human conditions.*

This is of course a speech for a festive occasion and thus, perhaps, a bit more elaborate than usual, but I still think that he manages to touch on some central issues. He clearly contrasts the English experimental school ("the art of experimentation" - *eksperimentérkunst* in Danish - as he liked to say), where one plunges into rather unprejudiced, direct studies of nature, with the more abstract and systematic German school. Elsewhere, he describes the English physicists as dilettantes, a term that he also used about his own approach to science. The word *dilettante* comes, after all, from the Italian *dilettare*: to delight or amuse, and the joy of nature and the fresh approach to the study of it - without too much erudition - was important to him. He places himself as a connecting link between these two schools. He wants to base his science on fundamental principles, but if an issue is sufficiently important one must take it up and *do something* even though one may not yet know the ultimate principles.

We see here also another important feature of Niels Bohr's approach to science. He believes that science is a truly global issue. I think he perceived the scientific community as a kind of global family, where each nation with its own distinctive character can contribute to progress in its own unique way. And which, incidentally, could actually be used as a model for a more peaceful world. It is also interesting that he has, both during his lifetime and after his death, been a very popular and respected figure in the UK, Germany, Sweden, Russia, USA, China and Japan, to all of whom he felt a special relationship while they each saw him as one of their own.

When Niels Bohr wrote his 1913 trilogy, he was acutely aware of the radical nature of his ideas and the huge difficulties to be expected in unifying them with the principles that had hitherto been so successful as the basis of theoretical physics. He presented his new vision in terms of two "postulates" [2]. The first one basically says that atomic systems possess a number of stationary states, which are dynamically stable despite being explicitly unstable by "ordinary mechanics". In these states the atom is invisible even though the electron is orbiting the nucleus at a high frequency. The atom only makes itself seen to the outside world when the electron jumps from one such state to another while emitting or absorbing light; and the second postulate states that the frequency of this light is not related in any simple way to the orbiting frequency of the electron, but to the difference between the energy of the initial and final states of the jump.

Perhaps this sounds, to us today, as reasonable assumptions, but if one thinks it over more carefully, one realizes that they preclude any "mechanistic" description of the process by which the electron orbits the nucleus or makes its jumps from one stationary orbit to another. That is, we cannot in detail follow the electron in a well-defined path around the nucleus, since this would immediately lead to the emission of electromagnetic radiation (i.e., light) along the way, with a frequency closely related to that of the electron in its orbit. Moreover the new rules also seem at odds with one of the most cherished principles of physics: *causality* - which expresses that everything has a "cause" and nothing can occur before its cause. This was formulated very pictorially by Rutherford in his initial reaction to the paper, when Bohr submitted it to him in the spring of 1913. After expressing his satisfaction with the new results obtained by Bohr, he wrote [3]: *There appears to me one grave difficulty in your hypothesis, which I have no doubt you fully realise, namely, how does an electron decide what frequency it is going to vibrate at when it passes from one stationary state to another? It seems to me that you would have to assume that the electron knows beforehand when it is going to stop.*

He was right: Bohr *did* fully realize this problem, but apparently, he was prepared for such a radical departure from classical mechanics - actually more like a jump into the abyss. Even after quantum mechanics was invented in 1925-26 it has remained a mystery how nature can behave so strangely, although we now know the rules for computation. In quantum mechanics, the wave function only determines the probability for a given outcome, and the standard assumption (often called the *Copenhagen Interpretation*) is that this is all that we can predict, and thus that randomness, probability and fortuitousness are ingrained in nature.

## 3 Philosophical outlook

Niels Bohr had a strong philosophy of life. For him, life made up a connected whole, and this allowed him intuitively to understand new scientific contexts, to consider political and human problems, and to keep going strong when facing adversity, scientific as well as human. The worst tragedy that hit him was undoubtedly the loss of his oldest son, Christian, who drowned on a sailing trip with Niels and his friends in 1934. Christian had planned a bicycle trip in Germany with his friend, the later painter Mogens Andersen, but Niels Bohr thought that Germany with Hitler at the helm was too unsafe for a bicycling trip for two young students (in particular for Christian whose father was known as an outspoken opponent of the Nazis) and in stead he brought Christian along sailing in Øresund, the sound between Denmark and Sweden. They came into bad weather near Varberg in Sweden, where unfortunately Christian fell overboard, and despite being a good swimmer he disappeared in the waves. This was a terrible tragedy for the whole family, but they succeeded in getting through it together. Niels Bohr was very moved by the warm expressions from Christian's young friends and he wrote a beautiful little piece "At the departure from home" [4], where he ends by saying that *each of us probably lives his strongest life in the thoughts of his fellow human beings.* For me that is a good thought.

Heisenberg believed that Niels Bohr was basically more a philosopher than a physicist [5]. And through discussions with Heisenberg, Pauli and, in particular, with Einstein he fought tirelessly to understand the overarching picture emerging from the new scientific discoveries in the quantum world. The duality between waves and particles occupied him long before quantum mechanics was developed. He knew intuitively that it would be impossible to unite the strange properties of light within the realm of classical physics. Already in 1920 - 5 years before quantum mechanics - he discussed this with Einstein, who, although he was the originator of the photon concept, did not look at it like that. Jokingly, he asked Einstein, whether he would advocate a German ban on photocells, where light, contrary to classical electromagnetic wave theory, behaves like a particle. He had a wonderful ability to formulate striking paradoxical observations, supplying an unexpected new perspective. As an example he would ask: "What is it that makes ghosts so scary?", and he would answer: "It is the fact that we don't believe in them!"

Some of his papers, in particular from his mature years, are almost devoid of

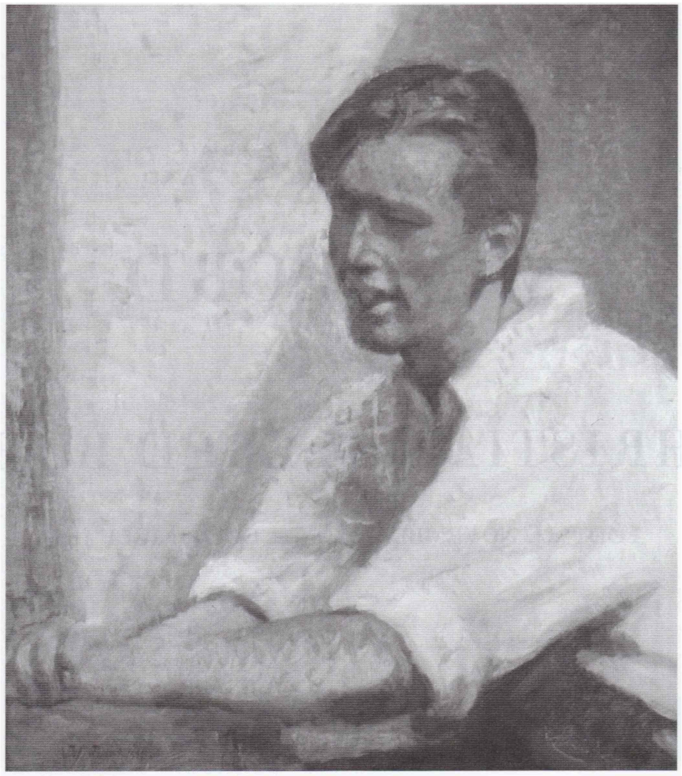


Figure 4: Niels Bohr's eldest son, who drowned shortly after his 19th birthday on a sailing trip with his father and his friends. Painting by Julius Paulsen.

mathematical formulas and their aim is to expound a new viewpoint or angle of attack on a scientific problem. A good example is his paper on the "compound" nucleus [6] - an atomic nucleus excited by an incoming projectile, such as a neutron. Viki Weisskopf (a frequent guest in Copenhagen) wrote [7]: *Rarely has a single paper dominated a field of physics as has Bohr's address to the Copenhagen Academy in 1936, in which he proposed the idea of a compound nucleus. During the 18 years since its appearance, it has been the decisive influence on the analysis of nuclear reactions.* This paper did not contain a single formula. On the other hand, it did (in an additional note) contain the picture shown in figure 6 - a rather original way of perceiving an atomic nucleus: as a collection of billard balls! He was the first to realize that the nucleus is a complex many-particle system, a tightly packed swarm of particles that self-organize, in contrast to an atom, where the central nucleus provides the guiding force. This implies that the time it takes for the nucleus to respond to, say, an impinging neutron, is much longer than the time needed for the neutron to move unimpeded through the nucleus. The neutron will quickly share its energy through impacts with the other particles, leaving the nucleus in a "heated" state, the compound nucleus, which will only gradually cool down by emitting radiation or particles, a sequence of events that has no direct connection to the incoming neutron, which in the meantime has disappeared in the crowd. He further understood that some of the lowest energy states in such a system are collective degrees of freedom like surface oscillations on a liquid drop.

Niels Bohr coined a useful new expression, the "deep truth". Usually, the oppo-

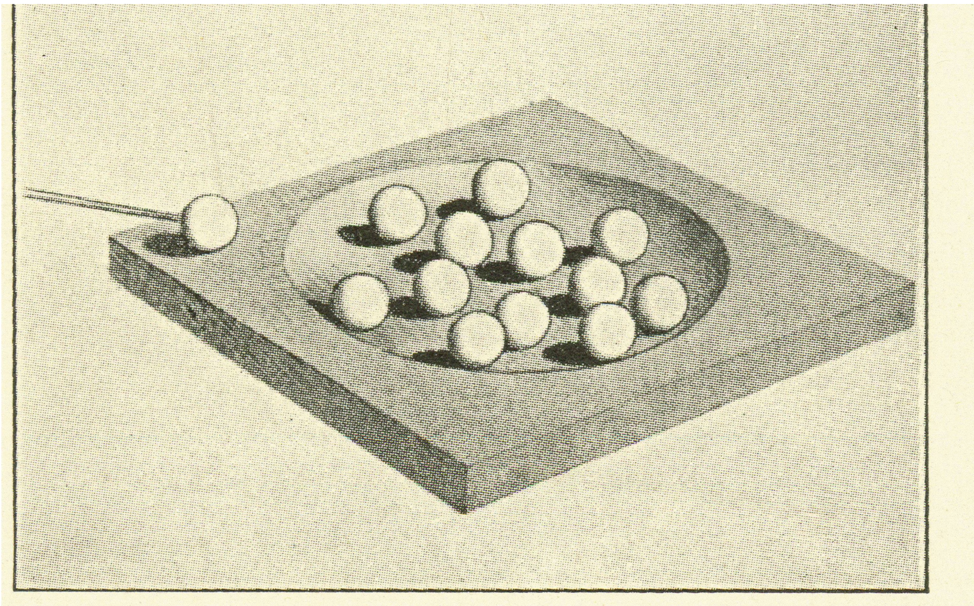


Figure 5: The atomic nucleus as a game of billiards (from [6]).

site of something true is simply something wrong, but for a deep truth the opposite is also a deep truth. And both aspects need to be included for a complete description. The statement "You should express yourself as clearly as possible" sounds very sensible, but the opposite: "You should *not* express yourself as clearly as possible" can also be sensible. For Niels Bohr "truth" and "clarity" were complementary terms: striving for too much for clarity leads to over-simplification, thereby compromising the complicated truth.

## 4 The art of being wrong

In a stimulating research environment, ideas float freely and exciting discussions can lead to important new results. This requires that the subject under discussion is more important than the people involved, so that exactly *who* gets the ideas and *who* is right or wrong becomes secondary. Niels Bohr liked to participate in these discussions - also in literature - and was wrong on several important occasions. One case was when he was more inclined to doubt the conservation of energy than to accept the existence of a new particle (the later neutrino) as predicted by Pauli. However, the fact that he had been wrong (which he quickly admitted when sufficient evidence was presented) never affected him.

Otto Robert Frisch describes the atmosphere at the Institute in the following way [8]: *From time to time there was alarming news of some experimental result which appeared to contradict what we knew. Such a contradiction was an enemy immediately to be attacked, against which Niels Bohr turned the full power of his mind. Sometimes it turned out that the experiment had simply been wrong, and everybody was relieved. But on other occasions Niels Bohr would tell us with even greater delight that it was he who had made a mistake, that the inconsistency disappeared when one had found the right way to think about it. He never hesitated for one moment* *to admit that he had been in error. To him it merely meant that he now understood things better, and what could have made him happier?*

In fact, he perhaps believed that the only way to learn is by making errors. Thus he would ask: *What is an "expert"?* Most of us would say that it is one who has absorbed all the world's knowledge in a certain field. Niels Bohr's formulation was [9]: *An expert is one who, from personal, painful experience, knows a little bit about the most serious mistakes that can be committed even within the smallest area.* Another good example is his reaction to Sommerfeld's work in 1916. Sommerfeld showed, perhaps not that Niels Bohr was wrong, but at least that the quantization of the hydrogen orbits led to an additional quantum number and a whole new family of orbits, not found by Bohr. This reached Bohr while he had just submitted a long work on these issues, a paper that was withdrawn, and only came out in 1918 [10]. In a letter to Sommerfeld 1916, written from Manchester, March 19, 1916 - in the middle of the first world war - he writes [11]:

*Dear Prof. Sommerfeld,*

*I thank you very much for your most interesting and beautiful papers. I do not think that I have ever enjoyed the reading of anything more than I enjoyed the study of them, and I need not to say that not only I but everybody here has taken the greatest interests in your important results.*
*...*
*The intention of writing all this is only to tell you how exceedingly glad I was to receive your papers before my papers were published. I decided at once to postpone the publication and to consider it all again in view of all, for which your papers have opened my eyes.*
*...*

*I do not know how to express, how I wish the present terribly sad state of the world may change soon. I am hoping very much to meet you soon again and send the kindest regards to you and all the other physicists in your laboratory not only from myself but from all here.*
*Yours very sincerely*
*N. Bohr.*

## 5 Raw power

Niels Bohr had a huge raw power. He was physically strong and tough. He went on long walks across Zealand, and could concentrate for days on complicated papers or calculations. In the summer of 1922, a few months before he won the Nobel Prize, he held in Göttingen within 10 days in June, 7 lectures (so-called *Bohr-Festspiele*), where he presented the entire quantum theory. Quite a physical performance - in all ways. Among the audience were the young students Werner Heisenberg and Wolfgang Pauli, who were fascinated by Niels Bohr's personality and lecture style where the open problems were constantly highlighted, instead of, as many contemporaries, highlighting the beautiful theoretical construction. He had this strength from childhood and in this connection it is interesting to read what his old schoolmate Aage Berleme (who helped collecting private funds for starting the Niels Bohr Institute


Figure 6: For the Danish cartoonist Bo Bojesen, Niels Bohr was a favorite victim. From the newspaper *Politiken* in 1958.

and whom my father, Aage, is named after) says [12]: *It sounds like a paradox, but during all the years when Niels was a small boy, I actually remember him as a very big boy. He was large of body, rather roughly hewn and strong like a bear, while I was the youngest in the class and a skinny little kid. In those years, Niels was certainly not afraid of using his strength and was always involved, when there was a fight. Fights were, then, very common during the school-breaks, and even took place outside the school at Skt. Ann square. I don't know what we were fighting about at that time, but Niels acquired a reputation as a strong boy, one can say a violent boy, since, during his entire childhood, he had problems judging the range of his actions, and probably many of the "bloody noses" he handed out were not intentional. He has beaten me numerous times.*

I once asked my father, whether my grandfather was actually modest. After thinking for a long time he answered that regarding his own contributions he was very modest, but if he had an idea or a point he wanted to make, he could keep on incessantly, often until the counterpart was on the verge of collapse. A well-know story in this connection is Schrödinger's visit in 1926. Schrödinger was invited to Copenhagen to tell about his new wave mechanics. He stayed with the Bohr's at the Institute, but became ill after the lecture - probably because of all the tiring discussions - and had to stay in bed. That did not, however, help him much because Bohr unrelentingly kept on the discussions at the bedside. They never quite agreed. Schrödinger believed that his wave function actually described the charge density of a particle, e.g., an electron, whereas Bohr maintained that the measurement of an electron always shows that it is localized, and thus that the wave function only can have a statistical significance. Heisenberg, who was present, and told the story, writes [5]: *... For though Bohr was an unusually considerate and obliging person, he was able in such a discussion, which concerned epistemological problems, which he considered to be of vital importance, to insist fanatically and with almost terrifying relentlessness on complete clarity in all arguments.*

This raw power was also at the base of his enormous written output. His "Collected Works" are available in a beautiful 12 volume edition [13], and testifies to both hard work and an unusually broad scope. In addition to the printed papers these well-edited volumes contain excellent introductions (among others by the chief editor Finn Aaserud) and a good selection of drafts and correspondence, which makes them very interesting reading.

## 6 Ability to think concretely

Niels Bohr is of course best known as a theorist, but in his early work on surface tension, he performed careful experiments on his own and e.g., learned how to blow glass to get the right equipment. The close relation to the experiments lasted all his life. When he got his own "Institute for Theoretical Physics" the basement was filled with experiments, and although he rarely made measurements himself, he maintained an exceptional ability to assess and interpret experimental data. Such data is always subject to a degree of uncertainty, and to the interpretation made by the experimentalist, which is not necessarily correct. Niels Bohr's work is filled with examples of how he has reinterpreted data in a very fruitful way. A famous example is found in the first paper in his famous "trilogy" from April 1913 [2]. Here he re-interpreted the so-called "Pickering Lines" - a series of spectral lines which were attributed to hydrogen, although they had half-integer quantum numbers - as helium lines. Despite the fact that they had not, at that time, been seen in helium, whereas the had been seen in hydrogen-helium mixtures! That led to harsh criticism from the spectroscopists but ended in October 1913 [14] as a great triumph of his theory, partly because new experiments showed that it was lines of ionized helium, partly because he succeeded, by taking into account that the nucleus is not infinitely heavier than the electron and that one therefore must use the "reduced mass" of the electron, in calculating the correction for the Rydberg constant of helium to 4 decimal places! Likewise, he reinterpreted, in 1914, Frank and Hertz's experiments in which electrons are sent through a gas. When the electrons move below a certain speed, they are not slowed down by the atoms in the gas, and Frank and Hertz explained this by postulating that they do not have enough energy to ionize the atoms. Niels Bohr found, however, by looking at their data, that they were far from the ionization energy, and that the lack of energy transfer occurred because electrons were not able to excite the atom to a new stationary state - in fine agreement with his theory. Yet another example is his entry into nuclear physics, the introduction of the compound nucleus, as described above. Here he faced an incomprehensible jumble of nuclear resonances obtained from neutron scattering, and his main contribution was perhaps to point out that, instead of trying to understand every single resonance in detail, it would be more fruitful to try to understand why they form such a complex tangle!

These abilities probably had to do with his well-developed practical sense and great interest in how things work. As a child he was known as being able to split a

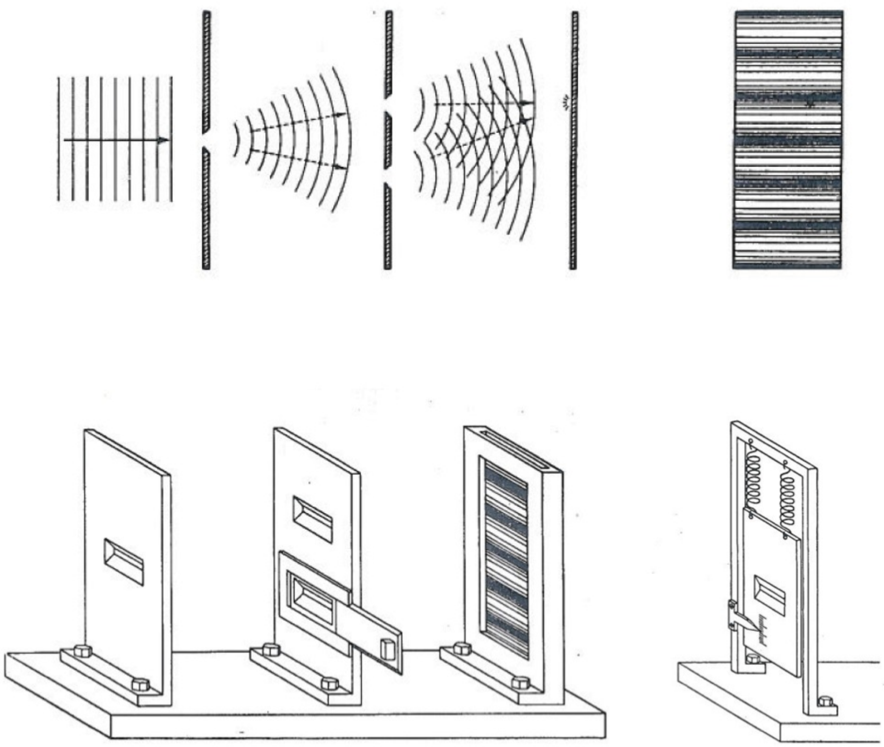


Figure 7: The “double slit” experiment in the standard version (top) and Niels Bohrs versions (below) (from [15]).

bicycle completely, and, indeed, put it back together again. When his institute was being built, he took part in every detail of the design and he was a frequent guest at the construction site where, as my grandmother used to say, he would have liked to build the whole thing with his own hands. Similarly, he always made scientific issues very concrete. One of the most difficult ones, one occurring again and again during his many discussions with Einstein about the interpretation of quantum mechanics and in particular, the wave-particle duality, was the double-slit experiment, as shown in figure 7 (top). It is also known as Young’s experiment, since Thomas Young in the early 1800s showed that light from a point source (a slit in the first screen) that impinges on a screen with two slits (second screen) will form an interference pattern on the rear screen. This was clear evidence that light is a wave phenomenon. Now, Planck and in particular Einstein had shown that light must also be seen as particles, and later de Broglie showed that atomic particles, such as electrons, also act as waves. It is very difficult to connect these two modes of description: a wave propagates simultaneously in many parts of space, while a particle is always localized. When one performs the double slit experiment with electrons, one cannot determine which of the two slits the electron passes (i.e., a particle property) without losing the interference (i.e., a wave property). For this situation Niels Bohr coined the term *complementarity.* The two description modes (wave and particle) are mutually exclusive, but both are necessary for a full description.

Einstein strongly disagreed with this interpretation. Of course, the particle must always go through one of the slits! Niels Bohr’s response was to make the design of the experiment more specific, as shown in the lower version. If we want to see interference, the slits must be fixed very precisely relative to each other and to the rear screen. This can be ensured by bolting them into the supporting fundament; but that simultaneously makes it very difficult to measure which slit the electron goes through, since the recoil from a collision with the slit determining the direction of the electron cannot be traced afterwards. The latter is possible, however, in the second variant of the experiment shown at the bottom right, where the slit is suspended by a spring. An electron, which is deflected upwards, will cause the screen to move downwards - but this will in turn move the slits relative to the rear screen, whereby the interference pattern disappears.

Niels Bohr's conclusion was that, in order to describe a particular phenomenon one must include the entire experimental setup - including bolts or springs. In his essay on the discussions with Einstein [15] he formulates it in the following way: *…evidence obtained under different experimental conditions cannot be comprehended within a single picture, but must be regarded as complementary in the sense that only the totality of the phenomena exhausts the possible information about the objects.*

Figure 8: Niels Bohr with Anne, his first grandchild, at his summerhouse in Tisvilde in 1946.

Figure 9: Niels Bohr with three grandchildren.

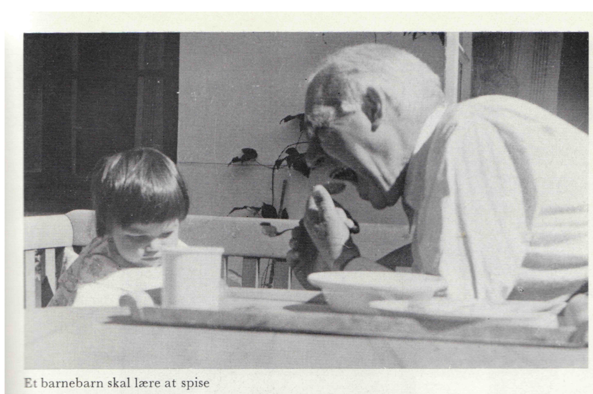



Figure 10: Niels Bohr trying to teach a grandchild to eat.

## 7 Family

The family was very important for Niels Bohr and the daily interactions with the family was undoubtedly a good way for him to recharge and get new inspiration. Niels Bohr was a wonderful grandfather, who gave us grandchildren the feeling that we were important to him, and that he liked to include us in his life. I have included a series of pictures that show this better than many words.

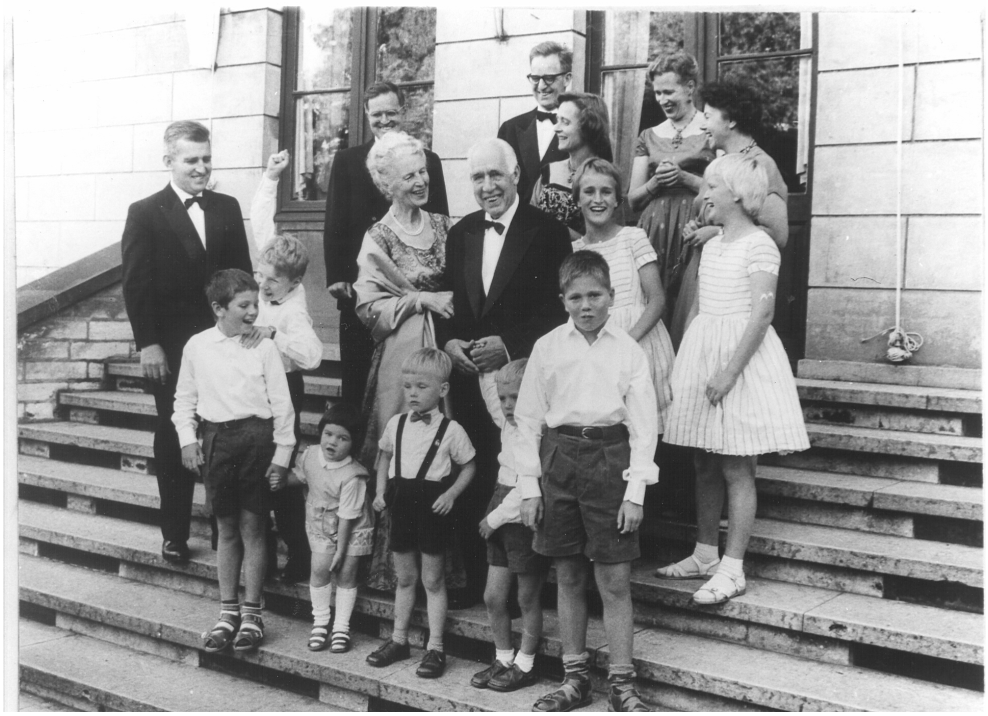


Figure 11: Niels Bohr with his wife Margrethe with some of their sons, daughters in-laws and grand children - all dressed up for Niels' and Margrethe's golden wedding anniversary in 1962 and trying to stand still. All in all he had 18 grandchildren.

## 8 Keeping things open

Finally and perhaps most importantly, I want to mention Niels Bohr's unusual ability to keep things open. When a new revolutionary theory appears, it often quickly becomes a new dogma. The view soon narrows down - freezes over, as an opening in the ice - and one tends to underscore the new theory's success rather than its shortcomings. We all need something solid to stick to, a well-defined theory or a collection of clear ideas, but Niels Bohr was a master of maintaining the openness, remembering the frailty of the fundament and keeping in mind how big the unsolved problems still were.

In his lecture in the Danish Physical Society in 1913 [16], shortly after the greatest success in his life - the description of the hydrogen atom and the determination of the Rydberg spectroscopical constant from fundamental physical constants -, he explains: *We stand here almost entirely on virgin ground, and upon introducing new assumptions we need only take care not to get into contradiction with experiment. Time will have to show to what extent this can be avoided; but the safest way is, of course, to make as few assumptions as possible.* And later he says: *You will therefore understand that I shall not attempt to propose an explanation of the spectral laws; on the contrary I shall try to indicate a way in which it appears possible to bring the spectral laws into close connection with other properties of the elements, which appears equally inexplicable on the basis of the present state of the science.*

In 1918, in "On the quantum theory of line spectra" [10] he writes similarly: *These difficulties are intimately connected with the radical departure from the ordi-*

*nary ideas of mechanics and electrodynamics involved in the main principles of the quantum theory, and with the fact that it has not been possible hitherto to replace these ideas by others forming an equally consistent and developed structure.* Later, after the development of quantum mechanics, which constituted precisely such a "consistent and developed structure", he writes in [15]: *... in dealing with the task of bringing order into an entirely new field of experience, we could hardly trust in any accustomed principles, however broad, apart from the demand of avoiding logical inconsistencies...* We cannot know how nature operates, but we must be open to what we observe. In their discussions - over more than 30 years - one of Einstein's famous objections to quantum mechanics was that "God does not play dice", to which Bohr replied something to the effect that Einstein should stop telling God what to do! In writing, where he was always more careful, he says [15]: *I replied by pointing at the great caution, already called for by ancient thinkers, in ascribing attributes to Providence in every-day language.* Niels Bohr's openness is also reflected

Figure 12: Niels Bohr travelling around 1954.

by the fact that he, as he said himself, tried never to express himself more clearly than he thought. In the paper on complementarity [17], he writes: *The hindrances* [in formulating the quantum laws]... *originate above all in the fact that, so to say, every word in the language refers to our ordinary perceptions. In the quantum theory we meet this difficulty at once in the question of the inevitability of the feature of irrationality characterizing the quantum postulate.* He does not write: *we meet this difficulty in the inevitability...*, but rather in the *question* of the inevitability... Could it be that he considers the question of whether something is rational or not as a, to large extent, linguistic problem?

Openness - at all levels - was a central point for Niels Bohr. Politically, he has often been seen as naive, because he proposed mutual openness: the Americans should share the secrets of the atomic bomb with the Russians at the end of the war in return for reciprocal control - something that he actually, at least for a time, managed to convince Roosevelt of. We talk less about how naive the Allies were when they thought that they could keep something that important secret - Russians conducted their first test of a nuclear device in 1949 - or how dangerous and destructive openness actually is for undemocratic rulers. In the open letter to the United Nations in 1950 [18] he writes: *Looking back at those days* [the end of the war], *I find it difficult to convey with sufficient vividness the fervent hopes that the progress of science might initiate a new era of harmonious co-operation between nations, and the anxieties lest any opportunity to promote such a development be forfeited.*

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[9] My translation of a passage from a taped discussion between Niels, Aage and Margrethe Bohr, and others in 1959 (Niels Bohr Archive).

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