Chapter 5
Hermann Haken and the “Stuttgart School” 1960 – 1970: Their Contribution to the Development of Laser Theory

5.1 General Introduction to the History of the Laser

The history of the laser has been written by scientists involved and historians several times. Great efforts to trace the lines of development were particularly made in 1985, when the science community celebrated the 25th anniversary of the “birth” of the laser by Theodore Maiman. The most important activity had been undertaken in the United States of America with the *Laser History Project* of the years 1982 to 1988. No less than four important scientific associations joined forces: the *American Physical Society*, the *Institute of Electrical and Electronics Engineer’s Quantum Electronics and Applications Society,* the *Laser Institute of America* and the *Optical Society of America*. With regard to the jubilee they interviewed living contemporary witnesses in order to document the historical development. More than 80 interviews were recorded and resulted in the seminal book by Joan Lisa Bromberg:[170] “*The Laser in America*“.

As the title declares, Bromberg concentrated on the development taking place in the United States. It was here that the pioneering work had been done, especially in the prehistory of the subject. Some Russian protagonists were also interviewed, as a result of the Nobel prizes that had been awarded meanwhile for their maser and laser research Parallel developments in Europe and in other countries worldwide were given a secondary role or no role at all in the project.[171]

Even before the publication of Bromberg’s book the Italian experimental physicist Mario Bertolotti came out with his “*Masers and Lasers – an Historical Approach*“[172]. In 2005 it was succeeded by an enlarged edition.[173] Bertolotti’s books are guided by the experimental approach to the laser, a subject in which he

The original version of this chapter was revised: Figures 6 and 8 have been updated. The erratum to the chapter is available at DOI: 10.1007/978-3-319-11689-1_11

[170] (Joan Lisa Bromberg, 1991)

[171] The records of the project are kept as *Sources for the history of Laser (SHL)* at the *Nils Bohr Library of the American Institute of Physics (AIP)* in New York.

[172] (Mario Bertolotti, 1983)

[173] (Mario Bertolotti, 2005)

B. Kröger, *Hermann Haken: From the Laser to Synergetics*,
DOI: 10.1007/978-3-319-11689-1_5

had been involved personally. There are many other historically relevant sources, mainly journal and magazine articles and the memories of physicists involved.[174] All these sources concentrate on the technical and experimental development of the laser. Theoretical research is only marginally mentioned.

Sole exception is the habilitation treatise by Helmuth Albrecht “*Laserforschung in Deutschland 1960 – 1970“,* where he describes explicitly the development of the laser theory at the “Stuttgart School” led by Hermann Haken.[175] This description is enlarged and refined in the following, made possible by new interviews with the physicists involved and taking into account the personal archive of Hermann Haken.

It should be clear when evaluating the above sources it is noticeable that the development of the maser and the laser, having been accomplished mainly in the United States during the 1960s, is outlined in great detail. But (with the exception of Albrecht’s work done in Germany) something is wanting: a description of the parallel developments in other parts of the world, especially in Europe. Another striking point is that the application of the laser in scientific research is given a wide berth. Very little notice is given to the application of the laser in medicine, industry and technology, which is at least equally important. Considering the importance of the laser for these fields this is amazing, and offers a vast open field for future historical research.

In the following chapter the theoretical development of laser research will be examined, starting with the seminal work of Townes and Schawlow in 1958.[176] The “Stuttgart School“ and the two US-American theory schools of Willis Lamb Jr. and Melvin Lax will be investigated in detail, particularly in view of the competition between them.

The “Stuttgart School” was disregarded by American researchers and had to fight for a long time for recognition. This disappointed Hermann Haken and caused an element of bitterness.

We follow up the original published papers chronologically and try to shine light on the reasons for this temporarily oblivion.

5.2 From Maser to Laser[177]

One of the most fundamental discoveries of the 19th century was the detection and means of creation of electromagnetic waves by Heinrich Hertz. In the years to come the fundamental social and economic influence of this discovery became

---

174 (Carroll, 1964), (Fischer, 2010), (M. Bertolotti, 1985), (C. M. Townes, 1999), (Hecht, 2005), (Lemmerich, 1987), (Joan L. Bromberg, 1988 (10))

175 (Albrecht, 1997). Especially chapter 3.2.2.

176 (A. Schawlow & Townes, 1958).

177 For the most part the presentation in this sub-chapter follows (Mario Bertolotti, 1983), (Mario Bertolotti, 2005), (Joan Lisa Bromberg, 1991), (A. L. Schawlow, 1973), (C. M. Townes, 1999).

clear in the technological breakthroughs of radio, the telephone and television. The field of electromagnetic waves thus attracted many leading scientists, and in applied sciences the profession of electro-engineering was established.

Electromagnetic waves, created by oscillating charges, are mostly monochromatic and coherent. That means that they oscillate within a very small bandwidth and, at some distance from the source, are “plane waves”. At the beginning of the 20th century it was possible to artificially create electromagnetic radiation with wave lengths of some hundred meters. Every emission and reception of electromagnetic waves is influenced (sometimes extremely negatively) by two types of noise: thermal noise (depending on the temperature) and “quantum mechanical noise“ (depending on the number and distribution of photons). Engineers and scientists try to suppress this noise as much as possible because it disturbs their measurements. The continuous struggle against noise and fluctuations in these phenomena was well known in the scientific community.

In the years up to the Second World War technological advances led to shorter and shorter wave lengths, finally reaching the so called “meter-regime”. Due to the phenomenon of diffraction of electromagnetic waves (they are “scattered“ by obstacles) the radio engineers were not particularly interested in shorter waves. It was common understanding that mountains, houses, forests etc. would absorb or disturb the waves in such a way that the transmission of a signal over a long distance would not be possible. When it became apparent that this was a false conclusion the race for shorter and shorter waves was on.

It is characteristic of electromagnetic waves that they are deflected and reflected by metallic surfaces. Thus the signal emitted by a source and reflected by an object could be received and analysed. However the accuracy of the distance determination crucially depended on the power of the source and the wave length of the electromagnetic wave. Unsurprisingly this led to great efforts in the development of radar-technology during the Second World War. The goal was to create ever shorter wave lengths and higher power output of the source so as to detect aeroplanes and battle ships more precisely at ever greater distances.

The electromagnetic waves were amplified by cavity resonators, their size being adapted to the wave length. Typical dimensions had been just a few centimetres. Arthur Schawlow summed it up[178]:

> „One of the requirements for building an electronic oscillator to generate such short electromagnetic waves is the resonator to tune it. For microwaves, which have length ranging from millimeters to centimeters, tuning is usually achieved with some kind of cavity resonator whose dimensions are comparable to the wavelength. When the desired wavelengths are a small fraction of a millimeter, construction of cavity resonances becomes a difficult task.”

178 (A. L. Schawlow, 1973), p. 115.

Over time transmitter and receiver technology became ever more elaborate. Perhaps even more important is the fact that after the Second World War many scientists and experts were available who had genuine knowledge in the field of high frequency technology.

One of these scientists was Charles H. Townes. Born in South Carolina in 1915, he studied physics at the *California Institute of Technology,* where he took his doctoral degree with work on nuclear spin and isotope separation. The United States of America had not entered the war. Townes then joined the research laboratory of the *American Telephone and Telegraph Company (AT&T)* - the famous *Bell Laboratories* - located in Lower Manhattan (New York) at that time. He soon was assigned to radar work[179] and stayed associated with this subject even after the entry of the USA into the war. He was thus not involved in the development of the atomic bomb at Los Alamos, as were many of his colleagues.

After the second world war, Townes turned his scientific interest to molecular microwave spectroscopy, where he could profit from his experience in radar technology. Molecular beam spectroscopy had been developed by Isidor Isaac Rabi[180] during the late 1930s. It allowed high precision measurements by resonance phenomena triggered by radiation transitions of excited molecular beams into the ground state. In 1948 Rabi offered Townes a professorship at *Columbia University* (New York). Townes remembered fifty years later[181]:

> “During the 12 years I was a full-time member of the department, in addition to Rabi, Kusch, and Lamb, other professors there included T. D. Lee, Steve Weinberg, Leon Lederman, Jack Steinberger, Jim Rainwater and Hideki Yukawa; all were to receive Nobel Prizes. Rabi was the only one so recognized when I arrived. Students during that period included Leon Cooper, Mel Schwartz, Val Fitch, Martin Perl and Arno Penzias, my doctoral student who, in 1965, was co-discoverer (with Robert Wilson) of the cosmic background radiation (CBR), the relic photons from the big bang. All these were also to receive Nobel Prizes. Hans Bethe and Murray Gell-Mann were visiting professors there before receiving their Nobel Prizes. Then there were the young postdocs: Aage Bohr, Carlo Rubbia and my postdoc and close associate, Arthur Schawlow, now Nobel laureates.”

---

179 (C. M. Townes, 1999).

180 Isidor Isaac Rabi (1898 - 1988) was an Us-American physicist of Austrian origin. In 1944 he received the physics Nobel Prize for the development of the molecular beam resonance method leading to the measurement of magnetic properties of the atomic nucleus.

181 (C. M. Townes, 1999), p. 48.

The further development of the maser and the laser was then highly influenced by the connection of Townes with Willis Lamb and Arthur Schawlow.

Amplification by cavity resonators was the conceptual hurdle required to advance to the electromagnetic wavelength millimetre and sub-regime, as was the usual way in radar technology. It seemed impossible to construct cavities of such a small size with the necessary precision to achieve the amplification.

> "The main problem [...] was that generating millimeter waves by conventional means required a very small resonant cavity. Only a wavelength, or a small multiple of a wavelength, in size. Making precise, delicate parts about a millimeter across is not easy. And to generate significant power one would have to pump considerable power through it, which wasn't easy. It would have to be strong and able to cope with a lot of heat"[182].

The idea for the solution of the problem came to him during a conference some 18 months later. Townes described the moment in his article of 1999[183]:

> "In musing over the problem and his frustration with it, he [Townes] suddenly realized that molecules could produce much more than thermal radiation intensities if they were not thermally distributed but had more molecules or atoms in an upper than in a lower state. Within about ten minutes he had invented such a system using a beam of ammonia and a cavity, and calculated that it seemed practical to get enough molecules to cross the threshold of oscillation. This meant that molecular-stimulated emission at a given radiation intensity would be greater than energy loss in the walls of the cavity".

Until then the whole radiation field, all frequencies, was amplified then a single frequency (or a small frequency band) was selected and the others suppressed. This technology had been highly complex and sophisticated. Townes knew Ansatz planned to amplify a single frequency with the help of the induced emission phenomenon.

The principle of induced emission will be outlined briefly. Normally atoms stay in the most energetic efficient state, called the ground state. When energy is supplied to the atoms they are stimulated to take on different and higher energy states. However, these excited energy states are only stable for a very short time, then the atoms return to the ground state, emitting a photon of the frequency that corresponds to the energy difference between the excited state and the ground state. This is true not only for electronic excitations but also for rotational and

---

[182] (C. M. Townes, 1999), p. 55.

[183] (W. Lamb, Schleich, Scully, & Townes, 1999).

other oscillations because there charges are also accelerated and thus radiate. In his spectroscopic research Townes himself had been occupied with the ammonia molecule. It consists of three hydrogen atoms and one nitrogen atom showing a pyramidal structure, the nitrogen atom being located at the top of the pyramid. Due to the symmetry of the configuration the nitrogen atom easily takes the lower position. There is of course an energy difference between the two states corresponding to a frequency of 23,786 gigahertz or a wavelength of 1.25 cm.

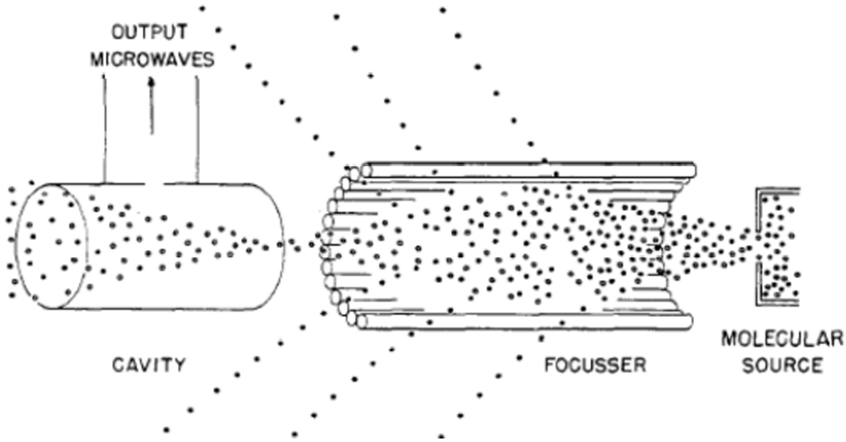

Fig. 3 Principle of the maser. (from (C. H. Townes, 1972), p. 62)

The principle of the maser is illustrated in the picture above. Ammonium rays are heated and thus excited, exiting the oven through a small hole. Atoms still in the ground are deflected away. Only excited molecules enter the cavity resonator. By means of stimulated emission a self-intensifying electromagnetic wave is created, leaving the cavity as a maser beam.

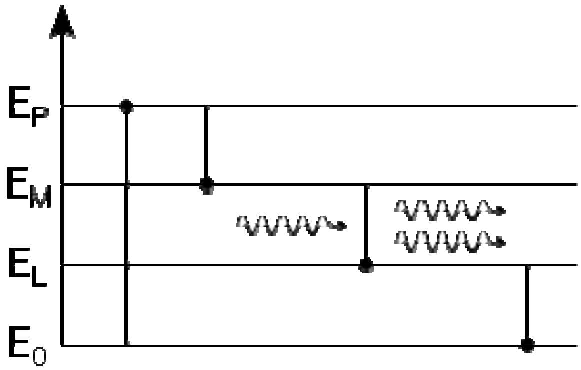

Fig. 4 Principle of the stimulated emission process (E_o ground state)

Stimulated emission is the decisive mechanism creating the maser and the laser effect. The principle of stimulated emission was introduced by Albert Einstein as early as 1916. He published his findings under the headline "Zur Theorie der Strahlung" in the mostly unread *Mitteilungen der Physikalischen Gesellschaft Zürich*[184], and shortly afterwards in the respected *Physikalischen Zeitschrift*.

How does stimulated emission work? Imagine an electron is in an excited ("upper") state. If a photon of the exact frequency corresponding to the energy difference between the upper state and the ground state is induced, the electron drops down to the ground state emitting another photon of the same frequency as the induced photon. Thus the intensity of this frequency is enhanced. Compared to spontaneous emission it is important that the stimulated photon oscillates not only in the same direction but also in phase with the primary photon. Coherent radiation is created.

It took another two and a half years until, in 1954, Townes was able to present, together with his doctoral students James Gordon and Herbert Zeiger, the first operational maser[185]. This team also created the name MASER, which is an acronym for **M**icrowave **A**mplification by **S**timulated **E**mission of **R**adiation.

Similar ideas were advanced by the Russian physicists Nikolai Basov and Alexander Prokhorov working at the *Lebedev Institut*e in Moscow, around the same time, but due to the language barrier their work has gone unnoticed in the United States.[186]

During the years to follow maser research flourished. It received an extra boost when Prokhorov, and Basov, as well as Nicolas Bloembergen, succeeded in constructing a solid state maser.

Only late in 1956 did Townes concentrate on maser research again, after taking a sabbatical working in Europe at the Institute of Alfred Kastler in Paris and in Japan at the *University of Tokyo*. During his stay in Japan he received a crucial stimulus about which he wrote in his scientific memoires[187]:

> "I settled down at the University of Tokyo,[…] As it happened, the faculty there included Koichi Shimoda, who had been a postdoc with me at Columbia and had participated in maser work.[…]
> Also on sabbatical there was another Columbia man, a biologist named Francis Ryan. We had known each other pretty well at Columbia. Naturally, we got to talking. He was studying an unusual paper by a British theoretical chemist, Charles Alfred Coulson, devoted to a treatment of microbial population growth. Coulson wanted to describe, quantitatively, the

---

184 Mitteilungen der Physikalischen Gesellschaft Zürich Nr. 18 (1916) and (Einstein, 1917).
185 (Gordon, Zeiger, & Townes, 1954).
186 The development of this work is described by (Mario Bertolotti, 1983), (Joan L. Bromberg, 1988 (10)), (Prokhorov, 1972).
187 (C. M. Townes, 1999), p. 84.

> population fluctuations that occur when microbes are both dying and multiplying at the same time. In his paper, Coulson presented and discussed the solutions to an equation that allowed for both the probability of microbe multiplication by division and also a probability of death.
>
> I recognized immediately that this was exactly the kind of mathematical formulation we needed to understand some aspects of the maser, in which photons are both dying (being absorbed) and being born (stimulated into existence) simultaneously, as the result of the presence of other photons. To Coulson's expressions, I knew I had to add another term to account for the spontaneous appearance of photons in a maser—which contrasts with the fissioning of microbial parents—since for microbes there is no chance of spontaneously creating life! But the basic approach, devised for a problem in a field far removed from physics, seemed just what was needed for a precise theory of noise fluctuations and amplification in a maser."

The drive for shorter wavelengths reaching down to visible light frequencies was widespread among physicists, but three strong reasons seemed to prevent its realisation. Firstly, in molecules the rate of spontaneous emission of energy (photons) increases with the fourth power of the frequency. To achieve higher frequencies and thus shorter wavelengths a disproportional amount of energy must be supplied to get the excited ("upper") states populated.

Secondly, according to the well-known formula,

$$E = h \cdot \nu = k \cdot T$$

(E = energy; h = Planck's constant; ν = frequency of the photon; k = Boltzmann's constant; T = temperature),

a high frequency corresponds to a high temperature. In gas – by means of the proper motion of the molecules – Doppler shift broadens the line width considerably. Last but not least it didn't seem possible to create a cavity resonator the size[188] of a few microns.[189]

Coming back from Japan Townes discussed the insights gained in Paris and Tokyo with his brother-in-law Schawlow[190]. At that time Schawlow was working on the subject of superconductivity at the *Bell Laboratories*. He convinced Townes that a cavity resonator of such a small dimension would not be necessary.

---

188 One micron corresponds to one part of a million of a meter.

189 (W. Lamb et al., 1999).

190 In 1951 Art Schawlow had married the younger sister of Townes. He had got to know her during his time as post-doc with Townes.

A so called Fabry-Perot-Interferometer (two plane-parallel mirrors, mounted at some distance from each other), well know from optics, would do. In the period that followed both scientists occasionally worked on the problem, but discussions with colleagues and reading the literature convinced them that other groups were also working on the problem of an optical maser. On the other hand they knew it would take some time before they could realise a prototype optical maser, which they planned to realise with potassium vapour. They decided to publish their thoughts in an article (but only after the *Bell Laboratories* had submitted a patent application).[191] They submitted their paper titled "Infrared and Optical Masers" on the 26th August 1958 to the *Physical Review* journal, where it appeared in the 15th December issue. This article became one of the most quoted works in laser physics, attracting more than 1000 citations.[192]

In their paper Townes und Schawlow started their calculations by defining the number of atoms that had to be excited (energetically "pumped" to a higher state). The value they found was about 100 million atoms[193] leading to the comment "this number n is not impractically large". They then derived the energy necessary that needed to be fed into the system and declared:

> „the input power required would be […] 10 milliwatts. This amount of energy in an individual spectroscopic line is, fortunately, obtainable in electrical discharges".

In the next step they tackled the problem of the size of the cavity resonator with its large dimensions compared to the wavelength of light and wrote[194]:

> „We shall consider now methods which deviate from those which are obvious extensions of the microwave or radio-frequency techniques for obtaining maser action. The large number of modes at infrared or optical frequencies which are present in any cavity of reasonable size poses problems because of the large amount of spontaneous emissions which they imply. […] However, radiation from these various modes can be almost completely isolated by using the directional properties of wave propagation when the wavelength is short compared with important dimensions of the region in which the wave is propagated".

---

191 Concerning the long-lasting „patent war" with Gordon Gould see (Hecht, 2005).

192 Science Citation Index recalled 28. February 2011.

193 (A. Schawlow & Townes, 1958), p. 1941.

194 (A. Schawlow & Townes, 1958), p. 1943.

When calculating the mirror spacing of a Fabry-Perot interferometer they got a value of 10 cm that could be handled quite easily. Their publication ended up with a definite example of an experimental set-up for potassium vapour giving its atomic and spectroscopic values. As well as s the gaseous potassium vapour approach they dealt with the question of whether one could realise a solid state optical maser, and remarked:

> „There are good many crystals, notably rare earth salts, which have spectra with sharp absorption lines […]“
> [but]
> „the problem of populating the upper states does not have as obvious a solution in the solid case as in the gas“.

All the elements required to create an optical maser had been reported in this trend-setting publication. The door had been opened wide. Of course this was realised immediately by many colleagues and scientists working in the field and the “race“ to build the first fully operational laser began.[195]

Scientific discussions do not only take place via publications. Sometimes what is more important is encountering people through conferences, workshops and guest lectures. To discuss and evaluate the new developments a conference “*Quantum Electronics – Resonance Phenomena*“ was held at Shawanga Lodge, High View in the state of New York in September 1959. Financial support came from the American *Office of Naval Research*. Charles Townes acted as organiser and chairman. During preparation for the conference the subject matter had mainly been the maser. But the possibility of realising an optical maser (=laser) occupied much time, especially in private conversations. One of the conference participants had been Theodore Maiman[196] who gave a talk on “Temperature and concentration effects in a ruby maser“. Maiman had been no outsider. He finished his doctoral studies with Willis Lamb Jr and then joined the *Hughes Laboratories* in Malibu (California). Certainly Schawlow was present at the conference. He reviewed the Schawlow-Townes paper from December 1958 now referring to it under the headline “Infrared and optical masers“. The register of attendees shows 164 entries. Only 18 participants came from overseas. The former Soviet Union had sent A. Barchukov, N. Basov, L. Kornienko and A. Prokhorov. Germany was

---

195 The details are given in (Joan L. Bromberg, 1988 (10)), (Joan Lisa Bromberg, 1991), (Mario Bertolotti, 1983), (Hecht, 2005)

196 Theodore H. Maiman (1927 - 2007) was an US-American physicist. He was doctoral student with Willis Lamb Jr. and performed industrial research afterwards. His life is recalled in his autobiography (T. H. Maiman, 2000). It is hard to understand that Maiman did not receive the Nobel Prize for the first realization of the laser.

represented only by the scientists Helmut Friedburg[197] from the *University of Karlsruhe* and Christoph Schlier[198] coming from the *University of Bonn.*[199]

It took Theodore Maiman only nine months after the conference to realise and construct the first laser with the help of a contaminated ruby crystal.[200] Initially there had been some doubts about whether the effect could really be seen, but then the experiment was repeated at the *Bell Laboratories* and confirmed. Shortly afterwards the laser-effect was demonstrated with a helium-gas laser[201] and, one year later, in semiconductors.[202]

5.3 Semi-classical Laser Theory Until 1964

Meanwhile the theoreticians in the field had not been inactive. At the front line we have to mention the US-American physicist Willis Lamb Jr., born in 1913.[203]. Lamb was a disciple of Robert Oppenheimer, finishing his doctoral studies with a work on the theory of x-ray emission at the *University of Berkeley* (California) in 1938. He made important contributions to the theoretical and experimental development of quantum mechanics. During the Second World War he had been engaged in radar technology and thereafter did research in atomic hydrogen spectroscopy. In his experiments he provided evidence of the energetic displacement of the so called 2s and 2p level of the electron trajectories in the hydrogen atom. This effect can only be understood in terms of quantum mechanics. For his achievements Lamb was awarded the Nobel Prize in Physics for the year 1955. Theodore Maiman, who realised the first laser in 1960, had been a doctoral student with Lamb in the early 1950s, when Lamb had been Professor at the University of Stanford.

In the beginning Lamb had a hard time finding his place in the US-American science establishment. In part that might have been because he was married to the

---

[197] Helmut Friedburg (1914 - 2007) was a German experimental physicist. He was a student of Wolfgang Paul and became professor at the *TH Karlsruhe* in 1958.

[198] Christoph Schlier is a German physicist. He wrote his thesis on molecular beams at the *University of Bonn* in 1956. He got a chair in physics at the *University of Freiburg* early in the sixties.

[199] (C. Townes, 1960).

[200] (T. Maiman, 1960).

[201] (Javan, Bennett, & Herriott, 1961).

[202] (Basov, Vul, & Popov, 1959).

[203] Willis Lamb Jr. (1913 - 2008) was an US-American theoretical physicist. In 1955 he was awarded the Nobel Prize in physics for the interpretation of the fine-structure spectrum of the hydrogen atom. Lamb, along with Melvin Lax, was the most important competitor of Hermann Haken in the development of the laser theory. Nevertheless they always have been on cordial terms. Life and work of Lamb Jr. are described in (Cohen, Scully, & Scully, 2009).

German emigrant Ursula Schäfer.[204] Despite being a renowned and respected physicist awarded with a Nobel Prize, Lamb was not offered a physics chair at a prestigious university, so in 1956 he accepted an appointment at the British *Oxford University*, where he lectured until 1962. During this time[205] "he pioneered the use of density matrix calculations", a mathematical tool that later on would become important in the formulation of his laser theory.

In retrospect Lamb's Oxford period cannot be judged as really satisfying. He had not a single doctoral student and could not gather a group of co-workers to perform experiments. Nonetheless, during this time he wrote the influential article "Theory of Optical Masers"[206] which only appeared late in 1964. Before its publication, in the course of 1962, he transferred to *Yale University,* staying there until 1974. During the Yale period he wrote the important articles on laser theory we are going to discuss.

The above mentioned article "Theory of Optical Masers", already written at Oxford, was a further development of his work on maser theory at the *University of Stanford* during the years 1954 to 1956. These results had only been published as a supplement to the doctoral thesis of his Stanford student J. C. Helmer.[207] It was only in 1960 that they were finally published in a peer-reviewed journal.[208] His previous student and co-worker Sargent III noted[221]:

> „The treatment [of the maser] utilized probability amplitudes for a two-level system and introduced the corresponding density matrix. It justified the popular rate equation method in appropriate limits and dealt with both weak- and strong-signal operation. Much of that maser theory applies directly to single-mode, homogeneously broadened laser operation."

After the laser effect had been shown by Maiman, Lamb remodelled his theory of the maser to a semi-classical laser theory of several modes (frequencies). This adapted theory showed an arbitrary broadening of the emitted frequency due to the "Doppler-motion" of the atoms. Lamb discovered that the intensity of the radiation decreases when the laser is tuned through the centre of the frequency line. This effect was later named, after him, "Lamb-dip".

---

[204] This might have been consequences of the notorious „McCarthy-era", when many scientists had been suspected of „non-American machinations". Famous is the "Case Oppenheimer".

[205] (Cohen et al., 2009), p. 9.

[206] (W. E. Lamb, 1964).

[207] Cited after (Sargent III, 1974).

[208] (Willis Lamb, 1960).

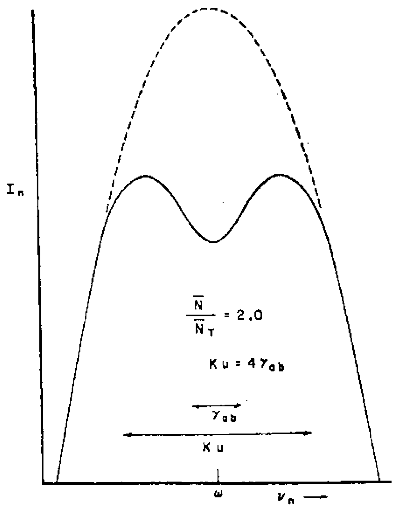

Fig. 5 “Lamb-Dip“. Depending on the frequency, typical reduction of laser intensity. (from: (W. E. Lamb, 1964)).

Once again, as in the case of his maser theory, Lamb did not publish the results in a well-known journal. Instead in 1961, he informed his friends Walter Bennett[209] and Eli Javan working at the *Bell Laboratories* by letter, and asked them to search for the phenomenon. Subsequently the Lamb-Dip was detected by these researchers and their co-workers in August 1962.[210]

5.4 The Crucial Role of Laser Conferences

An exponential growth in experimental results was seen after the verification of the laser effect. This called for a *Second Quantum Electronics Conference*. From the 23rd until the 25th of March 1961 the meeting was held in Berkeley (California) under the heading “*Advances in Quantum Electronics*“, and attracted not less than 448 participants. This was a threefold increase on the number of only eighteen months before.[211] But again the conference was dominated by American scientists who outnumbered all other nations with 436 attendees. Only two German researchers, H. Friedburg of the *Technischen Hochschule Karlsruhe* and G. Wiederhold of the *University of Jena* belonged to the small group of twelve participants from overseas. Another German physicist at the conference was

209 (Bennett, 1962).
210 (McFarlane, Bennett, & Lamb, 1963), (Szöke & Javan, 1963).
211 The proceedings have been published in the same year: (Singer, 1961).

Wolfgang Kaiser[212], but he represented the *Bell Laboratories* at that time. The reports at the meeting were characterised by the dynamic evolution of experimental results. Ali Javan presented the first Helium-Gas Laser and Garrett, Kaiser and Wood gave a report on "Fluorescence and optical maser effects in $CaF_2:Sm^{++}$". Coming from the *Hughes Research Laboratory* in Malibu (California), where Theodore Maiman was working, W. Wagner and G. Birnbaum gave a short theoretical talk on "A Steady State Theory of the Optical Maser". In their paper of this semi-classical theory they cited the famous Schawlow and Townes publication of 1958 and referred to an article of their own that had appeared in the 1961 July issue of the *Journal of Applied Physics*.[213]

The next important conference took place in spring 1962, in Heidelberg.[214] The meeting was held in u of the retirement of the German physicist Hans Kopfermann and was titled "*Konferenz über optisches Pumpen*". Willis Lamb, in 1962 still working at the University of Oxford before moving on to Yale later that year, was one of the participants. It was here that Lamb and Hermann Haken met for the first time. Haken came from nearby Stuttgart and presented a talk on the "Theory of the laser and optical pumping".[215]

As described in the previous chapter Haken had been working as a visiting associate professor at *Cornell University* in New York and – simultaneously – at the research laboratory of the *General Electric Company* in Schenectady. During this time he received an invitation to stay at the renowned Bell Laboratories. He remembered his stay at Bell in one of the interviews:

> "I had been in the group eleven. Group head had been Phil Anderson who later on won the Nobel Prize. Other famous members of the group were Wannier, a solid state physicist, and coincidentally Melvin Lax, a solid state physicist as well. Anderson himself was an educated solid state physicist […], this shows that I had been invited because I was viewed as a solid state theoretician. […] First I continued my work on excitons, but then I recognised that laser was the up-coming subject. At

---

212 Wolfgang Kaiser (born 1925) is a German experimental physicist who made important contributions to ultra-short-time laser spectroscopy. In 1952 he finished his doctoral studies at Erlangen where he came to know Hermann Haken. He worked at the Bell Laboratories at the time when Haken was visiting associate. A guest professorship offered by Haken in 1962 made it possible for him to habilitate in Stuttgart. Shortly afterwards he received a call from the *Technische Universität München* to a physics chair that he accepted in 1964.

213 (Wagner & Birnbaum, 1961). Submitted 1. February 1961.

214 The conference was held 26. – 28. April 1962 to honor the 67th birthday of Hans Kopfermann, (1895 – 1963).

215 Published proceedings of the conference could not be identified. A list of participants, the names of the referees and the titles of their lectures as well as a short abstract of Haken's talk have been found in Haken's archive.

> Bell there was […] Wolfgang Kaiser, a good friend of mine, and we spent whole nights discussing this subject. Later I had talks with Harry Frisch – I spent countless nights with him [laughs]. At Bell I wrote an article on the first phase of the operation of the laser, but discontinued this work later on. It is a fact that I was introduced to the subject of lasers by Wolfgang Kaiser".[216]

Back in Stuttgart Haken launched an ambitious programme on laser theory. He delivered first results on a semi-classical version of his theory at the above mentioned Heidelberg conference in spring 1962. Looking back he remembered:

> "At the conference I met Willis Lamb. I don't remember the name of my talk … of course about the laser, but Lamb did not attend the lecture, he was out shopping. [loughs]. But we discussed the subject soon after, during the meeting. I told him what I was doing. And he said, well I did the same. We discussed how to handle the spontaneous emission … and then I showed him my equations. He responded that he had found corresponding equations. But there had been a difference: from the very beginning Lamb had called his theory semi-classical, because he used the density matrix. I had called it quantum theory, because I used the second quantization formalism".[217]

Haken published his results under the heading "Nonlinear Interaction of Laser Modes". Early in 1963 the article appeared in the journal *Zeitschrift für Physik* (co-authored with his diploma student Herwig Sauermann) where it had been submitted on the 11th February. In a footnote to that article Haken recounted the discussions with Lamb in Heidelberg:

> „Prof. W.E. Lamb, jr. has kindly informed one of us (H.H.) in a private discussion at Heidelberg, spring 1962, that he has derived similar equations for the gas laser."

Lamb as well remembered this meeting:

> „I ran into Haken for the first time at Heidelberg. […] I was pretty far along on the laser theory at that time, but I didn't talk about it at the conference. I talked on something else. But there was a talk by Haken about laser theory, and it seemed to me that he had some very good ideas, and I was a little upset, […]

---

[216] Interview with Herrmann Haken 21.9.2010. (Haken-Archive).
[217] Interview with Herrmann Haken 21.9.2010. (Haken-Archive).

> because it seemed to me, that Haken might very well be a serious competitor, which in fact he certainly has been."[218]

In their publication Haken and Sauermann cited the article of Schawlow and Townes as well as the work of Wagner and Birnbaum[219]. The most important result of their calculations was that by taking into account non-linear effects a small deviation of the laser frequency occurs. This effect had been demonstrated in gas-laser experiments.

> „the main result of our analysis will be, that an increased pumping rate supports also off-resonance modes and leads to a repulsion of frequencies".[220]

The face-to-face exchange of ideas between the leading theoreticians was very strong during this time. Theoretical results were desperately needed because experimental results were , avalanche-like. An important event in early 1963 constituted the third international conference on "*Quantum Electronics*"[221], attracting more than 1000 participants from 15 countries. The meeting took place in Paris from 11 – 15 February 1963. The venue, this time in Europe, saw 74 attendees from Germany. Coming from Stuttgart were Hermann Haken, Herwig Sauermann and R. K. Sun [a guest professor]. The other German universities and *Technischen Hochschulen* sent 31 scientists, the German industry had 25 delegates and other research institutions were represented by 17 participants.

The topics of the conference were grouped into the following subjects[222]

- Theory of Coherence and Noise
- Optical Pumping and Magnetometers
- Molecular Beam Masers
- Gas Lasers
- Spectroscopy of solid state maser materials
- Solid State Masers
- Solid State Lasers
- Laser Modes and special techniques
- Non-Linear Optics
- Semiconductor and Photon Masers

---

218 Interview Willis Lamb Jr. with Joan Bromberg from 7. March 1985. (AIP Niels Bohr Library & Archives. Call Number: OH 27491).
219 (A. Schawlow & Townes, 1958), (Wagner & Birnbaum, 1961).
220 (H. Haken & Sauermann, 1963b), p. 262.
221 (Grivet & Bloembergen, 1964)
222 (Grivet & Bloembergen, 1964)

It is striking that a special section on laser theory was missing. But, during the meeting in Paris, Haken and Sauermann obtained new and additional information on the current state of research in the United States. Therefore, while proof reading[223], they attached a note to their above-mentioned article[224]:

> "Note added in proof. After the present paper has been submitted for publication several talks (by W.E. Lamb, N. Bloembergen, D. McCumber, H. Statz) were given at the 3rd International Conference on Quantum Electronics, which consider the interaction of modes brought about by the nonlinear response of the atomic systems. From these papers the one of Lamb is most closely related with our present work, although the formalism and also the physical System are somewhat different from our case, Lamb treats moving atoms in gases with a Doppler broadened line, whereas we treat fixed atoms with a homogeneously broadened Lorentzian line. The two investigations give, however, similar results, for instance for the mode repulsion effect. On the other hand, Lamb's dipping effect has no analogue in our case. For a detailed comparison of results, however, the publication of Lamb's paper must be waited for.
> At the same Conference E. Snitzer reported results of Nd-doped glasses, which show additional modes appearing with higher pumping and also a repulsion of modes in good qualitative agreement with our analysis."

We have to mention that the talk at the Paris meeting given by Willis Lamb Jr. is not printed in the conference proceedings. The corresponding article only appeared in the Physical Review [225] (received 13th January 1964) in 1964. To claim some priority Lamb remarked:

> „The main results of the paper were reported at the Third International Conference on Quantum Electronics, Paris, February 1963. Lectures on some of the material were given at the 1963 Varenna Summer School."

Even before the publication of Lamb's article Haken and Sauermann extended their first paper with another contribution that they submitted on the 6th of June

223 The contributions mentioned in the note were titled: N. Bloembergen: "Optique Non-Linéaire"; D.E. McCumber: "Unified Theory of Steady State Cavity Masers"; H. Statz, C. Tang: "Zeeman Effect and nonlinear Interactions between Oscillating Modes in Masers".

224 (H. Haken & Sauermann, 1963b)

225 (W. E. Lamb, 1964).

1963.[226] In this article they analysed the frequency shifts in laser modes that occur due to the non-linear behaviour of the active laser material. It seems curious that they cited the paper of Lamb that had not been published at that point but presumably had been circulated as a pre-print.

Less than two month after the Paris conference had finished, the next “*Symposium on Optical Masers*” was organized for 16 – 19 April 1963, in New York. The publication of the proceedings was delayed and they appeared only in 1964.[227] The book presented articles by 92 different authors, among which only two German scientists could be found: K. Gürs and R. Müller of the research laboratory from the *Siemens und Halske* corporation. Not unexpectedly the majority of the attendees had been American scientists. Some Japanese researchers also gave talks but only referring to experimental results. The lecturers on laser theory had been N. Bloembergen, E. Wolf, E.C.G. Sundarshan, P.A. Grivet, B. Lax (on “Semiconductor masers“), H.A. Haus and J.A. Mullen, as well as G. Toraldo di Francia. Their contributions dealt with theoretical specialties, with no attempt at an encompassing theory such as those of Haken and Lamb.

In the period from 1963 until 1966 the meetings and contacts of the scientists involved in laser theory research followed each other in quick succession. From 1953 the Italian Physical Society organised regularly its famous physics summer schools at the Villa Monastero on the waterfront of Lake Como. They are named after Enrico Fermi, the renowned Italian physicist and Nobel Prize winner. Charles Townes headed the XXXI summer school that was held from the 19th until the 31st August 1963 dealing with “Quantum Electronics and Coherent Light“.[228] These meetings had a twofold purpose. First they offered a genuine possibility for a selected bunch of young and eager scientists to learn about the newest theoretical developments. Secondly it was an invaluable chance to become acquainted with exceptional professionals in the field. The renowned lecturers at this summer school comprised, as well as C. Townes, the names W. Lamb, A. Schawlow, B. Lax, J. Gordon, N. Bloembergen, F. Arecchi and A. Javan. Hermann Haken was not on the list. In 1963 he was not yet known to the community as a laser theoretician. That would change quickly. About 60 doctoral students and post-docs had been invited. Among them were, coming from Stuttgart, were Haken’s assistant Hannes Risken and his doctoral student Herwig Sauermann. Sauermann got the opportunity to give a talk on the results of the laser theory work he co-authored with Haken.[229] This is why, even though Haken had not been present, in the proceedings we find the contributions of Lamb “Theory of optical maser oscillators“ and Haken/Sauermann “Theory of laser action in

[226] (H. Haken & Sauermann, 1963a)
[227] (Fox, 1964).
[228] The Proceedings were published in 1964: (Miles, 1964).
[229] Haken and Sauermann cited the work of Townes of the year 1961; Townes in his article referred to the paper of Haken and Sauermann in the *Zeitschrift für Physik* 173 (1963), 261.

solid-state, gaseous and semi-conductor systems“ in immediate succession. We can also assume that there had been a close dialogue between Lamb, Risken and Sauermann.

This contact was intensified when in the following year, 1964, a further summer school was held at the French mountain village Les Houches. Again Lamb and Sauermann were participants. These summer schools “*Ecole d'eté de physique théorique Les Houches*“, in close proximity of the *Mont Blanc Massive* had been held since 1951. Organised by the French physicist Cécile deWitt from the University of Grenoble these summer schools pursued the same intentions as the Italian ones. The proceedings of the meeting did not give a list of attendees, but the participation of Herwig Sauermann can be clearly derived from the following quotation in the report contributed by Willis Lamb:[230]

> "W. E. Lamb, Jr., Yale University: INTRODUCTION
> These lecture notes on the theory of optical masers were taken by Messrs. B. Decomps, M. Durand, B. Gyorffy and H. Sauermann, while assistance in their arrangement was given by Mme. A. Fouskova. For reasons mentioned below, the notes were not prepared in advance of the course, and I have not had sufficient opportunity to correct them. Because I declined to answer certain questions of an offensive nature, renewal of my passport was withheld by the U. S. Department of State. My lectures at the School were only made possible (on very short notice) by the Supreme Court decision in the case of Aptheker and Flynn vs. The Secretary of State."

Other speakers at Les Houches were Roy Glauber giving a lecture series on “Optical Coherence and Photon Statistics”, Willis E. Lamb talking about the “Theory of Optical Maser”, Ali Javan presented the latest results on “Gaseous Optical Maser“ and Nicolas Bloembergen lectured about “Non-Linear Optics“.

Hermann Haken, in his *Zeitschrift für Physik* article dated 4th July 1964, referred to the fact that its contents had been presented by his student Herwig Sauermann at the summer school in Les Houches. This seems plausible taking into account the duplicity of the events with the summer school in Varenna the year before.[231] In the proceedings there is no written evidence of this talk. The participation of Sauermann at the school is proven by the statement in Lamb's article.

---

[230] (deWitt, Blandin, & Cohen-Tannoudji, 1965), p. 331. Again another evidence of Lamb's problems with the US-American authorities concerning his „un-American“ activities.

[231] In an interview with Joan Bromberg as of 7th March 1985, Lamb confirmed the meeting with Sauermann. (AIP Niels Bohr Library & Archives. Call Number: OH 27491).

5.5 The Fully Quantum Mechanical Laser Theory

On 4th July, 1964 Haken submitted his seminal article to the *Zeitschrift für Physik* “A Nonlinear Theory of Laser Noise and Coherence I“. This work constituted an important step forward towards a fully quantum mechanical laser theory. In this non-linear theory Haken explicitly mentioned the crucial difference in the nature of the laser radiation below and above the laser threshold.[232]

> „In contrast to linear theories there exists a marked threshold. Below it the amplitude decreases after each excitation exponentially and the linewidth turns out to be identical with those of previous authors (for instance WAGNER and BIRNBAUM), if specialized to large cavity width. Above the threshold the light amplitude converges towards a stable value, whereas the phase undergoes some kind of undamped diffusion process”.

To demonstrate the situation at the threshold Haken chose the analogy of a potential. The illustration is given in Figure 6.

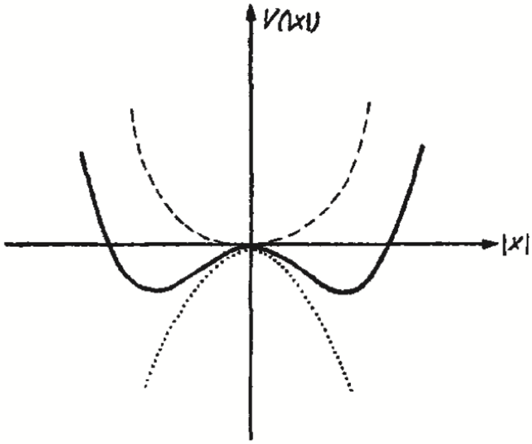

Fig. 2. Plot of "potential energy" versus light amplitude. – – – below threshold (*linear and nonlinear* theory); ········ above threshold, *linear* theory leads to instability; ——— above threshold, *nonlinear* theory

Fig. 6 Behaviour of the potential below and above laser threshold for linear and non-linear theories

232 (H. Haken, 1964), p. 96.

The calculations showed that, pumping the laser above threshold in the nonlinear quantum theory two stable minima of the potential exist, whereas in the linear theory no stable values occur. Because of the fact that this result depends strongly on the energizing pump-process nothing comparable could be found in maser theory. At the end of his article Haken summarised:

> „The main objective of our paper was to bridge the gap between linear and nonlinear theories of laser action. As we have shown linear theories represent a very good approximation at small inversion. On the other hand there is a marked threshold beyond which the system behaves qualitatively very differently from below threshold, its amplitude oscillating around a stable value".

Only three months later, on the 22nd September 1964, Haken published the second part of his work "A Nonlinear Theory of Laser Noise and Coherence II".[233] In the meantime Willis Lamb had published his nonlinear laser theory in the *Physical Review*[234] and Haken cited it. The second article expanded the first publication by the following aspects:

- Several laser modes are dealt with, not only a single mode,
- Standing waves were discussed and
- Non-complete cavity-resonance was calculated.

The noise source had been the optical transition of fluctuating dipols. It seems important to note that the methods for introducing noise (quantum mechanical, thermical, gaussian shape, etc.) into the calculations varied according to the particular authors. Different approaches often led to the need for a different mathematical treatment.

In autumn that year another possibility opened up for Hermann Haken to present his new theory at a meeting in Switzerland. "*Physik der Laser und deren Anwendungen*"[235] was the title of an international symposium held from 12th to 15th October 1964. This conference, organised on the initiative of the *Suisse Committee of Light- and Electro-optics* and by the *Institute of Applied Physics* of the *University of Bern,* attracted more than 250 participants from 22 countries.[236] The names of the attendees could not be found in the proceedings. Looking at the roster of talks given it seems reasonable to say that mainly non-American experiments and works was presented. Hermann Haken gave his lecture on "Nonlinear Theory of Noise and Coherence" at the session called "General Laser Physics".

---

233 (H. Haken, 1965).
234 (W. E. Lamb, 1964).
235 Translates into: Laser physics and its applications.
236 See "Introduction of the proceedings", printed in *Zeitschrift für Angewandte Mathematik und Physik Band 16* (1965). (Meyer, 1965).

During the years 1964 and 1965 laser theory developed dynamically. A race evolved between Hermann Haken and two US-American scientists, Willis Lamb Jr. and Melvin Lax. The previous exponents, Lamb and Haken, intensified their efforts by bringing in colleagues and students. Especially Hermann Haken was able to activate many co-workers (see Chapter 5f). A new competitor, the US-American theoretical physicist Melvin Lax, working at the *Bell Laboratories*, showed up. He had been working primarily on the theory of noise and coherence in classical and quantum mechanical applications. He was now going to apply this knowledge to the laser. The connection of the laser with noise and coherence phenomena is a consequence of the physical nature of the photons and the atomic structure of the laser active material (gas, solids, semi-conductors). In his article of 1964 Haken had already hinted at this connection.

The coherence theory of electro-magnetic waves, as well as non-linear optics, were a highly active research field at that time. Major contributions came from Roy Glauber and Nicolas Bloembergen who were later rewarded with the Nobel Prize for their work.[237] Because these segments had not been the focus of laser development we do not consider and evaluate them in depth in this article.

Until the end of 1964 laser theory had been advanced mainly by Willis Lamb and Hermann Haken, then a further group of theoretical physicists, Melvin Lax and his co-worker William Louisell at *Bell Laboratories* in Murray Hill (New York), joined the race.

For ten years Melvin “Mel“ Lax had been a member of the scientific staff at *Bell Laboratories.* He headed the “Theoretical Physics Department“ from 1962 until 1964.[238] Haken had met Lax for the first time during a solid state conference in 1958.[239] During his time as guest researcher at Bell in 1960, Haken and Lax intensified their acquaintance when simultaneously they were both members of the theory division 11 11 working under the leadership of Philip Anderson.

Lax was born in New York City in 1922 where he also spent his youth. Hampered by the Second World War he finished his doctorate at the *Massachusetts Institute of Technology* in 1947 and then moved to *Syracuse University* (New York State) where he stayed until 1955. During this time his research interest was focused on solid state physics, the field receiving a boost with the detection of the transistor effect. Whereas W. Lamb and C. Townes had been brought up scientifically with radar- and micro wave technology, Lax’s education and focus on solid state physics showed some parallels to the scientific history of Hermann Haken. After the war, *Bell Laboratories* were regarded as the world’s leading industrial research laboratory in solid state physics. When a separate theory division was installed at Bell in 1955, Lax unsurprisingly accepted a position as the first theoretician employed. Throughout his career he remained affiliated with Bell, even when he finally took a chair as physics professor at the

---

[237] Details on their work on coherence and quantum optics can be found in: Roy Glauber: (Grandin, 2006) and Nicolaas Bloembergen in: (Frängsmyr, 1993).

[238] (Birman & Cummins, 2005), see also (Millman, 1983).

[239] Hermann Haken (private communication).

City College at *University of New York* in 1971. Reading through his papers, and as also mentioned in his obituary, Mel Lax had "a deep interest in random processes".[240] This curiosity induced him to study the phenomena of fluctuations and quantum-mechanical noise in the laser process in detail. At the end of 1964 Lax gave up his direction of the theory division at Bell and concentrated again on scientific research. He cooperated with his colleagues J. P. Gordon and especially William H. Louisell[241], joining the race for a quantum-mechanical laser theory. In the course of eight years, from 1960 to 1964, Melvin Lax published not less than 18 articles on stochastic processes like noise and fluctuations.[242]

A first meeting of the exponents of the different theoretical laser schools occurred during the *Fourth International Quantum Electronics Conference*, held in San Juan (the state capital of Puerto Rico; an US-American territory in the Caribbean) from 28th to 30th June, 1965. The proceedings[243], repeatedly quoted afterwards, were published in 1966. The convention was dominated by American attendees because the venue was accessible only with great difficulty from abroad.[244] From the 257 scientists recorded on the roster not less than 222 came from the United States. France delegated 13 participants, the former USSR sent seven. Germany was represented by only two researchers: Hermann Haken from the *Technischen Hochschule Stuttgart* and Wolfgang Kaiser from the *Technischen Hochschule München*. This was sparse compared to the *Bell Laboratories* in Murray Hill with 25 employees and the *Massachusetts Institute of Technology* which was alone represented by 15 participants

We should thus not be astonished that laser theory and the theory of quantum electronics was presented mainly by American scientists. One talk each came from Great Britain, from the *Royal Radar Establishment* dealing with "Photon-counting statistics", and the Moscow *Lebedev Physics Institute,* speaking on the topic of "Dynamics of a Two-mode Operating Laser". According to Hermann Haken he also delivered a talk which was rejected for printing in the conference proceedings "due to its length".[245]

The other papers in the proceedings had been allocated to the other three known American theory groups:

- *Harvard University* in Cambridge (Mass.): Roy Glauber and his doctoral student Victor Korenman

[240] See (Birman & Cummins, 2005).

[241] William H. Louisell (born 1924) in Mobile (Alabama). He studied physics at the *University of Michigan* and received his doctoral degree in 1953. Thereafter he became member of the technical staff at Bell Telephone Laboratories (Murray Hill, N. J.), where he stayed until he assumed a physics professorship at the *University of Southern California* in 1967. (Source: Proceedings of the I.R.E. QE3 (1967), p. 97).

[242] For a summary see table 3, page …..

[243] (Kelly, Lax, & Tannenwald, 1966).

[244] Hermann Haken remembered that he crossed the Atlantic Ocean with a cargo vessel and went ashore in Venezuela. Then he took the airplane and flew into San Juan. (Hermann Haken, private communication).

[245] Hermann Haken, private communication.

- *Bell Laboratories* in Murray Hill (New Jersey): J.P. Gordon, Melvin Lax and William H. Louisell
- *Yale University* in New Haven (Connecticut): Willis E. Lamb and Marvin O. Scully

Attending the conference were Roy Glauber, J. P. Gordon, Willis Lamb, Melvin Lax, William Louisell, Marvin Scully and Charles Townes. During the three days of the meeting Haken had ample opportunity to speak with the most important American laser theoreticians.

Melvin Lax gave a talk titled “Quantum Noise V: Phase Noise in a Homogeneously Broadened Maser”. As can be seen by reading the article the term “Maser“ is equated with the word “Laser”. At that time the Bell Lab scientists were under the impact of a patent dispute with Gordon Gould.[246] The latter had coined the word “Laser”, whereas the Bell people used the name “Optical Maser“. In the abstract of Lax’s paper we find the following:[247]

> „Our result for the full width at half power above threshold:
>
> $$W = (\Delta\omega)^2\ (h\omega_o/2P_{tr})\ S(1 + \alpha^2)$$
>
> where P_{tr} is the transferred power, is an improvement over Lamb, Haken, and Korenman in three ways: $\Delta\omega$ (….) depends on both cavity and atomic widths; S (…) depends on both photon and atomic noise sources (….); and α (….) includes the effects of detuning.”

Furthermore Lax cited Haken’s papers in the *Zeitschrift für Physik* volumes 181 and 182, as well as his article in volume 13 of the *Physical Review Letters*. He also mentioned a work of Hannes Risken that was in print. Willis Lamb was quoted with his contribution in the proceedings of the Les Houches lecture course of 1964.

Melvin Lax numbered his articles on noise and fluctuations, differentiating between classical and quantum-mechanical noise. Looking at the chronological order and numbering of his works one has to take into account a peculiarity. Articles published in the proceedings of a conference are mostly prepared in retrospect. Normally there will also be proofreading. It means that the last editorial intervention – the chance to quote the latest new articles – might be some month, up to a year, after the conference took place. It seems that this was the case with Lax’s article at the Puerto Rico meeting. The title of his published talk runs under the number “Quantum Noise V“. But his foregoing work on “Quantum Noise IV“ was only published on the 6th of May 1966 and had been submitted on November 16th 1965 at the *Physical Review* , five months after the conference at San Juan.

---

[246] On this “patent war” see especially (Hecht, 2005).

[247] (Melvin Lax, 1966).

In “Quantum Noise IV. Quantum Theory of Noise Sources” Lax treated the fluctuations mathematically via the Langevin-equations, as Haken did with his Stuttgart school. Classifying and differentiating his approach from the publications of Haken and Sauermann of 1963 and 1964 he remarked:

> „Quantum noise sources have also been introduced into maser calculations in a heuristic way, or by methods similar to the perturbation techniques adopted here“.

Then he gave reference to Haken and Sauermann in a footnote. In the time between submitting the paper on the 16th of November 1965 and its publication in May 1966, he noted that meanwhile the researchers in Stuttgart had also been active. Therefore he wrote a “Note added in proof“:

> “After the completion of this manuscript (and after the results summarized in secs. 1 and 6 were presented at the 1965 Puerto Rico Conference) we have learned that several members of the Haken school have adopted a Markoffian approach closely related to our own. See H. Haken and W. Weidlich [Z. Physik 189, 1 (1966)]; C. Schmid and H.Risken [ibid. 189, 365 (1966)]. These papers treat the atomic fluctuations and lead to moments in agreement with ours. For the electromagnetic field, the noise sources are not derived by them but are taken from Senitzky— see, e.g., H. Sauermann, Z. Physik 189, 312(1966). Our procedure obtains the field noise sources by the same method as that used for the atomic noise sources, and moreover derives the independence of field and atomic sources.”[248]

These works, cited by Lax, had been submitted by Haken and Weidlich as well as Weidlich and Schmid to the *Zeitschrift für Physik* on 17th of August 1965 and 7th of September 1965 respectively. The Puerto Rico meeting came to an end on the 30th of June 1965. It remains a question whether Haken and his co-workers had made use of the results given there, and “in a hurry“ prepared fresh articles, or whether there had been preparatory work done before. The latter is indicated by the fact that Melvin Lax did not mention the work of Herwig Sauermann, which also appeared in volume 189 of the *Zeitschrift für Physik.* The article runs under the heading ”Quantenmechanische Behandlung des optischen Maser (Dissertation)“.[249] Submitted on the 17th of September it was overlooked by Lax, presumably because it was written in German. Sauermann recapitulated in detail the development of his considerations leading to his doctoral thesis:

---

[248] M. Lax: Quantum Noise IV. Pp. 120-121.
[249] (Herwig Sauermann, 1965)

> “In recent years one has been able to understand the essential classical properties of the laser on the basis of semi-classical theories. […] These theories, where the atoms of the active material are described by a density matrix, the amplitudes of the laser oscillation by c-numbers, cannot explain, by their very nature, some essential quantum-mechanical properties of the laser. Among them range essential questions such as the line-width and the intensity fluctuations of the radiated laser light. […]
> In the following period Lamb investigated the influence of the fluctuations in the cavity resonator using a semi-classical approach. Haken developed a non-linear quantum-mechanical theory of the fluctuations in the laser, where the pumping procedure is introduced explicitly as a stochastic process and the line-width, as well as intensity fluctuations, are calculated with the help of fluctuating dipoles. In contrast to Haken in our work we derive the fluctuations occurring in spontaneous emissions and pumping processes from “first principles“ and introduce them totally symmetrically, in exactly correct quantum-mechanical fashion. Moreover the thermal noise of the resonator is taken into account. […]“

At the end of his publication Sauermann added:

> *“ After having finished the present publication the author gained knowledge of a talk by M. Lax given at the conference on quantum electronics in Puerto Rico, June 1965, where the phase diffusion of a laser mode was reported. To the extent a comparison with our results is deemed possible, the findings agree essentially“.

Certainly this knowledge came from Hermann Haken who informed his co-workers and students about the papers delivered at the San Juan conference on his return. Nevertheless it also becomes clear that a doctoral thesis and other publications could not have been written in such a short time on the suggestion of Lax’s results. They had a long prehistory in Stuttgart (see chapter 5f).

The other published theoretical contributions to the San Juan conference proceedings, those of Korenman as well as Scully and Lamb, did not quote the work of the Stuttgart School. They only cited the article published by W. Lamb in volume 134 of the *Physical Review* and the lectures of Glauber on coherence phenomena at the Les Houches summer school.

The race between Hermann Haken from Stuttgart with Melvin Lax continued in the following year. On May 2nd 1966 Lax submitted a paper titled “Quantum

Noise VII: The Rate Equations and Amplitude Noise in Lasers" to the *IEEE Journal of Quantum Electronics* that was accepted in a revised version on the 24th of October 1966. In turn, on the 21th of June 1966 Hermann Haken sent the fundamental article "Quantum Theory of Noise in Gas and Solid State Lasers with an inhomogeneously broadened Line I" to the *Zeitschrift für Physik*, written by him, his co-workers and students V. Arzt, H. Risken, H. Sauermann, Ch. Schmid and W. Weidlich.

Table 3 Articles published by Melvin Lax and co-workers on the theory of laser and noise

	Articles of Melvin Lax and co-workers	
	Classical Noise	
I	M. Lax: „Fluctuations from the Nonequilibrium Steady State", Rev. Mod. Phys. **32** (1960), S. 25	January 1960
II	M. Lax: „Influence of Trapping, Diffusion and Recombination on Carrier Concentration Fluctuations", J. Phys. Chem. Solids **14** (1960), S. 248	
III	M. Lax: „Nonlinear Markoff Processes", Rev. Mod. Phys. **38** (1966), S. 359	April 1966
IV	M. Lax: „Langevin Methods", Rev. Mod. Phys. **38** (1966), S. 541	July 1966
V	M. Lax: „Noise in Self-Sustained Oscillators", Phys. Rev. **160** (1967), S. 290	April 1966, published 23.2.1967
VI	M. Lax und R.D. Hempstead: „Self-Sustained Oscillators Near Threshold", Phys. Rev. **161** (1967), S. 350	published 28.3.1967
	Quantum Noise article	
Q0	M. Lax und D. R. Fredkin: „Oscillations of a Cavity Maser" (unpublished)	
QI	M. Lax: „Generalized Mobility Theory", Phys. Rev. **109** (1958), S. 1921	15.3.1958
QII	M. Lax: „Formal Theory of Quantum Fluctuations from a driven State", Phys. Rev. **129** (1963), S. 2342	11.10.1962; published 1.3.1963
QIII	M. Lax: „Quantum Relaxation, the Shape of Lattice Absorption and Inelastic Neutron Scattering Lines", J. Phys. Chem. Solids **25** (1964), S. 487	20.8.1963
QIV	M. Lax: „Quantum Noise: Quantum Theory of Noise Sources", Phys. Rev. **145** (1966), S. 110	16.11.1965
QV	M. Lax: „Phase Noise in a Homogeneously Broadened Maser", in (Kelly, et al., 1966), S. 735	June 1965
QVI	M. Lax und D. R. Fredkin: „Moment Treatment of Maser Noise (unpublished)	

Table 3 (*continued*)

QVII	M. Lax: „The Rate Equations and Amplitude Noise in Lasers“, IEEE Journal of Quantum electronics **QE 3** (1967), S. 37	2.5.66; published 24.10.1966
QVIII	H. Cheng und M. Lax: „Harmonic Oscillator Relaxation from Definite Quantum States“, in Löwdin, P.O. (ed.) „Quantum Theory of the solid State“. Academic Press. New York 1966.	
QIX	M. Lax und W.H. Louisell: „Quantum Fokker-Planck Solution for Laser Noise“, IEEE Journal of Quantum electronics **QE3** (1967), S. 47	2.5.1967; published 12.11.1967
QX	M. Lax: „Density Matrix Treatment of Field and Population Difference Fluctuations“, Phys. Rev. **157** (1967), S. 213	
QXI	M. Lax: „Multitime Correspondence Between Quantum and Classical Stochastic Processes“, Phys. Rev. **172** (1968), S. 350	15.1.1968
QXII	M. Lax und W.H. Louisell: „Density Operator Treatment of Field and Population Fluctuations“, Phys. Rev. **185** (1969), 568	
QXIII	M. Lax und H. Yuen: „Six-Classical-Variable Description of Quantum Laser Fluctuations“, Phys. Rev. **172** (1968), S. 362	19.2.1968

The above-mentioned articles of Lax and the Stuttgart School had only been published long after the subsequent *Quantum Electronic Conference* that had been held in Phoenix, Arizona (USA) from 12 until 15 April, 1966. Even though the publication date had been later, the contents of it and the results of the calculations had been presented and discussed in Phoenix. No book containing the proceedings of the conference had been edited, as with the former meetings, but many papers were reprinted in the second volume of the new journal “*IEEE Journal of Quantum Electronics QE 2(1966)*“, in the April, August and September issues respectively. The programme of the conference, for instance, is given in the April issue. Under the heading “General Laser Theory” we read[250]:

„April 12, 1966: 8:00 p.m.
Session 3A: General Laser Theory
Pizzarro /A room

3A-1: Theory of Noise in Solid State, Gas and Semiconductor Lasers
H. Haken

[250] See IEEE Journ. Quantum Electronics QE 2 (1966, April), XIX (special conference program edition).

3A-2: Quantum Noise and Amplitude Noise in Lasers
M. Lax and W.H. Louisell"

Haken and Lax gave their talks consecutively in the evening session of that day. Prior to the conference there had been some discussion between Lax and Haken which Lax commented upon in his article "Quantum Noise VII"[251]:

> „Haken has recently [Zs. f. Phys. 190 (1966), 327] questioned the validity of the shot noise treatment of intensity noise because he finds that the dominant noise source is the off-diagonal random force F_{12} rather than (say) F_{22}. As has been shown in QIV, and by Haken [Zs. f. Phys. 189 (1966),1] F_{22} appears in atomic rate equations and yields atomic shot noise."

[…]

> "[…] the major source of noise in an optical laser is the off-diagonal atomic force F_{12}. […] Haken now agrees with this viewpoint."

In a footnote he quoted as the source: "private communication at Phoenix Conference on Quantum Electronics". At least the face-to-face communication still holds.

Only four months later, the next encounter of the exponents of the competing laser theory schools took place in Kyoto (Japan). It was brought about by the local *Institute of Theoretical Physics* on the occasion of the "*Second Tokyo Summer Institute of Theoretical Physics*".[252] Haken lectured on "Dynamics of Nonlinear Interaction between Radiation and Matter", whereas Melvin Lax had chosen for his course the title "Quantum Theory of Noise in Masers and Lasers". The different headings of the lectures did not seem to have been selected purely by chance, as they reflected the different approaches to laser theory of the two scientists. Hermann Haken took the dynamics of many body systems as his starting point whereas Lax proceeded from the theory of noise and fluctuations. In the end, naturally, both theoretical laser theory approaches converge.

The Tokyo Summer School had been held in August 1966. Again it was a summer school that brought about the next meeting of the laser theorists. It took place in the context of the 42nd Summer School "Enrico Fermi" on "*Quantum Optics*", held from the 31st of July 1967 until the 19th of August 1967 at the *Villa Monastero* in Varenna at the shores of Lake Como (Italy). The director of the summer school had been Roy Glauber, bringing with him some of his American colleagues, Marlan Scully and William H. Louisell. Thus the three American laser

[251] (Melvin Lax, 1967a), page 37, 43, as well as page 46.
[252] (Kubo & Kamimura, 1967).

schools were present. Due to his illness and hampered by his work on the article for the physics "Handbook" Hermann Haken was prevented from attending.[253] His place was taken by his colleague and co-worker Wolfgang Weidlich. He was accompanied by his doctoral students Fritz Haake and Heide Pelikan. Hartmut Haug and Karl Grob had been sent by Haken's institute. In 1965 Grob had written his thesis on the theory of the stimulated Raman-effect supervised by Hermann Haken.

The Summer School was attended by 91 participants, mostly from Italy. But other European countries were also represented.

M. Scully gave a course on[254] "The Quantum Theory of a Laser". He thoroughly discussed the work of Glauber, Gordon, Haken, Louisell, Shen and Weidlich, quoting the following articles:

V. Korenman: Phys. Rev. Lett. 14 (1965), 293
- M. Lax; W. Louisell: Journ. Quant. Elec. Q.E. 3 (1967), 47
- M. Lax: Phys. Rev. 157 (1967), 213
- C. Willis: Phys. Rev. 147 (1966), 406
- H. Haken: Zs. F. Phys. 190 (1966), 327
- H. Sauermann: Zs. F. Phys. 189 (1966), 312
- H. Risken, C. Schmid, W. Weidlich: Phys. Letters 20 (1966), 489
- J. Fleck Jr.: Phys. Rev. 149 (1966), 322
- J. Gordon: Phys. Rev. to be published (also 1967/68)

In comparison, Y. R. Shen coming from the Physics Department of the *Lawrence Radiation Laboratory* (USA) delivered a talk on "Quantum Theory of Nonlinear Optics". He only cited the works of Lamb and Scully, neglecting the other contributors.

Roy Glauber, being the course director, referred to the papers of his colleagues in his introductory remarks "Coherence and quantum Detection"[255] :

> „When the fundamental equations of motion become nonlinear however, as they necessarily do in the case of the laser, the problem of finding the density operator assumes greater proportions. A number of lectures of our school have been devoted to this problem; it is discussed from various standpoints by Scully, Haken, Weidlich, Louisell and Gordon."

Of some interest is the contribution of H. A. Haus[256], a physicist from the Massachusetts Institute of Technology, who recounted the measurement of the signal to noise ratio in lasers. He reviewed the theoretical situation as follows:

---

253 See in detail pages …. of this book.
254 (Marvin Scully, 1969).
255 (Glauber, 1969), page 32.

> "While the experimental work on the intensity Fluctuations of lasers was progressing, Glauber obtained a quantum-theoretical description of radiation from coherent sources, a description better suited to deal with laser-radiation. The quantum theory of the laser oscillator proceeded apace. Even though the fluctuations observed in experiments could be satisfactorily explained by a semi-classical theory the need for such a quantum theory existed and was successfullly met by several authors [27-34]. The understanding of the measurement itself advanced along with the theoretical developments on the description of optical radiation and the description of fluctuations in optical masers."

The references given cite the work of Haken, Scully, Lamb, as well as Lax and Korenman, under the numbers 27-34.

In their talks Gordon and Louisell quote only their own papers (Bell-Lab-Team) and the first article of Scully and Lamb, which was in print. The work of the Stuttgart School was not even mentioned.

Finally Haken and Weidlich, although only Weidlich was present, could reap the fruits of Haken's labour on the "Handbook" article. In their lengthy lecture, comprising 49 printed pages, they analysed in detail the preparatory work on laser theory and structured the different phenomena. They made extensive references to all works of the different groups working on laser theory[257]:

> „At the 1963 Varenna summer school on the laser, two types of theories were presented. F. G. Gordon calculated the noise properties of the laser treating it as a linear device and gave a qualitative discussion of the nonlinear region. Lamb, Haken and Sauermann, Grasjuk and Orajewskij neglected laser noise but treated the laser quantitatively as a nonlinear system. Nonlinearity plays a decisive role in the stability of laser modes. Their coexistence and so on. These nonlinear theories, however, predicted no laser action at all below a certain threshold, and an infinitely narrow line above threshold. Thus there was a need for a theory which interconnected both aspects, nonlinearity and noise. Because laser noise stems primarily from spontaneous emission. which is a typical quantum-mechanical effect, this theory also ought to be quantum-mechanical. Since 1964 three essentially equivalent methods were developed to achieve this goal, namely

[256] (Haus, 1969), p.112.
[257] (Glauber, 1969), p.630.

a) the Heisenberg Operator equations with quantum-mechanical Langevin forces.
b) the density matrix equation for atoms and light field.
c) a (generalized) Fokker-Planck equation.”

According to Weidlich and Haake[258] there had been intense discussions among the participating theoreticians at Lake Como during the three weeks of the seminar. One of the results had been that, after finishing his thesis, Fritz Haake joined Roy Glauber at *Harvard University* as a post-doc. There they co-authored some articles.

Thus we can ascertain that the leading scientists of the theoretical laser schools were in close contact and correctly quoted each other in their publications at the end of the year 1967. But other US-American researchers working in the field experimentally or theoretically had a tendency to cite only American sources.

During the years 1966 to 1968 a wealth of articles appeared that finally led to the definite formulation of a quantum-mechanical laser theory. Along with Haken and his Stuttgart School, Lax, and W. H. Louisell at *Bell Laboratories* Willis Lamb again came into the picture, this time publishing with his doctoral student Marlan Scully.[259] Scully was born in Casper (Wyoming, USA) in 1939, and was only 26 years old when he was awarded his doctorate, supervised by Willis Lamb at *Yale University* in 1965.[260]

As mentioned above the different groups closely followed the work of the competing groups and always cited their results. Thus we have a good understanding of the development in the subject. A synopsis of the time structure of the publications is given in Table 4, comprising the works from 1966 until 1970.

In reviewing the contents and focus of the different publications we essentially follow the analysis given by Haken in his seminal handbook article[261], as well as the contribution by Haken and Weidlich in the proceedings of the Varenna-meeting, published by Roy Glauber.

In 1964 the first move was made by Haken[262] using the Langevin-approach[263] (Heisenberg-picture) explaining the crucial difference in the characteristics of the laser light below and above the threshold. Below the laser threshold the light resembles that emitted by an ordinary lamp. It consists of different randomly distributed light waves emitted by spontaneous emission and amplified by stimulated emission. Above the threshold the laser acts as a self-stabilising oscillator, having steady c-number amplitude complemented by small fluctuations.

---

258 Fritz Haake, private communication.
259 (Schleich, Walther, & Lamb, 2000).
260 Besides being professor at the *University of Arizona* Marlan Scully had been working for many years at the *Max Planck Institute for Quantum Optics* in Munich.
261 (Hermann Haken, 1970). See also (Glauber, 1969).
262 (H. Haken, 1964).
263 See figure 8 on page ….

The phase of the laser radiation still shows non-damped diffusion.[264] Above the threshold the fluctuations of the phase and the amplitude can be calculated and resonance effects are observed.[265] Haken's theory predicted a decrease of the fluctuations in the vicinity of the threshold at increasing laser intensity.[266] This was soon independently verified by three different experiments.[267]

Choosing the density matrix "Ansatz" (Schrödinger-picture), mostly utilised by Weidlich and his co-worker Haake, as well as by Scully and Lamb, one is able to calculate the change of the photon statistics at the laser threshold.[268] Below the threshold laser light obeys

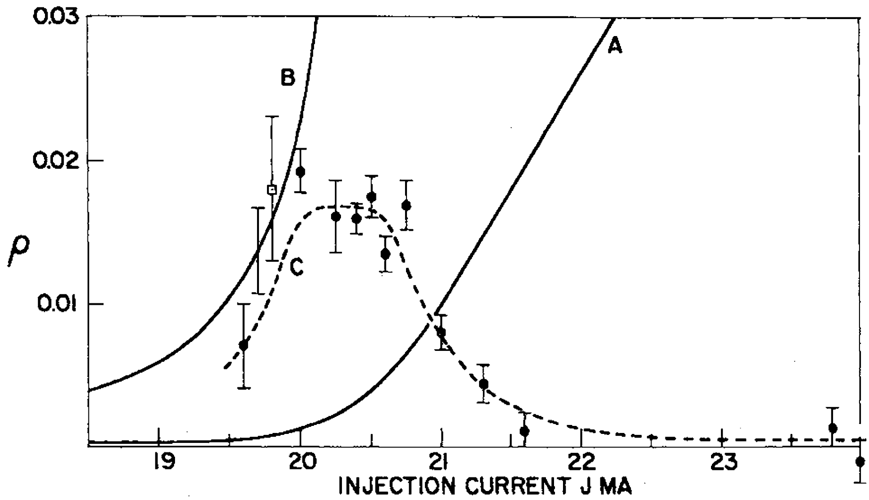

Fig. 7 Relative intensity fluctuation ρ measured for the strongest mode versus injected current J. (from: (Armstrong & Smith, 1965)

Bose-Einstein-statistics. Here the variance of the photon distribution reads

$$\Delta n^2 = n\,(n+1)$$

Above threshold we find a completely different variance subject to a Poisson distribution. Its value reads

$$\Delta n^2 = n$$

---

[264] (H. Haken, 1964), p. 96.; Lamb in (deWitt et al., 1965); Lax in (Kelly et al., 1966); (H. Haken & Weidlich, 1966), p. 1.

[265] (H. Haken & Weidlich, 1966).

[266] (H. Haken, 1964).

[267] (Armstrong & Smith, 1965), (F. T. Arecchi, Berné, & Bulamacchi, 1966), (Freed & Haus, 1965).

[268] (Weidlich & Haake, 1965a), (Weidlich & Haake, 1965b), Scully and Lamb in (Kelly et al., 1966) p. 759 and (M. Scully & Lamb, 1966), (Melvin Lax, 1967b), p. 213, (Weidlich, Risken, & Haken, 1967).

Hannes Risken, Haken's assistant at Stuttgart, advanced a third approach, solving the problem of the quantum-mechanical laser theory, extending the method of Fokker-Planck equation. First he set up a semi-classical Fokker-Planck equation[269]. Then, above the threshold, by using quantum-mechanical defined dissipation and fluctuation coefficients he was able to solve the problem with a linearization "Ansatz".[270]

Lax and Louisell were then able to derive a c-number Fokker-Planck-equation for the electro-magnetic field and its fluctuations.[271] Other macroscopic variables such as the laser field, the collective atomic dipole moment and the total inversion rate were then calculated by the Stuttgart School in the Fokker-Planck-picture[272] as well as with help of the density matrix approach.[273]. J. P. Gordon from *Bell Laboratories* presented his solution in the course of the Varenna School.[274]

In Table 4 we document in chronological order the dates of the submission and publication dates of the most important articles concerning quantum-mechanical laser theory. As can be seen, the Stuttgart School often has a slight publication edge that diminishes in time. We would also like to mention that it is often not possible to assess the "real" chronological order because we do not know exactly when pre-prints had been distributed in advance of publication dates.

Table 4 Chronological order of publication dates of the articles on quantum-mechanical laser theory by the three laser schools of Hermann Haken, Willis Lamb and Melvin Lax.

	Date	**H. Haken and the Stuttgart School**	**M. Lax and co-worker**	**W. Lamb and M. Scully**
1	Submitted on 4.7. 1964	**H. Haken**: "A Nonlinear Theory of Laser Noise and Coherence I". Zs. für Physik **181** (1964), 96 - 124		
2	10. Oktober 1965	**H. Haken**: "Theory of Intensity and Phase Fluctuations of a Homogeneously Broadened Laser", Zs. f. Phys. **190** (1966), 327		
3	Submitted 21. June 1966	**H. Haken et al.**:"Quantum Theory of Noise in Gas and Solid State Lasers with an Inhomogeneously Broadened Line", Zs. für Physik **197** (1966), 207		
4	Submitted on 2.5.66; revised 24.10.1966; published January 1967		**M. Lax**: „The Rate Equations and Amplitude Noise in Lasers", IEEE Journal of Quantum electronics **QE 3** (1967), S. 37	

269 (Risken, 1965), (Hempstedt & Lax, 1967).

270 (H. Risken, C. Schmid, & W. Weidlich, 1966a), (H. Risken, Ch. Schmid, & W. Weidlich, 1966), (H. Risken, C. Schmid, & W. Weidlich, 1966b).

271 (M. Lax & Louisell, 1967).

272 W. Weidlich, H. Risken, H. Haken, 1967.

273 W. Weidlich, F. Haake, 1965.

274 J.P. Gordon, in: Glauber, 1969.

Table 4 (*continued*)

	Date	H. Haken and the Stuttgart School	M. Lax and co-worker	W. Lamb and M. Scully
5	Haken: Submitted 14.2.1967 Scully: 9.2.1967	**H. Haken, W. Weidlich, H. Risken**:"Quantummechanical Solutions of the Laser Masterequation I", Zs. für Physik **201** (1967), 396 - 410		**M. Scully, W. Lamb**: „Quantum Theory of an Optical Maser. I. General Theory" (thesis Scully), Physical Review **159** (1967), 208
6	Lax: 2.5.1967; published 12.11.1967 Haken: 3.5.1967;	**H. Haken, W. Weidlich, H. Risken**:"Quantummechanical Solutions of the Laser Masterequation II", Zs. für Physik **204** (1967), 223	**M. Lax und W.H. Louisell**: „QIX: Quantum Fokker-Planck Solution for Laser Noise", IEEE Journal of Quantum electronics **QE3** (1967), S. 47	
7	12.7.1966, revised 28.11.1966; published 10.5.1967		**M. Lax:** „QX: Density Matrix Treatment of Field and Population Difference Fluctuations", Phys. Rev. **157** (1967), S. 213	
8	Submitted 22.5.1967	**H. Haken, H. Haug**: "Theory of Noise in Semiconductor Laser Emission", Zs. für Physik **204** (1967), 262 – 275		
9	Submitted 30.5.1967	**H. Haken et al.**: "Theory of Laser Noise in the Phase Locking Region", Zs. für Physik **206** (1967), 369 - 393		
10	Submitted 10.7.1967	**H. Haken, W. Weidlich, H. Risken:** "Quantummechanical Solutions of the Laser Masterequation III", Zs. für Physik **206** (1967), 355		
11	Submitted 26.7.1967			**M. Scully, W. Lamb**: „Quantum Theory of an Optical Maser. II. Spectral Profile", Physical Review **166**(1968), 246
12	Submitted 31.1.1968			**M. Scully, W. Lamb**: „Quantum Theory of an Optical Maser. III. Theory of Photon Counting Statistics", Physical Review **179**(1969), 368

Table 4 (*continued*)

13	19.2.1968		**M. Lax und H. Yuen**: „QXIII: Six-Classical-Variable Description of Quantum Laser Fluctuations“, Phys. Rev. **172** (1968), S. 362	
14	Submitted 6.4.1968	**H. Haken, R. Graham:** “Quantum Theory of Light Propagation in a Fluctuating Laser-Active Medium”, Zs. für Physik **213** (1968), 420 – 450		
15	Submitted 4.5.1970			**M. Scully, D. Kim, W. Lamb:** „Quantum Theory of an Optical Maser. IV. Generalization to include Finite Temperature and Cavity detuning”, Physical Review **A2** (1970),2529
16	Submitted 4.5.1970			**M. Scully, D. Kim, W. Lamb**: „Quantum Theory of an Optical Maser. V. Atomic Motion and recoil”, Physical Review **A2** (1970),2529

5.6 Hermann Haken and the Stuttgart School

Willis Lamb essentially worked on laser theory only with his doctoral student Marlan Scully. At Bell Laboratories Melvin Lax joined forces with his two colleagues, J.P. Gordon and W.H. Louisell. But it was Hermann Haken, being the newly tenured Professor of Theoretical Physics at the *Technischen Hochschule* (later on *University of Stuttgart*) who had been able to involve a number of colleagues and assistants, doctoral as well as graduate students, into the laser project. This gave rise to the possibility that the three different approaches to quantum-mechanical laser theory could be executed simultaneously by the Stuttgart School. These are the Heisenberg-Ansatz using the Langevin-formalism, the Schrödinger-Ansatz by means of the density matrix equations and the route via the Fokker-Planck-equation. Haken outlined the different routes and presented them synoptically in graphical fashion in his seminal work[275] “Laser Theory“. We show the illustration in Figure 6.

[275] (Hermann Haken, 1970).

In 1963 Haken appointed his first assistant Hannes Risken. He had studied physics at the *RWTH Aachen* and finished his studies with a thesis in solid state physics on “Zur Theorie heißer Elektronen in Many-Valley-Halbleitern“[276] in 1962. Risken won a grant from the *Deutsche Forschungsgemeinschaft* (DFG) and moved on to Stuttgart where Haken inspired him with laser theory. In company with Wolfgang Weidlich, Risken had been the most important collaborator of Haken in his first Stuttgart period. Risken stayed for eight years in Stuttgart and, after having written his professional thesis on “Zur Statistik des Laserlichtes“[277], received a call to the physics chair of the newly founded *University of Ulm*, which he accepted in 1971.[278]

Because Risken, with his DFG grant, was not on the institute payroll, Haken could offer another assistant position to Wolfgang Weidlich in 1963. This strengthened the research capacity in Stuttgart markedly. Haken and Weidlich knew each other from their time in Erlangen, where Weidlich had been assistant, after Haken had received the status of a “Privatdozent“. In 1959 Weidlich went back to Berlin, from which he had come, to finish his doctoral studies. Three years later he received his degree, writing a thesis on a topic in quantum field theory.[279] Then, early in 1963, Weidlich’s scientific mentor, the theoretical physicist Günther Ludwig, accepted a call to the physics chair at the *University of Marburg*. Haken, who appreciated the personal qualities of Weidlich and was also looking for colleagues, approached him. He remembered the situation in an interview:

> “I was acquainted with Weidlich through our joint assistant time in Erlangen. He then went back to Professor Ludwig in Berlin. Afterwards, early in the 1960s, it was not clear how his professional career would develop. Thank god I had to fill in an assistant position in Stuttgart and, valuing Weidlich highly as a scientist and in his personality, I offered the position to him in [19]63, which he finally accepted. […]
> Being in Stuttgart he worked his way into laser theory enthusiastically („he was on fire“). Coming from the United States in 1960 I started to develop laser theory. […] I organised a regular seminar on this topic in my office at the Azenbergstrasse. Regularly Weidlich and others had been participants. That is how we started our collaboration. I persuaded the laser subject with the quantum-mechanical Langevin-equations, Risken, whom we mentioned earlier,

276 “Theory of hot electrons in many-valley semi-conductors”.

277 ”On the statistics of laser light“.

278 Cited following (Albrecht, 1997), p. 236, Footnote 337 and Archiv-info des Deutschen Museums 1. Jg. Heft 1 (2000). Findbuch Nachlass Hannes Risken (1934-1994); Signature NL 131.

279 Wolfgang Weidlich: „Die inäquivalenten Darstellungen der kanonischen Vertauschungsrelationen in der Quantenfeldtheorie“, Dissertation, FU Berlin 1962.

> interpreted it semi-classically with the Fokker-Planck-equation and Weidlich introduced an aspect of his own, the density matrix-equation or, as it is called sometimes, the master-equation“.[280]

Haken had been called to the TH Stuttgart, being a well-known solid state theorist and specialist in exciton theory. We were therefore not surprised to learn that the first diploma students of Haken worked in this field.[281] Already in 1964 Herwig Sauermann (born 1938) had been the first to finish his studies with a diploma thesis in laser theory.[282] The cooperation with Herwig Sauermann, who later also did his Ph.D. with Haken[283], played an important part in Haken’s work on semi-classical laser theory[284]. It had been Sauermann who represented the ideas of the Stuttgart School at the summer schools in Varenna in 1963, and at Les Houches in face of the US-American physicists.

Only three years after his appointment in Stuttgart Haken received two offers of physics chairs at the Universities of Münster and Bonn. In the course of retention negotiations that were finished at the end of the year 1963, Haken was able to allocate another permanent assistant position to his institute and to redouble the funds for scientific supporting staff.

The former assistant position was converted into a senior assistant position that was awarded to Hannes Risken in 1965. On top of that, the funds for guest professors were increased. The guest professorship position had been a matter very close to his heart.

Haken was deeply impressed by his experience of collaboration with Walter Schottky and his colleagues at the Siemens laboratory during his Erlangen time. Having seen the positive effects of the interaction between industry scientists and academia in the USA the ability to constantly exchange ideas with renowned scientists in his field was very important. As early as 1960 when he negotiated the conditions of his professorship at the *Technische Hochschule Stuttgart* he had ensured that funds for a semi-annual guest professorship position had been granted. In 1963 the funds were increased to 27,000 DM per annum. Haken used this money to invite well known scientists to Stuttgart, such as Rudolf Haag of the *University of Illinois* and Y. Toyozawa of the *University of Tokyo*, as well as his friend Wolfgang Kaiser.

---

280 Interview with Hermann Haken 16.11.2010, page 6.

281 Hartmut Haug (1963); Dieter Forster (1964); Roland Hübner (1964); Manfred Lang (1965). See also Appendix …

282 Herwig Sauermann (1964).

283 Herwig Sauermann: „Theorie der Dissipation und Fluktuationen in einem Zwei-Niveau-System und ihre Anwendung auf den optischen Maser“, Dissertation TH Stuttgart 1965; (H. Sauermann, 1965).

284 See chapter 5d and 5e for details.

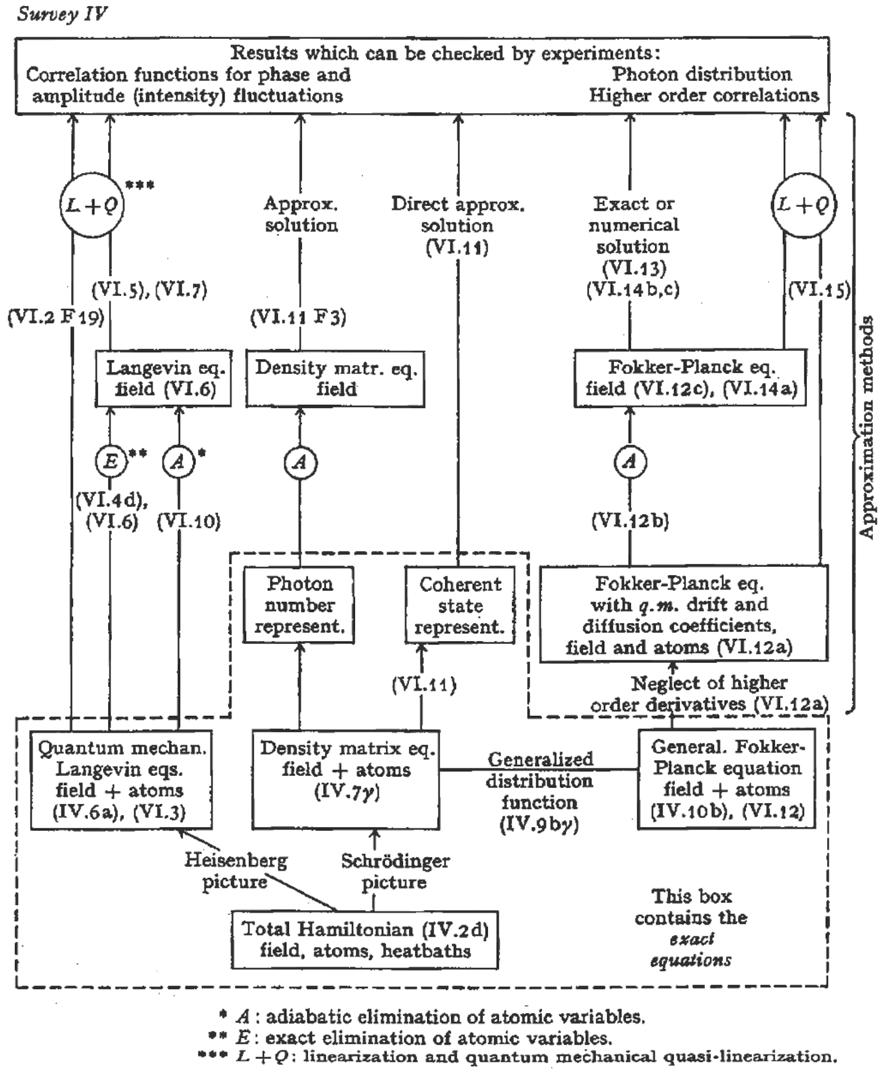

Fig. 8 Representation of the mathematical treatment of the quantum-mechanical laser theory. All three possible methods had been dealt with by the Stuttgart School. (from (Hermann Haken, 1970).

Kaiser has been one of the pioneering researchers in experimental laser physics. In consultation with Haken he used this time to finish his habilitation treatise. Immediately afterwards he received the offer of an experimental physics chair at the *Technische Hochschule München*. Haken remembered the situation:

> “During the six months he [Wolfgang Kaiser] had been in Stuttgart [being guest professor], he undertook two important

> experiments. And he had two graduate students[285], that was great. He gave a speech at the annual German Physical Society Association meeting. This talk had been attended by Maier-Leibnitz[286] from Munich. Afterwards he immediately called him to Munich".[287]

The better financial resources allowed for an expansion of his research activities. New students and co-workers were acquired: Christhard Schmid, Robert Graham, Fritz Haake and Robert Hübner reinforcing the team of Haken, Risken and Weidlich. Together with his collaborators, Haken now pushed his investigations concerning a fully quantized laser theory. His co-worker Wolfgang Weidlich recalled:

> "I had worked on relativistic quantum theory before: the so-called second quantization. It was important not to stop at the Dirac equation but to work on with the second quantization. Then you are dealing immediately with a multi-particle system. That is necessary if you want to make diversifications. I already knew how to deal with the problem in a relativistic way. It was very nice to see that Haken also mastered the second quantization. In terms of Heitler.
>
> […] Haken knew all about it. And with the second quantization, with creation- and annihilation operators, he held the key to "quantize" the laser problem, which – I think – the Americans did not. [Using the second quantization formalism] one quantizes the atoms as well as the photons - where the relativistic "Ansatz" is inherent – and their interactions. In the Heisenberg picture you then see just how to introduce the dynamics, and the equations became clear. From a present day perspective this has been a straight forward procedure".[288]

In the years from 1963 until 1970 the Stuttgart School published no less than 58 articles on laser theory and related areas. Table 5 displays the wide range of the publications.

---

[285] Dieter Pohl: „Einige Untersuchungen über die Ausstrahlungseigenschaften von Festkörperlasern", unv. Diplomarbeit TH Stuttgart 1964. („Some experiments on the emission properties of solid state lasers". Diploma thesis).

[286] Heinz Maier-Leibnitz (1911 -2000) was a highly influential German nuclear physicist and long-time president of the German Research Association. Professor at the *Technische Universität München*. Retired in 1974.

[287] Interview H. Haken 21.9.2010, page 23.

[288] Interview W. Weidlich 18.1.2011, page 12.

Table 5 List of the publications of the Stuttgart School concerning Laser Theory during the years 1963 – 1970

Nr.	Year	Authors	Title and place of publication
1	1963	H.Haken, H. Sauermann	„Nonlinear Interactions of Laser Modes “. Zs. für Physik **173** (1963), 261 - 275
2	1963	H.Haken, H. Sauermann	"Frequency shifts of Laser Modes". Zs. für Physik **176** (1963), 47 - 62
3	1963	H. Haken, E. Haken	"Zur Theorie des Halbleiterlasers". Zs. für Physik **176** (1963), 421-428
4	1964	H. Risken	"Calculation of laser modes in an active Perot-Fabry-Interferometer." Zeitschrift für Physik **180** (1964), 150-169
5	1964	H. Haken	"A Nonlinear Theory of Laser Noise and Coherence I". Zs. für Physik **181** (1964), 96 - 124
6	1964	H. Haken, H. Sauermann	"Theory of laser action in solid-state, gaseous and semiconductor systems". in: (Miles, P.A. Hrsg.) Quantum electronics and coherent light, Proc. Int. Summerschool "Enrico Fermi" XXXI (1964), S. 111 - 155
7	1964	H. Haken	"Theory of Coherence of Laser Light". Phys. Rev. Lett. **13** (1964), 329
8	1964	H. Haken, E. Abate	„Exakte Behandlung eines Laser-Modells“. Zs. für Naturforschung **19a** (1964), 857
9	1965	H. Haken	"A Nonlinear Theory of Laser Noise and Coherence II." Zs. für Physik **182** (1965), 346 - 359
10	1965	W. Weidlich, F. Haake	"Coherence-properties of the Statistical Operator in a laser model", Zeitschrift für Physik **185** (1965), 30-47
11	1965	H. Haken, Der Agobian, M. Pauthier	„Theory of Laser Cascades“.Phys. Rev. **140** (1965), A 437
12	1965	W. Weidlich, F. Haake	"Master-equation for the Statistical Operator of solid State laser", Zeitschrift für Physik **186** (1965), 203-221
13	1965	H. Haken	„Der heutige Stand der Theorie des Halbleiterlasers“. Advances in Solid State Physics **4** (1965), 1 - 26
14	1965	H. Sauermann	„Dissipation und Fluktuationen in einem Zwei-Niveau-System“. Zeitschrift für Physik **188** (1965), 480-505

Table 5 (*continued*)

Nr.	Year	Authors	Title and place of publication
15	1966	H. Haken, W. Weidlich	"Quantum Noise Operators for the N-Level-System". Zs. für Physik **189** (1966), 1 - 9
16	1966	H. Haken	"Theory of Noise in solid state, gas and semiconductor lasers". IEEE Journ. of Quantum electronics **QE 2** (1966), 19
17	1966	H. Sauermann	„Quantenmechanische Behandlung des optischen Masers." Zeitschrift für Physik **189** (1966), 312-334
18	1966	C. Schmid, H. Risken	"The Fokker-Planck equation for quantum noise of the AZ-level System ." Zeitschrift für Physik **189** (1966), 365-384
19	1966	H. Haken	"Theory of Intensity and Phase Fluctuations of a Homogeneously Broadened Laser". Zs. für Physik **190** (1966), 327
20	1966	H. Risken	"Correlation function of the amplitude and of the intensity fluctuation for a laser model near threshold." Zeitschrift für Physik **191** (1966), 302-312
21	1966	H. Risken, C. Schmid, W. Weidlich	„Quantum fluctuations, master equation and Fokker-Planck equation." Zeitschrift für Physik **193** (1966), 37-51
22	1966	H. Risken, C. Schmid , W. Weidlich	„Fokker-Planck equation. Distribution and correlation functions for laser noise". Zeitschrift für Physik **194** (1966), 337
23		H. Haken, V. Arzt, H. Risken, H. Sauermann, Ch. Schmid and W. Weidlich	"Quantum Theory of Noise in Gas and Solid State Lasers with an Inhomogeneously Broadened Line". Zs. für Physik **197** (1966), 207
24	1967	R. Bonifacio, F. Haake	"Quantum mechanical masterequation and Fokker-Planck equation for the damped harmonic oscillator". Zeitschrift für Physik **200** (1967), 526-540
25	1967	H. Risken, H. D. Vollmer	"The influence of higher order contributions to the correlation function of the intensity fluctuation in a Laser near threshold." Zeitschrift für Physik **201** (1967), 323-330
26	1967	H. Haken, W. Weidlich, H. Risken	"Quantummechanical Solutions of the Laser Masterequation I". Zs. für Physik **201** (1967), 396 - 410

Table 5 (*continued*)

Nr.	Year	Authors	Title and place of publication
27	1967	H. Haken, W. Weidlich, H. Risken	"Quantummechanical Solutions of the Laser Masterequation. II". Zs. für Physik **204** (1967), 223
28	1967	H. Risken , H. D. Vollmer	"The transient Solution of the laser Fokker-Planck equation." Zeitschrift für Physik **204** (1967), 240-253
29	1967	H. Haken, H. Haug	"Theory of Noise in Semiconductor Laser Emission". Zs. für Physik **204** (1967), 262 - 275
30	1967	H. Haken, W. Weidlich	"A theorem on the calculation of multi-time-correlation functions by the single-time density matrix". Zs. f. Physik **205** (1967), 96 - 102
31	1967	H. Haken, W. Weidlich, H. Risken	"Quantummechanical Solutions of the Laser Masterequation. III". Zs. für Physik **206** (1967), 355 - 368
32	1967	H. Haken	"Dynamics of Nonlinear Interaction between Radiation and Matter". In: "Dynamical Processes in Solid State Optics" (ed. R. Kubo and H. Kamimura), Syodabo, Tokyo and W.A. Benjamin, Inc. New York , S. 168 - 194
33	1967	H. Haken, H. Sauermann, Ch. Schmid, H.D. Vollmer	"Theory of Laser Noise in the Phase Locking Region". Zs. für Physik **206** (1967), 369 - 393
34	1968	H. Haken, R. Graham	"Theory of Quantum Fluctuations of Parametric Oscillator". IEEE Journ. of Quantum Electronics **QE4** (1968), 345
35	1968	H. Haken, M. Pauthier	"Nonlinear Theory of Multimode Action in Loss Modulated Lasers". IEEE J. of Quantum Electronics **QE4** (1968), 454
36	1968	H. Haken, R. Graham	"The Quantum Fluctuations of the Optical Parametric Oscillator. I". Zs. für Physik **210** (1968), 276 - 302
37	1968	R. Graham	"The quantum-fluctuations of the optical parametric oscillator II ". Zeitschrift für Physik **210** (1968), 319-336
38	1968	H. Haken	"Exact Stationary Solution of a Fokker-Planck Equation for Multimode Laser Action". Physics Letters, **27A** (1968), 190

Table 5 (*continued*)

Nr.	Year	Authors	Title and place of publication
39	1968	R. Graham	“Photon statistics of the optical parametric oscillator including the threshold region. Transient and steady State Solution”. Zeitschrift für Physik **211** (1968), 469-482
40	1968	H. Haken	“Exact generalized Fokker-Planck equation for Arbitrary Dissipative Quantum Systems”. Physics Letters **A28** (1968), 286
41	1968	H. Haken, R. Graham, F. Haake, W. Weidlich	“Quantum Mechanical Correlation Functions for the Eletromagnetic Field and Quasi-Probability Distribution Functions”. Zs. für Physik **213** (1968), 21 - 32
42	1968	H. Haken, R. Graham	“Quantum Theory of Light Propagation in a Fluctuating Laser-Active Medium”. Zs. für Physik **213** (1968), 420 - 450
43	1968	K. Kaufmann, W. Weidlich	”Mode interaction in a spatially inhomogeneous laser”. Zeitschrift für Physik **217** (1968), 113-127
44	1969	H. Haken	“Exact Stationary Solution of a Fokker-Planck Equation for Multimode Laser Action Including Phase Locking”. Zs. für Physik **219** (1969), 246 - 268
45	1969	H. Haken, R. Graham	“Analysis of Quantum field statistics in Laser media by means of functional stochastic equations”. Physics Letters **A29** (1969), 530
46	1969	H. Haken	“Exact Generalized Fokker-Planck equation for Arbitrary Dissipative and Nondissipative Quantum Systems”. Zs. für Physik **219** (1969), 411 - 433
47	1969	F. Haake	“On a non-Markoffian master equation I. Derivation and general discussion”. Zeitschrift für Physik **223** (1969), 353-363
48	1969	F. Haake	„On a non-Markoffian master equation. Application to the damped oscillator.” Zeitschrift für Physik **223** (1969), 364-377
49	1969	F. Haake	„Non-Markoffian effects in the laser“. Zeitschrift für Physik **227** (1969), 179-194
50	1970	H. Haken	“Theory of Multimode Effects including Noise in Semiconductor lasers”. IEEE J. of Quantum Electronics **QE6** (1970) , 325

Table 5 (*continued*)

Nr.	**Year**	**Authors**	**Title and place of publication**
51	1970	H. Haken, R. Graham	"Functional Fokker-Planck Treatment of Electromagnetic Field Propagation in a Thermal Medium". Zs. für Physik **234** (1970), 193 - 206
52	1970	H. Haken, R. Graham	"Functional Quantum Statistics of Light Propagation in a Two-Level System". Zs. für Physik **235** (1970), 166 - 180
53	1970	H. Haken, R. Graham, W. Weidlich	"Flux Equilibria in Quantum Systems far away from Thermal Equilibrium". Physics Letters **32A** (1970), 129
54	1970	H. Haken	„Laserlicht - Ein neues Beispiel für eine Phasenumwandlung?". Schottky's Festkörperprobleme **X**, Pergamon, Vieweg 1970, S. 351 - 365
55	1970	H. Haken, R. Graham	"Laserlight - First Example of a Second-Order Phase Transition Far Away from Thermal Equilibrium". Zs. für Physik **237** (1970), 31 - 46
56	1970	H. Haken	"Laser Theory". Handbuch der Physik (Flügge, S. Hg.) Band XXV/2C. Springer, Berlin-New York 1970.
57	1970	H. Haken, R. Graham	"Microscopic Reversibility, Stability and Onsager Relations in Systems far from Thermal Equilibrium". Physics Letters **33A** (1970), 335
58	1970	H. Haken	"Quantum Fluctuations in Nonlinear Optics". Opto-Electronics **2** (1970), 161 - 167

In 1965 Haken took over the task of writing a detailed review article for the new edition of the renowned *Handbuch für Physik*. His personal aim was to present a encompassing survey of laser theory in all its facets: rate equations, semi-classical theory and quantum-mechanical laser theory, referring to the original works.

This turned out to be a very time consuming and exhausting effort. Haken and his collaborators were very much absorbed in this task during the years 1966 and 1967. Weidlich remembered his feelings:

> "To write the book responsible-minded Hermann Haken ordered the file of the original laser articles that had been published since 1960. This file comprised about 6,000 publications to which about 100 articles were added monthly. Even the strongest would be knocked down by this.

Whilst concentrating on the most important contributions, to which belonged his own works and that of the Stuttgart Laser School – about 25 doctoral thesis – he would not listen to his wife. Writing the book, night after night he drank too much coffee, until a "vegetative dystonia" set in, for which an impolite euphemism is burnout. But his strong human nature and the recreational surroundings of the Black Forest made it possible: Hermann Haken recovered rather quickly"![289]

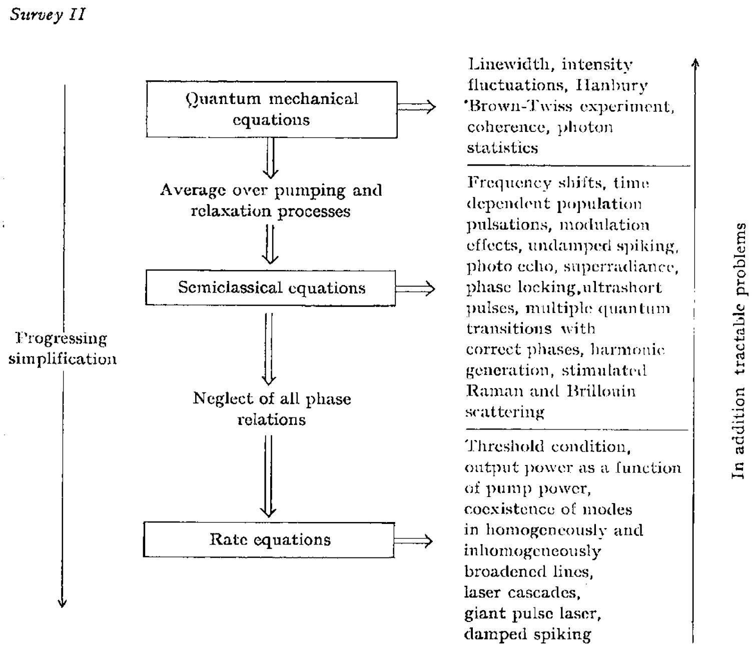

Fig. 9 Haken's survey on the increasing correctness of the different approaches to laser theory and the parameters that could be determined and checked experimentally.[290]

The "file of the original works" mainly included four collective volumes: the anthology "*Laser Literature" – A permuted Bibliography 1958 – 1966*" by Edward Ashburn[291], the contents of which had been previously published in the issues of the "*Journal of the Optical Society of America*" from May 1963 until

[289] W. Weidlich in his „Laudatio inofficialis. Unpublished manuscript written on the occasion of Hermann Hakens 80th birthday. (Archive Haken).

[290] (Hermann Haken, 1970), p. 8.

[291] (Ashburn, 1967).

January 1967; the book "*Laser Abstracts*" edited by A. Kamal[292], "*The Laser Literature – An Annotated Guide*" by K. Tomiyasu[293] and the German book "*Laser – Lichtverstärker und –Oszillatoren*" written and compiled by D. Röss.[294]

While Haken was working on the handbook article he received another offer of the theoretical physics chair of the *Universität München*.[295] Again, in the course of the following retention negotiations, he was able to extend his institute personally and financially. Another assistant lecturer position, more funds for guest professors as well as a new tenured professorship on theoretical solid state spectroscopy (including two assistant posts) were allocated. At the same time, in summer 1966, due to the "Hochschulreform" (reform of the universities) Wolfgang Weidlich was appointed to the newly constituted Second Chair of Theoretical Physics at the TH Stuttgart. It had been these positive developments that allowed Haken to provide appropriate positions to his most able co-workers Risken, Graham, Haake, Sauermann and Weidlich, thus linking them to his institute.

At last Haken had to pay attention to his diverse activities. Apart from his stressful retention negotiations and his normal duties as professor he had been traveling to and participating at the 4th Quantum Electronics Conference in Arizona (USA) in April. Only three months later he lectured in Japan and then plunged into work for the handbook article on laser theory. These activities finally surpassed his physical and mental strength. During the winter 1966 he faced burnout and had to take a forced break, so that the manuscript for the handbook article could not be finished completely.

To bring the manuscript to a close Haken applied for a research sabbatical during the summer term 1967.

> "Hereby I ask for a research sabbatical during the summer term to come, keeping my full earnings. […] Since September 1960 I have been appointed to my chair [of theoretical physics] at the *Technischen Hochschule Stuttgart* and have not availed myself of several offers for guest professorship, taking a research sabbatical. For some time past I have been occupied in writing an article on the laser for a handbook, having by far overrun the manuscript deadline due to strain. Moreover I greatly have fallen behind with my research on laser theory. On these two grounds I am badly dependent on having a focus on writing the handbook article and on the other work during the summer term".[296]

292 (Kamal, 1964).
293 (Tomiyasu, 1968).
294 (Röss, 1966).
295 Personal file Hermann Haken; University Archive Stuttgart.
296 Letter to the TH Stuttgart dated 8.2.1967; Personal file Haken.

This application was supported by the director of the mathematics and physics section and was forwarded to the Dean of the Faculty of Natural Sciences and the Humanities. The latter added:

> "Herr Haken had expressly avoided naming his illness as the reason for his application. One should be aware of the fact that Herr Haken has had a severe breakdown due to a circulation disorder and exhaustion during this term, from which he has not yet recovered completely".[297]

After the request was initially turned down, with the renewed intervention of Wolfgang Weidlich it was finally granted.[298]

Immediately after his recovery in spring 1967 Haken continued his research activities. He worked jointly with Weidlich and Risken on the seminal article "*Quantummechanical Solutions of the Laser Masterequation*" that appeared in a series of three contributions in the *Zeitschrift für Physik* in the same year. In 1967, the fundamental papers of Melvin Lax, as well as that of Marlan Scully and Willis Lamb, were published, indicating the consolidation of the first phase of the quantum-mechanical laser theory that was finally achieved during the year 1968.

5.7 Synopsis of Laser Theory in Book Form; ca. 1970

As we have shown in the preceding chapter, the essential elements of quantum-mechanical laser theory had been arrived at in the summer of 1968. Hermann Haken finally finished the manuscript on "*Laser Theory*" for the handbook in February 1969. Its delayed release due to his illness had at least one advantage: he could include the latest developments of the years 1967 and 1968 in the manuscript:

> „The main part of the present article had been completed in 1966, when I became ill. I have used the delay to include a number of topics which have developed in the meantime, e.g. the Fokker-Planck equation referring to quantum systems and the theory of ultrashort pulses."[299]

The raw manuscript for the laser article had been ready in its essential parts in spring 1967. Robert Graham, describing the situation, confirmed this in his interview:

---

[297] Letter dated 16.2.1967; Personal file Haken.

[298] Letter from Wolfgang Weidlich to Reg. Dir. Kammerer dated 10.4.1967; Personal file Haken.

[299] (Hermann Haken, 1970) Preface.

> "As I wrote my diploma thesis [during the winter term 1966/1967] Haken became seriously ill. … The article [Handbook – article Laser Theory] existed in its first version – in a raw copy – with which I could start. He [Haken] had already given it to me when I started with my diploma work. Of course, in the beginning, I had to plough through [the manuscript]. It was the first text from which I learned the subject".[300]

Even some time before 1969 Melvin Lax had left the race. The "*Brandeis Lectures on Statistical Physics, Phase Transition and Superfluidity*" written in 1968, constituted the first detailed review of his works.[301] The Brandeis Summer School in Theoretical Physics had been held at the *Brandeis University* in Waltham/Boston (Massachusetts) in June and July 1966. In his "article", comprising not less than 200 pages, Lax summarised the results of his six "noise"- and, until then – twelve "quantum-noise" papers.[302] The most recent reference was to a research paper that had appeared in volume 172 of the *Physical Review.* The issue in question had been published in January 1968, therefore the manuscript of the Brandeis Lectures could have not been finished before that date. Comparing his results to the work of the other laser schools Lax came to a well-rounded conclusion:[303]

> „Lamb and Scully made a calculation of the density matrix field + atoms and adiabatically eliminated the atoms at the start. […] When our equation […] is translated into an equation for the density matrix […] we find (see for example QX) complete agreement with corresponding equations of Scully and Lamb. […]
> Haken and coworkers have introduced a quantum Langevin procedure similar to ours. However, they proceeded to introduce a classical Fokker-Planck equation which ignores the commutators. […] Risken repeated this work for the lowest four modes obtaining results in excellent agreement with ours.
> In summary, no disagreements seem to remain, in the discussion of noise and coherence in masers [optical masers = laser]. Our work, moreover, provides a bridge between the Lamb-Scully and Haken treatments."

The comprehensive review of his Brandeis lectures constituted a kind of legacy from Lax with respect to the subject of noise and coherence. Afterwards he again

---

300 Interview with Robert Graham 29.3.2011. (Archive Haken (University Archive Stuttgart)).
301 (Melvin Lax, 1968).
302 See the table on the Lax „noise"-articles on page 73–74
303 (Melvin Lax, 1968), pp. 295-296.

turned towards the problems of phonon transport in solid state physics. This subject was of great interest for semi-conductors and was investigated in detail experimentally at the *Bell Laboratories*. After having worked for sixteen years with *Bell Labs*, Lax accepted a physics chair at the *City College* of the *New York City University* in 1971.

Finally it was his long time co-worker William H. Louisell who wrote a monograph of their mutual work in 1973.[304] In the preface of his book, titled “*Quantum Statistical Properties of Radiation*”, Louisell wrote:

> „The invention of the laser was directly responsible for a tremendous development in the field of nonequilibrium quantum statistical mechanics. Although many people have made important contributions, W. E. Lamb, Jr., of Yale University, H. Haken of the Technische Hochschule in Stuttgart, Germany, and M. Lax of Bell Telephone Laboratories and City College of New York and their collaborators have been the trail blazers.”

In 1974, as the last book in this “series“, the textbook “*Laser Physics*“ written by Lamb, Scully and Sargent III was published.[305] Written from the very beginning as a text book for university use it had a significant impact in English speaking countries. Within only three years it achieved three print runs and is regarded as the standard reference on laser theory, especially in the United States. Having the character of a textbook and, as different from Haken in his handbook, there are only few references to the original publications. This had been done deliberately and the authors justify themselves in the preface of the book:

> „[…] The laser theory discussed in this book tends to follow the approaches of the Lamb school. Parallel work of the Bell Telephone Laboratories group has been presented in the book by W. H.Louisell, “Quantum Statistical Properties of Radiation”, (John Wiley & Sons, New York, 1973), while H. Haken’s contribution, “Laser Theory,” in Encyclopedia of Physics, Vol. XXV/2c, edited by S. Flügge, Springer-Verlag, Berlin, 1970; also Chap. 23 in Laser Handbook, gives a very complete account of the Stuttgart work.
> In keeping with the text format, no uniform attempt is made to assign credit to the original papers.”

In addition to these three comprehensive monographs by the leading laser theoreticians, the publication of a multi-volume encyclopaedia, the “*Laser*

---

[304] (Louisell, 1973).
[305] (Sargent III, Scully, & Lamb, 1974)

Handbook“ commenced in 1972.[306] It was the first effort to cover the broad experimental and theoretical results of laser research. The proposal for such an undertaking had come from Hermann Haken.[307] Haken contributed the article on “The theory of coherence, noise and photon statistics of laser light” and Sargent III and Scully wrote on the “Theory of Laser Operation“.

The achievements in laser theory by Hermann Haken and his Stuttgart School were finally acknowledged by the American scientists. They manifested themselves not least by the fact that Haken was elected into the programme committee of the 3rd Rochester-Conference “*Coherence and Quantum Optics*”, held in 1973. Other members included, among others, Nicolas Bloembergen and Melvin Lax.

5.8 Summary of Laser Theory

The history of the development of the quantum-mechanical laser theory has, as yet, not been described in detail. Bromberg and Bertolotti[308], in their comprehensive overviews of the history of the laser, nearly make no mention of it. Not only did they ignore Hermann Haken and the Stuttgart School, even the American theoreticians Lax, Louisell and Scully were not mentioned. According to their narrative, laser development occurred on an experimental basis alone, unrelated to theoretical considerations. This could not have happened, because many physics effects of the laser are only to be understood by means of quantum mechanics. Quantum-mechanical effects play a decisive role in spectroscopy precision measurements.

This can be shown by a succinct piece of information in Bertolotti’s book from 1983:[309]

„ Later, in 1966, Lamb et al. finally established the quantum theory of lasers“

that completely led astray too.

One can distinguish four different stages in the chronology of laser theory development, as we have briefly shown.

The first phase was that of maser research. This preliminary work had been dominated by the American physicists Townes and Schawlow, as well as the Russian scientists Basov and Prokhorov. The decisive stimulus, theoretically and experimentally, was laid by the seminal work of Townes and Schawlow in 1958.[310] When in 1960 Maiman demonstrated that the laser effect could be achieved by many other laboratories, the Bell Labs in particular demonstrated its existence in different materials. In this second step the theoretical efforts concentrated on classical rate equations. Here the occupation numbers of the different atomic levels play the crucial role.

306 (F. Arecchi & Schulz-Dubois, 1972).
307 (F. Arecchi & Schulz-Dubois, 1972), Vol. 1 Page XI.
308 (Joan Lisa Bromberg, 1991), (Mario Bertolotti, 2005).
309 (Mario Bertolotti, 1983), p. 238.
310 (A. Schawlow & Townes, 1958).

From 1962 until 1964 Willis Lamb Jr. and Hermann Haken developed, independently of each other and nearly simultaneously, a semi-classical laser theory, denoting the third step. These theoretical approaches were then discussed intensely at different conferences and "summer schools".

The final stage then was triggered by Hermann Haken in 1964, pointing out and explaining the crucial difference in the radiation behaviour of the laser below i.e. above laser threshold. Together with his co-workers and students, Haken rapidly investigated different aspects of laser radiation especially at and above threshold. Line-width, fluctuations and photon number of the radiation were determined theoretically. This had been done in competition with Melvin Lax and William Louisell, American theoreticians from Bell Lab. In the past they had made important contributions to the theory of noise and fluctuations, now applying their results to the laser where they played an important and crucial role. At the same time, and in parallel, the scientific subjects of non-linear optics were developed by Nicolas Bloembergen and Emil Wolf and his colleagues at *Rochester University* as well as the theory of coherent radiation. The latter was especially advanced by Roy Glauber. During the 1970s and 1980s these efforts converged. The mathematical methods to describe the quantum-mechanical and stochastic effects of these fields are quite analogical and finally coalesced into the field of research called non-linear quantum optics.

Analysing the chronological order of the publication of the different papers, one can understand Haken's statement:

> "Back then it was a strong competition … but one has to say explicitly, and we are still proud of it, that in Stuttgart we had always been the first to publish the theories, something the Americans will not admit voluntarily or not at all".[311]

Haken, Risken and Weidlich, representing the Stuttgart School, consistently published some months prior to their American colleagues. But it is also true that in between submitting the papers, revising and the final publication date there was often overlap.

There is one thing that is entirely singular and exceptional in the work of the Stuttgart Laser School, and that is dealing simultaneously with laser theory through three different approaches: the Heisenberg-model, the density matrix or master equation "Ansatz" and using the Fokker-Planck equation. This can only be ascribed to the rare liaison of three distinguished physicists: Hermann Haken, coming from solid state physics and exciton research; Wolfgang Weidlich, who brought from Berlin his knowledge of the mathematical tools of quantum field theory, and Hannes Risken immersing himself in the use of the Fokker-Planck formalism. A comparable situation of this character did not happen in the United States.

---

[311] Cited after (Albrecht, 1997), p. 241.

If we ask ourselves why the results and efforts of the Stuttgart Laser School did not subsequently receive the attention it deserved, we are left with speculations. One factor that should not be underrated might be its final publication in book form. Haken published his detailed review in the new edition of the renowned "*Handbuch der Physik*", thoroughly citing all relevant papers. These handbooks normally are very expensive, one will find them in libraries and often you cannot borrow them. Therefore students only rarely consult them in depth and they do not use it in their usual studies. Scully, Sargent III and Lamb on the other hand published their work in the English language, explicitly written as a textbook for students. Of course, the book was widely disseminated. Even though they mentioned the different laser theory schools in their foreword, as time went by this awareness was lost in the users of the book.

In the years before data based publishing was common in the physical sciences, bibliographies played an important role, when a scientist wanted to follow the development of a special area of research. Therefore it seems striking that in the early years of laser research the German journal *Zeitschrift für Physik* had not been referenced in one of the leading American bibliographies, and thus the articles that appeared in this journal had not been cited. In comparison, the publication of Kiyo Tomiyasu[312] had been the basis of five comprehensive bibliographies on lasers that had been published by the renowned "*IEEE Journal of Quantum Electronics*" from 1965 until 1967. Subsequently the developments of the Stuttgart Laser School, regularly publishing in the *Zeitschrift für Physik,* went unnoticed by some American laser scientists.

Nevertheless the work of Hermann Haken and his co-workers was clearly recognised in the circle of experts, especially after the publication of his review article in the *Handbuch der Physik*. This can also be seen in the many tenured professorships in theoretical physics that his students later received. Notably Fritz Haake and Robert Graham made significant contributions to the fields of quantum optics and stochastics. Graham finally was honoured with the *Max Planck* medal of the *German Physical Society*, the highest award a theoretical physicist can receive.[313]

Laser theory set the course of Hermann Haken for his further research programme. Late in the 1960s, recognition that the character of the laser radiation was completely different below and above threshold convinced him that the laser is a paradigm for phase transition.[314] This led him to intense activity with the theory of self-organising processes, far away from thermodynamic equilibrium. These so called (thermodynamically) open processes are dominant in nature and Haken finally led to the foundation of the "new science" of synergetics. This Greek word means a "theory of working together". Nevertheless it still holds true that the laser is the "trailblazer of synergetics" as he declared in a talk presented at the 4th Rochester conference in 1977.[315]

[312] (Tomiyasu, 1968).
[313] Haken received the Max Planck medal already in 1990.
[314] (Graham & Haken, 1970).
[315] (Mandel & Wolf, 1978), pp. 49-62.