Chapter 4
On Hagedorn

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Abstract Theoretical physics is not based on dogmatic truths. It is the search for ever improving formal constructions that can agree with the new experimental discoveries. At each step new unknowns appear, new domains are opened. This is the immense fascination of fundamental research.

4.1 In Times Past

When CERN was created 60 years ago I was a student of physics. The technology applied in the creation of the CERN particle accelerator and the super powerful computers was the frontier of excellence in the years after the second world war. The nucleon-nucleon collision in the region of the GeV per particle is the creation in the laboratory of processes not existing on planets and on stars. In the Earth we have molecular interactions in the range of fractions of eV, from extremely cold to fire. In the Sun we have nuclear interactions in the range of MeV, inside the core. With collisions in the GeV region we explore interactions that are beyond the dynamics of the known island of permanence, stars and planets, therefore we explore something that belongs to cosmology. The transition from nuclear to subnuclear physics is not only the search for high energy scale of interactions, or small space scale of structures, but is a new challenge to the dualism microscopic and macroscopic, quantum theory and gravitation.

I met Hagedorn at CERN in the years 1970–1973. He was a great man who loved the truth, not the authority. His mind was rigorous, calm, curious, and wide. He did not sit on his success but continuously extended his horizon of research. His name was connected to the concept of fireball and limiting temperature. Fermi was the first to apply the language of statistical physics for the subnuclear interactions. Hagedorn extended Fermi's approach, taking into account the multitude of hadron resonances.

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He obtained a very satisfactory description of the experimental particle production data produced at CERN. The discovery of Hagedorn's limiting temperature in 1964 happened just in exactly the same year which brought cosmology and the Big Bang to the experimental realm by the observation of the cosmic background thermal photons.

At that time three theoretical approaches coexisted, the analytic S matrix, the Hamiltonian model, and thermodynamics, the work of Hagedorn. The S matrix approach needed a simplicity in the domain of resonances that was not compatible with the experimental data. The Hamiltonian theory developed into the construction of an Hamiltonian with an ever increasing number of discrete symmetries. Cosmology is facing a triple dilemma: gravitation for the understanding of the large scale morphology, quantum formalism for the microscopic world, and thermodynamics that acts in between. Thermodynamics contains the arrow of time, while gravitation and Hamiltonian quantum mechanics contain time reversal symmetry. This is the problem of future physics. Finally notice that the terrestrial biosphere also contains the arrow of time through the immensely complex link of the interaction between the living organisms and the inorganic molecular thermodynamics. I turned my interest to the study of the biosphere. Not easy, not immediate. Other physicists of my generation followed this course. Among the senior scientists that encouraged such turn I can mention Bethe and Hagedorn.

I had the fortune of interacting with Hagedorn in the three years at CERN and also later on. But at this point let me open a parenthesis.

Every important step in the advancement of physics has two articulations: the broader theoretical horizon that is opened, and the technology that is implied in the research itself. Technology has in its turn military and civilian consequences. This is true since the time of Archimedes and his offensive concave mirrors, solar weapons. Each scientific advance leads to a new weapon: the birth of metallurgy moved from swords to guns; modern molecular thermodynamics and exothermic reactions among molecules nourished the development of all kinds of explosives. Then arrives quantum mechanics with the discovery of nuclear reactions, very rapidly exploited in the creation of the fission bomb, and a little later the fusion H-bomb. On the civilian use side, the thermodynamic control of the nuclear exothermic reactions was achieved in the domain of fission, not yet for fusion.

What does this have to do with Hagedorn? In the second half of the twentieth century both the USA and the Soviet Union developed high level laboratories devoted to nuclear weapon research and production. The dream was the subnuclear bomb, a thousand times more powerful than the H-bomb. The eyes were focused on particle accelerators where protons are smashed. The message coming from Hagedorn was very clear: no exothermic reactions, but instead particle fragmentation. Stop to the bombardiers. The impact of these events that I summarize, and that are unknown to the general public, has been very important for the large scale international financing of research. We understand that several young scientists turned their energies to the understanding of complex systems. This phenomenon was particularly relevant in USA and Soviet Union. In particular the research on the biosphere takes strength in those years.

4.2 Wide Field of Interests

I had several conversations with Hagedorn on general subjects which are my preeminent field of interest today: these are the life in the Universe and the understanding of time and evolution. What is life? In some sacred ancient books is a gift of God; later we find the concept of evolution, further on with the birth of quantum photochemistry the concept of biosphere and the deep complexity of genetics can be formulated. This immense domain of problems fascinated Hagedorn and was the attraction of my interaction with him.

Consider the process of star formation and the new stars of second generation which come with planets. The planets are, in the universe, the tiny domains of permanence for the existence of inorganic molecules, and possibly the existence of the fragile complex organic molecules. We are born within the terrestrial biosphere; no wonder if along the millennia we have developed a geocentric vision of life. But modern cosmology forces us to rethink our place in the Universe. Hagedorn's mind was fascinated by these questions.

In 1994 I gave Hagedorn (Fig. 4.1) a copy of my book *Thermodynamics of Complex Systems*. Months later we had a meeting at CERN and he returned the book to me covered with corrections, recalculations, plus handwritten pages and pages of remarks and proposals. The size of the book was doubled. He said: "you

Fig. 4.1 Standing: Rolf Hagedorn—Across of Maurice Jacob and Luigi Sertorio; Between Luigi and Maurice: Ms Mary Bell, next to Maurice Jacob: Mrs Van Hove; On Hagedorn Side Torleif Ericson (*left edge*) and Chris Lewellyn Smith (*bottom edge*) Mrs Helga Rafelski on *left* of Hagedorn and Mrs. Zinoviev on *right*. *Image credit: CERN Image 199406-066-018*

should rewrite it, there is much more to say, I will help with my criticism". Several, also personal, difficulties stepped in, and I was unable to continue in the way he was suggesting. However, the light of his encouragement was extremely important for the continuation of my work since.

This is an example of my personal experience with Hagedorn. This was not the exception but the rule how Hagedorn interacted with his friends, and with his colleagues, even those he had not yet met but who sent him their work asking for his opinion.

My friendship with Hagedorn was deep, and it was with very great personal satisfaction that I organized The Erice meeting in October 1978, where we celebrated his work and his 60th birthday. I could also be present and support in many essential ways the 1994 Divonne meeting where we celebrated Hagedorn's 75th birthday, a splendid fest of science supported by NATO Scientific Affairs Division.

Hagedorn was always available to discuss physics, in every situation. Once, I don't remember the year, we met in his office at CERN and at the end of the afternoon we moved to the parking lot. He was going to drive to his home nearby in France; I was on the way to take my return trip to Torino driving my loved Alfa Romeo. The parking area goodbye developed into a conversation on the definition of boundary for the complex system biosphere, that lasted over one hour. The problem is still open today. And that was the last time I talked with Hagedorn.

4.3 Retrospective

When Hagedorn made his path breaking discovery, CERN was young, about ten years of age, a concentration of talent, creative interactions. Today CERN is 50 years older, has grown to be a revered international organization from which we expect a leadership of excellence. The present work on relativistic heavy ions collision is inspired by the revolutionary ideas of Hagedorn. A flow of ideas and new problems were originated in those beautiful years, and are a challenge for our future.

It is a great honor for me to be able to write these notes in memory of the 50th birthday of the creation of the paradigm of limiting temperature of hadrons, and in this way to contribute to the lasting memory of Hagedorn's path breaking contribution made at CERN. As I have tried to explain the work of Hagedorn had a broad impact, not only limited to the CERN community. I can certainly say that the time of Hagedorn was a great time.