Chapter 5
Hungarian Perspective

István Montvay and Tamás Biró

Abstract Rolf Hagedorn is introduced from the personal perspective of two Hungarian physics generations. A colleague (IM) and a student (TB) recount memories and events from the early-70-s to mid-80-s, and evaluate Hagedorn's impact on present particle and nuclear Hungarian physics community.

5.1 Influence Spreads to Hungary

The Statistical Bootstrap Model was presented by Rolf Hagedorn in the proceedings of the 1974 Balatonfüred Symposium on High Energy Hadron Interactions co-edited by one of us (IM). However, to the best of our memory, Hagedorn never was able to actually visit Hungary. Yet when we look around today, a disproportionately large fraction of Hungarian Physics is engaged in the fields he pioneered. Both the emigrees, as well as those who made their lives in Hungary behind the iron curtain have espoused the soft hadron production and related fields. This mystery has many origins and the best way to address this is by taking under the microscope a few momentary events reported by key eyewitnesses. Maybe our two complementary contributions do not completely answer this question but we make a first step.

Hungary joined CERN in 1992, but Hungarian groups have participated in numerous experiments at CERN almost since its foundation. These collaborations were coordinated by the KFKI Research Institute for Particle and Nuclear Physics (RMKI) and Institute of Nuclear Research (ATOMKI) of the Hungarian Academy of Sciences, of the Departments of Atomic and Theoretical Physics of Loránd Eötvös University in Budapest and the Institute of Experimental Physics of the University of Debrecen. Hungarian research groups have contributed to many experiments at CERN. And, indeed, some theorists including István Montvay could also visit CERN for extended periods of time.

I. Montvay (✉)
DESY, Hamburg, Germany

T. Biró (✉)
Wigner RCP, Budapest, Hungary

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5.2 Memories by István Montvay

I met Rolf Hagedorn in 1972 when I was the first visiting scientist from Hungary invited for one year at CERN. This visit was for me an outstanding possibility to work at one of the leading research institutes of the world. First, I wrote papers on quark and parton models but I was soon fascinated by the theories of multiparticle production in high energy hadron collisions, in particular, by the statistical bootstrap model of fireballs and hadron thermodynamics of Hagedorn which predicted a highest temperature of hadronic matter due to the exponentially increasing density of states.

This "Hagedorn temperature" showed up in the experimentally observed universal transverse momentum distribution of the produced hadrons (mainly pions) at high collision energies. Under the guidance of Hagedorn, I discovered the possibility to explicitly solve the integral equations for fireball decay. (I. Montvay, Phys. Lett. B **42** (1972) 466; Nucl. Phys. B **53** (1973) 521.) With time my collaboration with Hagedorn became more intensive. At the end of my visit at CERN we wrote a paper together on a model study in hadron statistical bootstrap. (R. Hagedorn and I. Montvay, Nucl. Phys. B **59** (1973) 45.)

During the time at CERN and in Geneva I learned a lot, especially on topics related to statistics and thermodynamics. Hagedorn's help was invaluable—not only in physics but also in everyday life in the "western world" to a large extent unknown until then by me and by my wife. At the time the situation in Europe was very different. For example our visas were valid only for Switzerland but not for France where much of CERN is located. Hagedorn had a solution to the problem: i remember how he smuggled us in his car through the French border at Saint-Genis. This was very exciting for us both because we could enjoy Hagedorn's hospitality in Sergy-Haut, and several times in the excellent French restaurants in the surroundings. We realized that though these deeds were somewhat illegal, should we be caught we would not serve time in a gulag. That was a very different world compared to home.

The second time I had the opportunity to work with Hagedorn was in 1978 when stopping at CERN on my way out of Hungary going on "vacation", and I soon settled down together with my family at first in Bielefeld and then in Hamburg at DESY.

I rejoined Hagedorn's team at CERN. We were, three of us together with Johann Rafelski, a very intense and enjoyable collaboration addressing different questions of the thermodynamics of nuclear matter within the framework of the statistical bootstrap model. We worked out a detailed picture of high temperature hadronic phases: a gaseous phase at low nucleon density and a liquid phase at high density. In our work Hagedorn's concept of "highest temperature" was evolving from an absolute highest temperature towards the "highest temperature of hadronic form of matter". In a study of the properties of Hagedorn singularity, Cabibbo and Parisi considered the possibility of its interpretation as a phase transition. This feature, however, was absent in the original Hagedorn's Statistical Bootstrap Model (SBM) they considered.

Our effort extended and modified physical ideas of the SBM allowing us the study of phase boundary. A detailed description of the outcome of our lively discussions at the blackboard in Hagedorn's office at CERN was written down in a nascent format (R. Hagedorn, I. Montvay and J. Rafelski, CERN-TH-2605, Dec 1978, 99 pp) for the Proceedings of the Erice Workshop held in October 1978 on "Hadronic Matter at Extreme Energy Density" (edited by Nicola Cabibbo and Luigi Sertorio, Plenum 1980). This work developed soon into a complete and consistent model description of the phase transition from hadronic to quark-gluonic phase.

While I enjoyed the phenomenological approach taken by Hagedorn and Rafelski, my interest grew in more exact, numerical lattice characterization of the properties of strong interactions. This work took me via Bielefeld to DESY in late 1978. In my work I continued the Hagedorn legacy, but in a very different, much more abstract setting, much different from the intuitive Hagedorn work.

5.3 Tamás Biró Grows up with Hagedorn

I came to strong interaction physics and the nascent field of QGP just when István was moving out of Hagedorn circle to pursue a more exact description of fundamental interaction on lattice. I joined the field and was noticed right away because of my interest in understanding strangeness production, an observable of the quark-gluon plasma phase that appeared in the proposals for relativistic heavy ion experiments made by Hagedorn and Rafelski in 1980. Under supervision of my advisor J. Zimányi I received my diploma in 1980, and my Ph.D. in 1982. To be able to pursue the hot hadron and quark matter with strangeness I had to read the relevant papers and thus I had gained the 1970s view of thermal strong interaction physics.

Although I never met Rolf Hagedorn personally, I was growing up in physics with his ideas spreading wide over particle and nuclear physics. A statistical, horrible dictu thermodynamical approach to high energy elementary systems and the very notion of a quark-gluon plasma became widespread in the 1980s and has only grown and matured since then.

The young Hungarian particle physicists, István Montvay, Peter Hasenfratz, Julius Kuti and Zoltan Kunszt—and a few others, mainly former students of George Marx, led the theory research in Budapest in the 1970s, but after their departure from Hungary their influence dispersed onto the international stage. Nuclear physicists took over introducing the new fields, the heavy ion experiment and quark-gluon phase production, the quest for this Holy Grail of matter exceeding the Hagedorn temperature. The noteworthy participants were József Zimányi, István Lovas and Judit Németh in Budapest and soon also in Debrecen. As relations of Hungary with western countries gradually eased, more and more physicists visited western institutes and our research ideas developed much in parallel with the world's leading institutes.

Being a student of József Zimányi I remember a paper from 1979, which he co-authored with his former colleague in Budapest, István Montvay, discussing nuclear reactions in terms of hydrodynamics of hot nuclear matter (I. Montvay and J. Zimányi, NPA 316 (1979) 490). My same-generation-colleague Anna Hasenfratz next door to my office was working on the connection of lattice

QCD renormalization with more conventional schemes together with her brother (A. Hasenfratz and P. Hasenfratz, PLB 93 (1980) 165). As early as 1981 Julius Kuti headed the first lattice SU(2) calculation on an East-German computer in Hungary (J. Kuti, J. Polonyi and K. Szlachanyi, PLB 98 (1981) 199).

These examples show that the thermal interpretation of strongly interacting bulk hadronic, later quark, matter and the thinking in terms of a phase transition became ubiquitous as I entered the field of physics in the 1980s. The initiation and renaissance of experimental relativistic heavy-ion programs for decades to come followed this development. It triggered anew theoretical work in terms of thermodynamics and hydrodynamics. The phrases 'hydrochemistry' and 'quarkchemistry' were coined for the study of the time evolution of hot nuclear matter, and lattice gauge theory, followed by lattice QCD conquered the world of computing with theoretical physics purposes.

To date the physical picture has been refined: it turned out that QCD describes a crossover type transition between the hadronic and quark-gluon plasma stages of elementary matter; even signs of the finite heat bath have been rediscovered in the curving of particle spectra and number distribution. Yet, the transition still occurs near to the temperature obtained by Hagedorn in his model in 1964: around $T_{\mathrm{H}} \approx 160\,\mathrm{MeV}$.

In my own work I recently was able to pick up the thread of Hagedorn limiting temperature, within the newly rising context of non-extensive statistical physics and quark coalescence (T.S. Biró and A. Peshier, PLB 632 (2006) 247). This work was motivated by the earlier studies, including one by Hagedorn (R. Hagedorn, La Revista del Nuovo Cimento, 6 (1983) 1), that a cut power-law distribution is a much better fit to particle spectra than the exponential—used in the original limiting temperature considerations. We studied production of hadrons arising from power-law tailed distribution of massless partons formed in coalescence. We found that this generates an exponential growth of the multiplicity of hadrons with mass m. The cut power-law distribution leads to a nonlinear equipartition formula, $E/N \sim T/(1-T/T_0) + T/(1-2T/3T_0) + T/(1-T/3T_0)$, showing that $T < T_0$ even at infinite energy.

5.4 Hagedorn Remembered

Rolf Hagedorn's impact on physics is farther reaching in the indirect than in the direct way. At first he was pretty much alone, but persisted in the application of thermodynamics in the field of particle production and strong interaction physics. However, within a decade, in the late 1970s and 1980s of the twentieth century, the thermal and hydrodynamical models of high energy nuclear collisions became worldwide fields of interest and helped to successfully interpret bulk features of soft strongly interacting matter phenomena in CERN and BNL experiments.