CC/NUMBER 21
MAY 21, 1984

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Hagedorn R. Statistical thermodynamics of strong interactions at high energies. *Nuovo Cimento Suppl.* 3:147-86, 1965.
[Theory Division, CERN, Geneva, Switzerland]

From the postulate ('statistical bootstrap') that highly excited lumps of hadronic matter are not essentially different from the hadronic resonances observed at lower excitation, a mathematical self-consistency condition on the hadron mass spectrum is derived. This forces the spectrum to grow exponentially with the further consequence that there exists a 'highest temperature,' $T_0 \approx 10^{12}$ °K, for hadronic matter. [The *SCI*® indicates that this paper has been cited in over 460 publications since 1965.]

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February 24, 1984

"In 1975, at the European Organization for Nuclear Research (CERN), F. Cerulus and I calculated particle production at what was to become CERN-PS. We computed hundreds of phase space integrals, in Monte Carlo, at various energies and included all then known particles and resonances. In 1962, L.W. Jones[1] proposed the computation of large angle elastic pp cross sections, presumably proportional to the ratio [two-body phase space]:[sum over n-body phase spaces]. Our archived results were dug out and predicted an energy dependence ~ exp (-const. E), in agreement with experiments.

"During a party, two young research fellows, G. Auberson and B. Escoubès, asked me for a problem to work on. I proposed that they should prove analytically our numerical findings. The answer was shocking: the proof required the assumption that the particles be distinguishable. I was, however, ready to accept that, because in our numerical calculations so many different particle states had entered that two equal ones almost never fell in the same phase space cell: they were *'de facto* distinguishable.' We then worked out a model of massless distinguishable particles and found the partition function diverging at a volume dependent temperature: $T_0 \approx 160$ MeV$\cong 1.2 \cdot 10^{12}$ °K for the nucleon volume. This temperature had been known from cosmic ray physics and had puzzled physicists for a long time. Had we found the explanation? I started working on this hypothesis (without my young collaborators who judged it too speculative).

"At that time, an illness forced my wife to bed for several weeks and I stayed at home with her, where I had a lot of time to think. I realized that the *'de facto* distinguishable' particles should be replaced by the real thing they stood for: a rich mass spectrum. I found that the mass spectrum was not allowed to grow faster than exponentially and that it could not produce a singularity if it grew less than exponentially. Our old numerical results thus suggested it should grow just exponentially. But why? The solution came by intuition: the objects (called 'fireballs') described by the partition function consisted of all known and yet unknown particles, among them the 'resonances,' which were 'small' fireballs. Thus the object and its constituents should be the same: fireballs consist of fireballs, which consist... and all of them should be counted by the same mass spectrum. Mathematically this condition led uniquely to an exponential mass spectrum $\sim \exp(m/T_0)$ where $T_0 \approx 160$ MeV was a limiting temperature (today reinterpreted as that of the phase transition → quark-gluon matter).

"I believe the paper has been cited often because it marked the beginning of a new line of research and led to practical[2] and theoretical[3,4] consequences. References 5, 6, and 7 are review articles; reference 4 concerns a 1983 application."

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2. **Hagedorn R.** Hadronic matter at the boiling point. *Nuovo Cimento A—Nucl. Part. F.* 56:1027-57, 1968. (Cited 90 times.)
3. **Frautschi S.** Statistical bootstrap model of hadrons. *Phys. Rev. D—Part. Fields* 3:2821-34, 1971. (Cited 255 times.)
4. **Hagedorn R.** The pressure ensemble as a tool of describing the hadron-quark phase transition. *Z. Phys. C—Par. Field.* 17:265-81, 1983.
5. ------------. Thermodynamics of strong interactions. (Schatzmann E, ed.) *Cargèse lectures in physics.* New York: Gordon and Breach, 1973. Vol. 6. p. 643-716.
6. **Ilgenfritz E M, Kripfganz J & Möhring H J.** Statistical bootstrap approach to hadronic matter and multiparticle reactions. *Fortschr. Phys.* 25:123-65, 1977.
7. **Sertorio L.** Statistical mechanics at high energy density. *Riv. Nuovo Cimento* 2:1-130, 1979.