A new field of physics was created in Frankfurt beginning in 1968 – coincident with my meeting in classroom of my future thesis adviser and teacher Walter Greiner. The trigger of his interest was possible creation of superheavy elements.
What this is all about:

a passion for strong fields
Before WG ERA: Virtual Pairs: The vacuum is dielectric

The vacuum is a dielectric medium: a charge is screened by particle-hole (pair) excitations. In Feynman language the real photon is decomposed into a bare photon and a photon turning into a “virtual” pair. The result: renormalized electron charge smaller than bare, Coulomb interaction stronger (0.4% effect)

This effect has been studied in depth in atomic physics, is of particular relevance for exotic atoms where a heavy charged particle replaces an electron in orbit close to the nucleus. Topic close to Walter G Graduate Study work.
Relativistic Quantum Mechanics: Dirac sea, Klein's paradox, “anti” matter

Dirac equation has negative energy states: to stop collapse of matter Dirac invokes Pauli principle and postulates antimatter: Positrons are holes in the occupied sea of electrons.

After Klein's “paradox” paper Heisenberg recognizes tunnelling as a new quantum mechanism of pair production. Any electric field is unstable (with a very long lifespan except when fields “bridge” the gap. Nonperturbative quantum field physics ahead of Feynman diagrams. Quantum Aether

... with the new theory of electrodynamics we are rather forced to have an aether. – P.A.M. Dirac, ‘Is There an Aether?’, Nature, v.168, 1951, p.906.
The 1968 revolution: Walter Greiner teaches TH to 1st years, & starts strong fields research group with us
The beginning of WG Era

Literature filled with half-wrong ideas about the meaning of (Oscar) Klein paradox and how to fix the “atom” in strong fields

Sometime around 1965-9 Walter Greiner recognizes the need to understand the atomic structure of superheavy element Z=164
Greiner: The important thing is that for \( Z = 80 \) you have \( Z \alpha \) less than unity, but for super-heavy nuclei around \( Z = 164 \) it is suddenly larger than unity and you do not know whether the expansion in \( Z \alpha \) converges anymore. You really have to start from a completely different point of view and develop new methods.

Greiner: I would like to stress that this quantum electrodynamic problem is very interesting from a purely theoretical point of view. I mean no matter whether we can make nuclei with \( Z = 164 \) or not, it is interesting in itself to study theoretically what really happens. If however elements around \( Z = 164 \) were very unstable the problem would be merely academic.

We may ask ourselves what we may further learn from super-heavy nuclei. Let me mention a few other important aspects. I certainly do not have to convince you that there is nothing to learn about basic nuclear forces - let's forget this completely.

**Interior Electron Shells in Superheavy Nuclei**

1st step: Dirac Singularity solved: finite nuclear size 1965-68 (Pieper-Greiner)

**Strong Fields in High Z Atoms**

**Single Particle Dirac Equation**

\[
(\bar{\alpha} \cdot i \vec{\nabla} + \beta m + V(r)) \psi_n(\vec{r}) = E_n \psi_n(\vec{r})
\]

\[
V(r) = \begin{cases} 
-\frac{Z\alpha}{r} & r > R_N \\
-\frac{3}{2} \frac{Z\alpha}{R_N} + \frac{r^2}{2} \frac{Z\alpha}{R_N^3} & r < R_N 
\end{cases}
\]

Key feature: bound states pulled from one continuum move as function of $Z\alpha$ across into the other continuum.
Embedding a super bound electron in positron continuum

Solution of the Dirac Equation for Strong External Fields*

Berndt Müller, Heinrich Peitz, Johann Rafelski, and Walter Greiner
Institut für Theoretische Physik der Universität Frankfurt, Frankfurt am Main, Germany
(Received 14 February 1972)

The 1s bound state of superheavy atoms and molecules reaches a binding energy of $-2mc^2$ at $Z \approx 169$. It is shown that the K shell is still localized in $r$ space even beyond this critical proton number and that it has a width $\Gamma$ (several keV large) which is a positron escape width for ionized K shells. The suggestion is made that this effect can be observed in the collision of very heavy ions (superheavy molecules) during the collision.
What is (mostly) this about?

**(quasi)Atoms beyond** $Z \simeq 100$

**Single Particle Dirac Equation**

$\left( \bar{\alpha} \cdot \slashed{\nabla} + \beta m + V(r) \right) \Psi_n(\vec{r}) = E_n \Psi_n(\vec{r})$

**Supercritical fields**

The bound states drawn from one continuum move as function of $Z$ across into the other continuum. **Mix-up of particle/antiparticle states**


**Decay of the Vacuum**

- **Undercritical**
  - $+mc^2$

- **Overcritical**
  - $-mc^2$

If diving state ‘empty’ vacuum decays

$|Q = 0\rangle \rightarrow |Q = e\rangle + e^+$ by positron state occupied by an electron, ‘smooth’ transition of charge distribution
11

3rd step: HI Collisions replace the need for super-super-heavy nuclei

fields

HI collisions: electrons in quasimolecular fields
4th and 5th step: no stable vacuum, hence vacuum decay in Strong Fields
The last step 1973: Ffm Rathaus
Back in Frankfurt Summer 1977
Recognize external fields as a TEMPERATURE

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INTERPRETATION OF EXTERNAL FIELDS AS TEMPERATURE*

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Received 5 September 1977

We show that average excitation of the vacuum state in the presence of an external electric field can be described by an effective temperature \( kT = eE/(2\pi m) \). We present a qualitative generalization of our result to other interactions. Some phenomenological implications concerning matter at low temperatures in strong electric fields (10^6 V/cm) are offered.
A stimulating Frankfurt environment 1979-1983

Return to Frankfurt: Introduction of Quark-Gluon Plasma:

QCD vacuum and strangeness arrive
Joint Project
Book on Special Relativity 1982

Prof. Dr. rer. nat. Walter Greiner, geb. Oktober 1935, Promotion 1961 in Freiburg/Breisgau, 1962 – 1964 Ass. Prof. University of Maryland, seit 1964/65 o. Prof. für Theoretische Physik der Universität Frankfurt am Main und Direktor des Instituts für Theoretische Physik. Gastprofessor u. a. an der Florida State University, University of Virginia, Los Alamos Scientific Laboratory, University of California, Berkeley, Oak Ridge National Laboratory, University of Melbourne, Yale University, Vanderbilt University. Hauptarbeitsgebiete: Theoretische Kernphysik, Theoretische Schwerionenphysik, Feldtheorie (Quantenelektrodynamik, Theorie der Quantenfelder), Atomphysik. 1974 Empörer des Max-Born-Preises und der Max-Born-Medaille (Institute of Physics and Deutsche Physikalische Gesellschaft). 1982 des Otto-Hahn-Preises der Stadt Frankfurt am Main und der Ehrendoktorwürde der University of Witwatersrand, Johannesburg.

Dr. Johann Rafelski ist Professor für Theoretische Physik an der Universität Kapstadt. Er promovierte 1973 mit einer Arbeit über Quantenelektrodynamik der starken Wechselwirkung an der Johann-Wolfgang-Goethe-Universität Frankfurt/Main. Er war wissenschaftlicher Assistent an den Universitäten Frankfurt/Main und Pennsylvania; Wissenschaftler am Argonne National Laboratory, Chicago; Fellow beim CERN, Genève, sowie Professor an der Universität Frankfurt/Main. Der Schwerpunkt der heutigen Forschungsaktivitäten liegt in dem Sub-Nukleon-Bereich der starken Wechselwirkung. Herr Rafelski hat über 100 wissenschaftliche Arbeiten mitverfaßt, darunter einige längere wissenschaftliche Monographien.
With Walter’s strong support I become 1983/4 Chair of Theoretical Physics at the University of Cape Town

Serious differences develop soon:
I turn most energy to quark gluon plasma, a novel strong field domain/vacuum structure;

Some Frankfurt students dared to graduate in Cape Town

I appointed people both who are not educated in Frankfurt, and without asking permission!
We complete our second book 1983-86

W. Greiner
B. Müller
J. Rafelski

Quantum Electrodynamics of Strong Fields
With an Introduction into Modern Relativistic Quantum Mechanics
QED of Strong Fields Book: 1986

W. Greiner  B. Müller  J. Rafelski

Quantum Electrodynamics of Strong Fields
With an Introduction into Modern Relativistic Quantum Mechanics

With 258 Figures

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1. Introduction

The structure of the vacuum is one of the most important topics in modern theoretical physics. In the best understood field theory, Quantum Electrodynamics (QED), a transition from the neutral to a charged vacuum in the presence of strong external electromagnetic fields is predicted. This transition is signalled by the occurrence of spontaneous \( e^+ e^- \) pair creation. The theoretical implications of this process as well as recent successful attempts to verify it experimentally using heavy ion collisions are discussed. A short account of the history of the vacuum concept is given. The role of the vacuum in various areas of physics, like gravitation theory and strong interaction physics is reviewed.

1.1 The Charged Vacuum

Our ability to calculate and predict the behaviour of charged particles in weak electromagnetic fields is primarily due to the relative smallness of the fine-structure constant \( \alpha = 1/137 \). However, physical situations exist in which the coupling constant becomes large, e.g. an atomic nucleus with \( Z \) protons can exercise a much stronger electromagnetic force on the surrounding electrons than could be described in perturbation theory, and hence it is foreseeable that the new expansion parameter \((Z\alpha)\) can quite easily be of the order of unity. In such cases non-perturbative methods have to be used to describe the resultant new phenomena, of which the most outstanding is the massive change of the ground-state structure, i.e. of the vacuum of quantum electrodynamics.
Job accomplished: Visby 1986
Tucson, about 1988
2006: Walter at SQM
QGP and strangeness signature
A dear friend remembered: Michael Danos (picture 1995)
To Walter Greiner on his 80th Birthday