Quantum Mechanics_vacuum state

In quantum field theory, the **vacuum state** (also called the **vacuum**) is the quantum state with the lowest possible energy. Generally, it contains no physical particles. **Zero-point field** is sometimes used[*by whom?*] as a synonym for the vacuum state of an individual quantized field.

According to present-day understanding of what is called the vacuum state or the quantum vacuum, it is "by no means a simple empty space",[1] and again: "it is a mistake to think of any physical vacuum as some absolutely empty void."[2] According to quantum mechanics, the vacuum state is not truly empty but instead contains fleeting electromagnetic waves and particles that pop into and out of existence.[3][4][5]

The QED vacuum of Quantum electrodynamics(or QED) was the first vacuum of quantum field theory to be developed. QED originated in the 1930s, and in the late 1940s and early 1950s it was reformulated by Feynman, Tomonaga andSchwinger, who jointly received the Nobel prize for this work in 1965.[6] Today theelectromagnetic interactions and the weak interactions are unified in the theory of theElectroweak interaction.

The Standard Model is a generalization of the QED work to include all the known elementary particles and their interactions (except gravity).Quantum chromodynamics is the portion of the Standard Model that deals with strong interactions, and QCD vacuum is the vacuum ofQuantum chromodynamics. It is the object of study in the Large Hadron Collider and theRelativistic Heavy Ion Collider, and is related to the so-called *vacuum structure of strong interactions*.[7]

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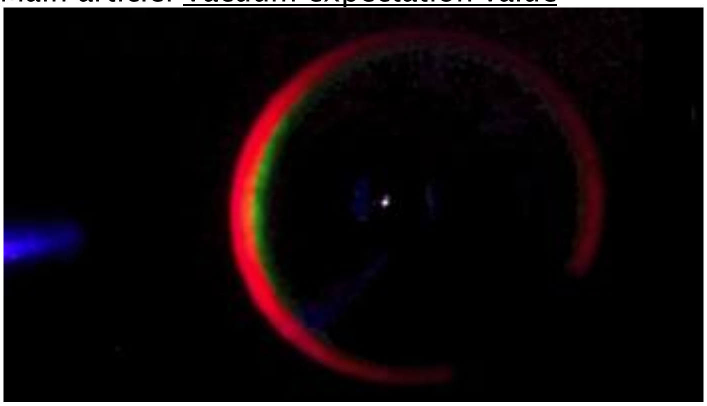

The video of an experiment showing vacuum fluctuations (in the red ring) amplified by spontaneous parametric down-conversion.

If the quantum field theory can be accurately described through perturbation theory, then the properties of the vacuum are analogous to the properties of theground state of a quantum mechanical harmonic oscillator (or more accurately, the ground state of a QM problem). In this case the Vacuum expectation value(VEV) of any field operator vanishes. For quantum field theories in whichperturbation theory breaks down at low energies (for example, Quantum chromodynamics or the BCS theory of superconductivity) field operators may have non-vanishing vacuum expectation values called condensates. In theStandard Model, the non-zero vacuum expectation value of the Higgs field, arising from Spontaneous symmetry breaking, is the mechanism by which the other fields in the theory acquire mass.

Energy

Main article: Vacuum energy

In many situations, the vacuum state can be defined to have zero energy, although the actual situation is considerably more subtle. The vacuum state is associated with a zero-point energy, and this zero-point energy has measurable effects. In the laboratory, it may be detected as the Casimir effect. In physical cosmology, the energy of the cosmological vacuum appears as the cosmological constant. In fact, the energy of a cubic centimeter of empty space has been calculated figuratively to be one trillionth of an erg.[8] An outstanding requirement imposed on a potential Theory of Everything is that the energy of the quantum vacuum state must explain the physically observed cosmological constant.

Symmetry

For a relativistic field theory, the vacuum is Poincaré invariant, which follows from Wightman axioms but can be also proved directly without these axioms.[9]Poincaré invariance implies that only scalar combinations of field operators have non-vanishing VEV's. The VEV may break some of the internal symmetries of theLagrangian of the field theory. In this case the vacuum has less symmetry than the theory allows, and one says that *Spontaneous symmetry breaking* has occurred. See Higgs mechanism, standard model.

Electrical permittivity

In principle, quantum corrections to Maxwell's equations can cause the experimental electrical permittivity ϵ of the vacuum state to deviate from the defined scalar value ϵ_0 of the electric constant.[10] These theoretical developments are described, for example, in Dittrich and Gies.[5] In particular, the theory of Quantum electrodynamics predicts that the QED vacuum should exhibitnonlinear effects that will make it behave like a birefringent material with ϵ slightly greater than ϵ_0 for extremely strong electric fields.[11][12] Explanations fordichroism from particle physics, outside quantum electrodynamics, also have been proposed.[13] Active attempts to measure such effects have been unsuccessful so far.[14]

Notations

The vacuum state is written as $|0\rangle$ or $|\rangle$. The Vacuum expectation value (see alsoExpectation Value) of any field ϕ, should be written as $\langle 0|\phi|0\rangle$, but is usually condensed to $\langle \phi \rangle$.

Virtual particles

Main article: Virtual particle

The presence of virtual particles can be rigorously based upon the non-commutation of the quantized electromagnetic fields. Non-commutation means that although the average values of the fields vanish in a quantum vacuum, their variances do not.[15] The term "vacuum fluctuations" refers to the variance of the field strength in the minimal energy state,[16] and is described picturesquely as evidence of "virtual particles".[17]

It is sometimes attempted to provide an intuitive picture of virtual particles based upon the Heisenberg energy-time uncertainty principle:

$$\Delta E \Delta t \geq \hbar ,$$

(with ΔE and Δt being the energy and time variations respectively; ΔE is the accuracy in the measurement of energy and Δt is the time taken in the measurement, and $\hbar$ is the Planck constant divided by 2π) arguing along the lines that the short lifetime of virtual particles allows the "borrowing" of large energies from the vacuum and thus permits particle generation for short times.[18]

Although the phenomenon of virtual particles is accepted, this interpretation of the energy-time uncertainty relation is not universal.[19][20] One issue is the use of an uncertainty relation limiting measurement accuracy as though a time uncertainty Δt determines a "budget" for borrowing energy ΔE. Another issue is the meaning of "time" in this relation, because energy and time (unlike position q and momentum p, for example) do not satisfy a canonical commutation relation (such as $[q, p] = i\hbar$).[21] Various schemes have been advanced to construct an observable that has some kind of time interpretation, and yet does satisfy a canonical commutation relation with energy.[22][23] The very many approaches to the energy-time uncertainty principle are a long and continuing subject.[23]

Physical nature of the quantum vacuum

According to Astrid Lambrecht (2002): "When one empties out a space of all matter and lowers the temperature to absolute zero, one produces in a *Gedankenexperiment* the quantum vacuum state."[1]

According to Fowler & Guggenheim (1939/1965), the third law of thermodynamics may be precisely enunciated as follows:

> *It is impossible by any procedure, no matter how idealized, to reduce any assembly to the absolute zero in a finite number of operations.*[24] (See also.[25][26][27])

Photon-photon interaction can occur only through interaction with the vacuum state of some other field, for example through the Dirac electron-positron vacuum field; this is associated with the concept of vacuum polarization.[28]

According to Milonni (1994): "... *all quantum fields have zero-point energies and vacuum fluctuations.*"[29] This means that there is a component of the quantum vacuum respectively for each component field (considered in the conceptual absence of the other fields), such as the electromagnetic field, the Dirac electron-positron field, and so on.

According to Milonni (1994), some of the effects attributed to the vacuum electromagnetic field can have several physical interpretations, some more conventional than others. The Casimir attraction between uncharged conductive plates is often proposed as an example of an effect of the vacuum electromagnetic field. Schwinger, DeRaad, and Milton (1978) are cited by Milonni (1994) as validly, though unconventionally, explaining the Casimir effect with a model in which "the vacuum is regarded as truly a state with all physical properties equal to zero."[30][31] In this model, the observed phenomena are explained as the effects of the electron motions on the electromagnetic field, called the source field effect. Milonni writes: "The basic idea here will be that the Casimir force may be derived from the source fields alone even in completely conventional QED, ..." Milonni provides detailed argument that the measurable physical effects usually attributed to the vacuum electromagnetic field cannot be explained by that field alone, but require in addition a contribution from the self-energy of the electrons, or their radiation reaction. He writes: "The radiation reaction and the vacuum fields are two aspects of the same thing when it comes to physical interpretations of various QED processes including the Lamb shift, van der Waals forces, and Casimir effects."[32] This point of view is also stated by Jaffe (2005): "The Casimir force can be calculated without reference to vacuum fluctuations, and like all other observable effects in QED, it vanishes as the fine structure constant, α, goes to zero."[33]

See also

- Pair production
- Stochastic electrodynamics
- Vacuum energy
- vacuum polarization
- Virtual particle
- False vacuum
- QCD vacuum
- QED vacuum
- Squeezed coherent state
- Vacuum
- Casimir effect
- Energy into Matter
- Free space
- Scharnhorst effect
- Van der Waals force

References and notes

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15. ^ Myron Wyn Evans, Stanisław Kielich (1994). *Modern nonlinear optics, Volume 85, Part 3*. John Wiley & Sons. p. 462. ISBN 0-471-57548-8. "For all field states that have classical analog the field quadrature variances are also greater than or equal to this commutator."
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17. ^ Milton K. Munitz (1990). *Cosmic Understanding: Philosophy and Science of the Universe*. Princeton University Press. p. 132. ISBN 0-691-02059-0. "The spontaneous, temporary emergence of particles from vacuum is called a "vacuum fluctuation"."
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19. ^ A vaguer description is provided by Jonathan Allday (2002). *Quarks, leptons and the big bang* (2nd ed ed.). CRC Press. pp. 224 *ff*. ISBN 0-7503-0806-0. "The interaction will last for a certain duration *Δt*. This implies that the amplitude for the total energy involved in the interaction is spread over a range of energies*ΔE*."
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Further reading

- Free pdf copy of The Structured Vacuum - thinking about nothing by Johann Rafelski and Berndt Muller (1985) ISBN 3-87144-889-3.
- M.E. Peskin and D.V. Schroeder, *An introduction to Quantum Field Theory*.
- H. Genz, *Nothingness: The Science of Empty Space*
- Maybe this should discuss Star Trek and/or Star Gate: Engineering the Zero-Point Field and Polarizable Vacuum for Interstellar Flight
- E. W. Davis, V. L. Teofilo, B. Haisch, H. E. Puthoff, L. J. Nickisch, A. Rueda and D. C. Cole(2006)"Review of Experimental Concepts for Studying the Quantum Vacuum Field"

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