December 25, 2025

Vacuum: the invisible medium of all fields

How $\langle H \rangle$, radii and Y_S structure the "empty" state

Key Insight. Vacuum is not empty. In the octonionic model, it is a specific configuration of the internal structure: a vacuum expectation value $\langle H \rangle$ in $H_3(\mathbb{O})$, a choice of radius spectrum (a_0, b_0, c_0) and an electroweak scale Y_S. Masses, couplings and even vacuum energy arise as properties of this structured medium. The vacuum is the invisible actor that sets the stage for all visible physics.

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Vacuum as a configuration, not as nothing

In quantum field theory, the vacuum is the lowest-energy state of the system. In the octonionic setting, and within the unified master action $S[D, \Psi]$ introduced on December 24, this state is described by:

- a vacuum configuration $\langle H \rangle \in H_3(\mathbb{O})$,
- a radius spectrum (a_0, b_0, c_0) of the operator R,
- an electroweak scale Y_S defined by the minimum of a potential.

Symbolically, one may write the internal vacuum data as

$$\mathcal{V}_{\text{int}} = \big(\langle H \rangle; a_0, b_0, c_0; Y_S\big).$$

Fields are then fluctuations around this background; their masses and interactions are determined by how they probe this structured medium.

Masses and couplings from the vacuum

Several quantities introduced earlier in the calendar are now recognised as vacuum properties:

- Fermion masses: eigenvalues of $M = y\,\Pi(\langle H \rangle)$.
- Gauge couplings: norms of rotor commutators evaluated in the vacuum geometry, e.g. α, α_s, $\sin^2\theta_W$.
- Scales: exponentials of (a_0, b_0, c_0) define preferred energies.

What looks like a zoo of independent parameters from a naive perspective turns out to be a small set of derived quantities from $\mathcal{V}_{\text{int}}$.

Vacuum energy and dark energy

The cosmological constant Λ can be understood as a contribution to the effective action coming from the spectrum of an appropriate Dirac operator D and the vacuum configuration. In a spectral-action viewpoint,

$$S_{\text{spec}} = \operatorname{Tr} f(D^2/\Lambda^2)$$

contains a leading term that behaves like a cosmological constant (consistent with the gravitational and defect terms in the master action $S[D, \Psi]$ discussed on the previous day). In the octonionic setting:

- The internal structure encoded in $\langle H \rangle$ and R influences the spectrum of D.
- The corresponding vacuum energy becomes a property of the same medium that gives rise to masses and couplings.

This suggests a picture in which dark energy is not an exotic fluid but an aspect of the spectral vacuum defined by the octonionic geometry.

Vacuum as an invisible actor

It is tempting to think of particles and forces as the main characters of physics. In this model, the vacuum plays a more central role:

- It determines the scales at which different phenomena occur.
- It shapes the spectrum of excitations (masses).
- It contributes to the energy content of the universe.

Most of the "mystery parameters" of particle physics are reinterpreted as properties of a single invisible actor: the structured vacuum state.

Conceptual shift

The conceptual shift can be summarised as follows:

1. **From emptiness to medium:** vacuum is not the absence of structure but the most structured part of the theory.
2. **From input to output:** constants, scales and masses are not arbitrary inputs but derived characteristics of $\mathcal{V}_{\text{int}}$.

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3. **From fragmentation to coherence:** one unified internal configuration explains many seemingly unrelated numbers.

This completes the Advent narrative: from abstract octonionic algebra to a concrete picture in which the vacuum of the universe is a highly organised medium living in that algebra.

References

[1] H. B. G. Casimir, "On the attraction between two perfectly conducting plates," *Proc. Kon. Ned. Akad. Wet.* **51**, 793–795 (1948).

[2] S. Perlmutter *et al.*, "Measurements of Ω and Λ from 42 high-redshift supernovae," *Astrophys. J.* **517**, 565–586 (1999).

[3] [Internal notes on vacuum structure and spectral contributions: `unified-agebra.tex; chap16_neu.tex; appM_neu.tex; appE_neu.tex`.]

In the octonionic model, the vacuum is a structured medium specified by $\langle H \rangle$, (a_0, b_0, c_0) and Y_S. Masses, couplings and even dark-energy-like terms become properties of this medium rather than independent inputs, turning the "empty" state into the central player of the theory.

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