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FALSE-VACUUM DECAY AND FLAWS IN FRAMPTON'S MODEL OF THE ORIGIN OF LIFE*

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We briefly review false-vacuum decay and examine a recent proposal by Frampton to model the origin of the first single-celled organism (SCO) as a phase transition between no-life and life vacua. In his calculation, the exponent n entering the probability $P_{\rm SCO} \sim 10^{-n}$ has dimensions of inverse time: it is an energy barrier divided by the Planck constant, rather than a dimensionless tunnelling action. The resulting probability is mathematically ill-defined and does not determine a tunnelling rate. Apart from this dimensional issue, the assumed initial configuration, a toroidal structure made of long molecules, and its treatment in empty space are inconsistent with soft-matter physics and with the hot, collisional environment expected for prebiotic chemistry. Consequently, the claimed exponential suppression of biogenesis, and the inference that extraterrestrial life is likely absent, are not supported.

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1. Introduction

Metastable, or false, vacua and their decay by bubble nucleation have been studied in quantum field theory (QFT) since the 1970s. Lee and Wick [1] and, more extensively, Voloshin, Kobzarev, and Okun (VKO) [2] analysed the semiclassical tunnelling of bubbles in a scalar theory with two minima of the potential (see [3] for the historical context). Their work was extended and improved by Coleman [4, 5]. Related Euclidean semiclassical methods were developed independently around the same time by Stone [6, 7]. Coleman and Callan [8] determined first quantum corrections, while Linde [9–11] developed the corresponding analysis for the Weinberg–Salam model and for finite temperature in cosmology (for a pedagogical presentation, see [12] and for recent work and references, see, *e.g.*, [13]). A common feature of all these treatments is that the tunnelling probability is exponentially suppressed by a Euclidean action, not by an energy barrier (see below).

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In a recent paper [14], Frampton has proposed to use the false-vacuum formalism to address the origin of life on Earth. He regards a prebiotic state without life as a false vacuum and a state with life as the true vacuum, and models the appearance of the first single-celled organism (SCO) as the nucleation of a bubble of the true phase in a first-order transition. Treating the problem as a zero-temperature tunnelling process in vacuum, he arrives at a probability

$$P_{\mathrm{SCO}} \sim 10^{-n}\,, \qquad n \simeq 9.3 \times 10^{31}\,, \tag{1}$$

and, from the extreme smallness of P_{SCO}, concludes that the origin of life is so improbable that it has almost certainly never occurred elsewhere in the observable universe.

The purpose of the present note is to examine Frampton's model as an application of first-order phase-transition physics and to ask whether his conclusion (1) is reliable. We will argue that it is not. The problems fall into several classes: First, the tunnelling exponent is being misused. In VKO, Coleman, and Linde, the decay rate has the form $\Gamma/V \sim A\,\mathrm{e}^{-B}$, where $B \sim \sigma^4/\varepsilon^3$ is a dimensionless Euclidean action built from surface tension and energy-density difference and A carries the dimensions. Frampton instead exponentiates a barrier energy $E_{\max} \sim \sigma^3/\varepsilon^2$ and inserts the Planck constant h by hand, leading to an exponent n which has units of inverse time. The central quantity $P_{\mathrm{SCO}} \sim 10^{-n}$ is mathematically ill-defined: it is the exponential of a dimensionful quantity.

Second, the model assumes that, before life, the Earth already contained a planar rectangular sheet of long organic molecules that behaves as a homogeneous cell membrane, rolls into a cylinder, and closes into a torus. This object is then treated as a false vacuum which must tunnel to a spherical cell. Such a planar sheet is a very special, low-entropy configuration, and toroidal bubbles relax to spheres by elasticity, not by quantum tunnelling.

Third, the calculation is carried out as if the SCO nucleated in cold vacuum, whereas any plausible prebiotic environment is a hot, dense aqueous medium with collisions and thermal noise. Linde [9, 11] emphasised that in similar environments, the exponential suppression is tempered and zero-temperature vacuum tunnelling is no longer the right description.

Fourth, it is not at all obvious that life automatically starts with the change of topology from toroidal to spherical. There are many lumps of organic matter with the topology of a sphere which are perfectly dead.

This note is organized as follows. Section 2 summarises the treatment of thin-wall bubbles and the Wentzel–Kramers–Brillouin (WKB) exponent governing the vacuum decay. Section 3 describes Frampton's model, with particular attention to the definition and dimension of his exponent n. Section 4 critiques the assumed toroidal geometry and its dynamics.

The conclusion is that the false-vacuum analogy in Ref. [14] does not support any claim about the probability of life's emergence, let alone a statement about the (non-)existence of extraterrestrial life.

2. Metastable vacuum decay

False-vacuum decay can be described as quantum tunnelling of a scalar field from a metastable minimum of the potential (false vacuum) to a lower minimum (true vacuum). The decay proceeds by nucleation of bubbles of true vacuum which then expand, converting the surrounding false vacuum.

2.1. Thin-wall bubbles in a false vacuum

Consider a real scalar field φ with a potential $U(\varphi)$ that has two local minima with different energy densities. A prototype is a double-well potential tilted so that the minimum at $\varphi = \varphi_+$ is higher than at $\varphi = \varphi_-$.

VKO consider a spherical bubble of true vacuum φ_- of radius R inside the false vacuum. In the thin-wall approximation, the range of r where $\varphi(r)$ varies significantly (the wall) is narrow in comparison with the radius of the bubble R ([12], Section 5.2). The bubble wall has a surface tension σ (energy per unit area, resulting from φ being away from either minimum and from its gradient), and the difference of energy densities between the two vacua is

$$\varepsilon \equiv \rho_{\text{false}} - \rho_{\text{true}} > 0\,. \tag{2}$$

The energy of a static bubble of the lower-energy vacuum, of radius R, is

$$E(R) = 4\pi R^2\sigma - \frac{4\pi}{3}R^3\varepsilon\,. \tag{3}$$

The first term is the positive surface energy of the wall; the second, the negative volume energy gain from replacing false by true vacuum.

Extremising (3) with respect to R gives the radius at which $E(R)$ is maximum,

$$R_{\text{max}} = \frac{2\sigma}{\varepsilon}\,, \tag{4}$$

and the height of the energy barrier,

$$E_{\text{max}} = E(R_{\text{max}}) = \frac{16\pi}{3}\frac{\sigma^3}{\varepsilon^2}\,. \tag{5}$$

A bubble smaller than R_{max} shrinks away; a bubble larger than R_{max} grows and converts the surrounding false vacuum into the true one.

2.2. WKB exponent and the vacuum decay rate

VKO consider a zero-energy bubble of true vacuum, created by tunnelling in the false vacuum. They find the probability of penetrating the energy barrier to be proportional to $\exp(-B)$ with

$$B = \frac{2}{\hbar}\int_0^{R_c} |p_{\mathrm{R}}|\mathrm{d}R\,, \tag{6}$$

where p_{R} is the radial momentum of the wall and $R_c = 3\sigma/\varepsilon$ is the radius at which $E(R)$ returns to zero [2]. VKO find, up to a dimensionless factor,

$$B \sim \frac{\sigma^4}{\hbar c \varepsilon^3}\,. \tag{7}$$

Here, $\hbar = h/(2\pi)$ is the reduced Planck constant and c is the speed of light. In SI units $[\sigma] = \mathrm{J\,m^{-2}}$, $[\varepsilon] = \mathrm{J\,m^{-3}}$ (see Eq. (3)), so $[\sigma^4/\varepsilon^3] = \mathrm{J\,m}$, while $[\hbar c] = (\mathrm{J\,s})(\mathrm{m\,s^{-1}}) = \mathrm{J\,m}$. Hence, $B \sim \sigma^4/(\hbar c\,\varepsilon^3)$ is dimensionless, as an exponent must be.

3. Frampton's model of the origin of life

In his 2025 paper [14], Frampton models the origin of life on Earth as a phase transition between two vacua: without (false) and with life (true).

3.1. Summary of Frampton's argument

Frampton assumes that long organic molecules such as nucleic acids assemble into a rectangular sheet which rolls to form a cylinder, which subsequently closes on itself making a torus. Frampton identifies the torus-to-sphere change with the bubble nucleation event. The toroidal configuration is treated as a false vacuum, while a spherical configuration is treated as the stable true vacuum. Adapting the thin-wall bubble analysis of the false-vacuum decay, he writes the energy of a spherical bubble of radius R as a sum of volume and surface contributions, see Eq. (3), with ε interpreted as the difference in volume-energy density between the two configurations,

$$\varepsilon = \varepsilon_{\mathrm{torus}} - \varepsilon_{\mathrm{sphere}}\,, \tag{8}$$

which he estimates to be on the order of 10^{-3} in SI units, that is joule per cubic metre. σ is the surface tension of the wall, estimated as 2×10^{-3} J/m^2. He finds R_{max} as in Eq. (4) $E_{\mathrm{max}} = E(R_{\mathrm{max}}) = 16\pi\sigma^3/(3\varepsilon^2)$ as in (5). He assumes the probability of the tunnelling to be

$$P_{\mathrm{tunnelling}} = \exp(-E_{\mathrm{max}}) = 10^{-n}\,, \tag{9}$$

which defines the exponent n, with $n = E_{\max}/\ln 10$. Inserting a factor of the Planck constant h (Frampton uses h rather than $\hbar$) in the denominator to "restore the units from the use of $h = c = 1$ natural units", he finds

$$n = \frac{16\pi\sigma^3}{3\ln 10\, h\varepsilon^2}\,, \tag{10}$$

and claims $n = 9.3 \times 10^{31}$. This leads to the estimate of producing a single-celled organism,

$$P_{\mathrm{SCO}} \sim 10^{-n} \sim 10^{-9.3\times 10^{31}}\,, \tag{11}$$

a very small number. From the huge magnitude of the exponent, he concludes that the origin of life is so improbable that it is unlikely ever to occur elsewhere in the visible universe.

3.2. n is not dimensionless

The numerical estimate (11) rests on treating n as a pure number. However, n as defined in Eqs. (9)–(10) is not dimensionless. Obtained by dividing an energy by the Planck constant, it has units of inverse time. Substituting numerical values quoted in [14], one reproduces the magnitude 9.3×10^{31}, but with units of inverse seconds.

The source of this confusion is the use of the energy barrier $E_{\max}$ instead of the WKB exponent for the tunnelling bubble B (see Eqs. (6)–(7)). While B is dimensionless, the ratio $E_{\max}/h$ has units of inverse time.

Exponentials such as 10^{-n} are mathematically meaningful only if the exponent is dimensionless. With $[n] = s^{-1}$, the main result P_{SCO} in Eq. (11) is not well defined. Consequently, the spectacularly small number in Eq. (11) has no physical content.

4. Implausibility of the torus-in-the-vacuum model

Aside from the issue with the tunnelling exponent, the assumed degrees of freedom and environment in Ref. [14] are implausible for prebiotic chemistry.

Membrane composition

Frampton assumes that long organic molecules such as nucleic acids can assemble into a rectangular sheet, which then rolls into a hollow cylinder and closes into a torus. This starting point is already highly non-generic: long, flexible polymers are not, by themselves, likely membrane-forming materials. In contrast, much of mainstream origin-of-life work focuses on membranes made of simpler molecules (for example, fatty acids), which have a water-attracting head and a water-repelling tail, and can spontaneously self-assemble in water into closed bubbles called vesicles [15].

Laboratory work supports the plausibility of such compartments: fatty-acid-based vesicles can be stable over a wide temperature range (up to near boiling) and can retain encapsulated short nucleic-acid strands [16]. Recent prebiotic-chemistry experiments also demonstrate routes from relatively simple building blocks to membrane-forming lipids that self-assemble into protocell-like vesicles [17]. A concise review of protocell-based approaches and the idea that membranes and primitive genetic polymers likely co-evolved is given in Ref. [18]. For an accessible discussion in the context of extraterrestrial life, see the recent book [19].

Toroidal shapes relax classically

Now, suppose that a toroidal membrane is somehow formed. Let it be characterized by two radii a and b with $a > b$. Such a structure relaxes toward a sphere through classical dynamics; no quantum tunnelling is required. Intuitively, decreasing the large radius a at approximately fixed volume reduces the surface area, and the system can lower its free energy by shrinking the torus. This is consistent with experimental and theoretical studies of toroidal droplets and their shrinking instability [20–22].

Thermal environment and the relevant energy scale

Frampton treats the prebiotic toroidal structure as if it existed in vacuum. However, life has likely appeared in messy environments, so membrane shapes are influenced by thermal fluctuations and collisions. Frampton argues that the temperature T even near an oceanic thermal vent is low (when converted into energy using the Boltzmann constant $k_{\rm B} \simeq 10^{-4}$ eV/K) in comparison with the hydrogen ionization energy $E_{\rm H} = 13.6$ eV [14]. This argument is flawed since one can significantly distort a membrane with much less energy than the energy $\sim E_{\rm H}$ that is needed to turn it into plasma.

The ionization scale $E_{\rm H}$ is an electronic excitation energy, whereas the energy scale controlling membrane deformations is set by soft-matter elasticity. Membrane deformations are described by the Helfrich curvature elasticity [23], with a typical bending rigidity for lipid bilayers of order $\kappa \sim 20\, k_{\rm B}T$ [24]. At $T \simeq 373$ K, one has $k_{\rm B}T \simeq 0.032$ eV, hence $\kappa \sim 0.6$ eV, many times smaller than $E_{\rm H}$. Therefore, comparing T to 13.6 eV does not constrain membrane-scale distortions in the way implied in Ref. [14].

5. Conclusions

The goal of this note has been to compare Ref. [14] with the standard semiclassical description of false-vacuum decay. Section 2 recalled that in that framework, the decay of metastable vacuum is governed by a dimensionless exponent B, with the nucleation rate proportional to $\exp(-B)$. Barrier energies such as $E_{\max} \sim \sigma^3/\varepsilon^2$ appear only as ingredients of B, never alone in the exponent.

Reference [14] instead assigns to the tunnelling probability the form $P_{\rm SCO} \sim 10^{-n}$ with n proportional to a barrier energy divided by Planck's constant. The resulting exponent has dimensions of inverse time, so 10^{-n} is not a mathematically meaningful probability. Consequently, the numerical estimate $P_{\rm SCO} \sim 10^{-9.3\times 10^{31}}$ has no physical content and cannot be used to infer the rarity of biogenesis or to constrain the existence of extraterrestrial life.

Even setting aside this dimensional problem, the setup assumed in Ref. [14] is mismatched to prebiotic chemistry. The proposed initial state, a toroidal membrane built from long polymers, is not a likely membrane-forming configuration; toroidal shapes relax classically; and the relevant energy scales for membrane deformations are set by soft-matter elasticity (*e.g.* $\kappa \sim 20\,k_{\rm B}T \simeq 0.6$ eV), not by electronic ionization energies such as 13.6 eV. For these reasons, applying false-vacuum tunnelling formulas in vacuum does not provide a quantitative basis for the conclusions drawn in Ref. [14].

The overall message is optimistic: although the origin of life remains a mystery, its probability is not obviously prohibitively small. Perhaps we are not alone in the universe.

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