Quantum Field Mechanics: Complex-Dynamical Completion of Fundamental Physics and Its Experimental Implications

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This report provides a brief review of recently developed extended framework for fundamental physics, designated as Quantum Field Mechanics and including causally complete and intrinsically unified theory of explicitly emerging elementary particles, their inherent properties, quantum and relativistic behaviour, interactions and their results. Essential progress with respect to usual theory is attained due to the unreduced, nonperturbative analysis of arbitrary interaction process revealing a qualitatively new phenomenon of dynamic multivaluedness of interaction results and their dynamically entangled structure giving rise to universally defined dynamic complexity and absent in usual, always perturbative and dynamically single-valued models with the zero value of unreduced complexity (including substitutes used for “complexity”, “chaoticity”, “self-organisation”, etc.). It is shown how the observed world structure, starting from elementary particles and their interactions, dynamically emerges from the unreduced interaction between two initially homogeneous, physically real protofields. In that way one avoids arbitrary imposition of abstract entities and unprovable postulates or “principles”, let alone “mysteries”, of conventional theory, which now obtain unified, consistent and realistic explanation in terms of unreduced dynamic complexity. We complete the description of fundamental world structure emergence and properties by an outline of experimental implications and resulting causally substantiated change of research strategy.

1 Introduction

Despite the recognised essential incompleteness and ruptures of canonical fundamental science (see e. g. [1–15]), its scholar, “mainstream” development continues in the direction of purely technical variations of existing abstract models of reality that never solve the existing fundamental problems and confirm thus the famous “end-of-science” thesis [16]. In that way modern “exact” science persists in the tradition and impasses of so-called “new physics” that has appeared a hundred years ago as an “operational”, purely technical arrangement of qualitatively new experimental facts, but since then has failed to increase or even reproduce the internal consistency and realism of previous, “classical” form of science, in spite of hard enough efforts in that direction. After a spectacular “revolutionary” period at the beginning of the twentieth century, the “new” fundamental physics has itself been transformed into the next, quite conventional standard which, however, not only accepts, but actually welcomes a growing variety of inexplicable, but postulated “mysteries”, “paradoxes” and accumulating “unsolvable” problems, contrary to the previous kind of “well-established” science and suspiciously similar to quite different, openly esoteric knowledge, such as mystical cabbala or “experimentally confirmed” astrology.

That painful rupture between visible practical efficiency and conceptual incompleteness of official science paradigm gives rise to variously oriented attempts to find a “definite” problem solution within a less contradictory system of knowledge (see e. g. [17, 18]). Such kind of work can be justified also by a quickly growing number of practical difficulties in conventional science applications to more complicated systems or deeper levels of reality, which show that the famous “unreasonable effectiveness” of the standard paradigm [19] is quickly transformed into unjustified extension of the first, spectacular successes of new physics application to the simplest, elementary systems [20–24]. One could cite well-known cases of high-temperature superconductivity and other many-body quantum problems with irreducibly strong interactions and “complex” behaviour, among so many other “difficult” problems (e.g. in cosmology) growing in diversity and definitely escaping the “unreasonable effectiveness” of standard, “mathematically guessed” theory. That actually observed tendency shows that if the very essence of scientific method is to be preserved, including unreduced consistency and truly “exact” (objective) na-
ture of results, then it can be attained only within a qualitatively new concept, or “paradigm”, which should contain only the proven minimum of accepted “natural” assumptions and rigorously derive (rather than guess and impose) its main results, always remaining in close, inseparable entanglement with reality considered as a system of all its observed, interdependent properties.

In this paper we propose a review of such qualitatively new, intrinsically consistent concept and its application to simplest physical systems, starting from elementary particles and their interaction products. The general concept, embracing also the causally complete, i.e. physically and mathematically consistent, understanding of structure and behaviour of higher-level systems, is centred on the new, reality-based and universally applicable quantity of dynamic complexity, rigorously derived by the unreduced, universally nonperturbative analysis of arbitrary interaction process [24–33]. Its particular realisation at the lowest complexity levels, known as “quantum” behaviour, is designated as quantum field mechanics, including explicit, causally complete derivation of elementary entities (space, time, particles and fields) and their observed properties, such as space discreteness, time irreversible flow, particle mass, charge, spin, interaction forces, quantum measurement, quantum chaos, dynamically emerging classicality (in a closed elementary system), and all specific features of “quantum weirdness” (duality, indeterminacy, uncertainty, entanglement, complementarity), now demystified and naturally unified with the dynamically emerging “relativistic” effects [20–25,34–40].

In that way we show that all standard “quantum mysteries” and “relativistic effects” (actually postulated in usual theory) naturally emerge as unavoidable, totally consistent and realistic, but nontrivial, properties of dynamically multivalued, or complex, behaviour obtained, in its turn, just by the truly exact, unreduced analysis of underlying interaction processes and therefore appearing also in any system behaviour, within the causally derived and intrinsically unified diversity of forms. Note that main results of quantum field mechanics can be considered as a direct complex-dynamical extension of the “double solution” concept of Louis de Broglie [41–47] almost totally excluded from the scholar science framework, but now reappearing as implicit, but surprisingly advanced version of unreduced complexity at the lowest levels of world dynamics.\(^1\)

The attained causal completeness of the unreduced theory culminates in explicit, dynamically derived unification of causally extended versions of all known (correct) laws and principles of fundamental science within a single, unified law of conservation, or symmetry, of complexity [24–26,31], which remains always exact (i.e. is never “broken”) and intrinsically creative (describes explicit emergence of new entities), properly reflects the unified harmony of natural phenomena, and definitely eliminates the intrinsic separation, incompleteness and skewness of conventional science laws. Moreover, we rigorously show that the whole picture of usual theory, including both the postulated fundamental “mysteries” and recently advanced unitary versions of the “science of complexity”, corresponds to a heavily limited, effectively one-dimensional (or even zero-dimensional) projection of unreduced, dynamically multivalued (complex) world dynamics, which logically closes the theory by explaining consistently both relative successes of canonical theory applications to the simplest systems (i.e. the “unreasonable effectiveness”) and its persisting failure to complete the picture and understand more complicated system behaviour. We obtain thus a direct, dynamically multivalued extension of usual, dynamically single-valued, or unitary, theory, which is the expected natural way of development, correlating with the attained causally complete solution of accumulated fundamental and practical problems now shown to be indeed fundamentally unsolvable within the artificially limited framework of conventional, unitary science doctrine.

The basic framework and conclusions of the extended theory are considered in section 2, while various experimental manifestations of the obtained results are summarised in section 3, with the ensuing suggestion of necessary, practically important changes in particular applications and general research strategy.

2 Unified dynamic origin of elementary particles, their intrinsic properties, quantum and relativistic behaviour

Any real system structure and existence is determined by interaction between its components. The simplest, least structured initial configuration of a system is represented by two effectively homogeneous and infinite (“omnipresent”) fields attracted to each other. Guided by a strict version of Occam’s principle of parsimony, we should accept such interaction configuration as the basis of our world construction, provided that we can demonstrate explicit emergence of all its main structures and verified laws (patterns of behaviour) in that interaction process. Any “postulated” addition can be accepted only within a proven, necessary minimum for observed property appearance, so that one avoids the ambiguity of

\(^1\) The mentioned unreduced version of the double solution should be clearly distinguished from its reduced, schematic version first proposed by Louis de Broglie himself under the name of “pilot-wave interpretation”, then reintroduced by Bohm [48], further developed by his followers [5,49–53], and now often presented as the unique version of “causal de Broglie-Bohm approach” (see refs. [21,34,35] for more details).
arbitrary, subjectively “convenient” postulates of conventional, “positivistic” science that only fix the facts, but explain nothing at all. Well-specified realism and consistency of the assumed system configuration are additionally supported by the observed universality of two and only two distributed interaction forces, electromagnetic (e/m) and gravitational ones, which means that one of the protofields will eventually be responsible for e/m and another for gravitational interactions (see the end of this section). It means also that our interacting protofields are physically real fields, even though one can directly observe within this world only their interaction-driven perturbations forming the world structure. Being physically real entities, the protofields have their own internal structure (though usually inaccessible to direct observation) and related mechanical properties, including finite compressibility.

During interaction the e/m protofield degrees of freedom, $q$, are mixed, or “entangled”, with those of gravitational protofield, $\xi$, into a generally “nonseparable” combination, $\Psi(\xi, q)$, called state-function and describing the emerging world structure (in reality it measures the magnitude of e/m protofield perturbations, while a more inert, “heavy” gravitational medium is always “hidden” behind them and shows itself only through indirect effects, such as interaction between emerging entities, as it is described below). The state-function $\Psi(\xi, q)$ obeys a dynamic equation describing protofield interaction that will be called here existence equation. According to our rule of maximum self-consistency (or minimum assumptions), one has no right to use any particular “model” or postulated dynamical “principle” for that equation, and therefore it is accepted in the form that fixes only the fact of protofield interaction as such:

$$[\hbar(\xi) + V_{eg}(\xi, q) + h_e(q)]\Psi(\xi, q) = E\Psi(\xi, q),$$

(1)

where $h_e(q)$ and $\hbar(\xi)$ are “generalised Hamiltonians” for free (non-interacting) protofields (i.e. measurable functions eventually expressing dynamic complexity defined below), $V_{eg}(\xi, q)$ is an arbitrary (though eventually attractive and binding) interaction potential between the fields of $q$ and $\xi$, and $E$ is energy (generalised Hamiltonian eigenvalue). Being understood in a large sense, eq. (1) can correspond, up to minor details, to practically any particular “model” and actually reflects only the fact of protofield interaction as such. Its “Hamiltonian” form is also confirmed self-consistently by further interaction analysis [24–26, 31–37].

Let us note from the beginning the intrinsically “cosmological” nature of the theory formulation, where the demand of explicit dynamic emergence of any entity, together with its properties (expressed by “laws”), ensures that our derivation follows the main lines of real world structure emergence and evolution. In particular, there is no inserted “space”, “time”, or any other observed entities and properties in eq. (1): they will be obtained from its unReduced solution. On the other hand, one does need to have a primordial interaction behind the emerging world structure, in its minimal and correspondingly irreducible version, as opposed to the corrupt idea of “emergence from nothing” of finally postulated structures, underlying the growing “difficulties” of official cosmology and related to the general fallacy of “development without change” of unitary science (see [25, 37] and discussions below).

For a more convenient analysis of interaction process, we express $\Psi(\xi, q)$ in terms of complete system of eigenfunctions, $\{\phi_n(q)\}$, of the free e/m protofield Hamiltonian, $h_e(q)$:

$$\Psi(\xi, q) = \sum_n \psi_n(\xi) \phi_n(q),$$

(2)

which transforms eq. (1) into a system of equations:

$$[\hbar(\xi) + V_{00}(\xi)]\psi_0(\xi) + \sum_n V_{0n}(\xi)\psi_n(\xi) = \eta \psi_0(\xi),$$

$$[\hbar(\xi) + V_{nn}(\xi)]\psi_n(\xi) + \sum_{n' \neq n} V_{nn'}(\xi)\psi_n(\xi) = \eta_n \psi_n(\xi) - V_{n0}(\xi) \psi_0(\xi),$$

(3)

where $\eta_n \equiv E - \varepsilon_n$,

$$V_{nn'}(\xi) = \int dq \phi_n^*(q) V_{eg}(\xi, q) \phi_{n'}(q),$$

and we have separated the equation with $n = 0$, while assuming that $n \neq 0$ in other equations (here and below) and designating $\eta \equiv \eta_0$. Note that the obtained system of equations, eqs. (3), is just another, more relevant form of existence equation, eq. (1), that does not involve any additional assumption or result of interaction development. Such expression of system configuration in terms of dynamical “eigen-modes” (or “elements”) of a “free” component should always be possible, including the case of the formally “nonlinear” protofields, since we suppose that the internal dynamics of the latter is known, or “integrable”, at least in the scale range of interest (and does not involve itself the observed structure emergence).

Expressing $\psi_n(\xi)$ through $\psi_0(\xi)$ from eqs. (3) with the help of standard Green function technique [54, 55] and inserting the result into the equation for $\psi_0(\xi)$, we reformulate the problem in terms of effective existence equation containing only gravitational variables ($\xi$):

$$[\hbar(\xi) + V_{eg}(\xi; \eta)]\psi_0(\xi) = \eta \psi_0(\xi),$$

(4)
where the effective potential (EP), $V_{\text{eff}}(\xi; \eta)$, is given by

$$V_{\text{eff}}(\xi; \eta) = V_{00}(\xi) + \hat{V}(\xi; \eta), \quad (5)$$

$$\hat{V}(\xi; \eta) \psi_0(\xi) = \int d\xi' V(\xi, \xi'; \eta) \psi_0(\xi'), \quad (6)$$

$V(\xi, \xi'; \eta) = \sum_{n, i} V_{0n}(\xi) \psi_{ni}(\xi) V_{0n}(\xi') \psi_{ni}(\xi') \eta_n \psi_n(\xi). \quad (7)$

The general solution of existence equation, eq. (1), is then obtained as [24, 25, 34, 36]:

$$\Psi(\xi, q) = \sum_i c_i \left[ \phi_0(q) + \sum_n \phi_n(q) \hat{g}_{ni}(\xi) \right] \psi_0(\xi), \quad (8)$$

$$\psi_{ni}(\xi) = \hat{g}_{ni}(\xi) \psi_{0i}(\xi) = \int d\xi' g_{ni}(\xi, \xi') \psi_{0i}(\xi'),$$

$$g_{ni}(\xi, \xi') = V_{00}(\xi') \sum_{n'} \psi_{0i}^*(\xi) \psi_{n'i}^*(\xi') \eta_n - \eta_{n'} - \epsilon_n^0, \quad (9)$$

where $\{\psi_0(\xi)\}$ are the eigenfunctions and $\{\eta_i\}$ eigenvalues of the effective existence equation, eq. (4), while coefficients $c_i$ should be determined from the state-function matching conditions along the boundary where interaction vanishes. The observed system density, $\rho(\xi, q)$, is given by the squared modulus of protofield amplitude, $\rho(\xi, q) = |\Psi(\xi, q)|^2$.

The obtained problem expression and formal “solution”, eqs. (4)–(9), are known under the name of optical, or effective, potential method [54], which is usually applied, however, in a perturbatively reduced version, where the “nonintegrable” self-consistent links in EP and solution expressions to unknown eigenvalues and eigenfunctions are eliminated by one or another approximation transforming the effective problem solution into a “closed”, integrable form. We show that such reduction actually kills the qualitatively important features of unreduced solution that provide a universal source of dynamic randomness, entanglement of interaction components and related squeeze (or “reduction”) and extension cycles, leading to universally defined dynamic complexity of unreduced interaction process and the unified, causally complete understanding of elementary particles and all their “quantum” and “relativistic” properties.

The most important property of unreduced solution revealed by its EP expression, eqs. (4)–(9), is called dynamic multivaluedness, or redundancy, and provides the universal, dynamic origin of randomness appearing as irreducible “quantum indeterminacy” at the level of elementary particle dynamics. It is due to the unreduced EP dependence on the eigenvalues to be found, $\eta$, expressing the essential, dynamically emerging problem nonlinearity, which is not explicitly present in its initial formulation, eqs. (1), (3), that can well contain formally linear equations. Indeed, if $N_e$ and $N_g$ are the numbers of participating eigen-modes (or “elements”) of free e/m and gravitational protofields respectively (normally $N_e = N_g$ and $N_e, N_g \gg 1$), then the total number of eigenvalues for eqs. (4)–(6), determined by the maximum power of characteristic equation, is easily estimated as

$$N_{eg} = N_e N_g^1 = N_g (N_e N_g + 1) = (N_g)^2 N_e + N_g, \quad (10)$$

while the factor of $N_{eg}^1 = N_e N_g + 1$ is due to EP dependence on $\eta$, eq. (6), leading to the $N_g$-fold redundancy of ordinary eigen-solution sets plus a separate, reduced set of eigen-solutions that forms a specific “intermediate” state specified below. A detailed study, including “geometric” analysis of eqs. (4)–(6), confirms universality of dynamic multivaluedness and physical reality of redundant partial solutions called system realisations because each of them is “locally” complete and describes exhaustively a real system configuration [24, 25, 34, 36–39, 55].

All realisations are real and have “equal rights” to appear as a result of interaction development. But since each realisation is complete as such, the system can take only one realisation at a time, i.e. realisations are mutually incompatible and cannot be “superimposed”, “coexist”, or appear simultaneously. Therefore the system is “forced” (by the driving interaction alone) to take and permanently change its realisations in a dynamically random order, where randomness itself, and thus also chaos, obtains its universal, intrinsic origin and definition as the above dynamic multivaluedness of (any) unreduced interaction process. We can present this result in the form of genuine, really complete and therefore probabilistic general solution of a problem expressing the observed density $\rho(\xi, q)$, as a causally probabilistic sum of respective densities, $\rho_r(\xi, q) = |\Psi_r(\xi, q)|^2$, for individual realisations numbered by index $r$ here and below:

$$\rho(\xi, q) = \sum_{r=1}^{N_{eg}} \rho_r(\xi, q), \quad (11)$$

\[2\]This is a fundamental difference of our results from popular unitary imitations of complexity, where different “attractors”, or “unstable orbits”, or other empirically (or numerically) guessed “states” coexist in an abstract “space” of continuously developing trajectories, with a fixed, postulated system configuration.
where $N_R$ ($=N_g$ in our case) is the total realisation number, and the sign $\oplus$ serves to designate a special, dynamically probabilistic meaning of the sum. The latter implies that regular realisations appear and disappear, together with their causally derived densities $\rho_r(\xi,q)$ (see also below), in a dynamically random, “spontaneous”, “unpredictable”, or chaotic order, whatever is the time of observation and the number of registered events (an event is rigorously and universally obtained now as totally dynamic, interaction-driven realisation emergence and disappearance). The dynamically probabilistic sum of the general solution, eq. (11), includes, in its complete form, further levels of chaotically changing realisations obtained by application of the same EP method to the system of auxiliary equations, eqs. (7), and constituting hierarchically organised branches of extended, dynamically probabilistic fractal [25,29,31] that represents the unreduced, complex-dynamical result of interaction development and the emerging system structure.

Moreover, we obtain the a priori determined, causal (dynamic) probability, $\alpha_r$, of the $r$-th elementary realisation emergence as

$$\alpha_r = \frac{1}{N_R} \quad (r = 1, \ldots, N_R), \quad \sum_{r=1}^{N_R} \alpha_r = 1,$$

(12)

Since in many cases elementary realisations are not individually resolved in actual measurements and, being inhomogeneously distributed, appear in dense groups, or dynamic “tendencies”, containing various their numbers, the probabilities of appearance of such compound realisations are causally/dynamically determined by the numbers of constituent elementary realisations:

$$\alpha_r(N_r) = \sum_{N_r}^{N_R} \alpha_r(1, \ldots, N_r), \quad \sum_{r=1}^{N_R} \alpha_r = 1,$$

(13)

$N_r$ being the number of elementary realisations in their $r$-th group forming an actually observed, compound realisation. When the number of events (observation time) is large enough, the probabilistic sum of eq. (11) approaches usual expectation (average) value,

$$\rho_{ex}(q,\xi) = \sum_{r=1}^{N_R} \alpha_r \rho_r(q,\xi).$$

(14)

However, the dynamically probabilistic sum of eq. (11) and associated causal probability values, eqs. (12)–(13), preserve their meaning also for single, isolated events emerging in real time (and thus together with causally specified time itself, see below).

The second fundamental property of unreduced interaction result, the autonomous dynamic entanglement of interacting system components (two protofields in our case) within each realisation is specified in the obtained solution, eq. (8), by the dynamically weighted sum of products of functions of interacting degrees of freedom, $q$ and $\xi$ (this structure is reproduced at further developing levels of the dynamically probabilistic fractal [25,29,31]). The general interaction result, eq. (11), emerges thus as dynamically multivalued entanglement of system components, where entanglement as such determines the physical, tangible quality, or “texture”, of really new, emerging entities represented by system realisations, and similar to the above property of multivaluedness-chaoticity, that process of new quality formation by (fractal) dynamic entanglement is fundamentally absent in the unitary projection of conventional theory.

The process of realisation formation and change can be better understood if we specify the expressions for the state-function (density) and EP for an arbitrary, $r$-th realisation, by substituting its eigenvalues and eigenfunctions found from the effective existence equation, eq. (4), for their general designation in eqs. (5)–(6), (8)–(9):

$$V_{\text{eff}}(\xi;\eta^r_\xi) \psi_{0i}(\xi) = V_{00}(\xi) \psi_{0i}(\xi) +$$

$$+ \sum_{n,i'} \frac{\Omega_n}{\eta^r_n - \eta^0_{ni'} - \varepsilon_{n0}},$$

(15)

$$\Psi_r(\xi,q) = \sum_i c_i^r [\phi_0(q) \psi_{0i}(\xi) +$$

$$+ \sum_{n,i'} \frac{\phi_n(q) \psi^0_{ni'}(\xi) \int d\xi' \psi_{ni'}^*(\xi') V_{n0}(\xi') \psi_{0i}(\xi')}{\Omega_n} \eta^r_n - \eta^0_{ni'} - \varepsilon_{n0}],$$

(16)

$$\rho_r(\xi,q) = |\Psi_r(\xi,q)|^2.$$

It is not difficult to see [24,25,29,34,36,38,39] that because of resonant eigenvalue involvement in the denominators of unreduced EP and state-function expressions, eqs. (15), (16), each state function and EP realisation concentrates around certain eigenvalue $\eta^r_n$ that can be interpreted as a centre of emerging elementary particle and space structure (physical space “point”), or its dynamically emerging “coordinate”, while the difference of such eigenvalues for consecutively taken, “neighbouring” realisations, $\Delta \eta^r_n$, forms the elementary, discrete space distance (or length). It is important that due to the self-consistent dynamic relation between the state-function and EP structures, eqs. (15), (16), they concentrate around the same emerging space point, mutually amplifying each other, i.e. taking each realisation, the

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Note also the “cutting” role of “overlap integrals” in the numerators of eqs. (15), (16) and a convenient choice of eigenfunctions of the initial expansion basis in eq. (2), $\{\phi_n(q)\}$, in the form of highly localised, $\delta$-like functions.
system autonomously “digs up the potential well for itself” and simultaneously “falls” into it, without any inhomogeneity being artificially introduced into the uniform initial configuration. This essential dynamic instability of unreduced protofield interaction with respect to “spontaneous” dynamical squeeze, or collapse, or reduction around randomly chosen realisation centre is closely related to dynamic multivaluedness and (fractal) entanglement, where the former gives causal (dynamic) randomness and the latter drives the collapse and accounts for its self-amplifying, “catastrophic” development.

Due to finite protofield compressibility, local reduction process around a current realisation centre will stop at the moment of maximum possible squeeze. But the protofield interaction persists around the point of maximum squeeze (also due to the dynamically fractal interaction structure), and therefore at a moment where the dynamic amplification force of collapse vanishes, the same intrinsic instability that gives rise to reduction by self-amplified entanglement will cause the reverse, also self-amplifying disentanglement and extension process, leading to a quasi-homogeneous system state close to initial configuration of noninteracting protofields followed by another collapse to the next, also randomly chosen reduction centre, and so on. That is the detailed, dynamically inevitable mechanism of realisation change in any unreduced interaction [24, 25, 28, 29, 31–34, 36–39]. One obtains thus an infinite series of cycles of protofield reduction-extension around randomly chosen reduction centres forming the dynamical space structure. We designate this spatially chaotic, essentially nonlinear pulsation in the a priori homogeneous system of interacting protofields as quantum beat process and argue that it constitutes the complex-dynamical internal structure, and the very essence, of any massive elementary particle, exemplified by the electron as the simplest species.

Note the role of transient, extended state of quasi-free components during system transition between two successive localised realisations: it constitutes a specific, “intermediate” (or “main”) realisation, which has appeared in the unreduced solution analysis (in relation to eq. (10)), enters explicitly that solution [20-25], and forms the unified dynamical “link” and probabilistically structured “distribution ground” for all other, regular, localised realisations. As confirmed below, that intermediate realisation forms a physically real, causally complete version of the famous quantum-mechanical wavefunction, possessing all the necessary properties (“inexplicable” in unitary theory) and universally extendible to higher complexity levels (see also refs. [23–25,29,31–37]).

In particular, wave-particle duality is dynamically obtained in the form of permanent change between the squeezed, or “corpuscular”, and extended, or “undular”, states of the quantum beat process within any (massive) elementary particle that can also be called field-particle (that dynamic alternation of the two kinds of state is naturally reproduced and observed in interaction processes of elementary field-particles, see below).4

The intrinsically probabilistic nature of the wavefunction, remaining its most “mysterious” property in all unitary theory versions (especially in combination with its quite real manifestations, such as diffraction), also appears as inevitable, dynamic consequence of underlying unreduced, multivalued interaction process, where the canonical Born’s probability rule, used for practical calculation of regular realisation probabilities, follows directly from the dynamical “matching conditions” for the wavefunction and its dynamically squeezed transform, eq. (16) [24, 25, 31, 34, 36–39]. The wavefunction represents natural dynamical averaging between regular realisations performed, in agreement with the expectation value expression of eq. (14), in the “intermediate” realisation by the unreduced system dynamics itself. It is only that, “averaged”, or “main”, realisation that remains in usual, dynamically single-valued (unitary) description, while its intrinsic dynamical links to permanently appearing and disappearing “regular” (localised) realisations, as well as those realisations themselves, are arbitrarily thrown off (and then artificially reinserted, in the form of “corpuscular properties” to ensure “agreement with experiment”, but at the expense of postulated “quantum mysteries”, “relativistic paradoxes”, and ir-}

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4The realistic, complex-dynamical mechanism of quantum duality is naturally extended to the causally complete interpretation of a more general concept of “complementarity” introduced by Niels Bohr and known for its particular obscurity, even with respect to other “quantum mysteries”. Namely, causal complementarity refers to the intrinsically dualistic nature of unreduced, multivalued interaction dynamics unifying, contrary to its single-valued projection, such contradictory properties as locality (“structures”) and nonlocality (“transitions”), continuity and discreteness (quantization into realisations), regularity (configuration of each realisation) and randomness (realisation emergence and sequence), entanglement (mixture) and disentanglement (separation), quanticity and classicality (see refs. [24, 25, 28, 29, 31–39] for more details).
its two aspects of (1) unceasing flow (realisation change) and (2) unpredictability (randomness) of each next step (i.e. time flow direction towards growing total randomness naturally identified with growing dynamic entropy).

In that way we have obtained the minimum necessary basis for the consistent introduction of unreduced dynamic complexity, $C$, which can now be universally defined [24–38] as a growing function of system realisation number, $N_R$, or rate of their change, equal to zero for the (unrealistic) case of only one realisation: $C = C_0 f (N_R)$, where $df/dN_R > 0$ and $f (1) = 0$; for example, $f (n) = \ln (n)$ (this definition remains valid only if the unreduced, dynamically multivalued structure of a system or interaction process is explicitly obtained with all its internal dynamical links).

The above explicitly derived spatial structure and temporal change are main universal manifestations of unreduced dynamic complexity and give rise to any other observed feature of world structure and dynamics: realisation change “produces” a physically real space element $\Delta x = \Delta x^r$ and time increment $\Delta t = 1/\nu = \Delta x/c$, where $\nu$ is the frequency (expressing intensity) of realisation change process and $c$ is the velocity of perturbation propagation in the system. Since the simplest independent combination of space and time is given by action, $A$, we obtain the extended interpretation of action as a universal complexity measure accounting for the essentially nonlinear realisation change process: each realisation change cycle is described by an action increment $\Delta A = -E \Delta t + p \Delta x$, where coefficients $E$ and $p$ are identified as energy and momentum.

Since in the case of quantum beat dynamics one deals with the most fundamental world structure emergence, it is impossible to observe and measure the continuous, detailed course of the process. Observed effects and measurements start from the complete realisation change (reduction-extension) cycle of quantum beat, providing the basis and realistic explanation for quantization [see also below], only formally introduced in usual theory. It becomes clear also that at those lowest, “quantum” complexity levels $|\Delta A| = h$, where $h$ is Planck’s constant, and one obtains the causally complete explanation for both fixed, finite value of $h$ (indivisibility of the quantum beat cycle) and its universality for a very wide range of elementary entities and phenomena (first level of interaction between the same two protofields) [22], which is also taken for granted in usual theory.

For the field-particle at rest ($p = 0$) one obtains $\Delta A = -E_0 \Delta t$, where $E_0$ is the rest energy, and thus

$$E_0 = -\frac{\Delta A}{\Delta t} = \frac{h}{\tau_0} = h \nu_0 ,$$

where $\Delta A = -h$ (since $E_0, \Delta t > 0$), $\Delta t = \tau_0$ is the emerging “quantum of time” equal to a time period, $\tau_0$, of essentially nonlinear, spatially chaotic quantum beat process, and $\nu_0 \equiv 1/\tau_0$ is its frequency ($\nu_0 \sim 10^{20}$ Hz for the electron). One obtains thus the elementary, natural clock of the world driven by the autonomous complexity-dynamical mechanism of quantum beat and giving rise to the most fundamental level of time [25]. In agreement with the above complexity definition, system energy thus specified represents a (differential) measure of dynamic complexity (its integral measure is given by action $A$).

It is not difficult to see also that the spatially chaotic distribution of consecutive reduction centres of a quantum beat process within the elementary field-particle provides it with the universally defined property of mass remaining otherwise ambiguous in any unitary theory. Indeed, the quantum beat process can be considered as chaotic wandering of squeezed, corpuscular state of the field-particle, also called virtual soliton [25,34–37], within its wavefunction, where the basic property of inertia emerges in the form of resistance to change of that chaotic motion, already existing in any (massive) particle, in agreement with the heuristic concept of “hidden thermodynamics” of a single particle introduced by Louis de Broglie [47]. Therefore the field-particle rest energy, $E_0$, possesses, together with the underlying quantum beat process, the intrinsic property of inertia and should be proportional to the rest mass, $m_0$, expressing that property, $E_0 = m_0 c^2$ (where $c^2$ is a coefficient to be specified later), which leads to another form of eq. (17),

$$m_0 c^2 = h \nu_0 ,$$

proposed by de Broglie within physical derivation of the famous expression for the particle wavelength [41] (now known as “de Broglie wavelength”, see also [21]). We specify thus the dynamic origin of de Broglie’s “periodic phenomenon” (quantum beat), attached to a particle “mobile” that includes a localised entity (our virtual soliton), and the intrinsic link between them, eq. (18).

Now, if the field-particle is set in motion, its energy-complexity grows over the minimum of rest energy corresponding to the homogeneous distribution of realisation probabilities (see eq. (12)), while its action-complexity acquires a coordinate dependence characterising inhomogeneous distribution of realisation probabilities of the globally moving quantum beat process, so that eq. (17) for the particle at rest is replaced by expression relating the total and partial action derivatives:

$$\frac{\Delta A}{\Delta t} = \frac{\Delta A}{\Delta t} \big|_{x=\text{const}} + \frac{\Delta A}{\Delta x} \big|_{t=\text{const}} \frac{\Delta x}{\Delta t} ,$$

or

$$E = \frac{\Delta A}{\Delta t} + \frac{\Delta A}{\Delta x} \frac{\Delta x}{\lambda} = \frac{h}{\tau} + \frac{h}{\lambda} \nu = h N + p \nu ,$$

where

$$E = \frac{\Delta A}{\Delta t} \big|_{x=\text{const}} = \frac{h}{\tau} = h \nu$$
is the total system energy,
\[ p = \frac{\Delta A}{\Delta x} \bigg|_{t=\text{const}} = \frac{|\Delta A|}{\lambda} = \frac{h}{\lambda} \]  
(21)

is its universally defined momentum,
\[ v = \frac{\Delta x}{\Delta t} = \frac{A}{T} \]

is the global motion velocity, \( \lambda \equiv (\Delta x) \bigg|_{t=\text{const}} \) is the “quantum of space” emerging from the field-particle motion, \( \Delta t = T \) is the “total” period of nonlinear quantum beat of the field-particle in the state of motion with complexity-energy \( E \) (\( N = 1/T \) is the corresponding quantum-beat frequency), \( \Delta x = \Lambda \) is the “total” quantum of space, while \( \tau \equiv (\Delta t) \bigg|_{t=\text{const}} \) is the quantum-beat period measured at a fixed space point.

The wave field inhomogeneity induced by global field-particle motion and given by eq. (21) is none other than the particle de Broglie wavelength \( \lambda \equiv \lambda_B \), now understood thus as a result of complex-dynamical (multivalued and probabilistic) structure formation process, at this complexity sublevel \([21–25, 34–37]\). That structure emerges as averaged, regular part of globally moving quantum beat, described by the second summand in the particle energy partition of eq. (19), whereas the first summand accounts for the totally irregular (homogeneous in average) virtual soliton wandering “around” that average tendency. At the same time, every single jump of the virtual soliton preserves its dynamically probabilistic character, so that the whole content of the total energy possesses the property of inertia, which provides causal explanation and intrinsic unification of respective “relativistic” and quantum properties.

Since the two tendencies in the quantum beat dynamics of a globally moving particle, the regular global displacement of the wave field and totally random wandering of the virtual soliton around it, form a single complex-dynamical (multivalued) process, another dynamic relation, properly reflecting that essential link, should be added to the structure formation expression of eqs. (19)–(21). If we introduce the velocity of light \( c \) as the velocity of physically real perturbation propagation through the e/m protofield coupled to the gravitational protofield (as opposed to the postulated formal limitation of the abstract “principle of relativity” in standard theory), then it becomes clear that during a time period, \( \tau_1 = \lambda/c \), of global wave field advance of \( \lambda \equiv \lambda_B \), the virtual soliton should perform, in average, \( n_1 = c/v \) irregular jumps around it, which explains why our massive field-particle, being an e/m protofield perturbation, moves not with the velocity of light, but with the velocity \( v < c \) (we thus derive this “postulate” of standard relativity from a physically transparent picture of multivalued interaction dynamics). Since every jump duration is \( \tau \), we have \( n_1 \tau = \tau_1 \), or \( \lambda = V_{ph} \tau \), where \( V_{ph} = c^2/v \) is the fictitious, apparently superluminal “phase velocity” of “matter wave” propagation, appearing if one does not take into account the irregular, “multivalued” part of the field-particle dynamics \([41]\). Writing the obtained relation as \( 1/\lambda = (1/\tau)(v/c^2) \), multiplying it by \( h \), and using the energy and momentum definitions, eqs. (20), (21), one gets the famous “relativistic” dispersion relation between momentum and energy
\[ p = E \frac{v}{c^2} = mv \],  
(22)

where \( m = E/c^2 \), now by rigorously derived definition, in which \( c \) is the above physically based speed of light.

We obtain thus the causally complete, quantum interpretation of classical relativistic relation between energy and mass, specifying our previous assumption in eq. (18) and derived from the underlying complex, multivalued and dynamically quantized interaction dynamics. It provides the necessary completion of the original “phase accord” conjecture of Louis de Broglie \([41]\), and we obtain the final expression for the de Broglie wavelength by combining eqs. (21) and (22):
\[ \lambda = \lambda_B = \frac{h}{mv} \].  
(23)

A still larger implication of the causally derived dispersion relation of eq. (22) is that it provides, after (discrete or continuous) differentiation with respect to time, the rigorous substantiation of relativistic version of Newton’s laws of “classical” dynamics, revealing the irreducible role of underlying complex-dynamical (multivalued) structure emergence and including causally complete understanding of major entities of space, time, energy, mass, and momentum as various forms and measures of dynamic complexity. Due to universality of the above interaction analysis, we can see that those laws and the underlying dispersion relation, eq. (22), remain valid at any complexity level, provided we have a uniform enough regime of (averaged) interaction development, situated well outside of another complexity level emergence (such as relativistic particle transformations).

Inserting the dispersion relation of eq. (22) into the energy partition of eq. (19) and using energy definition of eq. (20), one gets a basic time relativity expression revealing now its genuine, complex-dynamic origin:
\[ \tau = T \left( 1 - \frac{v^2}{c^2} \right) \].  
(24)

We see that our causally defined time goes more slowly “within” a moving entity \( (T > \tau) \) because that, physically real time is explicitly produced by the same unceasing, spatially chaotic realisation change process that
gives rise to the global motion. A part of quantum beat energy that goes to the global motion is subtracted from the irregular component of dynamics just accounting for “internal” time of a moving system. In order to get the standard expression of time retardation effect, in terms of time period in the state of rest, \( \tau_0 \), we use an additional relation between motion frequencies \( \nu, \mathcal{N}, \) and \( \nu_0 \),

\[
\mathcal{N} \nu = (\nu_0)^2, \quad \text{or} \quad T = \frac{\tau_0}{\sqrt{1 - \frac{\nu^2}{c^2}}}. \tag{25}
\]

These relations express a physically transparent law of “conservation of the total number (frequency) of reduction events”, which is a manifestation of complexity conservation law \([25, 34–36]\). Using eq. (25) in eq. (24), we get the canonical expression of time retardation effect, but now causally derived in terms of underlying complex dynamics of the quantum beat:

\[
\mathcal{N} = \nu_0 \sqrt{1 - \frac{\nu^2}{c^2}} \quad \text{or} \quad T = \frac{\tau_0}{\sqrt{1 - \frac{\nu^2}{c^2}}}. \tag{26}
\]

Related relativistic effects (e.g. length reduction) are obtained as straightforward consequences of these results.

We can summarise the obtained intrinsic, complex-dynamical unification of causally complete versions of quantum and relativistic mechanics by combining in one expression the complex-dynamical energy partition into regular (global) transport and irregular (local) wandering, eq. (19), with the causally derived dispersion relation, eqs. (22), (23), and time (frequency) relation to dynamics, eqs. (26):

\[
E = h\nu_0 \sqrt{1 - \frac{\nu^2}{c^2}} + \frac{h}{\lambda_B} \nu = h\nu_0 \sqrt{1 - \frac{\nu^2}{c^2}} + h\nu_B = m_0 c^2 \sqrt{1 - \frac{\nu^2}{c^2}} + \frac{m_0 \nu^2}{\sqrt{1 - \frac{\nu^2}{c^2}}}, \tag{27}
\]

where \( h\nu_0 = m_0 c^2 \) (eq. (18)) and we introduce de Broglie frequency, \( \nu_B \), defined as

\[
\nu_B = \frac{\nu}{\lambda_B} = \frac{m\nu}{h} = \frac{\nu_{00}}{\sqrt{1 - \frac{\nu^2}{c^2}}} = \nu \sqrt{1 - \frac{\nu^2}{c^2}}, \tag{28}
\]

\[
\nu_{00} = \frac{m_0 \nu^2}{h}, \quad \lambda_{B0} = \frac{\nu}{\sqrt{1 - \frac{\nu^2}{c^2}}}, \quad \lambda_{B0} = \frac{h}{m_0 \nu}.
\]

Physical reality of de Broglie wave, obtained as a result of dynamically multivalued structure formation process in the system of two protofields, is confirmed by “usual” relation between its wavelength, frequency, and velocity, \( \lambda_B \nu_B = v \), comprising a nontrivial, essentially nonlinear and causally random, alternation of dual, undular and corpuscular, protofield structures permanently transformed into one another and thus preserving their “phase accord” \([41–47]\). It is not difficult to see from eq. (27) \([35, 36]\) that the quantities \( \alpha_1 = \frac{\nu^2}{c^2} \) and \( \alpha_2 = 1 - \alpha_1 = 1 - \frac{v^2}{c^2} \) represent dynamically obtained realisation probabilities for, respectively, global (regular) and totally random tendencies of the moving field-particle dynamics, in full agreement with the general definition of eq. (13), confirming once more the intrinsic unity of “quantum” and “relativistic” manifestations of unreduced interaction complexity.

The first term in the sum of eqs. (19), (27) taken with the opposite sign, \( \Delta A / \Delta t = pv - E \equiv L \), is known as system Lagrangian. Energy partition of eq. (27) provides thus the causally derived expression for the Lagrangian, together with its physical meaning of purely random, “thermal” part of multivalued (chaotic) system dynamics taken with the opposite, negative sign:

\[
L = -h\mathcal{N} = -h\nu_0 \sqrt{1 - \frac{\nu^2}{c^2}} = -m_0 c^2 \sqrt{1 - \frac{\nu^2}{c^2}}. \tag{26}
\]

This interpretation leads to the causally derived, realistic extension of the “principle of least action” \([25, 35, 36]\), anticipated by Louis de Broglie, whereas standard relativity postulates that principle and mechanistically guessed, formal expression for the Lagrangian and action (see e.g. \([56, 57]\)), tacitly adding these and other assumptions, essentially used in the theory, to the explicitly announced “principle of relativity”. The obtained negative sign of the Lagrangian is its universal property expressing the dynamic arrow (irreversibility) of time and its orientation to growing dynamic entropy and correspondingly decreasing dynamical information just represented by action-complexity, so that their sum, the total system complexity, remains unchanged \([24–26]\).

The multivalued version of elementary particle dynamics should be completed by explicit equation for its undular, wavefunctional state, causally introduced above (whereas action and its derivatives refer mainly to the localised state of virtual soliton). That wave equation is obtained with the help of causal quantization procedure \([22–26, 35–37]\) summarising quantum beat dynamics, which returns to the same state of wavefunction (intermediate realisation) in each reduction-extension cycle. It corresponds to system complexity conservation expressed by the product of action-complexity of corpuscular state, \( \mathcal{A} \), and that of the wavefunction, \( \Psi \), so that \( \Delta (\mathcal{A}\Psi) = 0 \) for each quantum beat cycle:

\[
\Delta (\mathcal{A}\Psi) = \mathcal{A}\Delta \Psi + \Psi \Delta \mathcal{A} = 0, \quad \text{or} \quad \Delta \mathcal{A} = -h \frac{\Delta \Psi}{\Psi}, \tag{29}
\]

since the characteristic value of \( \mathcal{A} \) is equal to \( h = h/2\pi \). The latter quantity is then additionally multiplied by the imaginary unit, i, which does not change the physical sense of quantization and accounts for the difference
between wave and corpuscular states in wave presentation by complex numbers:

$$\Delta A = -\hbar \frac{\Delta \Psi}{\Psi}.$$  \hfill (30)

Causal version of differential, “Dirac” quantization rules is then obtained by using the above definitions of momentum, eq. (21), and energy, eq. (20):

$$p = \frac{\Delta A}{\Delta x} = -\frac{\hbar}{\Psi} \frac{\partial \Psi}{\partial x}, \quad p^2 = -\frac{\hbar^2}{\Psi} \frac{\partial^2 \Psi}{\partial x^2},$$  \hfill (31)

$$E = -\frac{\Delta A}{\Delta t} = \frac{\hbar}{\Psi} \frac{\partial \Psi}{\partial t}, \quad E^2 = -\frac{\hbar^2}{\Psi} \frac{\partial^2 \Psi}{\partial t^2},$$  \hfill (32)

where quantization of higher powers of $p$ and $E$ properly reflects the wave nature of $\Psi$ [23, 25], and $x$ can be directly extended to a three-dimensional vector.

Inserting now the obtained quantization expressions into a version of eq. (27),

$$E = m_0 c^2 \sqrt{1 - \frac{p^2}{c^2} + \frac{\omega^2}{m}} \quad \text{or} \quad mE = m_0 c^2 + p^2,$$  \hfill (33)

we get the desired equation for $\Psi$, equivalent to the simplest form of both Dirac and Klein-Gordon equations:

$$i \hbar m \frac{\partial \Psi}{\partial t} + \hbar^2 \frac{\partial^2 \Psi}{\partial x^2} - m_0^2 c^2 \Psi = 0,$$  \hfill (34)

$$\frac{\partial^2 \Psi}{\partial t^2} - \frac{c^2}{\hbar^2} \frac{\partial^2 \Psi}{\partial x^2} + \omega_0^2 \Psi = 0,$$  \hfill (35)

where $\omega_0 \equiv m_0 c^2 / \hbar = 2 \pi \nu_0$ is the “circular” frequency of quantum beat pulsation at rest (see eq. (18)) accounting for the spin vorticity twirl [25, 34–36] (see also below). More elaborated forms of wave equation, taking into account particle interactions, can be obtained within the same causal quantization procedure [25], endowing formally identical usual versions with a realistic, complex-dynamic substantiation. In the nonrelativistic limit they are reduced to the Schrödinger equation, but provided with the causally complete interpretation.

One can also obtain Schrödinger equation by using causal quantization rules, eqs. (31)–(32), in the nonrelativistic limit of energy-momentum relation of eq. (33) for particle in external potential, $V(x,t)$ (which causally appears as a dynamically “folded”, “potential” form of complexity, or “dynamic information” [24–26, 37]):

$$E = \frac{p^2}{2m_0} + V(x,t) \rightarrow$$

$$\rightarrow i \hbar \frac{\partial \Psi}{\partial t} = -\frac{\hbar^2}{2m_0} \frac{\partial^2 \Psi}{\partial x^2} + V(x,t) \Psi(x,t) .$$  \hfill (36)

It can be shown [25] that for binding potentials eq. (36) can be satisfied only for discrete configurations of $\Psi(x)$ characterised by integer numbers of the same action-complexity quantum, $h$, that describes one quantum-beat cycle, or “system realisation change”, which explains the famous “energy-level discreteness” by universal complex-dynamic discreteness (or dualistic quantization) of unreduced interaction process. It means also that quantum-mechanical “linear superposition” of eigenfunctions and respective eigenvalue probabilities, including the special case of “quantum entanglement” for a many-body system, reflects multivalued dynamics of the underlying interaction, where the system performs unceasing “quantum jumps” (reduction-extension cycles) between eigenstates (see eqs. (11), (15)–(16)) with dynamically determined probabilities (eqs. (12)–(13)). Quasi-linearity of wavefunction behaviour is due to transiently weak, perturbative interaction character only within that particular, intermediate realisation of the wavefunction (see above), whereas measured eigenvalue emergence from that realisation, hidden within “inexplicable” standard postulates, is due to essentially nonlinear and physically real creation of respective regular realisations.

Similar to mass, every intrinsic property of elementary field-particle can be causally explained as a manifestation of physically real, but irreducibly complex, essentially nonlinear quantum-beat dynamics. Thus, the property of spin results from “shear instability” of collapsing protofield dynamics, leading to highly nonlinear vorticity emergence, similar to a weakly nonlinear case of a liquid escaping through a small hole from a basin under the influence of gravity [25] (and similar to a water twirl, the direction of spin vorticity, determining particle helicity, may be due to a weak rotational, or “CP”, asymmetry of the driving protofield interaction). The same rest energy of a particle, eq. (17), can then be presented, for example for a spin-1/2 particle like the electron, as

$$E_0 = h \omega_0 = \hbar \omega_0 = 2 \hbar \omega_0,$$

where $s = h/2$ is the spin angular momentum for each phase of reduction or extension of the quantum beat dynamics. Particle magnetic moment and magnetic field originate from the same quantum beat vorticity (in the extension phase) [25].

The property of electric charge expresses the long-range interaction between individual quantum beat processes through the common e/m medium. In view of the well-known proportionality relation between the squared elementary charge $e$ and Planck’s constant $h$, $\alpha \hbar = e^2 / c$ (where $\alpha \approx 1/137$ is the famous fine structure constant), it becomes clear that $e$ expresses the same dynamically discrete structure of protofield interaction complexity as $h$ (corresponding to one quantum beat cycle), but now with respect to phase-sensitive e/m interactions between different quantum beat processes. Universal quantization of electric charge in units of $e$ acquires thus a dynamic, causal origin, directly related to causal quantization of motion. The number (two) and “opposite” na-
nature of existing kinds of charge are explained by universal complex-dynamical phase synchronisation of individual quantum beat processes up to the opposite phase: quantum beat processes with opposite phases appear as unlike, “opposite” charges, dynamically attracted to each other [25]. In accord with our physically real origin of time, the same quantum beat synchronisation accounts for universality of time flow, also taken for granted in usual theory.

The standard relation between $e$ and $h$ can be presented in a form providing better insight into the underlying quantum beat dynamics:

$$m_0c^2 = \frac{2\pi}{\alpha} \frac{e^2}{\lambda_C} = N_R^e \frac{e^2}{\lambda_C}, \quad N_R^e = \frac{1}{\alpha}, \quad \lambda_C = \frac{\lambda_C}{2\pi}, \quad (37)$$

where $\lambda_C = h/m_0c$ is the Compton wavelength of the elementary field-particle with the rest mass $m_0$ and electric charge $e$ (actually represented by the electron or positron). The electron rest energy can be considered thus as a sum of $N_R^e = 1/\alpha$ e/m interactions between two elementary charges at a distance of $\lambda_C$. But since multivalued quantum beat dynamics consists of virtual soliton jumps between its realisations (reduction centres), we can consistently interpret the above relation by assuming that $\lambda_C$ expresses the length of elementary particle jump between its two consecutive localised realisations and $N_R^e = 1/\alpha \approx 137$ gives (up to its fractional part) the total number of system realisations, i.e., the number of possible reduction centre positions for the electron or, equivalently, the number of the constituent virtual photons in its extended phase. We obtain thus the new, intrinsic and complex-dynamical interpretation of both Compton length and fine structure constant. It implies, in particular, that the fine structure constant, $\alpha = 1/N_R^e$, coincides with the elementary realisation probability, $\alpha = 1/N_R$, defined by eq. (12).

The obtained expression for the Compton length corresponds to the de Broglie wavelength, eq. (23), for a particle simultaneously moving with the speed of light ($v = c$) and remaining globally at rest ($m = m_0$). That “impossible” combination of properties is practically realised, however, just for virtual soliton jumps within the electron remaining globally at rest but having individual jump velocity equal to $c$.

Preservation of spin orientation in the absence of external influences implies that all the next possible $N_R^e$ realisation centres for the electron are situated on a two-dimensional circle with a radius of $\lambda_C$ and length equal to $2\pi\lambda_C = \lambda_C$. Since the system of realisations is complete, they should fill in the circle length without remaining free space, so that the size of each localised realisation (or virtual soliton) is $D_e = \lambda_C/N_R^e = 2\pi e^2/m_0c^2 = 2\pi r_e = \pi d_e$ (or $\lambda_C = N_R^e D_e$), where $r_e = e^2/m_0c^2$ is the well-known “classical electron radius” (and $d_e = 2r_e$ the corresponding diameter), obtained by expression of the electron rest energy as “purely e/m (Coulomb) self-interaction”. This relation demonstrates the degree of nonlinear dynamical squeeze of e/m protofield in the virtual soliton state of the electron, which is of the order of $(2\lambda_C/D_e)^3 = (N_R^e/\pi)^3 = (\pi\alpha)^{-3} \approx 0.83 \times 10^5 \sim 10^5$, in terms of three-dimensional volume contraction. On the other hand, it provides a causally specified extension of usual, rather vague $\alpha$ interpretation as e/m interaction “strength”: $N_R^e = 1/\alpha$ characterises the width of EP potential well of the protofield interaction realisation for the electron, which is inversely proportional to its depth (and thus $\alpha$ is proportional to the depth) because the product of width by depth remains constant. Indeed, one can write $h = \lambda_C p_e$, where $p_e = m_0 c^2 = e^2 r_e c$ is the expression of the protofield EP depth in terms of momentum ($E_0$ is the EP depth value in terms of energy) and $\lambda_C = N_R^e r_e = r_e/\alpha$ is the corresponding EP well width, so that $\alpha = p_e r_e / h = E_0 r_e / \hbar = e^2 / \hbar c$ and $h = N_R^e (E_0 r_e / c) = N_R^e e^2 / c$.

One obtains thus a realistic interpretation of Planck’s constant as the “volume” of EP well for the protofield interaction, i.e., the product of EP well depth and width, for any elementary particle (emerging in the complex-dynamical interaction development), which explains the unlimited universality of $h$ and the origin of different particle species as different protofield interaction realisations with varying EP depths and widths, but permanent product of the two [22]. While the electron emerges as a massive field-particle with the widest and most shallow EP well (largest $N_R$ and smallest $\alpha$, $m_0$, and $c^2$), the heaviest, “strongly” interacting particles correspond to the most narrow EP well (effective $N_R$, $\alpha \sim 1$) and its biggest depths (maximum $m_0$ and “self-interaction” values). Two higher “generations” of elementary particles emerge as “excited” and therefore more chaotic (less stable) protofield EP realisations with increased amplitude (and correspondingly decreased widths), where the phenomenon of dynamic multivaluedness explains the very fact of multiple generations existence, remaining otherwise “mysterious” in the unitary theory framework, as well as the origin and basic features of particle spectrum in general (see also ref. [58] for possible further elaboration of detailed particle properties in a realistic framework inspired by quantum field mechanics).
form of attracting protofield separation) in order that it can produce the observed world structure and dynamics, in agreement with the universal symmetry (conservation) of complexity [24–26].

The origin, number, and properties of fundamental interaction forces between individual elementary particles are also causally and naturally derived in quantum field mechanics, together with their intrinsic, dynamic unification. Two most universal, long-range forces, the e/m and gravitational interactions emerge as inevitable interactions between individual quantum beat processes transmitted through, respectively, the common e/m and gravitational protofields starting from protofield deformations (tensions) that arise around every quantum beat pulsation. The detailed e/m interaction mechanism involves causally extended exchange of real “virtual” (transient) photons between different quantum beats, where photons are obtained as massless (but very slightly dissipative), dynamically quantized, and shallow-EP excitations of e/m protofield stabilized by its interaction (effectively weak in this case) with the gravitational protofield.

The absence of (long-range) gravitational repulsion shows that the gravitational protofield is qualitatively different, by its physical nature, from the e/m protofield and resembles rather a dense, dissipative medium, where all waves (excitations) transmitting interactions quickly decay as such, together with their phases that remain essential for the case of highly “elastic” e/m protofield (it is easy to see that such kind of difference between the “materials” of the two protofields should exist in any case for efficient structure formation during their interaction, which devalues all resource-consuming efforts of conventional science around long-range gravitational wave detection and usual quantization of gravity). The general, averaged “tension” is, however, always transmitted through the gravitational medium, giving rise to universal gravitation.

Two other, short-range interaction forces, “strong” and “weak” interactions, are conveniently explained as short-range interaction forces between discrete structure elements of gravitational and e/m protofields, respectively. It leads one to the conclusion about the physical origin of gravitational medium that appears to be a sort of “quark matter”, or “condensate”, which provides the natural, physical unification between gravity and strong interaction as between long- and short-range forces transmitted by the same medium, by analogy to the known “electro-weak” unification, which is only formally established in conventional theory, but now can be causally understood as physically unified long- and short-range interactions within the e/m protofield.

The number of fundamental forces (four), their origin and properties appear now exactly as they should be for interaction between two physically real protofields, where the forces can be “symmetrically” grouped into two couples by two principles, according to either their “protofield of origin” (electro-weak and graviti-strong interaction couples), or range of transmission (universality of perception of e/m-gravitational and weak-strong interaction couples). Moreover, all the four forces are naturally, dynamically unified within the quantum beat process (actually in its realization for strongly interacting particles, hadrons), where the direct, complete unification is attained in the phase of maximum dynamical squeeze (for the heaviest particles). One can compare this physically transparent and totally consistent kind of unification (suggesting, of course, further elaboration of details) with purely abstract and inevitably failing “unification” efforts in conventional, unitary theory.

It is clear from the above picture that each emerging interaction between quantum beat processes has a dynamically discrete, naturally quantized origin, which is especially important for the case of gravity that escapes any conventional quantization attempts. Moreover, it becomes clear why the geometric “model” and approach of Einsteinian general relativity cannot provide a consistent description of the intrinsically chaotic (multivalued) quantum beat dynamics, representing the universal, physically real mechanism of any “quantization”, while a purely formal mixture between quantized, tangible space and irreversibly flowing, immaterial time, attempted in the standard relativity framework, leads to deep contradictions on any scale.

By contrast, intrinsically quantized gravity of quantum field mechanics naturally leads to major observed effects of “relativistic” gravitation on a macroscopic scale, which do not originate in abstract, formally imposed postulates and “principles”, but causally emerge from the same unreduced, complex dynamics of microscopic interaction between the two protofields that gives particles themselves, their causally explained “quantum” properties and effects of “special” relativity, thus providing the intrinsically unified (and essentially complex-dynamical) framework for the whole fundamental physics, helplessly missing in standard, unitary theories [25,35–37]. In particular, the key effect of time retardation in gravitational field is causally derived in our approach as quantum beat frequency dependence on the local tension of the gravitational protofield created by other field-particles and expressed as the gravitational field “potential”:

$$hν_0(x) = m_0c^2\sqrt{g_{00}(x)}$$

(38)

where $ν_0(x)$ is the local quantum beat frequency, while “metric” $g_{00}(x)$ reflects in reality a relation to the gravitational protofield tension (or “potential”) taking the form, for the case of weak fields, $g_{00}(x) = 1+2ϕ_0(x)/c^2$, where $ϕ_0(x)$ is the classical gravitational field potential [57]. Since $ν_0(x)$ determines the causally derived
“time flow” (see above) and $\phi_p(x)$ has a negative sign ($g_{00}(x) < 1$) corresponding to gravitational attraction, eq. (38) substantiates a causal, dynamical version of “relativistic time retardation” in a gravity field. It is evident that “paradigmatic” light-bending effect of gravity is easily derived in a similar causal way as a physical “refraction”, rather than “geometric”, phenomenon.

Another important implication of the causal origin of gravity is renormalisation of Planckian units and solution of the “hierarchy” problem in particle mass spectrum [25, 36, 37], among many other modifications involved with those units. The problem arises from the fact that the absent real, dynamic origin of phenomena is replaced, in unitary theory, by a formal, mechanistic play with parameters leading, in particular, to confusion between the ordinary gravitational constant, anistic play with parameters leading, in particular, to ena is replaced, in unitary theory, by a formal, mechanistic play with parameters leading, in particular, to confusion between the ordinary gravitational constant, anistic play with parameters leading, in particular, to ena is replaced, in unitary theory, by a formal, mechanism of gravity is easily derived in a similar causal way as a physical “refraction”, rather than “geometric”, phenomenon.

In a similar way, the unreduced, dynamically multivalued analysis of nonbinding interactions leads to the causally complete theory of true quantum chaos [24, 25, 38, 55] and quantum measurement [25, 39] (both of them involving genuine randomness of the same origin), which extends essentially usual theory suffering just from the absence of intrinsic randomness and dynamic entanglement in their unitary basis. Note also causal solution of the famous quantum entanglement “mystery” in terms of dynamic, interaction-driven entanglement (see discussions after eqs. (14) and (36)) and the ensuing clarification of quantum many-body problems [23–25].

3 Practical consequences and experimental confirmation of quantum field mechanics

Having described, in the previous section, the fundamental framework and the ensuing structure of reality, we can now present a summary of results of more immediate practical importance (already mentioned above) and also those that provide experimental support for the theory, especially vs unitary framework. Practical implications of quantum field mechanics are described also in [21–25, 35–39, 55] (see e.g. section 3 in [22]).

(1) The first “practical” implication to be noted is still closer to unified consistency of quantum field mechanics, which is inseparable from the totality of observed phenomena. It is important to emphasize the difference with respect to “experimental verification” criterion of unitary science that prefers to emphasize separate points of quantitative agreement often obtained by mechanistic adjustment of desired number of “free” parameters and artificial, abstract entities, while at the same time it accepts, and often tries to mask, its para-scientifically high and growing number of strong, qualitative contradictions and deviations from reality, which are often even “postulated” as allegedly “unavoidable”, but actually desirable, “mysteries”.

Causally complete analysis of the universal science of complexity shows why that evident intellectual fraud is inevitable in the “new” fundamental physics: it tries to realise the basically impossible unification of explicit, strong manifestations of unreduced complexity (dynamically multivalued entanglement), constituting the true meaning of the “new physics” phenomena, with the dynamically single-valued, zero-complexity framework of its unitary “paradigm” (see also section 1).

By contrast, the unreduced, complex-dynamical description of reality suggests another, causally complete kind of agreement with the observed world properties, in the form of consistent system of correlations, including explicit derivation of real entities and their properties, where qualitative aspects play a greater role than separate cases of quantitative coincidence, since the former...
cannot be adjusted (while the number of entities should remain at its provable minimum).

Among general correlations within quantum field mechanics we can mention the number of space dimensions (three) that emerge dynamically from the same number of interaction entities (two protofields and interaction itself) due to the universal complexity conservation law (which is causally justified and supported by the totality of existing observations [25]). The unceasing and spatially chaotic time flow, naturally dualistic field-particles with universally defined mass, energy, electric charge, spin, unified quantum and relativistic properties without “mysteries”, the number and properties of dynamically unified interaction forces between particles, intrinsic classicality origin, true quantum chaos and dynamically probabilistic quantum measurement continue the list of explicitly obtained entities and unified correlations of quantum field mechanics (section 2), which minimises the probability of artificially “arranged” coincidence.

Note also recent experimental evidence in favour of quark-gluon liquid in high-energy collisions [59] (rather than quark plasma expected in usual theory) providing an additional, specific support for the proposed world construction and gravitational protofield structure.

(2) Causal renormalisation of Planckian units and explanation of observed particle spectrum (see also near the end of section 2 and refs. [25,36,37]). The important practical consequence here should be an essential change of accelerator research strategy and purposes (see also item 7 below), as well as serious modification of various cosmology, particle and quantum physics aspects where Planckian units play an important role. It includes the predicted absence of notorious Higgs particles, used in usual theory as a simplified unitary substitute for the missing property of mass (where a characteristic trick of mechanistic knowledge is performed in the form of substitution of an artificially invented, abstract entity for a tangibly present, universal property, in contradiction with Occam’s principle of parsimony and elementary consistency demand). Since we have explicitly obtained the intrinsic, complex-dynamic property of mass, the resource-consuming search for fictitious particles becomes definitely obsolete, while showing increasingly its practical uselessness already within conventional approach. The same actually refers to many other unitary substitutes for the missing fundamental properties (such as multiple unobserved entities appearing in abstract “unification” schemes of supersymmetry and string theory), which substantiates and specifies the inevitable, qualitative change of the whole research strategy in high-energy physics.

(3) Causal classicality emergence and macroscopic quantum effects. Our purely dynamic, intrinsic mechanism of emergence of classical, permanently localised type of behaviour in an elementary closed system, in the form of a new level of unreduced dynamic complexity [20–25,29,36,37] (see the end of section 2), is confirmed by, and practically important for, both transitions from quantum to classical behaviour and occasional “re-vival” of “quantum”, undular behaviour in large enough, normally classical systems under special conditions.

The causally complete understanding of inevitable transition from quantum to classical behaviour already on atomic scales is important for applications like nanotechnology and many-body quantum devices that involve complicated and “entangled” enough system structure [24,25], where “quantum measurement” and related classicality emergence cannot be separated any more from “quantum” dynamics as such and especially expressed by contradictory and “inexplicable” postulates (as it was still possible for simplest systems, though at the expense of essential loss in consistency). Dominating rejection of realistic, causally complete understanding in those fields produces a huge misleading effect [24].

The “reverse” transition to quantum behaviour in big enough, many-body systems is also rich in practically important applications and needs the unreduced problem solution of quantum field mechanics, without which the “clash” of inconsistent imitations reveals only ever deepening impasse of unitary approach. In particular, a popular interpretation of classical behaviour in terms of ambiguous “decoherence” enters in fundamental contradiction with abundance and diversity of “quantum revival” effects that find, on the contrary, their natural explanation in our intrinsic classicality version [20–25,29,36,37] (here again, unitary theory tries to reduce intrinsic property to extrinsic effect from abstract entities).

(4) Realistic quantum machines and causally substantiated nanotechnology. These quickly growing and extremely versatile applications involve the previous item aspects, but actually realise, due to arbitrary interaction structure, unified, many-sided verification of the whole micro-physics theory and “paradigm”. The necessity of change towards the unreduced description of quantum field mechanics (universal science of complexity) becomes thus especially evident (see [24,30] for more details). We can mention the consistent theory of quantum (and classical) chaos [24,25,38,55] and quantum measurement [25,39] as examples of essential constituents of the emerging unified description inevitably absent in the unitary theory framework.

(5) Quantum many-body problems with strong interaction. In relation to items 3–4, this group of applications derives from “canonical” studies, but where many-body systems of interest do not allow any more for usual application of perturbative approaches and necessitate the unreduced interaction analysis just provided by the quantum field mechanics (at the lowest complexity
levels). Indeed, it is easy to see [24,26,27,29–32] that an arbitrary many-body problem can be expressed by the same system of equations, eqs. (3), as the protofield interaction problem considered here (it should be expected physically). Characteristic applications of interest include complicated solid-state systems with “strong” interaction and “correlated electrons” (high-temperature superconductivity, quantum Hall effect, etc.), quantum atomic condensates and other “macroscopic quantum effects”, and causally complete understanding of nuclear dynamics (including true quantum chaos and nuclear stability estimate [22]). It appears, without any surprise, that such “difficult” cases of the “old” many-body stability estimate [22])

creativity cosmological evolution. As conventional, unity theory does not provide any creativity in principle (cannot explicitly describe autonomous structure formation process), its application to cases, such as cosmology, with explicit and “strong” structure emergence produces the highest number of mistakes and confusions. Due to “intrinsically cosmological” nature of quantum field mechanics (see the beginning of section 2), it “automatically” provides explicitly emerging universe structures, in their unreduced, realistic version, and thus naturally resolves, or even does not contain, many “difficult”, old and new, problems of unitary cosmology, such as the problems of space-time flatness, “wavefunction of the universe” (classical structure emergence), time flow (entropy), “quantum cosmology” (including “quantum gravity”), etc. The genuine, complex-dynamical basis of “relativistic” behaviour [21–25,35–37], outlined in section 2, is naturally involved with the intrinsically creative, dynamical framework of the new cosmology, as opposed to the mechanistically “geometric” and abstract imitations of unitary “models” that do not accept any explicit structure formation in principle.

Growing “new” problems of dark mass and dark energy, which seem to defy scandalously conservation of energy and matter itself, only summarise the inherent deficiency (“darkness”) of unitary, dynamically single-valued models used to simulate the dynamically multivalued reality: “missing” entities correspond to the majority of essential system realisations artificially excluded from unitary “models”. The underlying “official” thesis of universe appearance “from nothing” is overthrown by the unreduced interaction description, revealing the internal complexity transformation from dynamic information to entropy as the unique form of universal symmetry (conservation) of complexity determining any real system creation, evolution and dynamics [24–26,29,31–33,37]. The exact (never broken) symmetry of complexity is the real basis of essential, causally specified world progress, from two coupled homogeneous protofields to the fine-structured, conscious universe, while nothingness can produce only darkness, in science and in a real world.

(7) And finally, one should say several words about direct theory verification by “special” experiments. The problem with the quantum world case is that one deals here with the lowest, intrinsically coarse-grained (or “quantum”) levels of complex world dynamics, which necessarily implies balancing at the border of qualitative resolution and ambiguous “interpretations” of technically sophisticated experiments and their faint results (as opposed to clear and unified qualitative manifestations of unreduced complexity, emphasised by the quantum field mechanics). While the problems with interpretation of “fine” quantum experiments are well known and do not seem to decrease in usual science framework, we can still try to complete our picture with discussion of some experimental possibilities of that kind.

Because of fundamental, dynamically obtained quantization of unreduced interaction process, it is impossible to “catch” the quantum beat dynamics in any its “intermediate” stage or continuous development. However, one can think about some indirect, but special enough, effects of that dynamics related, in particular, to characteristic, internal resonances at certain parameter values.

Thus, de Broglie wavelength \( \lambda_B = h/mv \) becomes equal to the Compton wavelength \( \lambda_C = h/mc^2 \) at a total energy value \( E_r = \sqrt{2E_0} \) falling within accessible acceleration range \( (E_r - E_0 = (\sqrt{2} - 1) E_0 \approx 0,414E_0 = 211 \text{ keV} \) for the electron and 389 MeV for proton). Since \( \lambda_C \) is the size of purely random virtual soliton jumps around the average-tendency wavelength \( \lambda_B \), their coincidence for the unified quantum beat dynamics can produce an observable resonant effect at \( E = E_r \) (e.g. image sharpness change in the electron microscope at \( E - E_0 \approx 211 \text{ keV} \)).5 Similar kind of resonance can be expected for absorption or emission of photons (or other exchange particles) with the resonant frequency (or wavelength) coinciding with those for the average, “de Broglie” tendency \( (v_B, \lambda_B) \) or random, “Compton” tendency \( (v_C, \lambda_C) \) for a moving particle (eqs. (27)–(28)).

\footnote{This resonance can also be interpreted as equality between de Broglie frequency, \( \nu_B \), of regular quantum beat tendency and “Compton frequency” of its totally irregular tendency, \( \nu_C = \lambda_C/\sqrt{1 - v^2/c^2} \), with equal energy partition between the tendencies (see eqs. (19),(27)–(28)). Another possibility is the resonant equality of de Broglie wavelength \( \lambda_B \) and relativistically increased Compton wavelength, \( \lambda_C = c/\nu_C = \lambda_C/\sqrt{1 - v^2/c^2} \), occurring at the “golden mean” value of particle velocity, \( v/c = (\sqrt{5} - 1)/2 \approx 0.618 \) and \( E_r - E_0 \approx 0.272E_0 \).}
One more possibility of resonance involving quantum beat dynamics is particle bound motion or excitation with frequencies attributed to one, quasi-“photonic” particle realisation during the quantum jump phase, \( \nu = \nu_0/N_R \), which corresponds to exchange (e.g. photon) energy \( h\nu = m_0c^2/N_R \approx 3726 \text{ eV} \) for the electron (if \( N_R = 1/\alpha \approx 137 \), and one can find the actual \( N_R \) value).

At a higher complexity sublevel, quantum chaos effects in the scattering of swift charged particles in crystals should have a variety of observable manifestations (see ref. [55] for details). A very interesting combination of those two quantum complexity sublevels was used for the first experimental detection of quantum beat pulsation by resonance between \( \nu/\nu_C \approx \Lambda_C \) for channelled relativistic electrons and crystal atom spacing [60].

All those possibilities can provide convincing experimental confirmation of the quantum field mechanics picture, essentially exceeding the ambiguity of usual “interpretational” experiments but also promising novel practical applications, involving new ways of particle/energy transformation and structure analysis at a “subquantic” level. A more direct observation of virtual soliton wandering within its wave is not impossible either, but can be more problematic in its technical realisation.

In summary, the presented practical implications of the quantum field mechanics, items (1)–(7), seem to provide enough motivation for further development of the theory and related experiment. A real obstacle for further progress comes rather from the subjective rigidity of traditional, unitary science framework that does not want even to notice any true novelty, despite the evident degradation of its own methods and results. Successful completion of the present project will hopefully contribute to positive shift towards the unreduced creativity in both spirit and content of fundamental physics.

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