What is entanglement?

Lucian M. Ionescu

October 3, 2023

Abstract

Entanglement is information distributed over the parts of a system, classical or quantum. It can be modeled as a reduction of the structure group, of horizontal symmetries, extending the Gauge Theory paradigm.

Many conflicting interpretations are rooted in considering quantum properties as "intrinsic", e.g. in the Point-Form QFT / Gauge Theory, and needing a causal connection for "changing" the unknown state of the partner-particle, or confirming that QM is (was) "incomplete": EPR.

The natural explanation of entanglement starts with Einstein's time synchronization and takes advantage of the advancement in our models of particle physics and quantum computing. The "external variables" emerge from the "intrinsic variables" and the entanglement relations are in fact generalizations of conservation laws. New aspects will be discussed: beyond Noether Theorem, from gauge fiber to horizontal symmetry groups, Hopf algebras model change of symmetry group, analogous to creation-annihilation of pairs of particle-antiparticle, but for information, corresponding to entanglement.

Relations with quantum eraser, 2-slit experiment and retrocausality are discussed.

1 Introduction

The clash between, Special and General Relativity on one side, as a coronation of Classical Physics, and Quantum Mechanics, the new non-relativistic theory on the rise, was marked by the 1935 EPR paper.

The ensuing debates differ according to which period of development of Physics they belong:

a) Based on Schrodinger's Wave Mechanics 1925: its goes hand in hand with the Copenhagen interpretation, on "one corner" AND Heisenberg's revolutionary work introducing Matrix Mechanics 1925, on the other side, as a pre-Quantum Computing (and logic etc.) based on complex numbers. More will be said later on ...

b) The rise of Quantum Computing, on shoulders of giants like Feynman a.a. in the 1970s, work on entanglement Aspect-X-Y for experimental work, Aharonov-Bohm effect etc.

c) After 2020s it became clear that Quantum Physics is the "real physics" and that continuum Space, Time and Matter models emerge from it. The main point to be explained later on, is that this "dual Classical-Quantum Picture", supported by the Gauge Theory paradigm (external vs. internal degrees of freedom), is at the core at the misunderstanding, can be clarified, and that slowly Classical Physics will phase out as a historical development (nano-materials, superconducting quantum computers, gravity control technologies etc.).

In brief, *entanglement is a concept describing whether the observable coordinates of a quantum system are independent ...* [1]. This is distributed info corresponding to a reduction of structure group of a system which corresponds to a *generalized conservation law*, e.g. anti-symmetry of spin of a pair of entangled particles etc. It can be viewed as a "smooth-out" of the gauge group acting on fibers (vertical, internal symmetries, horizontally, like a Dirac infinite delta function when modeled as a distribution (generalized function), into a *horizontal component of the symmetry group*; i.e. from "intrinsic / internal" to "extrinsic/ external" (Classical Physics Space-Time framework).

Theory, Computations, Experiment and Manufacturing has no problem dealing with this: quantum states teleportation is an essential operation in Quantum Computing etc. But when comes to explain Classical Physics from it, there are still tensions/ debates. In this article we will resolve some of them by explaining the concept of *baryon space frame correlation*, analog to Einstein's clock sync, and point to the fact that this is the role of Gauge Group ($U(1)$ quantum phase for Relativistic Time; $SU(2)$ for Classical Space).

Out of these discussions, emerges that new theory is needed: beyond Noether's Theorem in Gauge Theory, using Hopf algebras in place of groups, to allow for creation / destruction (reduction) of symmetries, dual to the matter side of the picture; these new symmetries corresponds to generalized conservation laws, which involve entanglement as a measure of the "horizontal component" of the *generalized Gauge Group*[1].

Applications to Socio-Economics and Cybernetic Control of large systems of complex subsystems will be sketched, arguing that entanglement is not about size or "weird", but plain sharing / distribution of information [2].

What still seams "weird" comes from a yet *incompleteness of Quantum Physics* [5].

2 Intrinsic vs. Extrinsic

To clarify "intrinsic" vs. "external" degrees of freedom and associated variables, and apply to entanglement, we provide a few examples first.

2.1 Examples

Two good examples of entanglement are: a) Alice and Bob go on a date, meet and decide to get married; the separate, go home and Alice's Mom asks what's new" etc. (TB-continued ...); b) A neutral π^0-meson decays into two photons, sharing quantum properties, and separating in *opposite (external) directions* (not internal", given by unit vectors in a Hilbert Space, outside of a more complete description in terms of Gauge Theory!).

A third example is more important, yet more complicated: neutron-proton entanglement (we need baryons, because we know their 3D structure, although we might disagree on What quarks are?").

Example (a) is a sharing classical info, due to the *irreducible quantum systems* Alison and Bob, with classical memory capable of transporting that info. Answering A's Mom question reveals new info regarding the behavior of Bob.

Example b) refers to quantum information, referred to as intrinsic", since it has no classical space-time energy-momentum analog; nevertheless the information is encoded in a Gauge Theory formulation, in internal space" (quarl fields as a 3D frame), and is shared in an analogous way. The only difference is that the experimenter (observer) has no knowledge about it. The entangled two-particles proper frame is not space aligned / correlated with the Lab frame, hence a probabilistic model applies: a superposition of the possible outcomes (up / down) models their state, and the measurement reflects the probability of the corresponding amplitudes. What is essential to understand here, is that there is *no causal transfer between the two particles*; once one experiment yields the outcome, the relation between the two frames is established, providing the knowledge about the other experiment's outcome. Additional details will be provided.

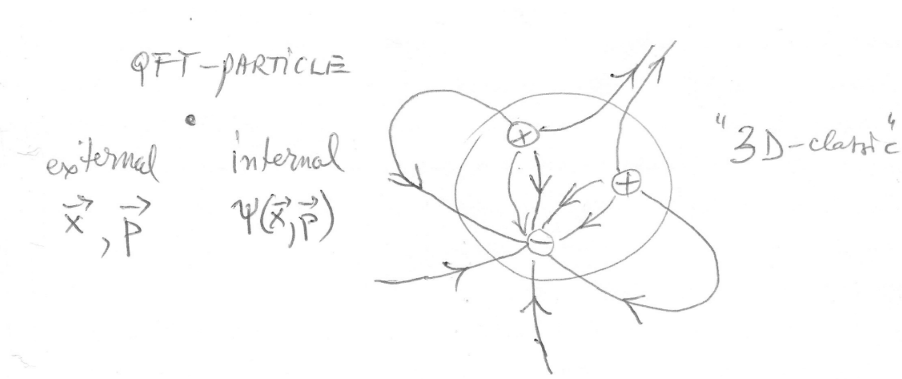
2.2 Internal vs. External Variables

The Point-Form QFT, e.g. Weinberg's book, separates external DOFs modeling particles as points in Space-Time and quantum states, "internal", as quantum fields: sections in the principal bundle of the corresponding gauge theory. Briefly, "external" is "classical" and "internal" is "weird", quantum.

Quark Line Diagrams go a step further, exhibiting the 3D-aspects of baryons with quarks as "external", at least visually ...

[1] The relation to Ward identities will be considered ...

[2] ... and *algebraic coproducts* are needed in Mathematics!



2.3 What is a reference frame?

We will describe what we see in the previous picture, Fig.1. For additional explanations regarding the quark model behind our viewpoint, see [4].

The QFT separation between external and internal can be resolved by a model of quark fields like the one introduced by H. Jehle [8]. It is a toroidal model, of the type "orbital", a 3D-manifestation of the toroidal Hopf fibration (quantum phase "internal", to be soldered with the "external" time [3]).

2.4 ... and entanglement

This is relevant for entanglement, e.g. in experiments using spins, since total spin (of quark spins) direction determines the responce of the particle in a magnetic field. *Without knowledge* about the baryon's orientation (RGB relative XYZ of the LAB reference frame), the prediction of spin direction outcome *is* probabilistic, even though its evolution is modeled by a S-Eq., with a superposition of up/down, as a conversion of a bit into a quabit relative to a classical info base.

The measurement of one particle's spin, provides the missing info, allowing to infer what the other particle's spin is, *not because of a cauzal connection*, but because now we know the relation between the LAB frame and QS-frame (of two particles as subsystems). In their *proper RF* the S-Eq works fine: if an experimenter within it, would prepare the spins, e.g. a polarization / beam splitter set-up, the process would be controlled as in a QC; but if a decay generates the two particles, then "God played dice" (but knowing perfectly the initial conditions and outcome, as via a Hopf algebra coproduct for generating an entangled state), and we can just guess ...

2.5 Momentum, spin, charge ...

Whether it is linear momentum entanglement (say we know the center of mass momentum and the decay happens: we need to measure one momentum to infer what the other one is), or spin in a Lab-given magnetic field (defining a Lab RF with a prefered direction), or just a chemical reaction where we measure the needed terms to solve for the missing info, like in any equation, conceptually it is *entanglement*, i.e. a distribution of info over the parts of a *coherent system*, we would should call *quantum*.

2.6 The Hierarchy and Tools needed

Let us consider a two levels hierarchy: a System consisting of a collection of subsystems that are coherent, hence exhibiting "quantum properties" (entanglement etc.), parts that interact by exchanging say mementa and energy, like the molecules of a gas (a lot of free space and interactions are random).

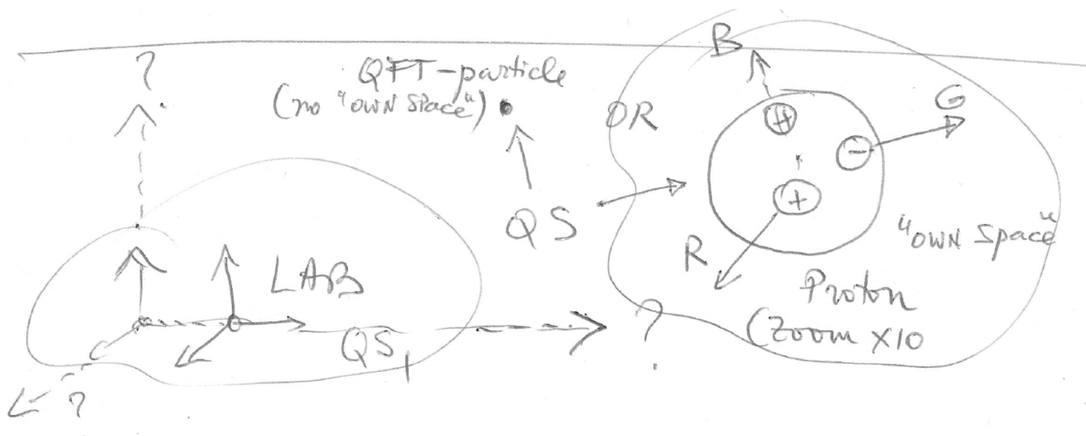
Each part as a quantum system, has its own parts (Network) in interactions mediated by bonds: nuclear or chemical etc.

Then the "big" system has to be modeled using a thermodynamic apporach, if only global parameters are of interest (volume, temperature, presure etc.) or probabilistic if finer states are needed in applications: Markov Systems etc. (e.g. a population of "individuals" with states and unknown interactions or transitions, due to lack of info). Yet the "individual parts", subsystems may have highly correlated structures, e.g. nuclei, molecules or biological systems.

Different levels of modeling and info available about their structure require different theories.

2.7 Two Reference Frames

Two QS with their RFs may be in a quantum or probabilistic or deterministic relation.



When the Lab frame is not spacial correlated to the QS (lack of data referring to the spin directions of quarks) then a quantum-probabilistic approach is needed: superposition of bit-states as a qubit, with a unitary evolution. The measurement of the state of the QS, e.g. the baryon spin, will provide info to correlate the Lab and proper RF (e.g. in polarization experiments). Then further experiments may be performed and the theory for one QS, with correlated parts applies.

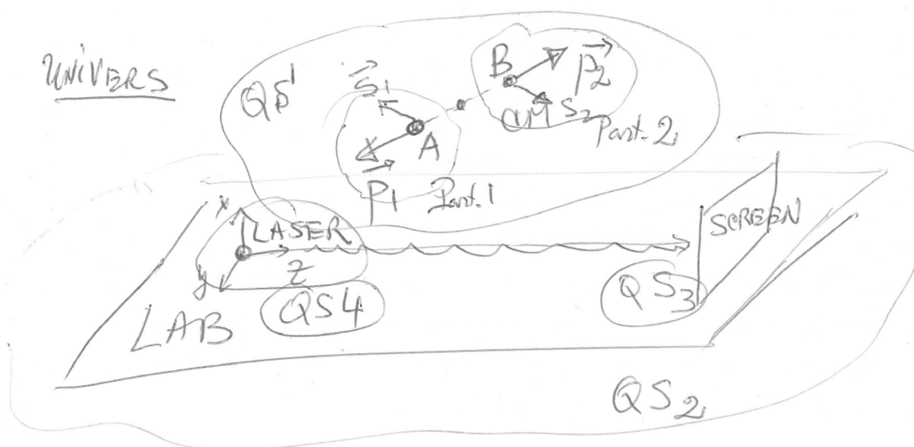
The main point is that a baryon or a mesonic channel relating two baryons in a scattering experiment have their own "Space-Time" frame, even if small and consisting of one or two subparts. The lack of "space alignment" prevents the use of Gauge Theory, because there is no knowledge about a common field (connection) due to all the subsystems involved.

2.8 When is Entanglement and when Not

Assume now that the QS consists of a pair of particles emerging from a fision / decay of the above QS (above baryon, but here could be a nucleon, excited baryon etc.).

The two particles resulting from decay have a common RF with well defined properties subject to conservation laws. Those refering to momenta and energy are well understood and comprehensible, while the other, not quite so, when only an "intrinsic" description, at the level of the GT fiber is used (no "external model").

When measuring the behaviour of one component in a magnetic field (Stern-Gerlach experiment, for instance), one can use that info (spin up, for example) to infer the spin down for the other component due to the conservation of spin and directions when were "born" from the decaying particle.



There is no spooky-action at a distance, no causal interaction. The historic debate originated from not accepting that such particles have their own RF since they were considered pointwise and with "intrinsic properties": "spin is an intrinsic weird property, quantum ... ("Shut-up and compute!").

2.9 ...and 2-slit experiment

This does not mean that a "bond" (leptonic or mesonic) may necessarely not be present (a different type of connection, e.g. a meson in a baryon-baryon scattering, atoms with a molecular bond etc.). But if such a bond is not present, the two particles are still entangled, sharing correlated values for one variable, e.g. spin up/down, relative to the NS direction of a magnetic field in the Lab.

Now, with a 2-clit experiment, is there a genus one channel joining the Laser, emitting photons (EM waves), forming a network due to the two slits? The author claims that such a channel is formed, of fermionic type, transmitting the photons as excitations (soliton model), one at a time. A measurement actually collapses the Net as in a discharge of electric charges, destroying it. It would correspond to the "colapse of wave function".

The justification is rather an extrapolation of what an electronic orbital is. If Einstein extended Planck's model that photons are emitted as discrete quanta, confirmed by Bohr's model of the atom, why not extrapolate the concept of orbital to bonds beyond the stable chamical ones? From Mach - Einstein, there is no "empty space", and the "vacuum fluctuations" are such fluctuating bonds/channels forming and disapearing; in the present experiment the claim is that, even if the Laser fires at intermittent moments, such discharges correspond to channels forming. In this picture, Feynman diagrams are more then helpful devices for computations: they model real physical channels in quantum networks.

2.10 Types of Systems, Interactions and Regimes

Together with the problem regarding what are the elementary particles and fundamental interactions, let's call this the "Democritus's Problem", we have "Plato's Problem: "What types (categories) of Irreducible Systems are there and how do they communicate" (to avoid overloading the term interaction). Here an *Irreducible System* should make precise "Being One", a "Whole", in the philosophical sense of Plato (not clear enough).

2.10.1 Transient vs. Steady-state "Interactions"

Two important aspects are neglected by theoretical Math-Physicists, but not by engineers: transient and steady-state regimes.

The steady-state "interaction", e.g. lepto-mesonic bonds, build QS, and lead to entanglement[3] and quantum "functioning" (loops, apparent retrocausality etc.).

In EM for instance, electronic bonds and orbitals are of this type: steady-states. The radiative phenomena, mandatory causal, are of transient type (connections built, transmition performed and then, decay, unless a "stable" bond is formed; but nothing is permanent, except change, so a decay may result due to an outside intervention via an interaction).

[3]But entangled variables may arise without them, via conservation laws.

The "causal" aspect implies: forcing; controlling; etc. The non-causal; resonances; flow, being; pulsing; servicing the Whole (QS) etc.

2.10.2 Who studies What?

Therefore various "Science Compartments" specialize in studying different types of systems and regimes, of course.

For example, Elementary Particle Physics studies transient and high energy (creation regime), point scattering[4]

2.11 ... and Occam's Razor

Beisides the Network Model other attempts were made to model a finner structure of "Reality", e.g. in the area of Quantizing Gravity: foam models, via triangulations, Planck scale lattice etc. Which Theory is "right" (not just "not even wrong")?

Criteria: a) Improve the conceptual understanding, resolving disputes and "paradoxes", seams more "natural", beautiful etc.; b) Are consistent with the succesful computations of prior theories; c) Predict new phenomena; d) Are "beautifull", without too manny assumptions, tayloring, antropocentric, "we exist therefore the the current constants are the ones we measure" etc.

The Network Model is (the) Universal (step); of course, Networks, Hardware and Software aspects, OS etc. should form an "expert system".

3 Mathematics models and Applications

The typical tool for modeling entanglement is the tensor product. The larger framework is that of Hopf algebras, with coproducts (group elements and Lie algebra ones) modeling physical split of a qubit in beam-splitters and alike (decays, fision etc.).

3.1 From Groups of Symmetry to Hopf Algebras

This is the natural progression to model such phenomena, including how a *gauge group "leakes" into horizontal direction*, i.e. from internal to external.

Noether Theorem relating groups of symmetry and conserved quantities extends to Hopf algebras involving such an *adjunction between internal to external symmetries of sections of principle bundles*.

3.2 Applications to Mechanics and Biology

An interesting example of entanglement was noted by Huygens: his clocks tended to synchronize on their own. The interaction would probably involve phonons.

This a good example for how a discrete "phase field", define don the network of clocks, keeping time, changes towards acquiring less "curvature", here quantity of information, corresponding to perhaps a *network distributed energy* (to be studied?).

The entropy of this degree of freedom decreases, as if temperature decreases (or the wave of an ocean calms down).

Why the entropy of the time lag (with some reference global time, of one clock), does not increases, so that *thermal death* would ensue, as predicted in Cosmology for instance?

Remark 3.1 *The macroscopic relativistic time is correlated with the quantum phase via the gauge potential [3]. A change of gauge amounts to a change of quantum phase origin in fibers: $A + df$; this is a local redefinition of "periodic time" (without higher order dials and carryover units: minutes, days etc. towards a portion of the linear time of Special-Relativity).*

[4] Like breaking a rack, billion times in a row;

3.2.1 ... and Fireflies

Similarly, it was observed that fireflies tend to synchronize their light emissions; here a "self-induced entanglement" takes place, as in many other situations involving societies and collectives of individuals ("monkey see monkey do"? a self-learning routine, biologically implemented through evolution?).

3.2.2 Other classical cases of entanglement

Again, entanglement here means a spread of information, which initially was more localized. The corresponding "state field" entropy decreases.

Societies achieve such an entanglement through conditioning and education. Modeling how local information (on the "fibre") spreads to the Network ("base") is a similar theoretical process.

3.2.3 Measurement and Entanglement

[2] studied the control of entanglement of a chain of entangled particles with spin through measurement. This is a good example of how entanglement spreads, leading to the growth of a *coherent quantum system*, like the formation of a crystal (aligned directions), which is hindered by measurements (intervention / perturbation), which breaks the one system components into smaller parts / fragments.

Separated fragments obey probabilistic models, while within one coherent quantum system, wave functions are a good model and entanglement allows to predict the state of the other elements of the System, with one measurement (non-destructive).

Similarly, populations of customers can be probed via surveys and *forced measurements* can be applied via adds.

The similarities here between classical and quantum entanglement here, is not due to to 'big vs. small", but rather to the fact that we know /(and understand) there is an internal structure to a "particle" of the Network, that holds the type of state we measure ('gauge group acting on the set of preferences", for a fibre bundle over a Network, like Voltage Graphs).

4 Conclusions

4.1 In essence ...

Entanglement is a universal process, a conserved "difusion" of a physical quantity, in a coherent, not entropy increasing way, to be modeled by coproduct/convolution structure within a Hopf algebra structure. It is akin to the creation of pairs of particle-antiparticles pairs, except it can occur through interactions of already existing particles of a coherent system ("synchronization" of a specific type; it is not about size or type, classical or "quantum"; in fact "everything is discrete", quantum), but then followed by a QM dynamics (e.g. Schrodinger's eq.) which maintains the entanglement as an analog to a classical conservation law (e.g. momentum).

4.2 Diversity ...

Physics phenomena involve transient and steady-state aspects, depending on the type of experiment: type of system studied, its preparation, type of measurement etc.

The main reason there are so many "debates", advocating *one* theory or another, is not to acknowledge that there are not only "clean types", quantum, probabilistic or deterministic correlations between the *parts* of a System, but usually a hierarchy of structures reflecting this; most common case is when a System is composed of Quantum Systems partially correlated: more then like the molecules of a gas, but not like a solid bellow the Reynolds point [5].

[5] Supraconductibility as a macroscopical manifestation of a *superconducting vacuum*, i.e. an $SU(2)$ connection 1-form A without curvature in the interior of the superconducting body: Meisner effect

4.3 Model "intrinsic property" as "explicit"

The advance in the SM (quark model) and spin (correlated to angular moment in the toroidal model of "elementary particles", e.g. H. Jehle [8]) allows to resolve the Einstein-Bohr demate: in some sense QM was enough developed to compute amplitudes regarding spin and entanglement, but not "complete" in the eyes of Einstein: not containing an "explicit model" (the spooky-action-at-a-distance was apparent because of the lack of understanding / model of space directions correlations, that comes with a connection in gauge theory).

4.4 2-Particle System in the Lab

Two subsystems maybe quantum correlated (entangled)[6], in a probabilistic relation (missing info, external and/or internal, if modeled in the traditional Gauge Theory) or deterministic: gun bullets etc. *It is not about the seize which makes things "quantum werird" or not ....*

4.5 What "Theory" to Apply?

So, it is rather a question of "What Theory does better, explaining the problem at hand?" (what "tool to use" is a skill ...).

Shrodinger's wave function applies to QS for which we also know the initial conditions; if the initial conditions are a "theoretical superposition", i.e. a *conversion of a bit into a qubit*, with no additional info built into that state, then we still are in a mixture-case, of a *quantum evolution of a probabilistic superposition*: our old friend The S-Cat.

In a 2-slit experiment, the beam splitter gives birth two an entangled pair of photons, belonging to one QS, and modulo an *initial condition qlobal quantum phase*, which we don't use or need ("When did the Laser fired the photon?"), it is governed by S-Eq etc. There are perturbations in its propagation preventing us from determining "where it will land", but wherever it does, statistically (perturbations: missing info: probabilistic model input into the interpretation), we can tell, compute and match with experiment.

4.6 Is QM complete "now"?

Even with a toroidal model of bound states of an electron in an atom or quarkl field [8], and even assuming the Network Model of interactions (lepto-mesonic bonds [5]), there is still a need to understand the "finner" geometries that come with electron transitions in an atom and the cylindrical model of a radiative emission-reception interaction [7]. This will also allow to understand even batter why the fine structure constant is the ratio between bound and free impedances, for EM (electrons as orbitals and EM waves as open similar structures, with geometry related to spin and polarization).

For the diversity of aspects *not yet modeled*, see for example [7]. It is natural to hypothesize that many other orbital geometries occur during such a transition, not stable, but rather similar to the Zoo of resonances in Elementary Particle Physics.

So, is QM complete? Obviously not, but the foundational language is (Quantum Computing).

References

[1] C. W. Johnson, O. C. Gordon, Proton-neutron entanglement in the nuclear shell model, 2210.14338

[2] C. Wood, Physicists Observe 'Unobservable' Quantum Phase Transition, Quanta Magazine, Sept. 11, 2023, https://www.quantamagazine.org/physicists-observe-unobservable-quantum-phase-transition-20230911/; see also https://arxiv.org/abs/1903.05124 for a QC perspective.

[3] L. M. Ionescu, On Emergence of Relativistic Time from Quantum Phase, https://vixra.org/abs/2303.0149

[6] hence why not considered two parts of just one!?

[7] A periodic polarized EM wave has such a periodic geometry, which corresponds to an elliptic curve, when "wrapping a fundamental length as a torus, for the corresponding frequency of the EM wave. The "photon" is a propagation of a quantum of E-p through such a transmission line: to be explained elsewhere [6]

[4] L. M. Ionescu, A Quark Fields Emergent Space-Time and Gravity, https://vixra.org/abs/2303.0030

[5] L. M. Ionescu, Some Unifications Needed in Particle Physics, https://vixra.org/abs/2301.0142

[6] L. M. Ionescu, Planck's constant and EM transmission channels, TBA.

[7] M. O'Dowl, What happens in a transition?, https://www.youtube.com/watch?v=j5HyMNNSGqQ; or https://www.quantamagazine.org/physicists-who-explored-tiny-glimpses-of-time-win-nobel-prize-20231003/

[8] H. Jehle, The relationship of flux quantization to charge quantization and the fine structure constant, https://onlinelibrary.wiley.com/doi/10.1002/qua.560030303; as well as his follow-up articles from 1971-1982 (see also https://vixra.org/abs/2308.0180)