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Elementary particles, the concept of mass, and emergent spacetime

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Abstract. It is argued that the problem of space quantization should be considered in close connection with the problem of mass quantization. First, the nonlocality of quantum physics suggests that if spacetime emerges from the underlying quantum layer, this emergence should occur simultaneously at all distance and momentum scales, and not just at the Planck scale. Second, the spectrum of elementary particles provides us with a lot of important information, experimentally inaccessible at the Planck scale, that could be crucial in unravelling the mechanism of emergence. Accordingly, we start with a brief review of some fundamental issues appearing both in the spectroscopy of excited baryons and in connection with the concept of quark mass. It is pointed out that experiment suggests the inadequacy of the description of baryonic interior in terms of ordinary spacetime background. Thus, it is argued that one should be able to learn about the emergence of space from the studies of the quark/hadron transition. The problem of mass is then discussed from the point of view of nonrelativistic phase space and its Clifford algebra, which proved promising in the past. Connection with the Harari-Shupe explanation of the pattern of a single Standard Model generation is briefly reviewed and a proposal for the reintroduction of relativistic covariance into the phase-space scheme is presented.

1. Introduction

Since the time quantum theory was originally formulated there have been many attempts to unite it with general relativity. As gravitational interactions are a consequence of malleable spacetime, proposals were put forward that spacetime is a purely macroscopic concept that somehow emerges from the underlying microscopic quantum degrees of freedom [1, 2, 3]. For example, the spin network idea of Penrose [3] posits that the continuous array of directions in 3D space emerges out of the quantum concept of spin in the limit of large quantum numbers. Since elementary particles exhibit other quantized properties beside that of spin, a simple extension of Penrose's idea would be to take them into account as well. Thus, one might hope that the inclusion of other spatial quantum numbers, internal quantum numbers and quantized particle masses should somehow lead to the emergence of further features of classical spacetime [1]. In particular, with mass being the source of gravity-inducing space distortions, it seems quite natural that the quantized mass should play an important role in the emergence of classical spacetime out of the quantum layer. Since a successful theory of mass and space quantization should express all particle masses in terms of one mass scale (say, Planck mass), elementary particle masses give us important experimental clues on space quantization itself - clues that are completely inaccessible at the minuscule Planck length scale. Consequently, an understanding of

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quantized particle masses, even if very limited, could be of great help in the construction of the sought emergence scheme. In particular, the very concept of mass should be critically studied as well. For this reason, we start with a brief description of some relevant problems associated with the concept of mass, and quark mass in particular.

2. The problem of mass

After putting aside the propaganda, it should be clear that the Higgs mechanism does not solve the problem of mass. In the author's opinion this mechanism may be regarded only as a lowenergy field-theoretical approximative description of the problem of mass generation. Indeed, there are many unanswered fundamental questions concerning the issue of mass in both the lepton and quark sectors. First, there is the intriguing observation of Koide that relates the e, μ , and τ masses in a formula involving two small integers only [4]. Putting in the central values of experimentally measured masses, this constraint on the masses of the three charged leptons works perfectly with the accuracy of five decimal digits (which is better than 1 standard deviation). It does not seem to be an 'accident' and thus it strongly suggests an algebraic origin of mass. While neutrino and quark masses are not known with sufficient precision to test for the analogues of Koide's charged lepton formula, the quark sector elicits important conceptual questions related to the standard 'unproblematic' notion of quark mass. Specifically, the macroscopic concept of mass, naturally applicable to leptons, cannot be extended to quarks in a simpleminded way. Indeed, the masses of leptons are directly measurable from leptons' free propagation over macroscopic distances. For quarks this route cannot be used since, due to confinement, individual free quarks do not appear in the asymptotic states.

Given this qualitative difference between leptons and quarks, a question emerges what meaning should be assigned to the concept of mass for a quark. In the Standard Model, quark mass is a parameter in the QCD Lagrangian. A calculational technique to deal with the issue of confinement is then offered by lattice QCD. Yet, one may ask questions that QCD (with or without lattice) answers in a somewhat carefree way. Specifically:

Can one assume the existence of the ordinary background spacetime within hadrons? After all, no clocks and rods — needed in the operational Einsteinian definition of space distances and time intervals — may be inserted into hadrons. In fact, as argued by Salecker and Wigner [5], the concept of spacetime cannot be consistently attributed to individually observable elementary particles at the strictly microscopic level. The situation with quarks is obviously worse since they are not individually observable. Are we then right when we imagine quarks as moving freely at small 'distances within hadrons'? Can one meaningfully talk about the concept of quark mass if the ordinary spacetime background within hadrons — in which quarks supposedly propagate — may not exist?

If QCD worked perfectly everywhere, we would have to assume that the QCD assumption of the underlying background spacetime corresponds well to reality. Yet, in spite of what one hears around, we will argue on experimental grounds that quantum chromodynamics does not work everywhere. In fact, we believe that QCD needs important modifications, at least at large distances.

2.1. Hadron spectroscopy problems

Quark confinement leads to the appearance of quark conglomerates such as $q\bar{q}$ (meson) or qqq (baryon) states. Consequently, an acceptable theory of large-distance quark interactions should describe the salient features of the observed meson and baryon spectra. It appears, however, that there are serious difficulties with the description of the spectrum of baryons. The problem is with the excited baryons. Within the standard SU(6) (flavor-spin) $\times O(3)$ (orbital) classification of baryon states in the old constituent quark model, the first levels with the three smallest

consecutive values of the principal quantum number N are decomposed as $[6]^{-1}$:

$$N = 0 (56, 0^+),$$

$$N = 1 (70, 1^-),$$

$$N = 2 (56', 0^+), (70, 0^+), (56, 2^+), (70, 2^+), (20, 1^+). (1)$$

Now, while almost all the N = 0, 1 states are experimentally seen, a large proportion of the N = 2 states is not observed. In particular there are no experimental candidates for the $(20, 1^+)$ multiplet.

There are two possible explanations of this shortage of states. The first possibility is that one of the two internal spatial degree of freedom is frozen (i.e. that, for unknown reasons, it does not get excited). This is the resolution suggested e.g. by the diquark model. In this model one accepts that from the two SU(6) multiplets, a priori possible for the diquark (on account of $6 \otimes 6 = 21 \oplus 15$), only the symmetric 21-plet is for some reasons permitted. Since $21 \otimes 6 = 70 \oplus 56$, the absence of the 20-plet (and several other N = 2 states) is thus qualitatively explained. The spectrum of the diquark model is definitely closer to the one we observe in experiments. The second possible explanation is that many of the N = 2 baryons are not seen simply because they do not decay to the experimentally accessible decay channels.

Although the above problem was originally identified in the old constituent quark model, it reappears in essentially the same way in lattice QCD. In particular, lattice QCD does not exhibit diquark clustering or freezing of one internal spatial degree of freedom [7]. Consequently, there is no satisfactory agreement between the calculated and the observed spectra of the excited baryons. ² A possible way out would be to prove the unlikely decoupling of *all* (or most of) the unseen states. Unfortunately, due to the enormous complexity of such calculations in lattice QCD, they are not feasible now.

Given the questionability of the existence of the ordinary background space within hadrons, our tentative conclusion is that the QCD description of excited baryons misses 'the problem of missing baryons' and, consequently, is not fully adequate. The situation is so serious that in their review on baryon spectroscopy Capstick and Roberts wrote [6]:

'These questions about baryon physics are fundamental. If no new baryons are found, both QCD and the quark model will have made incorrect predictions, and it would be necessary to correct the misconceptions that led to these predictions. Current understanding of QCD would have to be modified, and the dynamics within the quark model would have to be changed.'

Accordingly, we view QCD as appropriate for the description of hadron scattering at large momentum transfers, but deviating from reality for low momentum transfers and composite states, i.e. beyond the region of original idealization. There is nothing wrong in accepting that QCD is an idealization that works in a restricted range only. After all, all our theories are idealizations and approximations with limited ranges of their applicability [8]. We should keep this in mind and commit not the error of identifying an abstract description of certain aspects of nature with nature itself.

With lattice QCD description of baryon spectroscopy judged as not fully adequate, the detailed values of quark masses, as extracted via lattice QCD technique, cannot be trusted. Furthermore, since the shortage of excited baryons constitutes a hint that the concept of

¹ The notation is (dimension of SU(6) representation, L^P), where L, P are orbital angular momentum and parity. ² QCD (either via one-gluon exchange models or in lattice calculations) does describe the spectrum of groundbaryons successfully. Still, these baryons may be equally well described in approaches based on strictly hadronlevel dynamics (i.e. with pion and other meson exchanges or the related idea of meson cloud used in place of quark-gluon interactions [9, 10, 11]. The real challenge lies in the description of excited baryons.

background spacetime need not be fully applicable within hadrons, the concept of quark propagation within hadrons is additionally questioned. Consequently, one has to inquire into the very concept of quark mass itself.

2.2. Current quark masses

What can be therefore said about the concept of quark mass if we leave QCD considerations aside? Can we conceive of quark masses and extract them from the hadron-level data with reasonable accuracy and without using the uncertain QCD baggage, i.e. without adopting a specific concept of quark motion 'within' hadrons? The answer to that question is positive. There is a simple way in which the concept of mass was originally attributed to quarks. This simple way does not utilize QCD at all. The idea is based on the 50 years old algebra of *hadronic* currents ('Current algebra') that satisfy quark-level *symmetries* but do not treat quarks as ordinary particles. In particular, current algebra uses global and spacetime concepts defined at the *hadron* (not quark) level.

The current algebra way of extracting quark masses from experiment uses the Gell-Mann–Oakes–Renner (GMOR) formula [12]:

$$m_{\pi}^{2}\delta_{ab} = -\frac{1}{f_{\pi}^{2}} \langle 0|[Q_{5}^{a}, [Q_{5}^{b}, H(0)]]|0\rangle.$$
⁽²⁾

Here m_{π} , f_{π} are pion mass and decay constant, a, b – isospin indices, Q_5 is the axial charge, and $|0\rangle$ is the hadronic vacuum. The contribution of the quark mass term $m_q \bar{q} q$ in the Hamiltonian H(0) is evaluated from:

$$\begin{bmatrix} Q_5^b, \bar{q}q \end{bmatrix} = \bar{q}\tau^b \gamma_5 q, \begin{bmatrix} Q_5^a, \bar{q}\tau^b \gamma_5 q \end{bmatrix} = \delta_{ab}\bar{q}q.$$
(3)

Assuming that all other terms in H(0) commute with axial charges, one derives:

$$m_{\pi}^2 = -\frac{1}{f_{\pi}^2} (m_u \langle 0|\bar{u}u|0\rangle + m_d \langle 0|\bar{d}d|0\rangle), \tag{4}$$

where $\langle 0|\bar{q}q|0\rangle$ are expectation values of quark bilinears in the hadronic vacuum.

After extending isospin SU(2) to flavor SU(3) (for decay constants and vacuum expectation values, but not for the masses ³), one can use Eq. (4) together with an analogous formula for kaons to derive:

$$\frac{2m_s}{m_u + m_d} = \frac{m^2(K^0) - m^2(K^{\pm}) + m^2(\pi^{\pm})}{m^2(\pi^0)} = 25.9,$$

$$\frac{m_u}{m_d} = \frac{2m^2(\pi^0)}{m^2(K^0) - m^2(K^{\pm}) + m^2(\pi^{\pm})} - 1 = 0.56.$$
 (5)

The ratios of quark masses are here extracted from the hadron-level data without any assumption concerning the existence of spacetime background within hadrons. The absolute values of masses are then *approximately* determined by accepting that the strangeness-induced splitting of groundstate baryons requires $m_s - m_{u,d} \approx 140 - 150$ MeV. This leads to quark mass values $m_u \approx 4 MeV$, $m_d \approx 8 MeV$, $m_s \approx 150 MeV$ which are in half-quantitative agreement with those given in Particle Data Group tables [13]⁴.

 $^3\,$ Such a way of applying and breaking SU(3) has ample phenomenological support.

⁴ The values given in Ref. [13] are all smaller than our estimates by a single overall factor of around 1.5. The reason is that they are defined in a different way. Specifically, the masses given in Ref. [13] are defined at the field-theoretical mass scale of $\mu = 2 \text{ GeV}^2$. On the other hand, within the field-theoretical language the larger mass values extracted here are thought to correspond to $\mu \approx 1 \text{ GeV}^2$.

The above-described way of an approximate extraction of quark mass does not use the Dirac equation $(\not p - m)q = 0$. This is highly welcome, as the use of the on-mass-shell formulas for confined quarks is very questionable: these formulas and the standard propagator poles correspond to spatial infinity which cannot be reached by confined quarks. In fact, one may point out places, where the contribution from the on-mass-shell formulas and propagators leads to artefacts that are in direct contradiction with experiment [14, 15].

The GMOR-based extraction of quark masses is based solely on the global chiral properties of the fermion mass term. It does not use the classical relativistic connection between four-momentum and mass. It does not use the concept of quark momentum at all. It does not specify how quarks 'propagate' in spacetime. It does not use the concept of quark color ⁵. This leaves a lot of freedom for the connection between the concept of quark mass and the concept of macroscopic spacetime.

3. Spacetime, phase space, and quantum

3.1. Emergent spacetime

With gravity described as a consequence of spacetime distortion induced by the presence of masses, i.e. with the reduction of gravitational interactions to geometry, the idea of emergent spacetime is usually linked with general relativity. Since from the gravitational constant G, Planck constant h, and the velocity of light c one can form an expression of the dimension of length, it is at the resulting dimunitive Planck length scale that the quantum nature of space is generally supposed to appear and spacetime is supposed to emerge.

Yet, the problems at the intersection of the quantum and the classical do not appear solely when general relativity is considered. It is well known that a kind of tension exists also between quantum physics and special relativity. This tension manifests itself as Bell's nonlocality. It indicates that the mismatch between quantum physics and the concept of classical space appears at *all* distance scales, not just at the Planck length scale. Indeed, Norsen writes [16]:

A much higher-level inconsistency between quantum theory and (general) relativity has been the impetus for enormous efforts (...) spent pursuing "presently fashionable string theories of everything". How might a resolution of the more basic inconsistency identified by Bell shed light on (or radically alter the motivation and context for) attempts to quantize gravity?

In fact, the problem shows up even earlier than the intersection of quantum physics and special relativity. It appears also when nonrelativistic classical and quantum physics are juxtaposed. The problem exists because the two approaches are formulated on two completely different arenas: the ordinary 3D space and the Hilbert space. In addition, one is deterministic, the other one — probabilistic. Consequently, the quantum-classical mismatch appears already at the strictly nonrelativistic level and should be first attacked at this level. Indeed, this is the level at which Penrose's spin-network idea was originally formulated. There are therefore at least two reasons for working with the nonrelativistic approach. First, one should always start with the simplest things, and the interplay of quantum and classical physics is certainly simpler at the nonrelativistic level. Second, the existence of spatial quantum numbers (spin, parity, C-parity ⁶) may be deduced already at the nonrelativistic level. Thus, connecting particle masses and internal quantum numbers with the emerging macroscopic classical arena of events should be first attempted in the nonrelativistic scheme. Our insistence on the need to establish such a

 $^{^5}$ If color is introduced, the GMOR extraction refers to color-blind expressions involving the sum over three colors.

 $^{^{6}}$ Charge conjugation parity. Although the existence of particles and antiparticles was originally predicted by the relativistic Dirac equation, it may also be deduced without relativity via the linearization of the nonrelativistic Schrödinger equation [17].

connection need not be in disagreement with the expected space and time emergence at all the distance and interval scales: the scale of particle masses may be just most *useful* for unraveling the mechanism of this emergence.

3.2. From space and time to phase space

The discussion of the concept of emergence usually starts by challenging the statement that the ordinary 3D space is a background canvas on which things move and interact. In fact, this Democritean view was denied already by Aristotle who considered space 'as an accident of matter'. Many great physicists and philosophers, including Leibnitz, Mach and Einstein, subscribed later to this Aristotelian '... old and great idea that space and time are, so to speak, stretched out by matter...' [18]. In other words, space and time should be considered as defined by things. Yet, time is not defined by things in the same way space is. Speaking more precisely, time is defined by the change of things. This is how (astronomical) time was originally introduced by Ptolemy, and how it is understood by Mach and Barbour (see e.g. [19]).

Alternatively, one may say that space and time are defined by things and processes. One can claim then on philosophical grounds that things and processes should be treated on the same footing. This idea, when expressed in the language of physics, suggests a symmetric treatment of positions (defined by things) and momenta (defined by changes of things). Thus, one may argue that one should replace the Democritean description in terms of the background space and time by a more Heraclitean description in terms of the background position and momentum spaces, i.e. in terms of the background phase space. The original argument against the treatment of space and time as a background translates then into the argument against the treatment of phase space as a background. Therefore, if space and time are both emergent, their emergence may be regarded as a consequence of space and momentum space being emergent. The idea that it is the phase space that actually emerges first from the quantum layer seems to be particularly attractive as quantum mechanics 'lives and works in phase space' [20]. The known symmetries of space and time must then originate from the properties of phase space. Accordingly, all spatial quantum numbers must be interpretable in the phase-space language. Yet, as the number of phase-space dimensions is larger than that of 3D space and time, the language of nonrelativistic phase space may admit more symmetries than the language of space and time. While in the latter language these 'new' symmetries and the related quantum numbers (if any) cannot manifest as ordinary spatial ones, they might be still identifiable in experiments. Obviously, they would have to appear to us as the non-spatial ones.

3.3. Born's reciprocity

The idea that positions and momenta should be treated in a way more symmetric than the one actually used in current standard approaches, was originally proposed by Max Born [21, 22]. He noticed that various physical formulas, such as the Hamilton's equations of motion, the position-momentum commutation relations, or the expression for the orbital angular momentum are invariant under 'reciprocity transformation', i.e. under the interchange:

$$\mathbf{x} \to \mathbf{p}, \qquad \mathbf{p} \to -\mathbf{x}.$$
 (6)

At the same time, Born observed that the symmetry, expected on account of (6), between the relativistic momentum space invariant $P = E^2 - \mathbf{p}^2$ and the relativistic position space invariant $R = t^2 - \mathbf{x}^2$, is completely broken by the concept of (quantized) mass. In his own words:

(...) the distance P in momentum space is capable of an infinite number of discrete values (...) while the distance R in coordinate space is not an observable quantity at all.

In other words, quantized mass is always associated with momentum, never with position coordinates. Deeply dissatisfied with this asymmetric state of affairs, Born concluded:

'This lack of symmetry seems to me very strange and rather improbable'.

In fact, reciprocity transformation (6) suggests the existence of a new phase-space constant κ of dimension [momentum/distance], which, when the quantum constant h and the velocity of light c are added, defines the phase-space-related mass scale. With this scale being possibly very different from the Planck mass scale, its appearance indicates that the problem of quantized mass could be attacked in the language of phase-space, i.e. from an angle completely different from the seemingly more adequate language of curved spacetime. It might appear that the violation of the reciprocity symmetry by the concept of mass is an argument against the phase-space route. Yet, the failure of the reciprocity idea does not mean that symmetry between momentum and position could not be introduced in another way. Below we will argue that one can consider a different $\mathbf{x} \leftrightarrow \mathbf{p}$ symmetry as more appropriate for the generalization of the concept of mass.

3.4. Mass and phase-space heuristic

We start by noting that of the six phase-space coordinates the unknown mass-defining principle singles out the physical three-momentum as associated with the standard concept of mass. Indeed, the energy of any individually observable free particle is expressed (whether relativistically or nonrelativistically) in terms of a formula involving mass and three-momentum. The position variables are absent (violation of translational invariance could be avoided by admitting position differences only). We will call the 'canonical momentum' any three phasespace variables appearing (without their canonical partners) alongside mass in such a dispersion formula (i.e. in a Hamiltonian). The application of the reciprocity transformation (6) to such an expression for a free particle changes the three-momentum into a position three-vector, thus singling out the other three of the six phase-space coordinates as the possible coordinates of the canonical momentum. As Born noted, this leads to a formula that does not seem to describe any existing 'particle'. Still, six different choices for the canonical momentum exist in addition to the two just discussed. We list all eight of them below.

canonical		canonical			
position	momentum		position	momentum	
(x_1, x_2, x_3)	(p_1, p_2, p_3)	$\leftarrow \mathrm{Born} \rightarrow$	(p_1, p_2, p_3)	(x_1, x_2, x_3)	
(x_1, p_2, p_3)	(p_1, x_2, x_3)		(p_1, x_2, x_3)	(x_1, p_2, p_3)	
(p_1, x_2, p_3)	(x_1, p_2, x_3)		(x_1, p_2, x_3)	(p_1, x_2, p_3)	
(p_1, p_2, x_3)	(x_1, x_2, p_3)		(x_1, x_2, p_3)	(p_1, p_2, x_3)	(7)
even permutations		odd permutations			

The l.h.s (r.h.s.) pairs of entries in Eq. (7) constitute even (odd) permutations of the standard (top-left) choice. As indicated, the left- and right-hand sides of the first line above are connected (up to a sign) by Born's reciprocity argument. It was noted above that no quantized mass is associated with the top-right entry. We observe that this violation of reciprocity could actually originate from the distinction between even and odd permutations. If this is so, one would expect that quantized mass could also be associated with the second, third, and fourth canonical momenta on the left hand side, but not with the corresponding ones on the right hand side. Such a generalization of the concept of mass clearly violates its rotational invariance. Since our classical experience requires rotational invariance to hold, the corresponding 'particles' certainly cannot exist as individual objects in the macroscopic world. However, we do not see any reason why such 'particles' could not exist 'inside' conglomerates built of several such

objects, provided these conglomerates exhibit all the macroscopically expected covariance and invariance properties.

The appearance of new 'particles' which exist in triplicate and cannot be observed individually bears such a striking resemblance to quarks of the Standard Model that we feel forced to put forward a conjecture that the four options on the l.h.s of Eq. (7) actually correspond to a lepton and three colored quarks. We have to stress that for the above conjecture to hold one does not have to question the approximate adequacy of the field-theoretical description of quarks by bispinor fields q(x). However, these fields are clearly not expected to satisfy the classically motivated constraint $(\not p - m)q(x) = 0$. In other words, it is solely the adequacy of the standard concept of quark mass (and its connection to momentum) that is questioned here.

If the masses of the individual colored quarks are associated with the rotationally noncovariant canonical momenta, there is obviously no rationale for the description of quark behavior 'inside' hadrons with the help of standard fermion propagators. On the other hand, the replacement of physical momenta by the canonical ones does not affect the GMOR extraction of quark masses. As explained earlier at some length, the GMOR extraction is based on the properties of the fermion mass term only. The concept of quark momentum is not used.

More specifically, the conjecture of Eq. (7) suggests how the lepton Hamiltonian, which in the standard language is composed of two additive terms: the momentum term $H_l(p_1, p_2, p_3) = \boldsymbol{\alpha} \cdot \mathbf{p}$ and the mass term $H_l^0(m) = \beta m$, should be transformed into the Hamiltonians for three colored quarks. For example, for quark #1 it should be built as a sum of some canonical momentum term $H_{q1}(p_1, x_2, x_3)$ and some mass term $H_{q1}^0(m)$. Since the mass term used by GMOR refers to a sum over colors, the corresponding mass term of the phase-space language is expected to be built as a sum over colors as well, i.e. $H_{q1}^0(m) + H_{q2}^0(m) + H_{q3}^0(m)$. It is this sum that should exhibit all the necessary invariance properties. The actual construction and the explicit forms of all the relevant terms will be discussed in the last Section.

4. Clifford algebra of nonrelativistic phase space

The quantum concept of spin may be arrived at from the classical level by the linearization of the 3D space invariant \mathbf{p}^2 . The most $\mathbf{x} \leftrightarrow \mathbf{p}$ symmetric extension of this procedure to the case of the 6D classical phase space leads us to consider the linearization of the expression $\mathbf{p}^2 + \mathbf{x}^2$ and, consequently, to Clifford algebra $Cl_{6,0}$ [23, 24, 25, 27]. Since position and momentum do not commute in the quantum case, the relevant Clifford algebra calculations have to be supplemented with the subsidiary condition $[x_j, p_k] = i\delta_{jk}$ (we choose units such that $\hbar = 1$). Then, with \mathbf{A} and \mathbf{B} being six mutually anticommuting elements of $Cl_{6,0}$, one derives

$$(\mathbf{A} \cdot \mathbf{p} + \mathbf{B} \cdot \mathbf{x})(\mathbf{A} \cdot \mathbf{p} + \mathbf{B} \cdot \mathbf{x}) = \mathbf{p}^2 + \mathbf{x}^2 + R,$$
(8)

where the R term (classically absent) appears because position and its conjugated momentum do not commute. The elements **A** and **B** may be represented by eight-dimensional matrices:

$$A_k = \sigma_k \otimes \sigma_0 \otimes \sigma_1, B_j = \sigma_0 \otimes \sigma_j \otimes \sigma_2.$$
(9)

One calculates that

$$R = -\frac{i}{2} \sum_{k} [A_k, B_k] = \sum_{k} \sigma_k \otimes \sigma_k \otimes \sigma_3 \equiv \sum_{k} R_k.$$
(10)

The 7-th anticommuting element of our Clifford algebra is:

 $B = iA_1A_2A_3B_1B_2B_3 = \sigma_0 \otimes \sigma_0 \otimes \sigma_3.$ (11)

4.1. Gell-Mann-Nishijima formula

From B and R we construct now the elements I_3 and Y which, as it will turn out, have simple physical interpretation:

$$I_3 = \frac{1}{2}B, \qquad Y = \frac{1}{3}RB.$$
 (12)

It is straightforward to check that I_3 and Y are invariant under 3D rotations and reflections (generated respectively by S_k and P, which are defined by their actions on both A and B):

$$[S_k, I_3] = [S_k, Y] = 0,$$

$$[P, I_3] = [P, Y] = 0.$$
(13)

Since in addition the commutator $[I_3, Y]$ vanishes, and therefore the eigenvalues of I_3 and Y can be simultaneously specified, these elements constitute candidates for two internal quantum numbers. In order to proceed, we rescale the expression in Eq. (8) and take the lowest (vacuum) eigenvalue of $\mathbf{p}^2 + \mathbf{x}^2$:

$$Q \equiv \frac{1}{6} \left[(\mathbf{p}^2 + \mathbf{x}^2)_{vac} + R \right] B = I_3 + \frac{Y}{2}.$$
 (14)

With the eigenvalues of I_3 and Y being

$$I_{3} = \pm \frac{1}{2} \quad \text{(four times)},$$

$$Y = \sum_{k} Y_{k} \equiv \frac{1}{3} \sum_{k} R_{k} B = -1, \pm \frac{1}{3}, \pm \frac{1}{3}, \pm \frac{1}{3}, \pm \frac{1}{3} \quad \text{(twice)},$$
(15)

one naturally identifies Eq. (14) with the Gell-Mann–Nishijima formula for the electric charges of the eight fermions from a single generation in the Standard Model. Elements I_3 and Y denote, respectively, (weak) isospin and (weak) hypercharge. For the Y_k 's we introduce the name 'partial hypercharges'.

4.2. The Harari-Shupe model

The three partial hypercharges commute among themselves, i.e. $[Y_k, Y_m] = 0$ (k, m = 1, 2, 3). Consequently, their eigenvalues may be simultaneously specified. It is then instructive to analyse in detail the way in which the four eigenvalues of hypercharge Y are constructed out of the eignenvalues of Y_k 's. This is shown in Table 1.

Table 1. The structure of weak hypercharge in terms of its component partial hypercharges

Y_1	Y_2	Y_3	Y
$-\frac{1}{3}$	$+\frac{1}{3}$	$+\frac{1}{3}$	$+\frac{1}{3}$
$+\frac{1}{3}$	$-\frac{1}{3}$	$+\frac{1}{3}$	$+\frac{1}{3}$
$+\frac{1}{3}$	$+\frac{1}{3}$	$-\frac{1}{3}$	$+\frac{1}{3}$
$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	-1

It appears that the pattern of Table 1 is in one-to-one correspondence with the charge structure of the celebrated Harari-Shupe (HS) rishon model [28, 29], a model in which leptons

Table 2. Rishon structure of the $I_3 = +1/2$ members of a single SM generation in the Harari-Shupe model

ν_e	u_R	u_G	u_B	e^+	\bar{d}_R	\bar{d}_G	\bar{d}_B
VVV	TTV	TVT	VTT	TTT	VVT	VTV	TVV

and quarks are built of fermionic subcomponents (i.e. 'rishons' V and T of charges $Q_V = 0$ and $Q_T = +1/3$) as specified in Table 2 [23, 24].

The correspondence in question is:

$$Y_k = -1/3 \leftrightarrow V, \qquad Y_k = +1/3 \leftrightarrow T, \tag{16}$$

where k labels the position in the ordering of rishons in Table 2 (e.g. $[(Y_1, Y_2, Y_3) = (-1/3, +1/3, +1/3)] \leftrightarrow VTT$). Thus, rishons may be roughly understood as partial hypercharges. It has to be stressed that the correspondence between the HS model and the phase-space scheme refers to the charge structure only. Consequently, the shortcomings of the HS model (and there are many of them⁷) are all absent in the phase-space scheme. The shortcomings of the rishon model do not appear in the phase-space scheme because the partial hypercharges are algebraic components of the hypercharge operator only and do not reside on any subparticles. In other words, in the phase-space scheme we have symmetry-related sectors without symmetry-'explaining' subparticles ('preons'). Therefore, contrary to naive understanding, the phase-space approach is not a preon model. It does not provide a theoretical justification for the introduction of preons. Its success in the explanation of the working part of the HS model constitutes an argument against preons.

4.3. Even subalgebra of Clifford alegbra

The even subalgebra of our Clifford algebra contains 32 elements, which may be divided into two sets of 16 elements each, acting in sectors with $I_3 = \pm 1/2$ [25, 26]. Within each such sector the relevant 16-element set consists of a unit element and 15 generators of SO(6). The set of 15 generators decomposes further into SU(3) multiplets as $15 = 1 \oplus 8 \oplus 3 \oplus 3^*$. When looked at from the point of view of the ordinary 3D rotations, the singlet is a scalar, while the octet contains three familiar SO(3) generators. Multiplets 3 and 3^{*} generate 'genuine' 6D rotations in phase-space ⁸, and lead to lepton-quark transformations. For example, a rotation by $\pi/2$ induced by the generator $F_{+2} \equiv -\frac{i}{4} \epsilon_{2kl} [A_k, B_l]$ permutes quark #2 with a lepton while leaving quarks #1,3 unaffected [23, 24]. The corresponding transformation in phase space is

$$(p_1, p_2, p_3) \to (-x_1, p_2, x_3).$$
 (17)

Thus, Clifford algebra provides a highly non-trivial connection between the internal quantum numbers (i.e. weak isospin and hypercharge, Eq. (15)) and the phase-space (and mass) heuristic discussed in connection with Eq. (7). From our point of view, therefore, the three colored quarks should be regarded as leptons with canonical momenta rotated in phase space in three possible ways (cyclic counterparts of the r.h.s. of Eq. (17)).

⁷ The unwanted properties of the original HS model include: a problem with rishon statistics, the lack of explanation why TTT states are free but TVV are confined, various predictions (of unobserved fundamental spin-3/2 fermions, of unobserved $TT\bar{T}$ states, of the violation of baryon number,...) etc.

 $^{^{8}\,}$ By 'genuine' 6D rotations we mean in particular rotations that change some momenta coordinates into position coordinates and vice versa.

4.4. Odd part of Clifford algebra

The odd part of our Clifford algebra consists of 16+16=32 elements linking the sectors of opposite values of I_3 . Each 16-element subset decomposes in SU(3) as $16 = 1 \oplus 3 \oplus 3 \oplus 3^* \oplus 6$ (or its conjugate). The SU(3) singlet (and an SO(3) scalar) works in the lepton subspace Y = -1 only. Its explicit form is

$$G_0 \propto (1 - \sum_k \sigma_k \otimes \sigma_k) \otimes (\sigma_1 + i\sigma_2).$$
 (18)

Element G_0 and its hermitian conjugate (which belongs to the other 16-element subset) constitute the only odd elements of Clifford algebra which (1) have Y = -1 and (2) are SO(3)-scalars. Consequently, it is only from them that a candidate for an algebraic counterpart of the lepton mass term may be formed.

Application of the previously discussed finite rotation generated by F_{+2} transforms G_0 into

$$G_{22} \propto (1 + \sum_{k} \sigma_k \otimes \sigma_k - 2\sigma_2 \otimes \sigma_2) \otimes (\sigma_1 + i\sigma_2).$$
⁽¹⁹⁾

It may be checked that G_{22} and its hermitian conjugate have $Y = \pm 1/3$ and thus they both operate in the quark subspace. Furthermore, as expected, G_{22} and G_{22}^{\dagger} are not rotationally invariant. It is only from them that a (rotationally still noninvariant) candidate for an algebraic counterpart of the mass term may be formed for quark of color #2. Elements G_{22} and its two analogues (G_{11} and G_{33}) belong to the SU(3) sextet $G_{\{kl\}}$. This sextet decomposes in SO(3)into a scalar (the trace $\sum_k G_{kk}$) and a quintet. Thus, as originally anticipated, the summation over the color degree of freedom would lead to the restoration of rotational invariance for the algebraic counterpart of the effective quark mass term.

Although the basic element of the mechanism of quark conspiracy seems to work, one cannot directly use G_0 and G_{kk} (together with their hermitean conjugates) as the algebraic counterparts of lepton and quark mass. Specifically, it turns out that the 64-element Clifford algebra of nonrelativistic phase space is too small to reproduce the standard algebra leading to Dirac equation for a lepton ⁹. In the next Section we will enlarge the algebra and show how the problem could be solved.

5. Compositeness and additivity

If the phase-space approach is to constitute a successful idealization of certain aspects of nature, there should be a way to apply it to the description of the emergence and spatial behavior of colorless composite states (mesons and baryons). In the standard field-theoretical language this behavior is described via hadron propagation in the underlying background space of Democritus. On the other hand, within our Aristotelian philosophy of emergent phase space, the actual relation between hadrons (or leptons) and the classical arena of events is inverted: the macroscopic space is expected to be well defined only at the level of individually observable (colorless) particles. If space emerges in full starting only at the hadronic level (recall the issue of the frozen degree of freedom discussed in Section 2), the idea of space emergence should be regarded as constituting an unorthodox point of view on the problem of confinement. In other words, the emergence of the 'background' space (which space constitutes an input into QCD) and the problem of confinement (the emergence of composite states) might be considered as two faces of the same issue. Unfortunately, we have no detailed idea on how to construct the classical space from the quantum layer of spins, internal quantum numbers, etc.; we have no idea what are the rules that govern the emergence. Still, some expectations may be presented. These expectations are based on the concept of additivity which constitutes a basic element in the determination of the properties of composite systems of particles. Indeed, additivity is

 $^{^{9}}$ The hypercharge projector in G_{0} conflicts with the algebraic counterparts of momentum.

applied both to their quantum numbers (via the additivity of spins, flavors, etc.) and — in the case of individually observable particles — to their physical momenta. For example, the momentum of a system composed of leptons A and B is given as $\mathbf{p} = \mathbf{p}^A + \mathbf{p}^B$. The same formula is used for the determination of the momentum of a hadronic resonance formed when two hadrons collide. Such additivity prescriptions must constitute important ingredients in the way our classical world emerges out of its quantum components. Although they seem trivial and are generally not given much thought, in the case of quarks we must be more careful.

5.1. Additivity of quark canonical momenta

The problem is with the transition from the hadron to the quark level. It seems that for quarks a natural extension of the principle of the additivity of physical momenta consists in the additivity of the canonical momenta ¹⁰. Now, the canonical momenta of red, green, and blue quarks are (in order to distingush the positions of green and blue quarks, we renamed x_1 in Eq. (17) into y_1 , with similar cyclic changes in other places):

$$\mathbf{p}^{R} = (p_{1}, x_{2}, -y_{3}),
\mathbf{p}^{G} = (-y_{1}, p_{2}, x_{3}),
\mathbf{p}^{B} = (x_{1}, -y_{2}, p_{3}).$$
(20)

Addition of the canonical momenta of three quarks of different colors (the baryon case) leads to a translationally invariant expression:

$$\mathbf{p}^{R} + \mathbf{p}^{G} + \mathbf{p}^{B} = (p_{1}, p_{2}, p_{3}, x_{1} - y_{1}, x_{2} - y_{2}, x_{3} - y_{3}).$$
(21)

If different quarks conspire, the expression on the r.h.s. above can be made rotationally covariant as well. The r.h.s. of Eq. (21) is then expected to contain the total physical momentum \mathbf{p} of the resulting baryon. This weird conspiration constitutes a glimpse into the anticipated physics of space emergence which the phase-space approach suggests. The r.h.s. of Eq. (21) contains also the expression $\Delta = \mathbf{x} - \mathbf{y}$ formed out of selected components of interquark displacements. Since **p** is a vector, $\boldsymbol{\Delta}$ is expected to be a vector as well. If quarks were located in the 3D background space, there would be two independent displacements (spatial degrees of freedom) in each spatial direction. In our case, however, the constraint that Δ is built from three particular perpendicular vectorial components leads to an unexpected conclusion. To see what happens, one has to analyse the situation in the position representation. For example, one has to think of the blue quark as located at (x_1, y_2, z_3) , with analogous expressions for the other two quarks. Consider the three components of Δ as fixed perpendicular vectors (straight 'strings') connecting the relevant quarks. It turns then out that together they form an 'impossible triangle'. Therefore, the whole construction is noncontradictory only if this triangle converges to a point: each one of the three components of Δ must vanish. Thus, one of the two usually expected internal spatial degrees of freedom (for each of the three spatial directions) is necessarily frozen. We conclude that there appears an interesting analogy between our additivity-based reasoning and the existence of a phenomenologically established spatial constraint 'inside' the excited baryons.

The above argument is based on an attempt to extend the applicability of the macroscopic classical concept of space into the 'interior' of baryons, an idea we already argued to be wanting. The bizzare character of the obtained picture is assigned to the inapplicability of this extension ¹¹. In our view, therefore, the background space can be used 'inside' hadrons

¹⁰ Additivity of physical momenta of individual colored quarks cannot be experimentally tested, as all probes used for our studies of quark behavior (photons, weak bosons) are necessarily color-blind.

¹¹ We do not consider the seemingly crazy character of our construction to constitute sufficient grounds for its rejection. After all, our assumptions (extension to phase space, connection with internal quantum numbers via its Clifford algebra, extension of the additivity principle) look extremely solid.

solely as a rough appproximation. It cannot be used as a visualisation of what 'really' happens there. What is obviously badly needed is a more specific proposal for the mechanism of space emergence. Unfortunately, such a proposal is currently lacking (our arguments here, based on the additivity of canonical momenta, may be considered as hints only, indicative of the direction in which one should actually proceed). Yet, given the conceptual problems with the notion of quark mass and the phenomenological problems with the spectroscopy of excited baryons, we believe that important information on the details of this mechanism is hidden in the spectroscopy and properties of hadrons, i.e. in the emergence of hadrons out of quarks. In other words we think that one can learn about space emergence from a deeper understanding of the quark/hadron transition. After translating this idea into the standard language it means that the quark-confining interactions should be understood in geometro-algebraic (or pregeometric) terms. Embarking on such an ambitious agenda is clearly beyond our goal here.

In order to apply our additivity proposal to the discussion of mesons, we must interpret charge conjugation (i.e. the existence of antiparticles) in phase space terms. The more familiar operations of space inversion P and time reversal T are obviously represented as:

$$P: \quad (\mathbf{p}, \mathbf{x}) \quad \to \quad (-\mathbf{p}, -\mathbf{x}),$$

$$T: \quad (\mathbf{p}, \mathbf{x}) \quad \to \quad (-\mathbf{p}, +\mathbf{x}).$$
(22)

If one looks at the quantum case, the invariance of $[x_m, p_n] = i\delta_{mn}$ requires that time reversal be accompanied by complex conjugation $i \to -i$. The product of P and T is:

$$PT: \quad (\mathbf{p}, \mathbf{x}) \to (\mathbf{p}, -\mathbf{x}), \quad \text{and} \quad i \to -i.$$
(23)

Assuming that CPT = 1, the operation (23) is then identified with charge conjugation C. Indeed, for an ordinary particle the transition to the corresponding antiparticle is achieved by keeping the particle's momentum unchanged but reversing its charge Q.¹²

Adding the canonical momenta of a red quark $(\mathbf{p}^R = (p_1^R, x_2^R, -y_3^R))$ and its antiquark gives then

$$\mathbf{p}^{R} + \mathbf{p}^{\bar{R}} = (p_{1}^{R} + p_{1}^{\bar{R}}, x_{2}^{R} - x_{2}^{\bar{R}}, -y_{3}^{R} + y_{3}^{\bar{R}}).$$
(24)

Thus, translationally invariant expressions are obtained also for quark-antiquark systems. ¹³ In short, the requirement of translational invariance suggests the acceptability of qqq, $q\bar{q}$, and $\bar{q}\bar{q}\bar{q}$ systems as individually observable particles, and the nonacceptability of q, qq, $qq\bar{q}$, etc. This conclusion, which actually corroborates our assumption on the additivity of canonical momenta, is very similar to the analogous one obtained via the color-singlet argument of the standard quark model. Note that the requirement of translational invariance explains why in the HS model the combination TVV is confined but TTT or $TVV \otimes VTV \otimes VVT$ are not.

5.2. Additivity of colored quark Hamiltonians

We proceed now to the issue of the additivity of quark Hamiltonians. We postpone the discussion of the mass terms for the moment and start from the momentum part of the lepton Hamiltonian, i.e. from the (nonrelativistic) expression

$$H^L = \mathbf{A} \cdot \mathbf{p}. \tag{25}$$

 $^{^{12}}$ Since all our theories provide idealized descriptions of certain aspects of reality only and must not be identified with nature, it should not be considered strange (or unacceptable) that antiparticles may be recognized and described in a language different from that of the relativistic field theory.

 $^{^{13}\}operatorname{Rotational}$ covariance requires taking into account green and blue quarks as well.

Genuine 6D rotations of **A** and **p** (see e.g. Eq.(17)), when combined with appropriate sign changes in the matrix part, transform (25) into the following Hamiltonians for the three colored quarks:

$$H^{R} = A_{1}p_{1} + B_{2}x_{2} - B_{3}y_{3},$$

$$H^{G} = -B_{1}y_{1} + A_{2}p_{2} + B_{3}x_{3},$$

$$H^{B} = B_{1}x_{1} - B_{2}y_{2} + A_{3}p_{3}.$$
(26)

While ordinary 6D rotations necessarily yield plus signs in the above formulas, we have used here the possibility of redefining some of the elements A_k, B_k in a way that does not affect the (even in A_k, B_k) operators of weak isospin and hypercharge.¹⁴ Summation over quark colors gives the total quark Hamiltonian:

$$H^{Q-total} = A_1 p_1 + A_2 p_2 + A_3 p_3 + B_1 (x_1 - y_1) + B_2 (x_2 - y_2) + B_3 (x_3 - y_3).$$
(27)

If quarks of different colors are taken to be located at the same point, one obtains

$$H^{Q-total} = \mathbf{A} \cdot \mathbf{p}.$$
 (28)

This resembles the momentum part of the (nonrelativistic) lepton Hamiltonian (25) completely. The difference is that here a *sum over colors* is taken and contributions from quarks of different colors conspire to yield the momentum part of the total Hamiltonian *as if of a lepton*.

5.3. Special relativity

We are now in a position to discuss the issue of how to include mass terms and special relativity. For leptons this means that we want to extend the nonrelativistic algebraic equality

$$(\mathbf{A} \cdot \mathbf{p})(\mathbf{A} \cdot \mathbf{p}) = \mathbf{p}^2 \tag{29}$$

to a relativistic form, i.e. to an expression in which the r.h.s. above would be replaced with $\mathbf{p}^2 + m^2$. In its essence, we face the Dirac's problem. Indeed, as remarked earlier in Section 4.4, our tentative identification of a Hermitean combination of the Y = -1 elements G_0 and G_0^{\dagger} with the algebraic counterpart of the lepton mass term suffers from an incompatibility similar to the one encountered by Dirac. Specifically, there is a problem with the product of elements A_k and G_0 (G_0^{\dagger}): the mixed mp_k terms do not cancel.

The solution of the Dirac's problem consisted in the extension of the nonrelativistic Pauli algebra via a tensor product construction. We propose here a similar construction that generalizes our nonrelativistic Clifford algebra to an algebra that admits a relativistic generalization of (29). Specifically, we move the Y = -1 projector $y_{-1} \equiv \frac{1}{4}(1_4 - \sum_k \sigma_k \otimes \sigma_k)$ in Eq. (18) to a new tensor factor so that

$$G_0 - G_0^{\dagger} \propto M_0 \equiv y_{-1} \otimes \sigma_2 \to G_0' - G_0'^{\dagger} \propto M_0' \equiv 1_4 \otimes \sigma_2 \otimes y_{-1}, \tag{30}$$

and accept the following generalization of $\mathbf{A} \cdot \mathbf{p}$ in the lepton sector:

$$p_k A_k \to p_k A'_k \equiv p_k A_k \otimes y_{-1}. \tag{31}$$

Since the Y = -1 projector in M'_0 and $\sigma_k \otimes \sigma_0$ in A'_k work now in different tensor factors, therefore upon squaring

$$\mathbf{A}' \cdot \mathbf{p} + M_0' m, \tag{32}$$

¹⁴ For example, for the red quark the redefinition consists in $A_3, B_3 \rightarrow -A_3, -B_3$ while keeping the remaining A_k and B_k unchanged.

one readily reproduces the relativistic form $\mathbf{p}^2 + m^2$.

In order to extend our discussion to quarks, we consider a fully symmetric counterpart of (32) with the Y = -1 projector y_{-1} in the rightmost factor replaced by 1_4 . We separate then the color singlet and triplet (Y = -1 and Y = +1/3) subspaces via

$$p_{k}A_{k} \otimes 1_{4} + m1_{4} \otimes \sigma_{2} \otimes 1_{4}$$

$$= (p_{k}A_{k} + m1_{4} \otimes \sigma_{2}) \otimes y_{-1}$$

$$+ (p_{k}A_{k} + m1_{4} \otimes \sigma_{2}) \otimes y_{+\frac{1}{2}}$$
(33)

where

$$y_{+\frac{1}{3}} = \frac{1}{4} (3 \cdot 1_4 + \sum_m \sigma_m \otimes \sigma_m) \tag{34}$$

is the projector onto the color triplet subspace. Finally, we decompose the second term on the r.h.s. of Eq. (33) into contributions from quarks of definite color:

$$p_{k}A_{k} \otimes y_{+\frac{1}{3}} + m1_{4} \otimes \sigma_{2} \otimes y_{+\frac{1}{3}}$$

$$= (p_{1}A_{1} + x_{2}B_{2} - x_{3}B_{3}) \otimes y_{+\frac{1}{3}} + m1_{4} \otimes \sigma_{2} \otimes y_{+\frac{1}{3},1}$$

$$+ (-x_{1}B_{1} + p_{2}A_{2} + x_{3}B_{3}) \otimes y_{+\frac{1}{3}} + m1_{4} \otimes \sigma_{2} \otimes y_{+\frac{1}{3},2}$$

$$+ (+x_{1}B_{1} - x_{2}B_{2} + p_{3}A_{3}) \otimes y_{+\frac{1}{3}} + m1_{4} \otimes \sigma_{2} \otimes y_{+\frac{1}{3},3}, \qquad (35)$$

where $y_{+\frac{1}{3},k}$ are projectors onto the subspaces of red, green and blue quarks (see also Eq. (19)):

$$y_{+\frac{1}{3},k} = \frac{1}{4} (1_4 + \sum_m \sigma_m \otimes \sigma_m - 2\sigma_k \otimes \sigma_k), \tag{36}$$

that satisfy $\sum_{k} y_{+\frac{1}{3},k} = y_{+\frac{1}{3}}$. Eq. (35) constitutes the proposed extension beyond the nonrelativistic case discussed in Eqs. (27, 28). For the canonical momentum terms the rotationally noninvariant distinction between quark colors resides only in the first factor of the tensor product, while for the mass term this distinction resides only in the last factor. The total quark Hamiltonian looks like a Hamiltonian for a free relativistic particle used in pre-QCD current quark mass extraction procedures. According to our proposal the old (pre-QCD) form should be viewed as involving an explicit summation over colors for both the canonical momentum terms and the mass terms. As a result, translational, rotational and relativistic invariances are restored and the standard relativistically invariant couplings to external colorless objects may be introduced at the level of observable combinations of quark contributions. It is only at this colorless level, the level at which special relativity has to be recovered, that the concept of spacetime point becomes meaningful and the standard gauge interactions may be introduced. Since the concept of spacetime point constitutes a prerequisite for any talk of local gauge structure, it is the issue of spacetime emergence from the quantum layer that has to be successfully addressed before any attempt to introduce interactions is made.

6. Concluding remarks

In various approaches to quantum gravity, macroscopic spacetime is often imagined as emerging from the quantum layer at the minuscule Planck scale. The nonlocality of quantum physics suggests, however, that this emergence occurs simultaneously at all distance scales, from the Planck scale to the cosmological distances. The quantum-mechanically-related momentum scales span a correspondingly enormous range. Since this range includes in particular the masses of all elementary particles, their spectrum could provide us with important hints on the actual

7th International Workshop DICE2014 Spacetime - Matter - Quantum	Mechanics	IOP Publishing
Journal of Physics: Conference Series 626 (2015) 012022	doi:10.1088/1742-	6596/626/1/012022

mechanism of spacetime emergence. This relevance of the problem of mass to the idea of space quantisation was supported with a brief review of fundamental issues related to the concept of particle masses, both at the hadron and quark levels. The encountered problems suggest that important information on the idea of spacetime emergence could be accessed via the studies of quark/hadron transition.

An attempt to address such ideas, based on the Clifford algebra of nonrelativistic phase space, was briefly reviewed. It was recalled that the proposed scheme reproduces important features of the observed spectrum of elementary particles, including the appearance of internal quantum numbers of weak isospin and hypercharge that characterise leptons and quarks, and providing an explanation of the Harari-Shupe model. A definite asset of this explanation is that it does not assume the heavily criticized existence of fermionic 'preons' inside fundamental fermions of the Standard Model. It was also pointed out that the scheme offers an unorthodox, alternative view on the problems of quark and hadron masses and the issue of quark confinement. In particular, possible connections of phase-space ideas to quark and hadron phenomenology were indicated. A way to introduce relativistic covariance at the level of individually observable particles (leptons and hadrons) was also proposed and discussed.

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