

Unification Based on Electromagnetism¹⁾

A Simple Composite Model of Particles

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Abstract. The complex machinery of gauge theories and QCD is not the only possible avenue to understand the physics of elementary particles. There is another simple and more direct approach based on absolutely stable particles as constituents of all other particles. Mathematically the ensuing group structure is identical to the quark-lepton model, but the dynamics and the underlying physics is different. How all forces of elementary particles are already dynamically unified under electromagnetism is discussed.

Vereinigung auf der Basis des Elektromagnetismus. Ein einfaches Aufbauschema von Elementarteilchen

Inhaltsübersicht. Der komplexe Apparat der Eichtheorien und Quantenchromodynamik ist nicht der einzige Weg, die Physik der Elementarteilchen zu verstehen. Es gibt einen anderen, einfachen und mehr direkten Ansatz auf der Basis von absolut stabilen Teilchen als Bausteine aller anderen Teilchen. Mathematisch ist die daraus folgende Gruppenstruktur identisch der des Quark-Leptonen-Modells, aber die Dynamik und die zugrundeliegende Physik sind andere. Es wird diskutiert, wie bereits alle Kräfte zwischen Elementarteilchen im Elektromagnetismus vereinigt sind.

I. Geometrical Unification versus Dynamical Unification

Generally various unification programs consist of joining a number of different fields together into bigger geometric objects. The three main examples and directions are:

(i) Take the symmetric and antisymmetric parts of $g_{\mu\nu}$ to unify gravitation and *EM*.

(ii) Put the photon and other bosons together into Yang-Mills fields $A_\mu^{(i)}$ to unify electromagnetism, weak and strong interactions.

(iii) Take a field in a higher dimensional space, as in Kaluza-Klein idea, which when reduced to ordinary space-time, contains many new fields. This program goes back to Maxwell when \mathbf{E} and \mathbf{B} were put together into the tensor $F_{\mu\nu}$. But there is an essential dynamical difference: whereas Maxwell's electromagnetism has a single coupling constant (the coupling constants of \mathbf{E} and \mathbf{B} are related by the fundamental constant c), there is, in all other unification attempts, no understanding so far of the different strengths of weak, electromagnetic, strong and gravitational interactions. The different coupling constants are either put in by hand, or shifted to some other new parameters

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of the theory. In this sense it seems that we have no other truly “unified” theory beyond electromagnetism. It is for this reason that Treder refers to Pauli’s remark that “Was Gott getrennt hat, soll der Mensch nicht vereinen” [1].

There is another possibility. A single theory which when applied to different physical structures can manifest itself in widely differing strengths so as to look like different interactions. Consider the chemical force between neutral atoms. Its strength is enormously weak compared to Coulomb force. We could have described it as a new phenomenon and ascribed to it a new small coupling constant. But it is a weak manifestation of electromagnetism when applied to neutral atoms which are composite. Consider the α -decay process. It could be described by a new coupling constant between the parent nucleus, the daughter nucleus and the α -particle. It is generally very weak. But again it is a weak manifestation of electromagnetism, namely the tunnel effect. Or, consider as a third case, the ratio of the electric force between two electrons with the magnetic force between their magnetic moments, assumed to be pointlike, at the distance r

$$\frac{V_{\text{magn}}}{V_{\text{electr.}}} \sim \frac{\mu^2/r^3}{e^2/r} \sim 1/4m^2r^2.$$

This ratio is of the order of α^{-2} at the distance of Bohr radius $r = 1/m\alpha$, but of the order of $\alpha^{-2} \sim 10^4$ at the nuclear distance $r = \alpha/m = 2.8$ fermis. This is also how one compares the strengths of electromagnetic and gravitational interactions between two electrons, $F^{\text{el}}/F^{\text{gr}}$, a ratio of 10^{39} . Thus, electromagnetism can manifest itself very weakly (chemical force, alpha decay), or very strongly (magnetic force at short distances), or simply electromagnetically (Coulomb). The latter, the Coulomb force between the electrons is the standard strength given to electromagnetism. Instead of giving different names to the different manifestations of the same force, describing them by new fields and new coupling constants, one should try to identify the different manifestations of the single force and the different situation to which it is applied. So in this sense, I should like to rephrase the above quotation from Pauli as follows: “Was Gott vereint hat, soll der Mensch nicht trennen.” This second type of unification one may call the dynamical unification, in contrast to the geometric unification discussed at the beginning. In fact there is nothing to unify, it is already unified and we should have not separated the forces in the first place.

The proposed unification of electromagnetic, strong and weak interactions is precisely based on the simple idea of magnetic or spin interactions mentioned above, applied to appropriate models of particles, in the same way as we deduce the chemical force by applying electromagnetism to appropriate models of atoms (Heitler-London). As quantum mechanics removed the frontier between physics and chemistry, so the magnetism may remove the barrier between atomic physics and nuclear and particle physics.

II. Two General Principles on the Construction of Particles

By the word “elementary” in the subtitle of this paper I mean “from first principles” as well as “simple, or primary”. A simple composite model based on some very general and elementary properties of particle interactions. Generally, composite models first try to construct leptons and quarks, the latter in turn make the hadrons. It should be possible to go from the basic constituents directly to observed hadrons and leptons, since quarks are not seen freely anyway.

The model I shall describe is based on the following two general observations:

(i) The first observation is that all particle states eventually decay into the absolutely stable particles: electron, neutrino, photon, and perhaps proton, if it is absolutely stable.

All unstable particles can be viewed as resonances in the appropriate channels of particles into which they decay. Very unstable particles decay into a bit more stable ones, these in turn into even more stable particles, until only absolutely stable particles are left. It is therefore possible to construct all particle states from the stable ones as the reverse of the hierarchy of decay processes.

Even if the proton is stable it has many properties of a composite bound state. I shall therefore take as the most economical model one in which the basic constituents are electrons and neutrinos. Photons come in as part of the electromagnetic field. The theory does not exclude the possibility that the proton is absolutely stable, or an independent entity (perhaps made of monopoles which by the way is also electromagnetic).

A resonance in a particular channel can always be interpreted as a quasi-bound state of the particles in that channel due to some forces acting among those particles involved. Different decay modes of the same resonance will be interpreted as a rearrangement of constituents with possible additional pair production or pair annihilation.

Now electrons and neutrinos apparently do not have strong interactions. That is why physicists have introduced new strong nuclear forces in the thirties, and excluded the electron from the nucleus, to account for the strong interactions, and eventually further introduced new hypothetical particles, quarks and gluons. However,

(ii) our second fundamental observation is that magnetic spin forces between electrons can be very strong and localized at short distances, although they are well known to be weak at atomic distances. In other words, electrons at short distances behave as though they were strongly interacting, i.e. they were "quarks".

The effective interaction potential between two electrons for example, is such that at large distances it is essentially the usual Coulomb potential, but widely separated from it, at the nuclear distance, it can be a very strong attractive magnetic force followed at still shorter distances by a repulsive core. The magnetic forces show the remarkable phenomenon that it is possible for the same particles to have one type of interaction at lower energies and another type of qualitatively and quantitatively different interaction at higher energies, or shorter distances.

Thus instead of lepton-quark symmetry we propose to identify them. Moreover instead of assuming all the six leptons to be elementary we shall assume only the electron and neutrino to be elementary and absolutely stable, and construct explicitly all others as composed from these two. As to the forces we thus identify strong interactions with the spin forces and their various manifestations, like exchange, and further identify the weak decays of resonances with the tunnel effect through the magnetic potential barriers, also an electromagnetic phenomenon. In the magnetic region the Coulomb forces are small corrections to the magnetic forces, in the atomic region it is the other way around.

We have now two tasks:

(i) The kinematical problem of constructing all particle states from the basic two (e, ν_e), their composites, and composite of composites.

(ii) The dynamical problem of calculating masses of resonances of two and many body systems and establish contact with the phenomenology of particle interactions.

The first problem can be rigorously solved and exact grouptheoretical multiplets can be established isomorphic to the quark model as we shall see in the next Section.

The second problem of relativistic dynamics of magnetic interactions is a very complex and rich subject. It has been solved in various approximations. However, the scale of the masses and the interactions range can be easily established. They are determined by the scale of the magnetic moments $\mu = a(e/2m)$ of the constituents, rather than by the masses of the constituents. Thus for electrons the range of the magnetic inter-

actions is $r = e\mu = a(\alpha/2m) \sim 1$ Fermi (where a is the magnetic moment in Bohr magnetons), and resonance masses are of the order of $M \sim 2m/(a\alpha) = 140$ MeV. For the proton, if the magnetic moment is assumed to be localized and pointlike, we find $r \cong 4 \cdot 10^{-16}$ cm, and $M \sim 90$ GeV. We shall also see that the magnetic forces reflect the qualitative properties of the nuclear and strong interactions rather well. The main problem is to establish the relativistic behaviour of the magnetic moment at short distances. For this we have to develop nonperturbative methods in electrodynamics. But the theory has very few parameters and is in principle, falsifiable.

At this stage it may be useful to inject some caution about certain myths in high energy physics. The quark model is generally introduced as an inevitable consequence of (i) the successes of spectroscopy of hadron states as $q\bar{q}$ and qqq bound states, (ii) deep inelastic scattering "showing point-like free particles of fractional charges at short distances".

In fact the "quark realization" of the $SU(3)$ or $SU(n)$ representations is only one of the possible ones. There are other realizations with integrally charged particles, and a formal mathematical transformation exists of passing from one type of realization to another. The real problem is which are the true physical constituents and which mathematical constituents. For all results that depend on the group structure of hadrons are equally valid for all realizations of multiplets. The realization with quarks considered as physical particles brings new problem of confinement and new forces, the realization with stable physical particles does not.

As to the spectroscopy, all the dynamical potential models do not depend, as far as the quantum numbers are concerned, on the nature of the constituents except that they are fermions. The actual form of the potential is phenomenological, the QCD picture is not yet tested at all. The spin forces also play an essential role in quark spectroscopy. But they have been treated sofar as a perturbation. It turns out that they are as big or bigger than the unperturbed potential, and when treated non-perturbatively they wash out the original unperturbed bound states. It seems that one can not even trust at the phenomenological parameters of quarks obtained from spectroscopy.

III. Construction of Particle Multiplets

According to the first general proposition of the previous Section the most basic constituents of matter are the absolutely stable particles which we take to be the electron and the electron neutrino. (Level A-Table 1)

Next in order of stability are the two particles: proton and the muon-neutrino. They can be thought to be constructed from Level A particles as shown.

From now on an equality of the form $p = (e^+e^-e^-)$ will mean a simplest or a minimum realization of the quantum numbers of p . We can also write $p = (e^+\nu\bar{\nu})$, or a mixture

Table 1. Ordering of Particles in order of Stability

Level	Particles $Q = 0$	$ Q = 1$	Lifetime	Conserved Quantum Numbers
A	ν_e	e	$\tau_A = \infty$	$N_{\nu_e} \equiv L, N_e \equiv Q$
B	$\nu_\mu = (\nu_e\nu_e\bar{\nu}_e)$	$p = (e^+e^+e^-)$	τ_B	$N_{\nu_\mu}, N_p \equiv B$
C	$n = (pe^-\bar{\nu}_e)$	$\mu = (\nu_\mu e^-\bar{\nu}_e)$	τ_C	N_n, N_μ for $t < \tau_C$
D	$\Lambda_S = (p\bar{\nu}_e\mu^-)$	$\Lambda_C = (p\bar{\nu}_e\nu_\mu)$	τ_D	N_S, N_C for $t < \tau_D$

$p = (e^+[e^+e^- + \nu\bar{\nu}])$. One can always add additional pairs such as $p = (e^+e^+e^-)(e^+e^-)$, without changing the quantum numbers of p . The precise form of p and ν_μ is a dynamical question which also will determine the lifetime τ_p of these particles.

Although all the rest of the matter is in principle made of electron and neutrino pairs, the almost stable forms, p and ν_μ , can make new forms and can be considered to be constituents. Indeed for the next two most stable particles among all the unstable states, the neutron and the muon, we know the lifetimes and decay products. Thus we can consider the neutron as a resonance state $(pe^-\bar{\nu}_e)$, similarly for μ as shown in Table 1 (level C). Note that there is precise symmetry in the constitution of μ and ν_μ on the one hand, and p and n on the other hand, or how to go from level A to B and then to C. The large difference in the lifetime of n and μ is due to phase space, otherwise these two states are of the same structure.

To the extend of their stability the particle numbers N (number of particles—number of antiparticles) provide additively conserved quantum numbers. Thus N_e and N_ν are absolutely conserved which we identify with the electric charge and lepton number. N_p and N_{ν_μ} are almost absolutely conserved, and N_n and N_μ are conserved for all processes whose duration is shorter than the lifetime τ_c . In the decay processes, for example, N_μ will change by one. ($|\Delta S| = 1$)

These considerations immediately explain the conservation of charge, as well as the quantization of charge, for all charge in the world is due to electron. Similarly baryon number B counts the protons, the number of muons and muon neutrinos count the so-called strangeness and charm. If one starts with equal number of e^+ , e^- and forms protons according to $p = (e^+e^+e^-)$ we expect approximately equal number of protons and electrons in the world.

The next two particles, again in order of stability, are the mesons π and K , which we construct from the previous levels as lepton-antileptons. Clearly one can go on this way. However, in order to put this process of making more and more unstable particles from previous more stable particles into an algebraic scheme, and moreover, into a one-to-one correspondence with the quark-lepton model, we have introduced in Table 1, level D, two more baryonic states A_s^0 and A_c^+ with their indicated compositions. This will allow us to compare the two models at the $SU(4)$ level.

To go to the level of six leptons and six quarks we could add two more levels E and F to Table 1 representing τ and ν_τ and two baryon states A_b^0 and A_t^+ , respectively. But this is not necessary, for already all the states in Table 1 are in accordance with the general construction principle (Aufbau principle) that we are going to establish.

Concerning the uniqueness of the realizations of A^0, A^+ etc., we shall call two particle states to be equivalent, if their constituents differ by at most lepton pairs, when expressed in terms of levels A and B. For example, $(n\bar{\nu}_e\nu_\mu) \sim (pe^-\bar{\nu}_e\nu_\mu) \sim (p\mu^-\nu_e)$, using the row C in Table 1. Then the only other inequivalent forms of the type of level D are

$$A'_s = (pe^-\bar{\nu}_\mu), A'_c = (p\nu_e\bar{\nu}_\mu)$$

which is important for the discussion of CP-violation. Equivalent realizations as above represent rearrangements of the internal constituents of a state, hence account for different decay modes of the particle.

It is now easy to establish a precise correspondence to the quark model with colour degrees of freedom, although we have not introduced additional “coloured” objects as such.

Let us denote $b = (p, n, A_s, A_c)$ and $l = (\nu_e, e^-, \mu^-, \nu_\mu)$ and $l' = (e^-\nu_e\nu_\mu\mu^-)$. The set l' is just a relabeling of l . (In l , $(\nu_e e^- \mu^-)$ is an $SU(3)$ -triplet, ν_μ a singlet; in l' , $(e^- \nu_e \nu_\mu)$ is triplet and μ^- an $SU(3)$ — singlet). Then we construct all meson states as

$$M = l \otimes \bar{l} + l' \otimes \bar{l}', \tag{1}$$

and all baryon states as

$$B = b \otimes l \otimes \bar{l}'. \tag{2}$$

All higher leptonic states are

$$L = l \otimes l \otimes \bar{l}'. \tag{3}$$

Table 2 shows the ordering of the b , l and \bar{l}' -constituents and their correspondence to the quarks.

Table 2 has to be read as follows: In order to construct baryons according to eq. (2) take one element from column b , one from column l and one from \bar{l}' . The resultant multiplets are equivalent to those of qqq , one from each colour. In eq. (1) the two terms account for the mixing of mesonic states, e.g. $(e^+e^- + \nu\bar{\nu})$, etc.

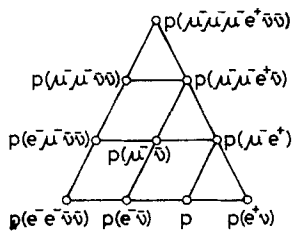
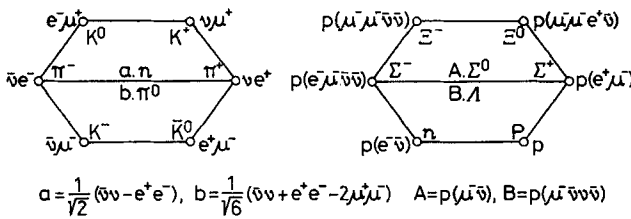
In Table 3 we give the realizations of the low lying mesonic and baryonic states.

Table 2. Relation between Stable Particles, Quarks and Colour, and Integrally charged Quarks

Correspondence to	Most stable Fermions			Average charge $\langle Q \rangle$ in each row
	b	l	\bar{l}'	
u	p^+	ν_e	e^+	$2/3$
d	n	e^-	ν_e	$-1/3$
s	A_S	μ^-	ν_μ	$-1/3$
c	A_C	ν_μ	μ^+	$2/3$

Correspondence to "colour"	'Green'	'Red'	'Blue'

Table 3. A Minimal Leptonic realization of low-lying Meson and Baryon States



IV. More on Magnetic Interactions at High Energy

We shall now discuss some features of the important problem of the dynamics of magnetic interactions. At low energies the electron behaves like a point magnetic dipole. The best values of the hyperfine splitting in hydrogen and in positronium are obtained when e and p are assumed to have pointlike total magnetic dipole moments.

At high momentum transfers we have the concept of magnetic form factors. The form factors of the electron as measured in unpolarized cross sections come from radiative corrections in QED. The proton shows considerable structure in the charge and magnetic moment distribution. The high energy experiments probe essentially the Born approximation of the interaction potential. Whereas in the calculation of the bound states and resonances we must treat the full potential nonperturbatively. If one studies the interaction potential in relativistic two-body equations for electrons one sees, as expected, that the magnetic terms at very high energies become much larger than the Coulomb potential. The signs of the magnetic terms in the potential are dependent on the orientation of spins. Even in Born approximation in scattering one can have large spin effects in polarized cross-sections. Indeed such large spin effects have been observed in polarized proton-proton experiments. The corresponding polarized electron scattering experiments have not yet been done, but I predict also large spin effects.

For highly localized states of two electrons, or e^+e^- , at distances of the order of 1 fermi, there are huge magnetic fields. We do not know the magnetic form factor of the electron in such situations, as the sum of infinitely many diagrams in perturbation theory. It can only be calculated nonperturbatively and selfconsistently.

A magnetic moment (electron) moving along a circle of the characteristic magnetic radius of $r = \alpha/m$ produces a self-magnetic field of the same order as the external field thus sustaining the rotation. This is analogous to a self focusing mechanism. It is on this basis that the masses of μ $\left(3/2 \frac{m}{\alpha}\right)$, of π, η, \dots $\left(2 \frac{m}{\alpha} n^2\right)$ as e^+e^- -magnetic resonances, of proton $\left(\frac{27}{2} \frac{m}{\alpha} - 9/\sqrt{3}\right)$ — as $e^+e^+e^-$ -resonance, and of “ Z_0 ” as $p\bar{p}$ -resonance has been calculated. In quantummechanical models such states are realized as massive positive energy resonances in deep potential wells localized at nuclear distances. Indeed, many models with magnetic forces show deep localized potential wells at short distances inside which the electron can be localized. What would be the observable effect of such strong localized magnetic forces in scattering? For we do not think that the electrons interact strongly, but protons and mesons do. If one scatters a particle against a potential barrier with a deep potential well essentially nothing happens except at those energies at which the potential well can support a resonance. At these energies the phase shift jumps by $\pi/2$ and we observe a sharp peak corresponding the the formation of the resonance. This is indeed what is observed say in e^+e^- -scattering. The Born approximation agrees with experiment, except narrow peaks at resonances like $\rho, \omega, \eta, \eta', \psi, \dots$ For the scattering of composite objects such π, p the situation is quite different. First of all there is either no barrier, or the barrier is at much shorter distances. Then the particles can come near to each other and being composite, the exchange of the constituents takes place. Even these exchange forces are due to magnetic forces of course, in the present point of view. Thus pointlike spin 1/2 particles exhibit resonance penetration (e, μ, τ) Large composite objects like π, p show broad strong interactions due to exchange of constituents.

V. The Neutrino. Parity Violation

We have taken the electron and the neutrino as the basic building block. The neutrino is the constant companion of the electron in many processes. The new “quantum” ($e\bar{\nu}_e$) accounts for the exchange and transitions in and between many leptonic and ha-

dronic transitions. Electron carries its ν with itself, like it carries its own electromagnetic field. In fact the ν -equation, like the equation for a photon, is really classical (\hbar drops out when $m = 0$ in Dirac equation), except for the Pauli principle.

In order to account for the binding of a ν to an electron, and further for the binding of e and $\bar{\nu}_e$ to a proton to form the neutron, etc., I have assumed a small magnetic moment for the neutrino of the order of about 10^{-9} Bohr magnetons. This is the only parameter of the theory. This small value reproduces the strength of weak interactions in the neutral current process $e\nu \rightarrow e\nu$, for example. It is possible that there is a more fundamental theory of the quantum $e\bar{\nu}_e$ as a single object. But for the time being we use the two entities separately.

In order to have a magnetic moment the neutrino must have four components. The coupling to the electromagnetic field is given by

$$\gamma^\mu p_\mu \psi = a \sigma_{\mu\nu} F^{\mu\nu} \psi. \quad (4)$$

One then wonders what happens to the parity violation and the fact that experimentally ν seems to interact lefthandedly only. To answer this it is important to realize that when $m = 0$ the left- and righthanded (Weyl) component of ν play automatically unsymmetrical roles. For free particles, ($F_{\mu\nu} = 0$ in eq. (4)), the little group for $m = 0$ states is E_2 and the action of this group E_2 is such that ψ_L (and for the conjugate E_2^* , ψ_R) are fixed points in the spinor space. That is E_2 transforms the spinor ψ into ψ_L , but a state ψ_L can never be transformed out of this one-dimensional subspace. It follows that the asymptotic states outside the interaction region are necessarily ψ_L and $\bar{\psi}_R$, and it is these states that one does the experiments with in the laboratory. However in the interaction region we must solve eq. (4) and we can have superpositions of ψ_L and ψ_R . It seems that, physically, the nonobserved ψ_R (and ψ_L) for neutrinos are quickly transformed into ψ_L (and $\bar{\psi}_R$). This is thus the explanation of both the parity violation, although eq. (4) conserves parity, and the apparent absence of right handed neutrinos. It is thus the result of the asymmetry contained in the structure of the Poincaré group for massless particles.

On Other Composite Models

The number of parameters (about 25) in the present quark-lepton and their apparent randomness has led many people to consider models based on subquarks or preons such that all the six leptons, and the six quarks each with three colours should be the bound states of these preons. One hopes again to have a simpler and more pleasing theory, although the quark-lepton model has been hailed as the ultimate, the theory of the world based on gauge principle (albeit badly broken). However all the leptons and quarks have spin 1/2, and any such preon model has to reproduce all these spin 1/2 ground states and no low lying spin 3/2-excited states. It does not seem possible to do this so far with few such preons. And these preons should be again confined like the quarks.

In contrast the model based on stable particles e and ν and on the hierarchy of stability of observed resonances is already a composite model. The absolute stability of e and ν will put a limit to successive quarks, subquarks, etc.

Further Results and Conclusions

Clearly there are numerous questions when one tries to rebuild the whole of particle physics of the last fifty years solely on the basis of electromagnetism. I have tried to answer these and establish contact with phenomenology [2]. I believe there is a good intuitive understanding of the high energy phenomena, abstract rules being clarified, unobservable entities being eliminated; a very conservative, down-to-earth approach in which particle physics now appears as a natural extension of atomic physics.

The basic ingredient is the strong magnetic interactions of the electrons at short distances. From the high energy e^+e^- -scattering experiments one might hastily conclude that the magnetic forces are small. However, these experiments do not directly test the strong, nonlinear, self-magnetic fields of localized e^+e^- -systems, which, selfconsistently, bind them. In a subtle way though, they test indirectly the formation of many sharp narrow resonances in the e^+e^- -channel which the magnetic interactions actually predict. We also understand the coupling constants of the weak and strong interactions in terms of α , the fine structure constant of electromagnetism, and the masses of heavy leptons and hadrons as multiples of the characteristic magnetic energy m/α .

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