Was Lorentz our first particle physicist ?

Talk by M. Veltman[†] in Leiden at the symposium "Zeeman, Lorentz & the electron" on 11 October 2002, on the occasion of the 100'th aniversary of the Nobel prize of Lorentz and Zeeman.

[†] NIKHEF, PO Box 41882, NL-1009 DB Amsterdam, The Netherlands

LORENTZ, Hendrik Antoon, 1853-1928 © Nobelstiftelsen
Nobel Laureate PHYSICS 1902

After a short introduction Prof. Gaemers enters the auditorium, clearly excited, comes up to Veltman and whispers something in his ear. Shortly after an actor made up to look like Lorentz enters, and a short dialog between Lorentz and Veltman follows.

Script optreden Lorentz op 11 Oct. 2002 te Leiden. V = Veltman, L = Lorentz
Tijd: 11:45. Plaats: Gorlaeus Laboratorium, Einsteinweg 55, Leiden

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The time of Lorentz seems far in the past, and yet it is not really that long ago. Here is what happened to me.

I am a member of a club for retired people. Two days after I got the Nobel prize we had a meeting. When I sat down my neighbour told me:

I wonder if they will wrap the streetlights in black cloth when you die.

I asked: Why that?

Well, I remember that when Lorentz was buried the burning street lamps along the funeral route through Haarlem were draped in black cloth.

My friend at that club did live in Haarlem at the time of Lorentz' death in 1928. As a 10 year old boy he saw the funeral procession. Since Einstein and Rutherford spoke at the grave he might have seen them as well.

This gave me a sense of connection. I may tell you another anecdote from someone who knew Zeeman. Zeeman was very proud of his distinctions. In Amsterdan he had the nickname 'Paasos' (Easter oxen). This was because whenever there was an occasion he would put on all the decorations that he had.

For the purposes of this symposium I read the Nobel lecture of Lorentz. First I was surprised to see that Lorentz knew that X-rays are a shortwave version of electromagnetic radiation. Furthermore Lorentz still believed firmly in the existence of the ether. But what hit me most was the enormous gap between the knowledge then and now. I would have big difficulties telling Lorentz anything about physics as we know it today.

Photo of Lorentz on overhead projector

Image for a moment that I was talking to the Lorentz of 1902.

Gaemers comes from behind, and whispers something in V's ear

(He actually said: Anaconda copper is down)

V: What !!! ??? !!!

V: (to audience) Someone tells me that some man claiming to be Lorentz was found lost in the middle of Leiden.

L enters the auditorium and walks up to a position opposite V.

V: Prof. Lorentz !!! !!!

L: **De Heer Wells uit Engeland kwam naar Leiden om mij zijn tijd-reis machine te tonen. Hij gaf me een uur in Leiden 100 jaar in de toekomst. Ik herkende niets meer. Vriendelijke omstanders hebben mij hier gebracht waar blijkbaar een herdenking plaats vindt.**

V: Prof. Lorentz, dit is een internationaal publiek.

L: **Wel, wat wilt U dat ik spreek, Frans of Duits ?**

V: Uh... Engels.

L: **Remarkable. My English is not very good, but I will try.**

V: Prof. Lorentz, reading your Nobel lectures I saw that you knew that Röntgen radiation was a short wave form of e.m. radiation. How did you know ?

L: **This became clear after the experiments of Mr Haga and Mr Wind from Groningen.**

V: Aha.

L: **Haga.**

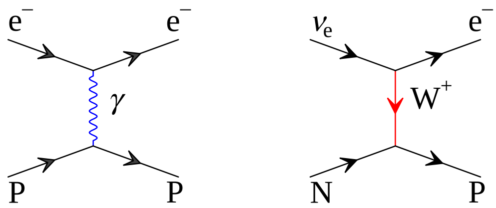
V: Yes. Would you be interested if I try to tell you what we know now ?

L: **Of course !!!**

V: Let me start telling you something about the known forces. In addition to gravitation and electromagnetism we have discovered that there exist other forces. For example there is the so-called weak force.

L: **Tell me about it.**

Projection of Coulomb and neutrino scattering



V: First, ordinary Coulomb scattering, scattering of an electron on a proton.

L: **Proton ? What is that ?**

V: Excuse me. A positively charged hydrogen ion.

L: **I understand. I suppose that the wavy line represents the Coulomb potential.**

V: Right. Now here a similar process involving the weak force. A neutrino scattering on a neutron......

L: **Neutrino ? Neutron ?**

V: Excuse me. A neutron is a neutral version of a hydrogen ion, it is actually part of Becquerel radiation. The neutrino is like an electron but without electric charge. It is also produced in Becquerel radiation. It is massless.

L: **No mass ?? How is that possible ?**

V: Uh.... Excuse me. Let us not go into that.

L: **What happens then ?**

V: Well, these weak forces do actually change particles. So the neutrino becomes an electron and the neutron changes into a proton.

L: **I suppose that the red line represents the potential of this new weak force ?**

V: Right.

L: **Why do you call it the weak force ?**

V: Acrually, it is a little bit stronger than the Coulomb force.

L: **Why then do you call it a weak force ?**

V: Let us not go into that.

L: **Well, you are not very clear. Can you tell me then if this new force is repulsive or attractive ?**

V: Uhhh... I do not know.

L: **Incredible. There is a new force and you do not even know if it is repulsive or attractive ! Let us start on something else. What about the ether ?**

V: The ether does not exist.

L: **Not even a single one ?**

V: None at all.

L: **What !!! So space is empty ?**

V: Uh.. Not really. There is a field in it called the Higgs field.

L: **Perhaps this is just another name for the ether ?**

V: Not really, it has different properties. For example, photons do not interact with it.

L: **Photons ?**

V: Excuse me. Electromagnetic radiation does not interact with this Higgs field.

L: **But does it interact with anything else ?**

V: It interacts with all matter.

L: **Well, that makes things easier. So you can do experiments to establish with what speed we move with respect to this Higgs field ?**

V: No, because this field is a scalar with respect to Lorentz transformations.

L: **What do you mean: 'scalar'?**

V: Excuse me. This gets difficult. Let us not go into that.

L: **Sir, I cannot say that you gave me much information. I am not sure that you understand what you are talking about. Let me ask you a question. Where are you from ?**

V: Waalwijk.

L: **Aha. This is in Noord Brabant if I am not mistaken. Where did you study, at least if you did.**

V: I went to the University of Utrecht.

L: **Aha. I understand. Perhaps you should attend some lectures in Leiden. Well, I have to go.**

Lorentz goes away, muttering loudly

L: **I suppose that not everybody is made to be a Nobel prize winner.**

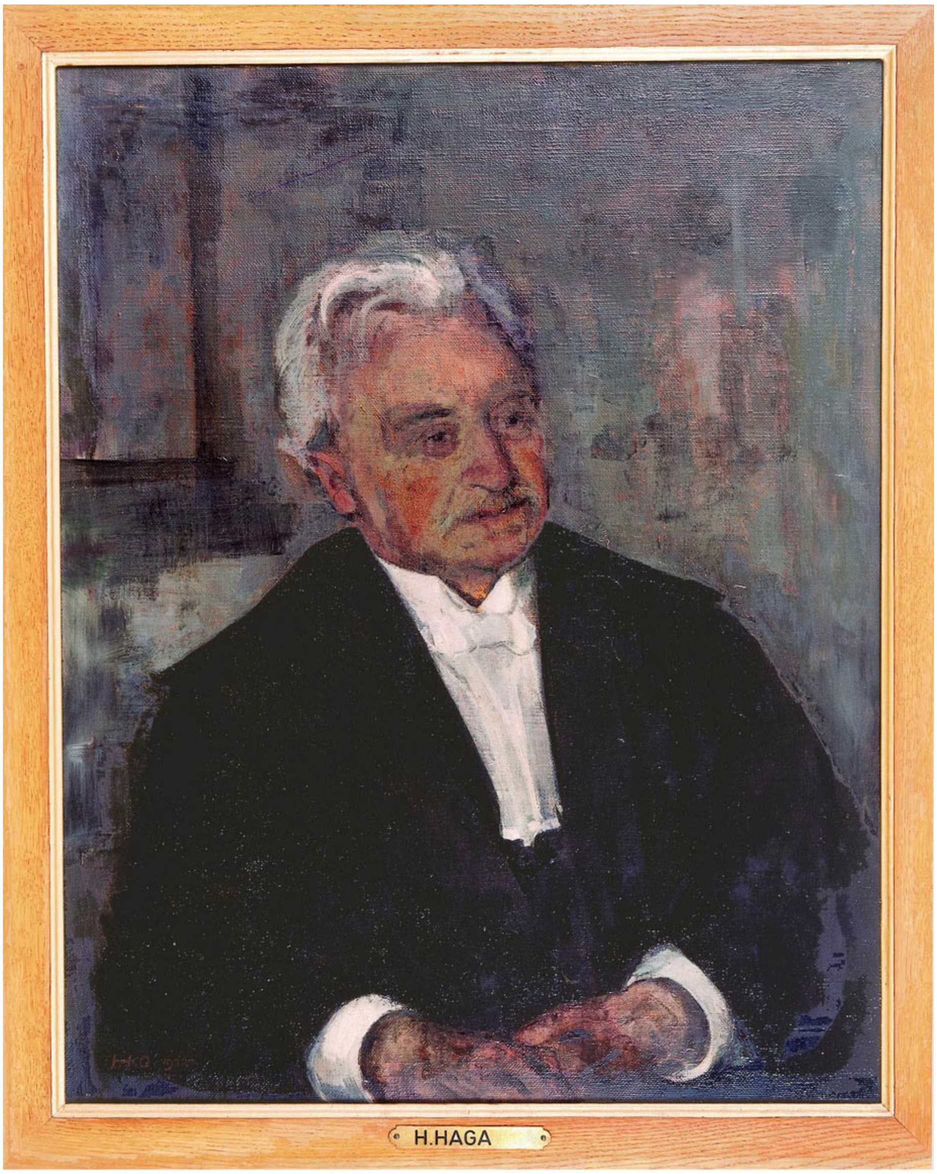
Prof. Lorentz raised here several questions, and now that he is gone I will try to address them. You realize how large the gap is between his and our understanding. In particle physics relativity has become a daily ingredient, for example, at the Brookhaven muon ring one can see an explicit demonstration concerning the twin paradox. One may compare side by side the lifetime of a muon at rest and of one circulating at high velocity in the ring.

First, let me explain my question concerning the nature of Röntgen rays. Everyone knows that von Laue had the splendid idea that scattering of Röntgen rays of a crystal would give the answer, and so it did. That was in 1914. How then did Lorentz know about it ? There was a lot of discussion about it and many speculations, among them the correct one. In his Nobel lecture Lorentz seems to be pretty sure. I then discovered that a crucial experiment had been done by two Groninger experimentalists, namely Haga and Wind. They illuminated a V-shaped slit with Röntgen rays, and discovered wave-like diffraction. They estimated the Röntgen rays to have a wavelength of about 0.1 Angstrom, which is correct. Their article was well known at the time and quoted for example by von Laue in his Nobel lecture.

It is interesting to know that Haga was rector of the University at the time that he did his work. Incidentally, that was also the case for Wilhelm Röntgen. Apparently one could be scientist and University manager at the same time in those long gone days.

While Haga and Wind deserve not to remain in obscurity, they have really nothing to do with particle physics. At the time the big issue was whether Röntgen rays were particles or waves, and I imagine Haga to be upset if I would have told him: both. But that is another matter.

There is the question if Haga was a student of Lorentz since he did his thesis work in Leiden. However, he got his Ph. D. in 1876, which is only one year after the Ph. D. of Lorentz. Interestingly, Prof. Berends remarked that Haga and Lorentz were classmates at their high school in Arnhem. Concerning Wind: he also got his experimental physics Ph.D. in Leiden, in 1894, however on something apparently done in Groningen.



HAGA, Hermannus, 1852-1936

Hermannus Haga, Oldeboorn 1852 - Zeist 1936. Thesis Leiden, 1876, Professor Groningen 1886 - 1922, Rector 1900. Designed new Physics Lab., ready in 1892.

Enige gegevens Wind.
Cornelis Harm Wind, Groningen 7 November 1867, Utrecht 7 Aug. 1911. HBS, student 1886 Wis en Natuurkunde. Proefschrift Leiden 1894. "De locaalvariometer van Kohlrausch en het magnetisch veld in het physisch lab. te Groningen". Nadat hij in Amsterdam en Berlijn zich vrn. op physische chemie had toegelegd, werd hij in 1895 benoemd tot lector in de math. physica en phys. chemie te Groningen. In 1902 hoofddirectoraat van het KNMI te de Bilt; 20 Febr. 1904 Hoogleeraar R.U. Utrecht, mathematische physica.

The question now who was our first particle physicist depends on how you define such a person. Certainly, Lorentz with his theory of electrons is a good candidate. But many of us see particle physics as a separate discipline only when no particles found in stable matter play a role. After all, we would not call anyone believing in atoms in those days a particle physicist.

A strong candidate to the title is a very unexpected person: Theodor Wulf. Let me explain.

Wulf (1868-1946) was a Jesuit physics teacher in Valkenburg, at the Ignatius college. Let me recall that in those days it was not at all uncommon to find Jesuits in physics: two Belgian Jesuits, Delsaux and Carbonella were the first to advance, around 1865, the correct explanation for Brownian motion. Mr Wulf apparently had the opportunity to do experiments on a limited scale, and he fabricated an electroscope that was highly leak proof. Nonetheless, no matter how he tried, the thing discharged. He correctly surmised that this was due to radiation, perhaps from the earth. He wanted to test this hypothesis, and wrote a letter to Langevin, asking him for help in doing the experiment at the Eiffel tower. This then worked out, and Wulf, after analyzing his results indeed very carefully concluded that the effect was not sufficiently less on top of the eiffel tower as would be expected on the basis of the absorption of radiation by the air. This was his published conclusion in 1909.

The Austrian Hess took up this investigation and started to make balloon trips to large heights (up to 6 km) to verify the issue. He used a 'Wulf electroscope', an electroscope fabricated by the industry according to the design of Wulf. It is of course Hess who is now officially recognized as the discoverer of cosmic rays, and he received the 1936 physics Nobel prize for that. It would not have been a bad idea if Wulf had been so honored as well. Here the original drawing by Wulf, and a picture taking at the occasion of a balloon flight made by the Fermilab group, re-enacting the historical balloon flights by Hess, using Wulf's electroscope. The Fermilab people did build themselves a Wulf electroscope, shown in the picture.

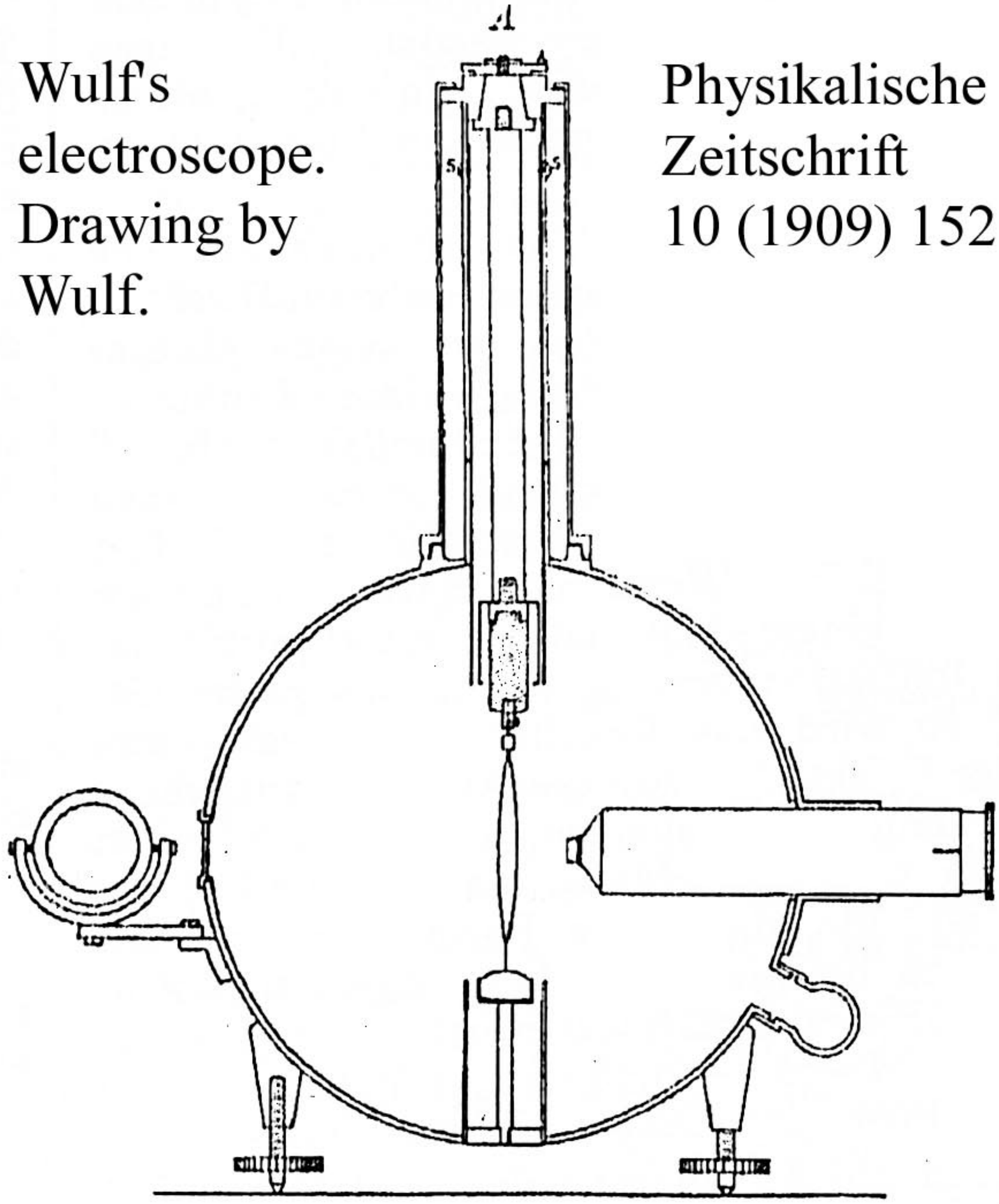
If we want to designate Wulf as our first particle physicist there is a note to be made. Wulf was a German, and at the time that he choose to become a Jesuit they were forbidden in Germany. So they all went to Netherlands, establishing a long line of Schools parallel to the German border. That is why Wulf went to Valkenburg. However, he became a teacher there and remained in Valkenburg for a long time, till 1936.

WULF, Theodor, 1868-1946

Our first Particle Physicist

Wulf's electroscope. Drawing by Wulf.

Physikalische Zeitschrift 10 (1909) 152



Balloon flight Fermilab group 2001.

HESS, Victor, 1883-1964

Just before his 1912 balloon flight

Repulsive or attractive ?

Let us now turn to the important points raised by Lorentz. First, are the weak forces repulsive or attractive ?

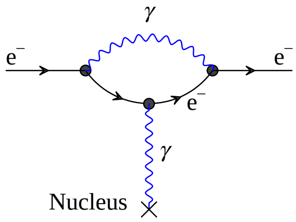
This is not a trivial question to answer. In principle one must prepare wave packets such that the incident particle passes at some distance, and then calculate whether it is bend upwards or downwards. Not an easy matter when using Feynman diagrams. But it seems reasonably clear what Lorentz had in mind when he asked this question, namely whether it would perhaps be opposite to the electric forces when it comes to short distances, so that perhaps the total self-energy becomes finite.

Lorentz of course had discovered that the electromagnetic field around the electron contains energy, and then contributes to the effective mass of the particle. In fact, he already said that the observed mass is the sum of the bare mass and the mass caused by the electromagnetic field. The formulae that he then started to develop were however not correct, and for a while different people derived different expressions. With hindsight we can understand this confusion: while the energy in the electromagnetic field perforce is treated in a Lorentz invariant way, theorists did not treat the electron energy as the fourth component of a vector. It had to wait till in the late thirties, when Dirac developed the theory of a point electron, before the matter was clarified. Even so, it is not something that you can deal with in a classical manner.

The influence of Lorentz extended further. His successor, Ehrenfest, and later Kramers and even van Kampen, Kramers student can be considered analytic continuations of Lorentz. The important one here is Kramers. My knowledge of Kramers is from the biography written by Max Dresden.

Ehrenfest was not an easy person to have as boss. He required total dedication to physics, to the point that he frowned on his pupils being engaged or being married. He created a somewhat oppressive atmosphere, in which a person like Kramers did not fit very well. He was 'exiled' twice, first to a high school in Arnhem. At some point Kramers got on his own to Copenhagen, to work with Bohr where he became involved with the emerging quantum theory. Later he came back to the Netherlands, and then was exiled for the second time, to Utrecht (albeit with letters of recommendation of Bohr, Planck and Lorentz). Lorentz' letter recommending Kramers was guarded, and he mentioned that Kramers often came late to his morning lectures.

By the time Kramers came back to Leiden, in 1934, as successor to Ehrenfest he was completely tamed. The best I can describe this is by saying that he had a cause but was no rebel. As we all know Lorentz did not really completely embrace Einstein's theory of relativity; likewise Kramers kept on working in a non-relativistic way. He was very interested in the self-mass of the electron, and often stated that the observed mass is the sum of the bare mass and the electromagnetic mass. Somewhere around 1937 he essentially discovered (in today's language) the diagram relevant to an electron in an orbit around the nucleus.



He expressed his understanding by saying that the Dirac theory did not completely describe the spectrum. What he had in mind is what we now call the Lamb shift.

The big change came after World War II, at the Shelter island conference. Kramers exposed his ideas, thus not just the matter of renormalization, but also the fact that there may be radiative corrections as generated by the previously shown diagram. Of course, that Lamb came out with his experimental results was crucial here. We all know the consequences of Kramers talk. In a very short time Bethe produced his estimate of the Lamb shift, agreeing very well with Lambs result. Then Feynman, Schwinger etc. formulated the correct relativistic theory of Quantum Electrodynamics.

It must have been a very difficult time for Kramers. First, neither Bethe nor Feynman credited Kramers in any way. It is only after Kramers death, in 1952, that he received full credit from Bethe. His disgust with particle physicists was undoubtedly large, and that was perhaps inherited by van Kampen who often made remarks in this sense. I would say to them: ”you have seen nothing yet”.

Of course, it must have been hell to Kramers to see Bethe do the calculations so quickly, while he had been busy with it for 10 years.

In any case, I consider the idea of renormalizable theories a heritage of both Lorentz and Kramers. I therefore tried to calculate the self-energy of the electron in the Standard Model using modern renormalization techniques.

Obviously this must depend on the ratio of the coupling constants of weak and e.m interactions. In modern notation this ratio is given by the sine of the weak mixing angle. Let us compute the divergent part of the electron self-energy.

To make a calculation that is free of questions concerning gauge invariance I will concentrate on the pole of the electron propagator S. In zero'th order we have, for an electron traveling from once source to another:

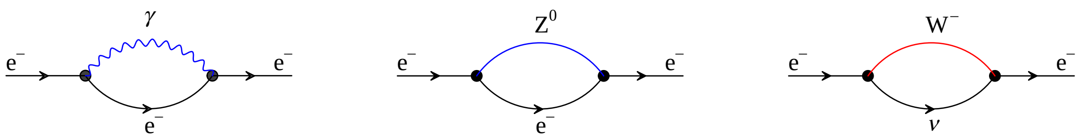
$$j^{in} S j^{out} = \frac{1}{(2\pi)^4 i}\; j^{in} \frac{1}{i\gamma k + m} j^{out}$$

or, by multiplying numerator and denominator with $i\gamma k + m$

$$\frac{1}{(2\pi)^4 i}\; j^{in} \frac{-i\gamma k + m}{k^2 + m^2} j^{out}$$

showing that we have a pole if k^2, the four-momentum squared, equals $-m^2$, which defines m to be the electron mass.

There are three relevant diagrams:



The first is due to e.m interactions, the second and third arise from the weak interactions. I ignore diagrams involving a Higgs disappearing in the vacuum, and I also neglect diagrams that have factors m/M (m = electron mass, M = vector boson mass). Only the infinite parts are considered. If we denote the sum of the contributions of these diagrams by P we have the well-known series:

$$j^{in}(S + SPS + SPSPS....)j^{out} = j^{in}S\frac{1}{1-PS}j^{out}$$

The whole results in the modified propagator:

$$\frac{1}{(2\pi)^4 i}\ \frac{1}{i\gamma k + m + P}$$

Working this out one finds:

$$\frac{1}{(2\pi)^4 i}\ \frac{1}{i\gamma k + i\gamma k(W_v + W_a\gamma^5) + m(1 + R_m)}$$

with

$$W_v + W_a\gamma^5 = \lambda(a^2 + b^2 + 2ab\gamma^5)\,, \quad R_m = 4\lambda(a^2 - b^2)\,, \quad \lambda = -\frac{g^2\Delta}{(2\pi)^4}$$

where g is the coupling constant of weak interactions and Δ is some infinite constant. The coefficients a and b differ for the three diagrams and relate to the vector and axial vector parts of the interactions. They are (s and c are the sine and cosine of the weak mixing angle):

$$a = -s, \quad b = 0 \quad \text{for the photon diagram}$$

$$a = \frac{4s^2 - 1}{4c}, \quad b = -1 \quad \text{for the } Z^0 \text{ diagram}$$

$$a = \frac{1}{2\sqrt{2}}, \quad b = \frac{1}{2\sqrt{2}} \quad \text{for the } W \text{ diagram}$$

Multiplying numerator and denominator of the propagator by

$$-i\gamma k - i\gamma k(W_v + W_a\gamma^5) + m(1 + R_m)$$

ignoring terms quadratic in W_v and W_a and furthermore factoring out $(1+2W_v)$ we obtain:

$$\frac{1}{(2\pi)^4 i} \; \frac{1}{1 + 2W_v} \frac{-i\gamma k - i\gamma k(W_v + W_a\gamma^5) + m(1 + R_m)}{k^2 + m^2(1 + \Delta m^2)}$$

with

$$\Delta m^2 = 2R_m - 2W_v = \frac{\lambda}{c^2} \, (14s^2 - 3)$$

We see that the electron selfenergy is finite if

$$s^2 = \frac{3}{14} = 0.214$$

This is a lowest order calculation, and higher orders might change this. The experimental value is:

$$s^2 \approx 0.23$$

My answer to Lorentz is: for the electron the weak interactions are attractive, possibly precisely balancing the electromagnetic forces at small distances.

That the value $s^2 = 3/14$ implies the vanishing of the logarithmic divergence for the electron mass has been noted earlier by J. Pestieau and P. Roy, Phys. Rev. Lett. 23 (1969) 349. They quote this relation in the form $\cot^2\theta = 3/11$.

I wish to thank Prof. K. Olaussen for informing me of the Pestieau and Roy paper concerning this particular value for the weak mixing angle.

The Ether

Finally then the matter of the ether. As you may have noted, at that time there was discussion on how many ether's there would be. We have had a similar discussion on the number of Higgs fields.

In 1975 Douglas Ross and I set out to investigate the question of multiple Higgs systems. We discovered quite quickly two important facts, and overlooked another one that I will mention also. However, I must first discuss some specific details on the Higgs system.

In the Standard Model there are four vector bosons, W^+, W^-, Z^0 and the photon. These bosons have initially mass 0, and the Higgs system provides the masses for the first three. Initially a mass zero vector boson has two degrees of freedom (like the photon with its two transverse polarizations), but a massive vector boson has three degrees of freedom (the three spin states of a system with angular momentum one). Thus three degrees of freedom must be provided by the Higgs system. Since at least one Higgs must survive as an independent physical degree of freedom (else we would have a renormalizable theory of massive vector bosons without any other particles) it follows that the Higgs system must have at least four degrees of freedom.

The most simple Higgs system for the Standard Model, introduced by Weinberg, has four Higgs fields, of which three become longitudinal vector boson states once the vector boson mass has been generated. These four fields appear in a totally symmetric way in the Lagrangian, in the form

$$\varphi_1^2 + \varphi_2^2 + \varphi_3^2 + \varphi_4^2$$

You do not need to be a genius to realize that there is an O(4) symmetry, rotating the φ fields among themselves. This is a 6 parameter group (like the four dimensional Lorentz group that applies to a similar form but with a minus sign in front of the fourth field). As is well known the O(4) symmetry may be decomposed into two SY(2) symmetries (apart from some discrete symmetries Z):

$$O(4) = SU(2) \times SU(2) : Z(2)$$

$SU(2)$, a three parameter group, is of course very much like the rotations in three dimensions, it is the usual spin $\frac{1}{2}$ group. These $SU(2)$ groups are often called $SU(2)_L$ and $SU(2)_R$ where L and R stand for left and right. The Standard Model has one SU(2) gauge symmetry, so clearly the Higgs system has more symmetry than needed for the Standard Model. There may be observable consequences related to that.

Here are then the two points that Ross and I discovered.

1. With the simplest Higgs system the three vector boson masses are equal; weak mixing changes the neutral mass by a factor $1/c^2$, where c is the cosine of the weak mixing angle. This leads to the relation

$$\rho \equiv \frac{M}{M_0 c^2} = 1$$

where M and M_0 are the masses of the charged and neutral vector bosons respectively. Use of additional Higgs systems with larger multiplets will invalidate that relation.

2. If there is more than one Higgs system there will very often be additional $U(1)$ symmetries, that after symmetry breaking give rise to massless scalar particles, implying long range fields.

The additional fact, realized some 10 years ago, is this:

3. If there is more than one Higgs system than there are ample fields available and in general also the photon will acquire a mass. The simplest Higgs system has no degree of freedom left for the photon, so there the photon remains perforce massless.

Since all three M, M_0 and c are experimentally measured we can check this relation and see if the ρ parameter (as it is now called) equals one. The result is that indeed ρ equals one. Radiative corrections modify this value, and the ρ parameter has become an important source for investigating these radiative corrections. This eventually led to a precise prediction of the mass of the top quark, which turned out to be correct.

Thus we have good reasons to believe that there shall be no Higgs systems that change ρ. What is still allowed is to have several identical Higgs systems, all with the $O(4)$ symmetry described. There would then be more than one Higgs in the vacuum. Before discussing that let us note that in such systems indeed usually massless (or near massless) particles occur. This was also noted by Weinberg and Wilczek in connection with the Peccei and Quinn attempt to cure strong CP violation. Such particles were called axions, and none have been seen. Massless scalars are hard to accommodate within today's body of experimental knowledge. The strong CP violation problem is still with us today.

We therefore can answer to Lorentz that there is only one Higgs vacuum. This has cosmological implications which I will discuss now.

After symmetry breakdown one of the four Higgs fields remains physical as an observable scalar field, and customarily one takes this to be φ_4 and designates that by σ. This σ field is neutral, like the photon, and one can say that this field defines, in the $O(4)$ space, what is neutral. If there is more than one Higgs field in the vacuum then normally one of them would be charged with respect to the other, and that would give the photon a mass.

Now back to a single Higgs system. Imagine that in some other part of the Universe another field (say φ_1) would be the surviving one. Locally that would define what is charge zero there. But φ_1 would to us be a charged field, with respect to our σ vacuum. We would perceive that far-away system as something with a different definition of charge. Their photon would not be ours. This is in principle still possible, but violent things (barriers) happen when these two vacua meet. Barring that we thus realize that the Higgs field must extend over the whole universe, to align everybody with the same idea of charge.

This creates the cosmological constant problem. It is still with us, despite attempts such as inflation.

It is really spooky. After 100 years we are essentially faced with the same problem in a different setting. Is there an ether (Higgs field) ? Is there somewhere a young man, in some patent office or something similar, who will come out, in 2005, with a revolutionary answer ? An answer that might be: there is no space, all space is virtual ?

Thank you.