A maximally simple model (MxSM)

Stig Sundman
Dragonvägen 12 A 5, FIN-00330 Helsinki, Finland

November 26, 2016

Contents

1 Introduction and summary **5**

2 A simple history of matter **12**
2.1 Literally nothing 12
2.2 Quantum leap 12
2.3 Universe 1.0 — the D particle 13
2.4 The law of conservation 14
2.5 Universe 1.3 — a pure QED world 14
2.6 The antimatter big bang 16
2.7 The law of change 16
2.8 Universe 2.0 — a matter-dominated world 16

3 The universe's mysteries and their explanation **18**
3.1 Fundamental questions 18
3.2 Simplicity versus complexity 18
3.3 Occam's razor 19
3.4 The expansion mystery 19
3.5 The time mystery 21
3.6 The energy mystery 22
3.7 The quantum mystery 23
3.8 The pointless space 24

4 A particle model takes form **26**
4.1 The flow equation 28
4.2 The pressureless space equation 32
4.3 The gravitational force 36
4.4 What the flow equation reveals about nature 40
4.5 The electron-structure constant 41
4.6 The muon–electron mass ratio 42
4.7 Physics for dummies — Feynman diagrams 43

4.8 The electron anomalous magnetic moment 47
4.9 Learning physics 49
4.10 The Higgs particle 51
4.11 Efforts to sell the model 54
4.12 The missing piece 56
4.13 Simulating the early universe 59
4.14 The pion parenthesis 61
4.15 Surprises afforded by the simulation 63
4.16 The superweak force 65
4.17 The Higgs–neutrino mechanism 67
4.18 Secrets revealed by the muon–electron mass ratio 69
4.19 Observations of a light Higgs particle 70
4.19.1 The muon $(g-2)$ experiment 73
4.19.2 The proton's missing spin 75
4.19.3 The nucleon's magnetic moment 76
4.19.4 The proton radius 76
4.19.5 The Hoyle state 77
4.20 Other possible appearances of a light Higgs particle 78
4.20.1 Seasonal variations in radioactive half-lives 78
4.20.2 The lithium problem 78
4.20.3 The flyby anomaly 79
4.20.4 The Pioneer anomaly 79
4.20.5 The neutron lifetime discrepancy 80
4.20.6 The tritium endpoint anomaly 80
4.20.7 The sun's hot corona 81
4.21 Conjectured mass of the heavy Higgs particle 82
4.22 Photon wavelength, frequency, and energy 83

5 Black holes and dark matter 84
5.1 The black holes take command 84
5.2 Early inflation of the universe 86
5.3 Dark matter 87
5.4 Formation of large-scale structures 90

6 Zooming in on "137.036" 92

7 Test of predictions made by MxSM 93

A Feynman diagrams 95
A.1 The Feynman diagrams of the standard model 95
A.2 Feynman vertices in the standard model 96

PREFACE

Deviations in *small* text you may skip without losing the thread.

Details in *footnotesize* are not meant to be read. I have included them for the benefit of readers who, for instance, want to check a mathematical derivation.

Numbers in the margin are page references. Notice Index on page **??**. **??**

In a classical universe, the law of conservation of energy cannot simultaneously hold locally (with mc^2 constant) and globally. However, in a quantum universe, it can. As a matter of fact, conservation of momentum and energy makes the evolution of elementary particles in an expanding quantum universe predictable.

Proof of this assertion is provided by a computer program that simulates the early evolution of the universe, and explains the roles played by the elementary particles in the process leading to the universe we observe today.

The program is astonishingly simple. Anyone who knows elementary mathematics and has some experience in computer programming should be able to understand it.

The history about the universe told by a "maximally simple model (MxSM)" based on the simulation program turns out to be both detailed and exhaustive.

History of the universe in a nutshell. The universe is born in a quantum leap from literally nothing — the perfectly symmetric state in which space doesn't exist and time isn't running — to a maximally symmetric material universe consisting of a single "D particle" in the shape of a relativistic harmonic oscillator, which forms an expanding spacetime bubble with its initial finite dimensions taken to be unity. That is, time starts running at $t = 0$, and the physical universe with spatial radius $R = 1$ appears at time $t = 1$.

Once matter exists, the law of conservation of energy prevents it from disappearing. That is, self-annihilating particles are forced to rematerialize in successively more complex shapes until stable matter — a proton–electron pair — is formed in a process requiring assistance from a set of weakly interacting particles created specially for this purpose.

The particles of the universe generate space that makes a sphere of radius r and volume $V = \frac{4}{3}\pi r^3$ grow at a rate proportional to E_V, where E_V is the total energy of the particles within the sphere. That is,

$$V \propto E_V t.$$

The expansion of the universe caused by the continuous creation of space induces a gravitational force between particles. Being but a by-product of the expansion, gravity cannot affect the rate of the overall expansion of the universe. Thus, its pull on nearby matter is counterbalanced by a repulsive push on very distant matter. As the universe grows in size, this double nature of gravity causes the matter of the universe to take on a fractal structure.

In the first versions of the universe, the energy E_V is constant. Consequently, the size of the expanding sphere is proportional to t. That is, $V \propto t$ and $r \propto t^{1/3}$. The Hubble expansion rate is defined as $H = r^{-1}\mathrm{d}r/\mathrm{d}t$, which means that $H \propto r^{-3} \propto t^{-1}$. From the fact that gravity is a by-product of expansion, it follows that the gravitational constant is directly proportional to H, or $G \propto H \propto t^{-1}$.

When the proton and electron take over as bearers of mass, the universe exits its original state of cosmic quantum indeterminacy, and particles begin to interact. The initially very strong gravity causes the bulk of the nearly three billion background photons to rapidly condense into a primordial black hole (PBH) with the proton at its center.

The energy swallowed by PBHs becomes effectively disconnected from the universe. This causes a decrease in E_V that leads to a rapid deceleration of the expansion, with accompanying decrease in H and G, as well as a sudden inflation of the visible universe, whose radius is $R = c/H$.

As the expansion continues to slow down and G decreases, the minimum black-hole mass, which is inversely proportional to the square root of G, increases and causes the lightest PBHs to release their "deep-frozen" contents through violent explosions, in which part of the colliding high-energy photons transform into stable "dark matter" — presumably heavy neutrinos.

The epoch of decreasing H and G characterized by exploding light-weight PBHs comes to an end when more energy is released by black holes circling each other than is trapped by solitary giant black holes at the centers of galaxies. The ensuing increase in H — that is, acceleration of the expansion — is mistakenly thought to be caused by a repulsive force of unknown origin often referred to as "dark energy".

Note the parallel: heavy neutrinos are created in exploding black holes while heavy elements are created in exploding stars.

1 Introduction and summary

Before physicists came to believe in inflationary cosmology, simplicity had been their guiding-star. For instance, the principle of maximum simplicity was used as a final guide in the development of quantum field theory (QFT) [1, pp. 94-96].

The maximally simple model (MxSM) of the universe applies the maximum-simplicity principle (MxSP) to elementary particle physics. The result is a well-defined particle model without adjustable parameters, which makes many detailed predictions and answers several questions that have up to now been regarded as unanswerable.

MxSM eliminates the mysteries from fundamental physics by providing easily-understood explanations for why and how the current elementary particles have come into being, why electrons and quarks appear in three generations, and why the mass of the originally particle–antiparticle-symmetric universe came to be carried by matter (positively charged protons and negatively charged electrons).

MxSM consists of an old part and a new part. The old part is identical to the basic version of the standard model (SM) of particle physics, which describes the dynamic interactions between the currently existing elementary particles.

The new part forms a kind of introduction to SM that describes the course of events leading to the universe of today. This part of MxSM results from applying MxSP to physics.

A general consequence of the principle of maximum simplicity is that the world can be intuitively understood and described mathematically. The well-known laws of conservation of momentum and energy provide the foundation for theoretical physics and have never been experimentally challenged. MxSP suggests that these laws are universally valid. This suggestion immediately leads to a couple of postulates:

1. *The law of conservation of momentum applies to space.*
2. *The law of conservation of energy applies to an expanding universe.*

Postulate 1 implies that the momentum equation — also known as the fundamental hydrodynamic equation — may be used to picture space. In its pressureless form, the momentum equation leads to a static (or stationary, $\partial/\partial t = 0$) hydrodynamic model of the electron, a kind of whirl in space that explains what charge and energy are, what spin is, and why the universe is expanding. Also, the same basic equation explains why the universe is a quantum world. In addition, it shows that expansion causes gravity. But as before, the dynamics of gravity is described by the theory of general relativity (GR). However, MxSM says that GR cannot be the ultimate theory of gravity, since it doesn't take into account the quantum nature of the universe.

Postulate 2 has the important consequence that the development of the new-born universe is unambiguously determined by the law of conservation of energy. Thus, the universe evolves from its initial version (universe 1.0 originally consisting of a single relativistic harmonic oscillator [2, p. 2]), via universes 1.1

and 1.2 (which are described by scalar QED, or quantum dynamics of spinless bosons [3, pp. 383–398]) and universe 1.3 (a world inhabited by photons and electrons in three mass states that is fully described by spinor QED), to the matter-dominated universe V2 of today.

According to experience, the symmetry-breaking quantum leaps that occur in nature are maximally short. For example, the comparatively symmetric nucleus of the uranium-235 atom does not decay in a single big leap to its highly asymmetric final state consisting of a lead-207 nucleus and 15 lighter particles (7 helium nuclei, 4 electrons, and 4 neutrinos). Instead, the decay takes place step by step in maximally short jumps, from one state to the nearest energetically allowed state.

Now, MxSP — as well as common sense — says that the elementary particles with their electromagnetic, strong, and weak forces must have been created in a similar way. Thus, maximum simplicity implies that universe 1.0 popped into existence in a maximally short jump. This means that the world was created in a quantum leap, from the perfectly symmetrical state of literally nothing to the simplest conceivable material universe consisting of a single unstable matter–antimatter-neutral D particle [2].

> Being a pure oscillation, the D particle starts to build up at the beginning of time ($t = 0$). The physical universe is born when the D particle becomes fully developed at time $t = 1$ (with the "time of creation" set equal to 1). In other words, time starts running at $t = 0$, and the age of the universe is $t - 1$ (with its "pregnancy" lasting one unit of time). The oscillation attempts to die out in the same length of time that it needed to build up. In other words, the lifetime of the very first particle is $\tau = 1$.

However, the birth of the D particle is accompanied by the law of conservation of energy that forbids the particle from annihilating back into nothing. (Because the law didn't exist in literally nothing, it couldn't prevent the D particle from generating energy out of nothing.) Consequently, once the material universe appears, it is doomed to remain forever.

> Using common sense, one may try to intuitively understand the process of creation of the D particle:
>
> In the perfectly symmetric state of literally nothing there is neither time nor space. Nothing happens. When time starts running, things begin to happen — "time ticks". The ticks of time may be identified with vibrations or oscillations taking place in three-dimensional space. Since these time ticks are pure energy, one may imagine that creation proceeds in the following way.
>
> Time t is the primary dimension of the universe. It starts running at $t = 0$. Simultaneously, time creates the energy that enables its ticking. Energy in turn creates the space required for its existence. After the first physical particle has been formed and a material four-dimensional space-time bubble created, the energy in the bubble continues to create space. Thus, the three spacial dimensions of the bubble grow as its temporal dimension t grows.

According to MxSM, energy is space in motion — space that oscillates or forms traveling or standing vibrating waves (open or closed vibrating strings). Similarly, a particle's self-energy (its mass multiplied by c^2) is stationary energy, as opposed to energy moving with the speed of light — that is, massless radiation.

Our present universe — universe V2 — is the result of a series of quantum leaps enforced by the law of conservation of energy. When universe 1.0 containing the unstable D particle threatens to annihilate into literally nothing, or when a later variety of the unstable particle–antiparticle-symmetric universe threatens to annihilate into massless radiation, conservation of energy enforces a quantum leap of the universe into a slightly less symmetric — that is, less simple — and thereby more complex universe.

> **Universe 1.0.** The D particle's annihilation into literally nothing is forbidden by the law of conservation of energy. Also, the D particle cannot decay because it is alone in the universe and particles it might be able to decay into don't yet exist. Consequently, at time $t = 2$, at the age of 1, the universe 1.0 is forced to make a quantum leap into the next simplest material world, universe 1.1.
>
> **Universe 1.1.** The D particle of universe 1.0 has been replaced by a dielectron ($\tau_0^+\tau_0^-$) built from two oppositely charged spinless electrons ($\tau_0^\pm$), the predecessors of the superheavy electron ($\tau^\pm$) of today. The ditauon is accompanied by a virtual photon (γ_τ) which mediates the electric force that makes the tauon pair stick together. As the tiny universe expands, the number of ditauons multiplies. At the same time the ditauons annihilate into diphotons ($\gamma_\tau\gamma_\tau$).
>
> Since photons lose energy (light is redshifted) as the universe expands, the law of conservation of energy forbids the existence of a massless, purely radiative, universe. Consequently, when the last ditauon annihilates, universe 1.1 is forced to make a quantum leap into universe 1.2 with the diphotons ($\gamma_\tau\gamma_\tau$) rematerializing into dimuons, or pairs of spinless electrons ($\mu_0^\pm$).
>
> **Universe 1.2** is similar to universe 1.1 except that, in addition to real dielelectrons annihilating into real diphotons ($\mu_0^+\mu_0^- \to \gamma_\mu\gamma_\mu$), it contains two types of virtual spinless electrons ($\mu_0^\pm$ and $\tau_0^\pm$) as well as two types of virtual photons (γ_μ and γ_τ). When the last real dimuon annihilates, universe 1.2 is forced to make a quantum leap into universe 1.3 with the diphotons ($\gamma_\mu\gamma_\mu$) rematerializing into quadelectrons, or pairs of pairs of ordinary electrons ($e^+e^-\ e^+e^-$).
>
> **Universe 1.3**, which is described by ordinary (spinor) QED, contains mass-bearing real quadelectrons and massless real diphotons ($\gamma\gamma$) as well as virtual photons (γ) and virtual electrons in three mass states: ordinary electrons ($e^\pm$), heavy muons ($\mu^\pm$), and superheavy tauons ($\tau^\pm$).
>
> **Universe 1.4.** In universe 1.4, down and up quarks ($d^{\mp 1/3}$ and $u^{\pm 2/3}$, or d, $\bar{d}$, u, and $\bar{u}$) replace the electrons as bearers of mass. Initially, the quarks combine into two pion pairs ($\pi^+\pi^-$), which rapidly annihilate and are succeeded by a proton pair (p^+p^-, or $p\bar{p}$). The energy, which is needed to build heavy pions and protons from quarks, is transferred to the quarks

by Higgs particles (H) coming in three light mass states. In addition, the construction of pions and protons requires help from several weakly interacting particles: Z, $W^{\pm}$, a heavy (125 GeV) Higgs, and a neutrino (ν) which appears in three mass states and is able to ocillate between these states. Finally, universe 1.4 ends with the law of conservation of energy enforcing a quantum leap in which the negative antiproton ($\bar{p}$) decays into an electron (e^-) and two high-energy photons (γ).

Universe V2 is the present universe. Because its expansion is determined by its energy content, the universe will continue to expand forever at an ever-decreasing rate. And, since expansion causes gravity, the force of gravity will slowly lose its strength and galaxy clusters, galaxies, and finally planetary systems will begin to disintegrate.

Chapter 2 is a popularly written introduction to MxSM. 12

Chapter 3 lists and discusses the fundamental questions of elementary par- 18
ticle physics.

Chapter 4 begins with a presentation of the considerations underlying MxSM. 26
In subchapter **4.1**, I present mathematical details of what I call the "flow 28
equation" — that is, the hydrodynamic, or momentum equation.
In subchapter **4.2**, a stationary "pressureless space equation" is derived from 32
the momentum equation. See Eq. (4.23). 33
In subchapter **4.3**, a modified gravitational potential is obtained. This po- 36
tential, presented in Eq. (4.31), explains how it is possible for the gravitational 37
force to "balance itself", which it has to do because MxSM implies that gravity is nothing more than a byproduct of the unperturbable expansion of the universe.
Subchapter **4.4** summarizes what the flow equation in its pressureless form 40
has to say about nature.
Subchapter **4.5**, discusses the computation of the electron-structure constant 41

$$B = 0.666\ 001\ 731\ 498, \tag{1.1}$$

which connects the fine-structure constant α to the uncorrected value of the muon–electron mass ratio via the relation

$$m_\mu/m_e = 1/B\alpha = 205.759\ 22. \tag{1.2}$$

See Eqs. (4.16) and (4.35). For details about derivation and calculation of 31, 42
the well-defined numerical constant B, see Ref. [5, p. 31]. The corresponding structure constant that characterizes spinless electrons is [5, p. 16]

$$B_0 = 0.978\ 396\ 4019. \tag{1.3}$$

In subchapters **4.10**, I conclude that a virtual Higgs particle appearing in the 51
electron propagator should lead to a correction of $-0.000\ 2076$ to the muon–electron mass ratio. See page 52. (The minus sign surprised me because I

had expected the correction to be positive, hoping that it would explain the difference between the value 205.759 22 in Eq. (1.2) and the measured value 206.768 28. Later, I discovered that the sign of this Higgs correction is indeed positive.) 52

In subchapter **4.12**, it is shown that a QED correction results in the improved 56
value

$$m_\mu/m_e = 1/B\alpha + 1/(1-2B\alpha) = 206.769\ 04 \tag{1.4}$$

of the muon–electron mass ratio. Also, it is noted that four additional Higgs corrections of $-0.000\ 2076$ totaling $-0.000\ 83$ would lead to a theoretical value of 206.768 21, which differs from the measured value $m_\mu/m_e = 206.768\ 28$ by only 0.3 ppm.

Finally, a computer simulation [4] shows that the Higgs particle transports mass from the electron pairs appearing in the photon propagators to the quarks four times. Also, it is seen that the task of the neutrino is to return unused mass back to the electron pairs. As a result, the theoretical value of the mass ratio becomes

$$m_\mu/m_e = 206.768\ 2832(1), \tag{1.5}$$

which agrees with the less accurate 2006 CODATA value of 206.768 2823(52). For a summary of the contributions to m_μ/m_e, see subchapter **4.18**. 69

> More precisely, the ratio becomes $m_\mu/m_e = 206.768\ 283\ 185(77)(7)(5)(5)$, with its uncertainties deriving from uncertainties in the values of α, G_F, m_π, and m_τ, respectively. G_F is the Fermi coupling constant, which is a measure of the strength of the weak force in a similar way as α is a measure of the strength of the electromagnetic force. The major uncertainty, 77, comes from $\alpha = 1/137.035\ 999\ 084(51)$, a value that in 2008 was computed from the experimentally measured anomalous magnetic moment of the electron (a_e).

The simulation program [4] tracks the evolution of the universe from its birth up to the point where the proton–electron pair (pe^-) — that is, hydrogen — takes over as bearer of mass and the universe exits its initial state of quantum indeterminacy when physical interactions between particles set in.

According to MxSM, the evolution of elementary particles is governed in detail by the law of conservation of energy. Consequently, the simulation should yield exact theoretical values for the initial electron mass ratios m_τ/m_μ (today measured to be about 16.82) and m_μ/m_e as well as the original photon–baryon number ratio (the number of photons in the universe, nearly 3 billion, at the instant when the first proton — a baryon — is formed).

As a byproduct of the simulation, one should obtain a precise theoretical value for the fine-structure constant α, which defines the strength of the electromagnetic force and is a “pure” numerical constant that is not subject to corrections from Feynman diagrams. To calculate α, it suffices to simulate universes 1.0 – 1.2.

However, the simulation program [4], which was written in 2007 and last updated in 2009, is only approximative and cannot produce exact results.

In spite of its shortcomings, the simulation program results in a number of comparatively detailed predictions. Already mentioned is the muon–electron mass ratio presented in Eq. (1.5) above. Another quite precise prediction is

$$n_\gamma / n_b \approx 2\ 786\ 275\ 000 \tag{1.6}$$

for the initial photon–baryon number ratio.

In summary, MxSM answers the fundamental questions of elementary particles physics:

- *How does the very first particle come into existence?*
- *How does the evolution of the elementary particles proceed?*
- *What is the purpose of each one of the elementary particles?*
- *Why do some of the elementary particles appear in three generations?*
- *Why and how is the mass-bearing matter–antimatter-symmetric electron pair (e^+e^-) replaced with the proton–electron pair ($p\,e^-$)?*

To this list, one should add the most puzzling of all fundamental questions in elementary particle physics:

- *What is the origin of the particle–antiparticle asymmetry observed in neutral kaon and B meson decays?*

Also this question appears to have a simple answer. As already mentioned,
in universe 1.4 the pion pair ($\pi^+\pi^-$) temporarily serves as bearer of mass. The 7
simulation demonstrates that during this brief "pion parenthesis" the mass of the antipion increases about one percent in comparison to the mass of the pion. That is, a particle–antiparticle asymmetry is created that (in our familiar local picture of the world where particle masses are constant) is expected to reveal itself as an asymmetric decay of certain particles and their antiparticles.

> The positively charged pion is built from an up quark and a down antiquark ($\pi^+ = u\bar{d}$). Similarly, the negatively charged antipion is built from an up antiquark and a down quark ($\pi^- = \bar{u}d$). The fact that both the neutral kaon and the neutral B meson contain a down quark ($K^0 = d\bar{s}$ and $B^0 = d\bar{b}$ with $\bar{K}^0 = \bar{d}s$ and $\bar{B}^0 = \bar{d}b$) suggests that the pion–antipion asymmetry, as well as the asymmetric decays of the two neutral mesons, originate from an asymmetry between down and down antiquarks. See
> discussion in subchapter **4.16**. 65

The predicted existence of light higgs particles of masses shown in Eq. (4.53) 72
provides a simple explanation for a number of puzzling anomalies that until now have been attributed to various kinds of "new physics" of unknown nature. See
subchapters **4.19** and **4.20**. 70, 78

A couple of the dozen anomalies listed have been disputed, but the discussions of these may still be of some interest. The existence of the notch in the

curve shown in subchapter **4.22** should be easy to experimentally verify if it 83
does indeed exist and is measurably large.

The evolution of universe V2 remains to be simulated. In chapter **5**, it is 84
shown that it begins with most of the initially 2786 million backgrond photons 10
coalescing into a black hole with the first proton forming the nucleus of condensation at the center of the hole. A computer simulation should tell how the black-hole dominated evolution leads to formation of the presently observed large structures: galaxies, clusters of galaxies, superclusters, and "great walls".

Time comes to a halt for particles "raining" down on the surface, or "event horizon", of a growing black hole. This means that the energy trapped in black holes is effectively removed from the rest of the world and doesn't contribute to the expansion and the gravitational force accompanying the expansion. Consequently, the simulation should give details about the initial deceleration and later acceleration of the expansion. Also, it should predict how soon the accelerating expansion of the universe will shift into a final, forever slowly decelerating expansion.

MxSM has no room for big-bang or inflationary-cosmology hypotheses. Instead, it presents a number of new challenges to researchers.

The search for a theory of gravity that takes into account the quantum nature of space — that is, the universe's lack of well-defined spatial coordinates — remains as the number one challenge of theoretical physics. MxSM's explanation for the origin of gravity, which shows that the gravitational force differs radically from the rest of the forces acting between particles, should provide physicists with important clues.

Note that an immediate consequence of MxSM is that particles contained in a black hole are preserved in a "deep-frozen" state and will be released when the black hole explodes, which the forever weakening gravity will eventually cause it to do. In other words, MxSM states that there is no loss of information associated with the formation of black holes.

Another interesting question is if the pressureless momentum equation ob-
tained in Eq. (4.21) and shown in subchapter **4.4** might find practical use in 33, 40
applied physics, such as in low-temperature physics. See question asked in the
deviation at the end of subchapter 4.3. 39

Finally, I want to stress that the simulation of the early evolution of particles
still remains to be perfected. In chapter **6**, I discuss how the initial values of 92
the tauon–muon and muon–electron mass ratios as well as the unchanging fine-structure constant α might be numerically determined. It ought to be a trivial task to compute these three values.

2 A simple history of matter

The only thing most people know about physics is that physics is difficult and boring. However, that physics is difficult is something I disagree with. Instead, I believe there is something fundamentally wrong with both the teaching in our schools and our system of further education.

With my attempt at a brief history of the universe, I want to show that an overview of the physical world may be simple enough for anyone to understand it.

2.1 Literally nothing

The maximally simple is absence of everything. Physicists call it *literally nothing*. It's a no-world, since neither time nor space exist in literally nothing.

We know that the universe exists and is expanding. Following the expansion backward in time via mathematical extrapolation, one ultimately reaches a point when the size of the universe is zero; that is, when the world doesn't exist. Consequently, the universe must have appeared out of literally nothing. But how was that possible?

2.2 Quantum leap

In physics, one talks about *quantum leap*, or *quantum jump*. It takes place when a particle or system of particles transforms from one physical state to another, for instance in *radioactive decay*.

The spontaneous emission of a helium nucleus, or *alpha particle*, by a heavy nucleus may signal the beginning of a series of quantum leaps through which more and more atomic nuclei are formed.

If I get it right, the decay of a nucleus of the uranium isotope U-235 leads in the end to 1 lead nucleus and 7 helium nuclei via 11 quantum leaps with the time lapse between two consecutive decays varying from a fraction of a second (lifetime of polonium-211, Po) to thousands of years (lifetime of protactinium-231, Pa).

In addition, 8 light particles — 4 electrons and 4 neutrinos — are created in the process. Thus, a single unstable particle, the heavy uranium nucleus, transforms into 16 particles via 11 quantum leaps.

> On my bookshelf I have a textbook in *nuclear physics* published in 1955. It says that the uranium isotope with 235 *nucleons* (92 protons and 143 neutrons) in its nucleus — it is denoted alternatively as ${}^{235}_{92}\mathrm{U}$, ${}^{235}\mathrm{U}$, U-235, or uranium-235, and is the type of uranium that many terrorists would like to have in their possession — decays into thorium and helium. Since the helium nucleus (or alpha particle) consists of two protons and two neutrons, the heavy thorium atom (${}^{231}_{90}\mathrm{Th}$, or Th-231) retains 90 protons and 141 neutrons in its nucleus.
>
> The decay releases energy in the form of heat. That is, the energy $m_U c^2 - (m_{Th} + m_{He})c^2$ appears in the form of *kinetic energy*, or energy of motion.

> In other words, the thorium nucleus and alpha particle are born with high temperature.
>
> The thorium nucleus, in turn, decays through emission of an *electron* (e^-) — also called *beta particle* (*β particle*) — and an invisible *antineutrino* ($\bar{\nu}_e$). Emission of a negatively charged electron implies that the positive charge of the nucleus increases. Therefore, the resulting protactinium nucleus ($^{231}_{91}$Pa, or Pa-231) contains $90+1=91$ protons and $141-1=140$ neutrons.
>
> The protactinium nucleus is unstable, too, and decays via emission of an alpha particle (helium nucleus).
>
> The decay chain continues until a stable lead nucleus ($^{207}_{82}$Pb, or Pb-207) with 82 protons and 125 neutrons has been created. At that point, provided my interpretation of the figure on page 202 in the textbook is correct, the uranium nucleus has shattered into 1 lead nucleus, 7 helium nuclei (α particles), 4 electrons (β^- particles) and 4 antineutrinos.

So, what do we learn from this example? Well, the lesson it teaches us is that in the quantum world — and we live in a *quantum universe* — the evolution of a system proceeds successively, step by step, from a simple state toward an ever more complex state. In a single quantum leap, a cold uranium nucleus does not transform into 16 hot particles — not even into three.

The conclusion can only be one. The assumption that the universe appeared in a *hot big bang* is incorrect: the universe wasn't created in a single giant quantum leap from literally nothing into a state containing a large number of immensely hot particles. Instead, the elementary particles must have been created via a series of successive, maximally short quantum leaps.

Consequently, at the exact instant of its birth, the universe must have formed a maximally simple world. In other words, the very first quantum leap was maximally short. All the same, the quantum jump from a no-world to a world with time and space must be very long, and the probability for it to happen exceedingly small. Still, since the probability isn't exactly zero, such a jump must take place sooner or later.

So, when does it happen? Well, since time doesn't exist in *literally nothing*, !
it happens at the beginning of time. !

2.3 Universe 1.0 — the *D* particle

At its appearance out of *literally nothing*, the universe is as simple as it can be. It consists of a single particle with energy and mass. That's all. The particle has neither *charge* nor *spin* — it is neutral and doesn't rotate. Also, there are no forces.

> The forces that act between elementary particles are mediated by so-called *gauge bosons*. For instance, the familiar electromagnetic force is mediated by massless *photons*. Since the primordial particle is alone, there are no other particles, not even gauge bosons. Consequently, there are no forces, either.

Still, the world isn't trivially simple. That's because time has begun ticking. And with time, the universe expands.

Very soon, the universe's expansion leads to a widening of its horizon, with the result that the initially lone primordial particle — *the D particle* — has been joined by several similar particles. In addition, the D particle has decayed into a pair of charged particles. These particles may be looked upon as electrons without spin. The particle pair isn't stable either, but its component particles, one positively and the other negatively charged, annihilate each other and become pure radiation in the form of massless pairs of photons.

> The photons of the universe's phase 1 mediated the electric force that acted between the "spinless electrons". They should not be confused with present day photons, which are bearers of a more complex, electromagnetic force. Also, it should be mentioned that the first photons always were pairwise entangled and never appeared as free particles.

The result is that, toward the end of its first phase, the universe consists of pairwise entangled massless photons together with pairwise entangled charged particles bound together by a photon-mediated electric force that makes particles of opposite charge attract each other.

2.4 The law of conservation

In the universe's first phases, the *law of conservation* controls the course of events.

One consequence of the conservation law is that the universe expands. Another consequence is that energy can be neither created nor annihilated.

> But, if the law of conservation says that energy cannot be created out of nothing, shouldn't the law have prevented the universe from appearing? No, the argument doesn't apply because the conservation law doesn't exist in the no-world of *literally nothing*. It comes into existence when the universe pops up.

Light rays traveling in an expanding universe lose energy as the rays, which consist of massless photons, stretch and the photon wavelength increases. The effect is referred to as *(cosmological) redshift*. Consequently, a universe consisting of radiation alone would lose energy, which is something the law of conservation forbids.

Therefore, when the last remaining pair of massive particles decays into a pair of massless photons, all photons in the universe immediately materialize and form a new generation of massive particles.

2.5 Universe 1.3 — a pure QED world

In phase 3 of its development, the world is still simple. It is inhabited by massless photons (γ) and mass-bearing electrons (e). At the end of the phase, a few femtoseconds (1 femtosecond = 1 fs = 10^{-15} s) after its beginning, the universe contains nearly three billion (or more precisely, about 2 786 275 000, which is the predicted initial value of the so-called *photon–baryon number ratio*) pairwise entangled photons and four entangled electrons (two electron–antielectron pairs).

> The antielectron is a positively charged electron (e^+). Particles and *antiparticles* are each other's opposites. On close encounter, they annihilate each other. In contrast to other antiparticles, the antielectron has a name of its own: *positron*.

The story of the universe's first two phases is the story of the D particle and its offspring — the electron. At the end of each of the two phases, continued existence of matter is secured through "freezing" of the radiation. That is, the law of conservation forces the massless photons which are the only remaining particles in the universe to rematerialize as mass-bearing particles.

> The D particle is unstable and disintegrates into a pair of electrons. These predecessors of the present electrons do not possess spin. They are a kind of spin-0 version (τ_0) of today's superheavy spin-$\frac{1}{2}$ electron, the *tauon* (τ). The pair of spinless tauons is also unstable and annihilates into a pair of photons. In summary, the evolution in phase 1 proceeds through the decay reactions $D \to \tau_0^+ \tau_0^- \to \gamma_\tau \gamma_\tau$. In the universe's transition from phase 1 to phase 2 the photons finally rematerialize as spinless *muons* (heavy spin-0 electrons): $\gamma_\tau \gamma_\tau \to \mu_0^+ \mu_0^-$.
>
> In phase 2, history repeats itself: $\mu_0^+ \mu_0^- \to \gamma_\mu \gamma_\mu$ with the difference that in the subsequent phase transition the freezing of radiation results in production of two pairs of pairs of ordinary spin-$\frac{1}{2}$ electrons out of one pair of phase-2 photons: $\gamma_\mu \gamma_\mu \to e^+ e^- \; e^+ e^-$.

The transition from phase 3 to phase 4 proceeds differently. This time, all massive particle pairs (that is, the electron pairs) do not decay into massless photons rematerializing in a new type of particle. Instead, the universe's matter is saved from extinction through the transformation of its last two electron pairs into a pair of charged pions.

> The *charged pion* ($\pi^\pm$) is a kind of "spinless proton". The charged pion and the *neutral pion* (π^0) consist of two quarks, whereas the proton and the neutron are built from three quarks. The charged pion is 273.13 times heavier than the electron while the proton is 1836.15 times heavier than the electron, and 6.7226 times as heavy as the charged pion.

After one of the pion pairs has decayed, the remaining pair is transformed into a proton pair consisting of a positive proton and a negative antiproton. When the proton pair in its turn threatens to annihilate, the matter of the universe is saved once and for all via the antiproton's transformation into a negative electron. As a result, the universe's matter now consists of an electron and a proton — particles that together form a *hydrogen atom*.

Replacing the electron–antielectron pair as bearers of mass with an electron–proton pair is a far from simple task. Since the pion is heavier than the electron, and the proton heavier than the pion, energy must be supplied to the process in two rounds.

To accomplish the task, a number of auxiliary particles are needed. Before the transition from phase 3 to phase 4 is completed, neutral Higgs and neutrino particles in four and three mass states, respectively, have been created. In addition, a neutral Z particle and a charged W particle have appeared.

2.6 The antimatter big bang

The antiproton's transformation into an electron is history's most violent nuclear detonation. In the explosion, practically all of the antiproton's mass (the proton and antiproton are 1836.15 times heavier than the electron), and thereby nearly half of the mass of the universe, transforms into radiation and kinetic energy.

> There are theories which say that the proton is unstable. *Proton decay* means that the structures of the universe slowly evaporate. However, this is probably not the case — those theories appear to be unnecessary and ruled out by Occam's razor. The conclusion is that the antiproton decay was an isolated case enforced by the law of conservation, which forbids the material world's self-annihilation.

2.7 The law of change

In the first three phases of the world, every particle pair and (in phase 3) every pair of particle pairs form an entangled system — a kind of closed world, which doesn't know about the existence of the other particles in the universe.

When the proton–electron pair is formed, the *indeterminate quantum state* of the universe ends as kinetic energy is created and particles begin to collide and interact with each other.

From now on, the universe's first law, the law of conservation, which supremely governs the evolution of the universe during its first phases, is accompanied by the universe's second law: *the law of change*.

2.8 Universe 2.0 — a matter-dominated world

At the beginning of the universe's phase 4, the set of elementary particles is complete. The electron comes in three varieties. The ordinary light electron (e) first appeared in phase 3. The almost 207 times heavier electron — the muon (μ) — is a relic from phase 2, and the superheavy electron — the tauon (τ) — is a reminiscence of phase 1, and nearly 17 times more massive than the muon. Also the neutrino (ν) and the quarks appear in three so-called *generations*, or families. Like the neutrino, the *Higgs boson* (H) comes in three light varieties (*light Higgs*). In addition, it appears in a very heavy version (*heavy Higgs*). The neutral Z and the charged W bosons complete the elementary-particle menagerie.

The proton (p) and the neutron (n), the latter created when a proton and an electron fuse, are composite particles consisting of three quarks.

In phase 4, after the universe has left its *indeterminate quantum state*, during which distances between particles are undefinable, the gravitational force begins
to act. The law of conservation implies that energy creates space, which makes 14
the universe expand. Also, it implies that the strength of the gravitational force is proportional to the universe's rate of expansion. Initially, the tiny universe is expanding very fast, and the gravitational force is very much stronger than today. Therefore, microscopic *primordial black holes* are rapidly formed and swallow the bulk of the universe's particles.

The energy-carrying particles captured by the first PBH disappear out of sight. That is, they effectively disappear from the universe and no longer contribute to its expansion. Consequently, the rapid expansion suddenly slows down and the originally very strong gravity abruptly drops in strength.

As the universe continues to grow in size, its now compartively slow expansion further decelerates. The accompanying weakening of the force of gravity means that the mass needed to form and maintain a black hole increases.

> The minimum mass (M) of a black hole is inversely proportional the square root of the gravitational constant G: $M \propto 1/\sqrt{G}$.

The result is that the lightest PBH explodes, which leads to a temporary increase in the rate of expansion and strength of gravity. As the expansion continues, and the remaining PBHs capture more of the particles surrounding them, the rate of expansion and the strength of gravity continue their steady decrease. As a result, the lightest of the remaning PBHs explodes in its turn.

In summary, the early days of phase 4 are characterized by black holes exploding at a rapid rate.

3 The universe's mysteries and their explanation

During the first half of the twentieth century, important breakthroughs were made in theoretical physics. The *special theory of relativity* explained what happens when particles move near the speed of light. The *general theory of relativity* gave a refined description of how gravity affects the motion of heavenly bodies. Finally, *quantum physics* explained how elementary particles interact with each other.

During the second half of the same century, the progress instead took place in experimental physics. Both the universe's smallest building blocks — the elementary particles — and its large-scale structure were surveyed in detail.

Yet, in spite of the advances in experimental physics and astronomy, and in spite of the invention of ever more complex theories, many fundamental questions remained unanswered.

3.1 Fundamental questions

Among the fundamental questions wanting answers are:

1. *Why is there a gravitational force?*
2. *Why is the universe expanding?*
3. *What governs the expansion of the universe?*
4. *Why does the electron come in three weights?*
5. *Why is there a weak force?*
6. *Why are there so many elementary particles?*
7. *Why isn't there as much antimatter as matter?*

With the enormous mass of knowledge about nature that theoreticians and experimentalists have gathered during the course of the centuries, it should be possible to answer at least some of the questions. Therefore, the conclusion can only be:

The pieces of the puzzle are known, but put together in the wrong way.

3.2 Simplicity versus complexity

Physicists have long known that two laws, the *law of conservation* and the *law of change* (but known under other names) control the course of the world. Also, they embrace a general principle, *the principle of maximum simplicity* (MxSP), which they use as a guide in their attempts to describe the world with the aid of mathematics.

The maximum-simplicity principle says that basically the world is just as simple as the simplest possible mathematically and logically consistent and working description of it indicates.

3.3 Occam's razor

Using simplicity as a guide implies among other things that one adheres to *Occam's razor* — a maxim saying that one shouldn't make more assumptions than necessary to describe things.

With reference to Occam's razor, theoretical physicists insist that only four forces exist: gravity and the electromagnetic, strong, and weak forces of elementary particle physics.

However, to explain the universe's coming into being and its evolution, cosmologists had to abandon Occam's razor because they believed the universe had been created in an enormous explosion — a *hot big bang* — that could only have been caused by some mysterious fifth force. The word "force" they avoided, though.

Later, it was suggested that, soon after its creation, the universe underwent a brief *inflationary phase* during which it expanded at an enormous speed, after which it returned to a relatively peaceful expansion. This hypothetical inflation of the universe can only have been caused by a sixth force. But again the word "force" is avoided when one describes the imagined phenomenon. Instead, the word "field" is used.

Finally, when new astronomical observations were interpreted to mean that the universe's rate of expansion increases (one talks about *the accelerating universe*), cosmologists began to theorize about a seventh force that pushes on the expansion. In this connection, too, cosmologists refrain from using the word "force", and replace it with the deceptively simple name *dark energy* without mentioning that "dark energy" stands for a variety of competing models.

> A textbook in cosmology discusses the following dark-energy models: the cosmological constant, quintessence, and other single field models, $f(R)$ models which are modifications of the geometry of spacetime, and models requiring extra dimensions.

3.4 The expansion mystery

For a long time, it was generally believed that the universe will forever expand at a steadily decreasing rate. However, toward the end of the twentieth century, astrophysical observations convinced cosmologists that the expansion is speeding up. They concluded that, most likely, the universe will continue to expand at an ever-increasing rate until galaxies, planetary systems, and finally atoms are torn apart in a *big rip*.

So, how is the universe expanding? The law of conservation provides the answer via the world's most exploited equation, the *flow equation*.

I call it the "flow equation" because I think it's a name that better explains what it is about than the "momentum equation" or the "fundamental hydrodynamical equation". The equation is based on the law of conservation, and describes how fluids (liquids and gases) stream, or flow. I believe it's the most exploited equation because meteorologists use it in their calculations, and I would suppose that weather forecasting requires the most computing power out of all constantly ongoing physical computations.

When the flow equation is written in a maximally simple form, its straightforward interpretation suggests that the universe is expanding by itself without any forces pushing on it. This means that the expansion of the universe isn't associated with inertia, and doesn't generate kinetic energy. Also, it means that the gravitational force that causes matter to clump into stars, galaxies, and galaxy clusters doesn't affect the rate of the overall expansion of the universe. Instead, the universe continues to expand forever at a steadily decreasing rate.

The flow equation suggests that the energy (E_V), which is contained in a cosmic sphere of volume V and radius r, creates space that causes the volume to expand at a rate proportional to E_V. That is,

$$\mathrm{d}V/\mathrm{d}t \propto E_V, \tag{3.1}$$

or (since $V = \frac{4}{3}\pi r^3$), $\mathrm{d}r/\mathrm{d}t \propto r^{-2}E_V$. It follows that the universe's rate of expansion — the so-called *Hubble expansion rate*, which is often referred to as the "Hubble constant" — is $H = r^{-1}\mathrm{d}r/\mathrm{d}t \propto r^{-3}E_V$. This means that, for small values of r (implying a very young universe), the sphere V is growing fast, with its expansion rapidly decelerating. Today, when the universe has already grown to enormous dimensions, the expansion is expected to be nearly constant, with the decrease in H and the accompanying decrease in G almost imperceptible.

Universal validity of the law of conservation means that the energy E_V remains constant over time (compare with subchapter 3.6) and that, consequently $H =$ 22
$r^{-1}\mathrm{d}r/\mathrm{d}t \propto r^{-3}$. In other words, the flow equation predicts that the universe will expand forever at a gradually decreasing rate.

But, if things are this simple, why is the universe's expansion said to be a big mystery? How can the recent observations suggesting that the "universe is accelerating" be understood? What lies behind the observations?

The obvious answer is: The PBHs (see subchapter 2.8) are responsible for 16
the accelerating expansion. That is, the same primordial black holes, which (through mergers and capture of surrounding particles) developed into the giant black holes that today form the centers of galaxies, are at present releasing particles at a faster rate than they capture particles. However, as the black holes lose more and more of their content, which once included nearly all particles — almost all the energy of the universe — their role will diminish and the universe return to its original rate of expansion determined by $\mathrm{d}V/\mathrm{d}t = \text{constant}$.

3.5 The time mystery

If one tries to apply the flow equation to *space* — that is, assumes that space may be compared to a fluid — one is led to the conclusion that the universe is expanding in the manner predicted by *Dirac's large-number hypothesis* (LNH), which Paul Dirac presented in 1937.

According to LNH, there exists a connection between three very large numbers in physics. One of the numbers is obtained via division of the electric force between two electrons by the gravitational force between the same particles. Another number is obtained if the age of the universe is divided by the time it takes light to travel a distance equaling the *classical electron radius*. In both cases, the result is roughly 10^{40}. Finally, one finds that the mass of the universe divided by the electron mass is about 10^{80}, or 10^{40} squared.

According to Dirac's hypothesis, it's not because of pure chance the three numbers happen to coincide at the epoch when intelligent life appears on the earth and humans make astronomical observations. Instead, LNH states that the three numbers are linked together, and have always been. Among other things, such a link means that the *Newtonian constant of gravitation* (G) decreases, so that, for instance, the gravitational force was ten times stronger when the universe was one tenth as old as it is today.

The hypothesis seemed plausible because the alternative was that gravity and expansion are unrelated phenomena, which by a twist of fate happen to balance each other. If there hadn't been an extremely delicate balance between the pull of gravity and the inertia of the expanding universe, either the universe would have collapsed soon after its birth, or it would have expanded so rapidly that macroscopic structures (stars and galaxies) wouldn't have had time to form.

To Dirac's — and my — disappointment, measurements performed by the Viking expedition to Mars in 1976 showed that that the gravitational force didn't decrease at the rate one had expected. The conclusion drawn from the result of the experiment was that the large numbers coincide by chance when we are here to observe them, and that gravity has always been as weak as it is today.

It turns out that the time mystery has a simple explanation. When the first primordial black hole appears, it swallows most of the particles surrounding it, with the result that the remaining amount of energy feeding the expansion sharply drops. The resulting decrease in the universe's rate of expansion is accompanied by a corresponding decrease in G, which means that the link between the strength of the gravitational force and the age of the universe breaks.

After the appearance of the first PBHs, there follows a period of gradually decreasing G, when the black holes swallow ever more of the free particles around them. Then follows a period characterized by mergers of PBHs into black holes of gradually increasing size. During this period, repeated collisions between the black holes cause them to release most of the particles they had once swallowed. Presently, part of these freed particles can be seen as galaxies orbiting giant black holes at their centers.

3.6 The energy mystery

A well-known aspect of the law of conservation is the principle of conservation of energy, which says that energy can be neither created nor annihilated. Even if energy may be transformed from one form to another, the total amount of energy in a closed system remains constant.

A consequence of the energy principle is that matter's inherent energy, such as the rest energy of the electron ($E_e = m_e c^2$), doesn't change with time. Since, according to the law of conservation, particle masses (such as m_e) are also conserved, the speed of light (c) must be constant, too.

This is the familiar *local picture* of the world. In laboratories on the earth, the picture is uncontroversial. In contrast, problems arise when one considers a cosmic volume, V (a group of galaxy clusters, say), which is expanding at the same rate as the universe.

Assume for simplicity that the masses in the volume V are stable, and that the incoming radiation balances the outgoing radiation. Let the total mass of the volume be M, and assume further that the free radiation within V consists of N photons of average energy $E_\gamma = hc/\lambda$, where h is the *Planck constant*, λ (*lambda*) the photon wavelength, and γ (*gamma*) denotes the photon. Finally, note that the expansion of the universe doesn't generate kinetic energy (see subchapter 3.4). 19

Because the mass M corresponds to the energy Mc^2, and the total energy of the radiation is NE_γ, the energy principle states that

$$Mc^2 + Nhc/\lambda = \text{constant}, \tag{3.2}$$

which is impossible because the wavelength λ (which increases as the universe expands and light is redshifted) is the only variable in the equation. Consequently — in the local picture — energy is not conserved in an expanding universe.

> When cosmologists base their calculations on the *general theory of relativity* (GR), they arrive at the same conclusion: *"energy is not conserved in GR in an expanding universe"*, as an expert in the field put it.

In the *global picture* of the world, things look different. In this picture, application of the energy principle implies that Eq. (3.2) holds true, which means that c varies with time and increases at a rate that makes the matter energy (Mc^2) grow to compensate for the decrease in radiation energy (Nhc/λ).

> A couple of examples illustrate the connection between c and λ in the global picture. First, assume that the volume V contains equal amounts of matter energy and radiation energy. If both the constants M and Nh and the variables c and λ are set equal to 1, Eq. (3.2) simplifies to $c^2 + c/\lambda = 2$, or $c^2 + c = 2$, with solution $c = 1$. An eightfold increase of V means that the volume's radius, and thereby the photon wavelength λ, grow by a factor of 2, which leads to the equation $c^2 + c/2 = 2$ with solution $c = \sqrt{2.0625} - 0.25 = 1.186$. In this case, a doubling of λ leads to an 18.6 % increase in c.

> If, for instance, the radiation energy is 100 times higher than the matter energy, the equation may be written as $c^2 + 100c = 101$ with c and λ initially equal to 1. A doubling of λ now gives $c^2 + 50c = 101$ with solution $c = \sqrt{726} - 25 = 1.944$. In this case, a doubling of λ leads to a 94.4 % increase in c.
>
> The conclusion is that c increases nearly at the same rate as λ if the radiation energy (as in the second example) dominates the universe, while c increases very slowly if matter energy dominates, which is the case today when the cosmic background radiation has lost practically all of its original energy.

In a universe without matter ($M = 0$), the decrease in radiation energy cannot be counterbalanced. Therefore, the law of conservation forbids the existence of a purely radiative universe. This means that the law forces the world to undergo a metamorphosis when, at the end of phase 3, it consists of photons and electrons, and the last pair of electron pairs is about to annihilate. In the profound transformation that follows, the proton is created together with a number of other strongly and weakly interacting particles.

In the global picture, the evolution of the universe before the metamorphosis can be simulated in detail. The simulation demonstrates that not only c increases as the universe expands, but also the *lifetime* (mean life, or average life), τ (*tau*), of the massive particle pairs as well.

The energy mystery has now been resolved, but instead a new mystery has come up: How can energy be conserved both locally and globally? Or alternatively: How can the speed of light, c, increase in the global picture when it proves to be constant in our familiar, local picture of the world?

Distance (d) is speed (v) times time (t). Therefore, we may specify an arbitrary distance as $d = c\tau$, where c is the speed of light and τ the half-life of a radioactive isotope. In our standard, local picture, d is naturally constant. But, in the global picture, the same distance d increases with time, since both c and τ increase.

Consequently, the new mystery may be summarized in the question: How can a given distance be constant in one picture and grow in another?

The answer is that the two pictures are mutually exclusive in a world where the laws of classical physics apply. But in our actual universe, the laws of quantum physics apply, and in the quantum world there is no conflict between the local and the global pictures.

3.7 The quantum mystery

To explain the mystery of energy conservation we must turn to the universe's fourth mystery: *quantum mechanics.*

An example highlighting the mysterious nature of quantum mechanics is the effect that has become known as *spooky action at a distance.* Simplifying things, one may say that the phenomenon means that, in the instant the spin direction of particle A is measured, particle B — which together with particle A forms an entangled pair with total spin zero — acquires the opposite spin direction. The instant effect occurs even when the two particles are very far from each other.

The phenomenon is interpreted to mean that particle A transfers information about its spin direction to B in a much shorter time than it takes for light to travel from A to B. It is said that the effect cannot be intuitively understood.

However, that's totally wrong. When one applies the flow equation to space, one is led to an explanation of the effect, which is so simple that a child can immediately understand it while physicists indoctrinated to believe that quantum mechanics conflicts with common sense may find the explanation difficult to accept.

3.8 The pointless space

The flow equation explains how fluids flow.

> In its most elementary form, the equation describes a so-called ideal gas in which there are no *van der Waals forces* acting between molecules, and which therefore doesn't possess inner friction, or viscosity. The equation gives a connection between time t and the pressure p, velocity v, and density ρ (*rho*) of the gas.
>
> For a *stationary flow*, the pattern of the flow doesn't change with time, which means that the density of the ideal gas is obtained as a function of only pressure and velocity: $\rho = \rho(p, v)$.
>
> In addition, it turns out that the pressure p may be eliminated from the equation and replaced with the *number of degrees of freedom*, f, of the molecules of the ideal gas. It means that the equation may be written in a pressureless form: $\rho = \rho(f, v)$. In practice, the density is now a function of velocity only ($\rho = \rho(v)$), since the number of degrees of freedom is a well-defined integer constant. For gases with molecules consisting of one atom (*monatomic gases*), two atoms (*diatomic gases*), or three or more atoms (*polyatomic gases*), f equals 3, 5, and 6, respectively.

Let's now assume that space may be regarded as a kind of ideal fluid, which naturally isn't an ideal physical gas, but might have some resemblance with one.

Different from a physical gas, space must lack inner pressure because otherwise it would expand uncontrollably (unless it's enclosed in some kind of pressure-cooker).

Since the molecules of a gas give the gas its pressure, and space lacks pressure, there is no reason to believe that space consists of molecules. On the contrary, the simplicity principle in the form of *Occam's razor* forces us to assume that there exist neither extended points (or molecules) nor points lacking extension (mathematical points) in the ideal fluid that makes up space.

And now we are coming to the heart of the matter. The space of physics is not the pointspace of mathematics — the space of the real world is no coordinate system. Space is not built from points:

Space is pointless.

The points of mathematics correspond in physics to molecules. In empty space, there are no molecules. Consequently, in empty space there are no reference points or coordinate points. Without reference points, position cannot be defined. Because distance is measured between two points, also distances are undefinable in empty space. Similarly, direction is undefinable — space has no north or south.

> The abstract point of mathematics is infinitely small. It cannot be visualized: Imagine a cube with sides of 1 decimeter that contains a mathematical point. You localize the point to a cube with sides of 1 millimeter and magnify the cube 1 000 000 times (its sides 100 times, from 1 mm to 1 dm). You may repeat the procedure — localize the point and magnify the volume — in your thought experiment indefinitely many times without ever catching sight of the point. Thus, the thought experiment proves that the points of mathematics cannot be visualized. Mathematical points are not pixels.

It's now clear why physicists toward the end of the nineteenth century were unable to detect any *ether wind*. It's the bombardment of the air molecules against your face that makes you feel the pressure of the wind. Without molecules, there is no wind.

Also the *spooky action at a distance* is explained. The particles A and B form a closed system — a small universe of their own — isolated from the rest of the world. Before either of them has been in contact with the world around them, there exists no definable distance between them. Also, the spins of the particles have no definable direction.

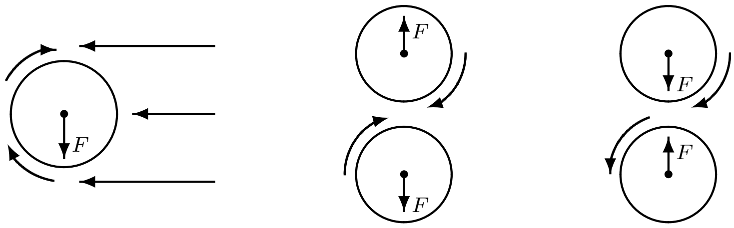
Only when particle A gets in contact with the macroscopic coordinate system that the laboratory represents, A's position and spin direction become defined. At the same instant, the direction of B's spin and B's distance from A are determined — quantities that now are measurable but haven't earlier been definable, and consequently haven't existed.

The "instant action at a distance" is now easily understood. In fact, it's very difficult to imagine that the phenomenon wouldn't exist. What would an alternative outcome of the experiment look like?

4 A particle model takes form

It's time to take a look at the *pressureless flow equation* discussed in subchap- 19
ter 3.4. But first I'll tell about how it all began as I want to make it clear that I've never had a brilliant idea or experienced any flash of genius, but that my conclusions result from a combination of chance and stubbornness. Also, I want to show that my theory is based on common sense combined with straightforward interpretations of long-known physical equations and principles.

I can't pinpoint when and how I began pondering about the possibility that the electron might be a kind of whirl in some fluid-like "ether" filling the universe. Perhaps it began when I read an explanation of why the path of a spinning tennis ball deviates from the trajectory of a non-spinning ball. See left figure:



The down-pointing arrow labelled F shows the force caused by the top spin of the ball when the ball is hit by the air indicated by horizontal arrows.

The same effect that causes the spinning ball's trajectory to bend must make a pair of balls, which are close to each other and rotate around parallel axes, repel each other if both balls are rotating in the same direction (middle figure) and attract each other if one of the balls rotates clockwise and the other anticlockwise (right figure). In the first case, an air cushion with overpressure tends to form between the balls. In the latter case, the moving air causes underpressure.

> As far as I can remember, I didn't know that the idea of *eternal motion*, according to which matter consists of whirls in some kind of *perfect fluid*, *ether*, or *primeval matter*, is several thousand years old. Only a few years later, I learned that my idea was far from new and that many people had speculated along similar lines before me.

I assumed that the electric field of force of an electron is spherically symmetric, and concluded that the particle must be rotating in two different ways. Its spin should be caused by a cylindrically symmetric rotation around and axis while a kind of spherically symmetric rotation should be responsible for the charge of the particle.

> A spherically symmetric rotation of a tennis ball is impossible to imagine because it means that the surface of the ball appears to move in exactly the same way, independent of from which direction one looks at the ball. However, this was a fact that didn't bother me. The spherically symmetric

> rotation of the electron simply proves that electrons and other elementary particles cannot be described in terms of classical physics, I reasoned. That I forty years later would arrive at the conclusion that such a rotation is impossible in the quantum world, too, I couldn't anticipate.

In the next two subchapters I will discuss the flow equation in more detail and
explain how I arrived at its solution presented in Eq. (4.23) — a previously 33
unknown "maximally simple" equation that holds for an ideal gas.

> At this point experts in quantum physics may object: "You can't apply a classical equation to quantum phenomena. The spin of the electron is an intrinsic property of the particle that is not caused by rotation of the particle around an axis with well-defined direction in space".
>
> However, the classical flow equation mathematically expresses the law of conservation of momentum, which says that once a motion has started it continues. And the law of momentum conservation — one aspect of the general law of conservation — is just as fundamental in quantum physics as in classical physics.
>
> (In relativistic QED one talks about "four momentum" which is a "four vector" composed of the three momentum components p_x, p_y, and p_z of a particle and a fourth component that is proportional to the particle's energy E. Conservation of four momentum implies that all four components of this four vector are simultaneously conserved.)
>
> In quantum field theory (QFT) the interpretation of Eq. (4.23) differs rad- 33
> ically from its classical interpretation. The quantum-theoretical equation has no other connection to its classical counterpart than formal similarity. Like other equations specific for QFT also this new equation has to be postulated. (QFT was developed via trial and error; equations that worked were retained, other proposed equations rejected and forgotten. Only long afterward, its theoretical foundation was chiseled out.)
>
> In QFT, v in the the equation $\rho = \rho_0(1 - \frac{1}{f}\frac{v^2}{v_0^2})^{f/2}$ presented in Eq. (4.23) is 33
> an unobservable field among other fields that cannot be directly observed. Also ρ is unobservable and no classical density. Finally, the value and meaning of the integer constant f differ from the value and meaning of f in classical physics.
>
> So, what's the point in deriving the equation for a physical fluid? Why not simply postulate it in QFT? The answer is that the classical derivation demonstrates the equation's agreement with the law of conservation.
> Thereby it suggests that, after its reinterpretation, Eq. (4.23) should be 33
> an acceptable candidate for the sought-after equation describing space.

As will be seen in subchapter 4.3, the result of the discussion surpasses all 36
expectations. Not only does the reinterpreted equation picture a particle with
spin, charge, and energy, but it also provides the answers to the first three
of the fundamental questions listed in subchapter 3.1 — why the universe is 18
expanding, what governs the expansion, and why there is gravity. The ultimate
proof of the new equation's applicability in elementary particle physics is found
in the first box on page 69. 69

4.1 The flow equation

According to my textbook in *theoretical physics* printed in 1958, the flow equation for a *nonviscous fluid* may be written as

$$\frac{\partial \boldsymbol{v}}{\partial t} + \frac{1}{2}\nabla \boldsymbol{v}^2 - \boldsymbol{v} \times (\nabla \times \boldsymbol{v}) + \frac{1}{\rho}\nabla p = \boldsymbol{G}. \tag{4.1}$$

It's a waste of time to try to understand it. Instead, look at it as a work of art.

In the book, Eq. (4.1) is called *the fundamental hydrodynamical equation*, but is better known under the name *momentum equation* because it derives from the principle of *conservation of momentum*.

The velocity $\boldsymbol{v}$ and force $\boldsymbol{G}$ are *vectors* with direction, while the pressure p, density ρ, and velocity squared ($\boldsymbol{v}^2$, or v^2) are *scalars*.

The cross product in the middle of the equation — in the book written as "[$\boldsymbol{v}$ curl $\boldsymbol{v}$]" — is zero for a so-called *potential*, or *irrotational flow*, for which $\boldsymbol{v}$'s *curl* is zero ($\nabla \times \boldsymbol{v} = 0$).

If in addition the flow is stationary (its pattern doesn't change with time) and unaffected by external forces ($\boldsymbol{G} = 0$), the equation simplifies to

$$\frac{1}{2}\nabla \boldsymbol{v}^2 + \frac{1}{\rho}\nabla p = 0, \tag{4.2}$$

where the symbol ∇ (*nabla*) — "grad" in the textbook — denotes *gradient*.

Gradient means slope or (in mathematics) change. The gradient at a given point shows the direction in which the change is largest (the slope steepest) and the size of this change. It is a vector described by three numbers — a kind of three-dimensional analogue of the derivative, which (lacking direction) is a scalar described by a single number.

For example, the derivative of the line $y = 4x$ is 4. That is, $\mathrm{d}y/\mathrm{d}x = 4$, or $\mathrm{d}y = 4\,\mathrm{d}x$. When drawing the line on paper, this means that y increases by $\mathrm{d}y = 4$ millimeter when x increases by $\mathrm{d}x = 1$ millimeter. The result is a line comparable to the "/" sign. Similarly, the line "\" should have a derivative of about $\mathrm{d}y/\mathrm{d}x = -4$.

Equation (4.2), which is a special case of the momentum equation (4.1), simplifies to *the Bernoulli equation* $v^2/2 + p/\rho + U = \mathit{const.}$ for constant ρ (*incompressible fluids*). Equation (4.1), in turn, is a special case of the so-called *Navier–Stokes equation*, in which also the viscosity of the fluid is taken into account.

In my first attempts to picture space as a fluid, I used equation (4.2) as a starting point. I thought that if the elementary particles are whirls in the fluid of space, then space must be structurally simpler than physical liquids or gases. Consequently, it cannot reasonably possess molecules, heat, or pressure, which means that the pressure p must be eliminated from the equation. By replacing p with $v_0^2\rho$, I arrived at the density function (May 1964),

$$\rho = \rho_0 \exp\left(-\frac{1}{2}\frac{w^2}{w_0^2} - \frac{1}{2}\frac{u^2}{u_0^2}\right), \tag{4.3}$$

which I assumed described an electron.

Changing the gradient ∇ in Eq. (4.2) to its corresponding one-dimensional operator $\mathrm{d}/\mathrm{d}x$ and noting that $\boldsymbol{v}^2 = v^2$, one obtains $\frac{1}{2}\mathrm{d}v^2/\mathrm{d}x + \frac{1}{\rho}\mathrm{d}p/\mathrm{d}x = 0$. With $p = v_0^2\rho$, the equation becomes $-\frac{1}{2}v_0^{-2}\mathrm{d}v^2 = \frac{\mathrm{d}\rho}{\rho}$, which upon integration from $v^2 = 0$ to v^2 and $\rho = \rho_0$ to ρ yields $-v^2/2v_0^2 = \log\rho - \log\rho_0 = \log\frac{\rho}{\rho_0}$, or $\mathrm{e}^{-v^2/2v_0^2} = \rho/\rho_0$; that is, $\rho = \rho_0\exp(-\frac{1}{2}\frac{v^2}{v_0^2})$.

A particle possessing a spherically symmetric rotation, w, acquires a density of $\rho_w = \rho_0\exp(-\frac{1}{2}\frac{w^2}{w_0^2})$. If it in addition possesses spin, the density becomes $\rho = \rho_w\exp(-\frac{1}{2}\frac{u^2}{u_0^2})$, or (since $\mathrm{e}^x\mathrm{e}^y = \mathrm{e}^{x+y}$) $\rho = \rho_0\exp(-\frac{1}{2}\frac{w^2}{w_0^2} - \frac{1}{2}\frac{u^2}{u_0^2})$.

In equation (4.3), u denotes a two-dimensional, cylindrically symmetric rotation thought to be responsible for the spin of the electron. Similarly, w denotes the three-dimensional, spherically symmetric rotation thought to create the electrostatic charge of the particle and its energy

$$E = \frac{1}{2}\int \rho w^2\,\mathrm{d}V \tag{4.4}$$

(in analogue with $E = \frac{1}{2}mv^2$ and $m = \rho V$ in classical physics).

The electrostatic force between two charges are inversely proportional to the distance between the charges. Calculations show that the same dependence holds for the force between two whirls, provided that w is inversely proportional to the square of the distance between them, or

$$w = \pm w_0 r_0^2/r^2. \tag{4.5}$$

Let there be two particles, one at $z = 0$ and the other at $z = -a$. Suppose, first, that both give rise to cylindrically symmetric rotations with axes of rotation parallel to the x axis. Consider a point in the yz plane at a distance $\boldsymbol{r}_1$ from the first and $\boldsymbol{r}_2$ from the second particle (i.e., $\boldsymbol{r}_1 = \boldsymbol{a} + \boldsymbol{r}_2$). The square of the sum of the two velocities is

$$w^2 = (\boldsymbol{w}_1 + \boldsymbol{w}_2)^2 = (\boldsymbol{\omega}_1 \times \boldsymbol{r}_1 + \boldsymbol{\omega}_2 \times \boldsymbol{r}_2)^2, \tag{4.6}$$

where ω denotes angular velocity (an object moving in a circle with radius r has a speed of $v = \omega r$). If instead $\boldsymbol{w}_1$ and $\boldsymbol{w}_2$ represent the corresponding radial velocities, then

$$w^2 = (\boldsymbol{w}_1 + \boldsymbol{w}_2)^2 = (w_1\boldsymbol{r}_1/r_1 + (w_2\boldsymbol{r}_2/r_2)^2 \tag{4.7}$$

holds. Since the velocities of the first case are perpendicular to the velocities of the second case, the resulting w^2 is the same for the two cases.

Assume, therefore, that for the three-dimensional rotation (which is a mathematical generalization that cannot be visualized) the same correspondence holds, and that, consequently, Eq. (4.7) may be used in the calculations. With $w_i = \pm w_0 r_0^2/r_i^2$ $(i = 1, 2)$ according to Eq. (4.5) and $\boldsymbol{r}_1 = \boldsymbol{r}$, Eq. (4.4) then yields for the interaction energy

$$\begin{aligned} E_{\text{int}} &= \pm\frac{1}{2}\int \rho\frac{2\,w_1 w_2}{r r_2}\boldsymbol{r}\cdot\boldsymbol{r}_2\,\mathrm{d}V \\ &= \pm\int \rho\frac{w_0^2 r_0^4}{r^3\mid \boldsymbol{r} - \boldsymbol{a}\mid^3}\boldsymbol{r}\cdot(\boldsymbol{r} - \boldsymbol{a})\,\mathrm{d}V \\ &= \pm w_0^2 r_0^4\rho_0\int_0^{2\pi}\mathrm{d}\varphi\int_0^{\pi}\sin\theta\,\mathrm{d}\theta\int_0^{\infty}\frac{r + a\cos\theta}{(r^2 + a^2 + 2ra\cos\theta)^{3/2}}\,\mathrm{d}r \\ &= \pm 4\pi\rho_0 w_0^2 r_0^4/a, \end{aligned} \tag{4.8}$$

since $\rho = \rho_0$ may be assumed for $a \gg r_0$.

The two-dimensional cylindrically symmetric rotation u is thought to generate the electron's spin. The simplest nontrivial expression for u that fulfills the requirement $\nabla \times \boldsymbol{u} = 0$ is (polar coordinates are used, which means that r is the distance from the center of the particle and $r \sin\theta$ the distance from the axis of rotation)

$$u = u_0 r_0 / r \sin\theta, \tag{4.9}$$

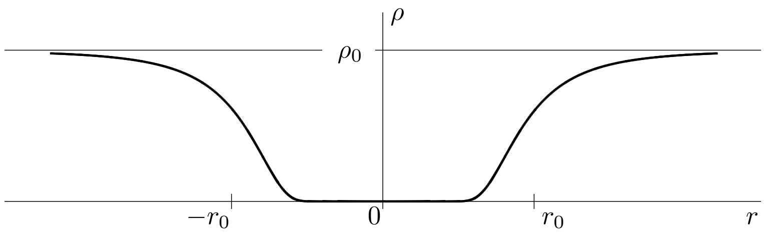
which, for the *angular momentum* of the whirl, or the spin of the electron, gives

$$s = \int r \sin\theta \, u \, \mathrm{d}m = m r_0 u_0 \tag{4.10}$$

with the mass m defined via $E = mc^2$.

The cylindrical symmetry of the rotation means that u's components u_r and u_θ are zero and only the component u_φ differs from zero. A look at a textbook in vector analysis shows that this fact implies that the φ component of the curl is zero and its r and θ components reduce to $(\nabla \times \boldsymbol{u})_r = \frac{1}{r \sin\theta} \frac{\partial}{\partial\theta} (\sin\theta \, u_\varphi)$ and $(\nabla \times \boldsymbol{u})_\theta = -\frac{1}{r} \frac{\partial(r u_\varphi)}{\partial r}$, respectively, which both disappear for $u_\varphi \propto 1/r \sin\theta$.
That the curl of a circular flow is zero may seem strange. However, the textbook in theoretical physics explains: *"we might at first sight expect that in a flow where curl* $\boldsymbol{v}$ *is zero everywhere the circulation along every curve would have to vanish. But [. . .] the circulation may, in certain cases differ from zero even when the flow is irrotational. This contradiction arises because the region is no longer simply connected after we cut out the point O, i.e. there now exist closed curves which cannot be closed into a point without passing out of the region."* For $u = u_0/rsin\theta$ in Eq. (4.9), the point O is $r = 0$, where there is no fluid, since $u = \infty$ gives $\rho = 0$ in Eq. (4.3).

The figure shows how the density varies with distance from the center of the particle in the case where the particle is spinless ($u = 0$):



$$\rho = \rho_0 \exp\left(-\frac{1}{2}\frac{w^2}{w_0^2}\right) \text{ with } w = \pm w_0 r_0^2 / r^2$$

The energy of the particle is proportional to the integral

$$B = r_0 \int_0^{\pi/2} \sin\theta \, \mathrm{d}\theta \int_0^{\infty} (\rho/\rho_0) \, \mathrm{d}r / r^2 \tag{4.11}$$

with value $B = 0.755\ 777$.

In classical physics the interaction energy between two electrons is

$$E_{\text{int}} = \pm e^2/a \tag{4.12}$$

(using *Gaussian units* in which the MKSA system's $4\pi\epsilon_0$ is set equal to 1). Equating this expression with the hydrodynamic expression (4.8) for the interaction energy gives

$$4\pi\rho_0 w_0^2 r_0^4 = e^2, \tag{4.13}$$

which may be used to eliminate the unobservable parameter ρ_0.

Inserting Eqs. (4.5) and (4.13) into (4.4) and integrating over all space, one obtains the relation

$$r_0 mc^2/e^2 = B/2 \tag{4.14}$$

between the electron's radius, mass, and charge. The electron-structure constant characterizing this relation is

$$B = r_0 \int_0^{\pi/2} \sin\theta \, \mathrm{d}\theta \int_0^{\infty} (\rho/\rho_0) \, \mathrm{d}r/r^2, \tag{4.15}$$

which follows from Eq. (4.14) together with Eqs. $mc^2 = E$, (4.4), (4.5), and (4.13), and noting that $\int \mathrm{d}V = \int_0^{2\pi} \mathrm{d}\varphi \int_0^{\pi} \sin\theta \, \mathrm{d}\theta \int_0^{\infty} r^2 \mathrm{d}r = 4\pi \int_0^{\pi/2} \sin\theta \, \mathrm{d}\theta \int_0^{\infty} r^2 \mathrm{d}r$ for polar coordinates and cylindrical symmetry.

After ρ/ρ_0 is eliminated using the "hydrodynamic electron equation" (4.3), it is seen that the integration in Eq. (4.15) produces a well-defined numerical constant. When ρ/ρ_0 given by Eq. (4.3) is used, and the variables $x = r/r_0$ and $y = \cos\theta$ are introduced, the integral takes the form $B = \int_0^1 \mathrm{d}y \int_0^{\infty} \exp(-1/2x^4 - 1/2x^2(1-y^2)) \, \mathrm{d}x/x^2$, for which numerical integration gives the value $B = 0.755\ 777\ 022\ 030\ 643$.

The assumption that the particle model pictures an electron with charge e and spin $s = \frac{1}{2}\hbar$ means that $u_0/c = 1/B\alpha = 181.318$, where (in Gaussian units with $4\pi\epsilon_0$ set equal to 1) $\alpha = e^2/\hbar c = 1/137.035\ 999$ is the so-called *fine-structure constant*, which defines the strength of the electromagnetic force.

Multiplication of Eq. (4.14) by Eq. (4.10) gives $sr_0mc^2/e^2 = mr_0u_0B/2$, or $s = Bu_0e^2/2c^2$. Since the spin of the electron is $s = \hbar/2$, the relation becomes $\hbar = Bu_0e^2/c^2$, and with $\alpha = e^2/\hbar c$ finally $1 = B\alpha u_0/c$.

The constant 181.318 is of the same order of magnitude as the ratio $m_\mu/m_e = 206.768$ between the muon and electron masses. Assuming that it isn't a chance coincidence, but that $u_0/c = m_\mu/m_e$, or

$$m_\mu/m_e = 1/B\alpha \tag{4.16}$$

holds, one obtains for the ratio between the two masses the theoretical value

$$m_\mu/m_e = 181.318, \tag{4.17}$$

which is about 12 percent less than the measured value.

In summary, the mathematical experiment shows that a simple hydrodynamic equation may:

- describe the electron's charge and rest energy (and thereby its mass),
- describe the spin of the electron, and
- give an approximate value for m_μ/m_e.

The weakness of the model is that it leads to more questions than it answers, questions such as:

- Why is $p = v_0^2\rho$?
- How can the model be further developed without new ad hoc assumptions?
- How can other forces than the electromagnetic be included in the model?

The experiment demonstrates the problem with ad hoc assumptions. An assumption specially tailored to answer a single question and explain a specific aspect of reality will in general produce a number of new questions. A well-founded theory, on the other hand, is expected to answer more questions than it generates.

4.2 The pressureless space equation

Equation (4.3), which is assumed to model a charged spinning particle, results from the tentative assumption $\nabla p = v_0^2\nabla\rho$. To arrive at a more credible model, the pressure gradient ∇p must be replaced with an expression that can be derived with the help of generally known physical relations. In other words, the challenge is to find a logically tenable way of eliminating the pressure p from the flow equation. Finally, it succeeds (November 1966).

> In the same textbook where I found the flow equation, I find two pieces of the puzzle. The first piece says that in an *adiabatic* process (a process in which heat is neither added nor removed)
>
> $$p\rho^{-\gamma} = p_0\rho_0^{-\gamma}, \tag{4.18}$$
>
> with p_0 and ρ_0 the undisturbed pressure and density at large distances from the whirl and γ a numerical constant. This connection means that the fourth term in the flow equation (4.1) on page 28 may be written $\frac{1}{\rho}\nabla p = p_0\rho_0^{-\gamma}\rho^{-1}\nabla\rho^{\gamma}$.
>
> For the gradient, normal rules of derivation apply. It means that the symbol ∇ may be replaced with the derivative $\mathrm{d}/\mathrm{d}x$ in formal calculations. Using the rule $\frac{\mathrm{d}}{\mathrm{d}x}y^k = ky^{k-1}\frac{\mathrm{d}y}{\mathrm{d}x}$ on each side of the equality $\rho^{-1}\nabla\rho^{\gamma} = \frac{\gamma}{\gamma-1}\nabla\rho^{\gamma-1}$, one obtains in both cases the result $\gamma\rho^{\gamma-2}\nabla\rho$, which shows that the mentioned equality holds and that, consequently, $\frac{1}{\rho}\nabla p = p_0\rho_0^{-\gamma}\rho^{-1}\nabla\rho^{\gamma} = \frac{\gamma}{\gamma-1}p_0\rho_0^{-\gamma}\nabla\rho^{\gamma-1}$.
>
> The second piece of the puzzle says that $v_0^2 = \gamma p_0/\rho_0$, or $p_0 = \rho_0 v_0^2/\gamma$ holds for sound in a gas. With its help, p_0 can be eliminated, which gives $\frac{1}{\rho}\nabla p = \frac{1}{\gamma-1}v_0^2\rho_0^{-\gamma+1}\nabla\rho^{\gamma-1}$. Thus, the flow equation takes on the pressureless form
>
> $$\frac{\partial \boldsymbol{v}}{\partial t} - \boldsymbol{v}\times(\nabla\times\boldsymbol{v}) + \nabla\left(\frac{1}{2}\boldsymbol{v}^2 + \frac{1}{\gamma-1}v_0^2\rho_0^{-\gamma+1}\rho^{\gamma-1}\right) = \boldsymbol{G}. \tag{4.19}$$
>
> The equation (4.19) looks rather cryptic and difficult to interpret. This is because one piece is still missing. I find it in a textbook in *Thermodynamics and Statistical Mechanics*, which gives the connection
>
> $$\gamma = 1 + 2/f \tag{4.20}$$

between the constant γ and the *number of degrees of freedom* f of the molecules of the gas (see page 24). When $\gamma - 1$ is replaced with $2/f$, Eq. (4.19) takes on 24
its final form shown in Eq. (4.21).

Upon elimination of the pressure p from the flow equation (4.1), it takes on the 28
form

$$\frac{\partial \boldsymbol{v}}{\partial t} - \boldsymbol{v} \times (\nabla \times \boldsymbol{v}) + \frac{1}{2}\nabla\left(\boldsymbol{v}^2 + f v_0^2 (\rho/\rho_0)^{2/f}\right) = \boldsymbol{G}. \tag{4.21}$$

After $\partial\boldsymbol{v}/\partial t$, $\nabla\times\boldsymbol{v}$, and $\boldsymbol{G}$ have been set equal to zero — compare with Eq. (4.2) 28
— integration of the equation gives $\boldsymbol{v}^2 + f v_0^2(\rho/\rho_0)^{2/f} + C = 0$, where C is a constant of integration, which the boundary condition $\boldsymbol{v}^2 = v^2 = 0$ for $\rho = \rho_0$ determines as $C = -f v_0^2$.

Thus, for a stationary flow on which no external forces act, the flow equation may be written as

$$v_0^2(\rho/\rho_0)^{2/f} = v_0^2 - v^2/f. \tag{4.22}$$

After both sides of Eq. (4.22) have been raised to the power of $f/2$, one finally arrives at the "pressureless space equation"

$$\rho = \rho_0 \left(1 - \frac{1}{f}\frac{v^2}{v_0^2}\right)^{f/2}. \tag{4.23}$$

Equation (4.23) applies to an ideal gas consisting of atoms or molecules. Therefore, when applying it to space, v_0 and f have to be reinterpreted. Since sound waves do not, but light waves do, propagate through space, v_0 should be the velocity of light, c. Also, it is clear that the number of degrees of freedom can hardly be anything else than $f = 3$ for the three-dimensional spherically symmetric rotation w, and $f = 2$ for the two-dimensional cylindrically symmetric
rotation u. Consequently, Eq. (4.3) should be replaced with 28

$$\rho = \rho_0 \left(1 - \frac{1}{3}\frac{w^2}{w_0^2}\right)^{3/2} \left(1 - \frac{1}{2}\frac{u^2}{u_0^2}\right), \tag{4.24}$$

meaning that the value of B changes from 0.755 777 to $B = 0.669\ 605$.

After change of variables to $x = r_0/\sqrt{2}\,r$ and $y = \cos\theta$, the integral (4.11) becomes $B = 2^{1/2} \int_0^{(3/4)^{1/4}} (1 - \frac{4}{3}x^4)^{3/2}\,\mathrm{d}x \int_0^{(1-x^2)^{1/2}} (1 - \frac{x^2}{1-y^2})\,\mathrm{d}y$. Numerical integration gives $B = 0.669\ 605\ 309\ 417\ 211$.

The fact that the two terms in Eq. (4.24) — the first term representing the electric field, and the second the magnetic (spin) field of the electron — are multiplied together is a reflection of the *superposition principle*.

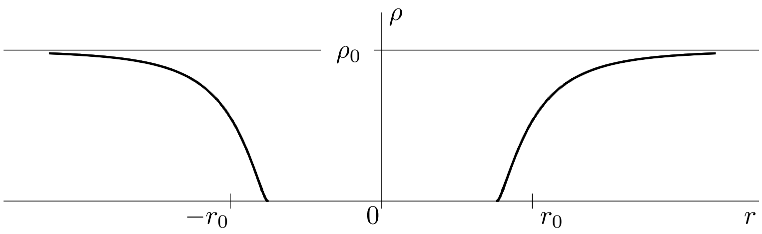
Two principles are assumed in elementary particle physics, both of which are believed to be exact. One of them is special relativity. The other is superposition of quantum mechanical amplitudes.

With the new value of B, the theoretical mass ratio becomes

$$m_\mu/m_e = 1/B\alpha = 204.652, \tag{4.25}$$

which differs by 1 percent from the measured value of 206.768. This difference should be compared with the difference of 12 percent obtained when $p = v_0^2\rho$ 31
was assumed to hold.

The figure shows how the density falls off with decreasing distance from the electron's center when the effect of u is neglected:



$$\rho = \rho_0 \left(1 - \frac{1}{3}\frac{w^2}{w_0^2}\right)^{3/2} \text{ with } w = \pm w_0 r_0^2/r^2$$

Interestingly, the space disappears for $r < 3^{-1/4} r_0$, which means that a *cosmological radius* appears inside the particle. In other words, the central part of the electron forms a true *hole in space*.

It would take time before I understood the significance of the existence of the space hole. Thirteen years after my discovery of Eq. (4.23), I read in a book that the most symmetrical compactification of the ten-dimensional field of the *spinning-string theory* induces a cosmological radius for space-time that is "about the same size as the internal six-dimensional space". Although I found this observation intriguing, it didn't lead me anywhere. Instead, another twenty years would pass before I stumbled on a theory that connected the hole in space to fundamental theoretical physics.

According to *quantum electrodynamics, QED*, the electron mass,

$$m = m_0 + \delta m, \tag{4.26}$$

consists of a naked, or *bare mass*, m_0, and a *self-mass*, δm, which together make up the total *dressed mass* m of the electron. The so-called JBW, *finite QED*, or *pure-QED* hypothesis was developed in the early 1960s and later mostly forgotten. It says that the bare mass of the electron is zero, which means that the particle's total mass m is identical to its self-mass δm generated dynamically by a cloud of unobservable, or virtual photons surrounding the center of the electron.

One can hardly imagine a more beautiful application of the *principle of maximum simplicity* (MxSP). In one stroke, the JBW hypothesis rids QED from a number of infinities and unanswerable questions. Three infinite quantities that haunt QED — the mentioned self-mass (or "mass

> correction") δm and the renormalization constants Z_3 and $Z_2 = Z_1$ — become finite (in practical, so-called perturbation-theoretical calculations they still appear as infinite quantities; Eq. (4.49) shows an example). 71
> And, even better, three unresolved and probably irresolvable questions disappear: the origin of the bare mass of the electron, the ratio of the electron's bare mass to its measured mass, and the contribution of the *vacuum-polarization loops* to the electron mass (which is zero according to the JBW theory).
>
> One may ask why such an appealing hypothesis has fallen into oblivion. My answer is: by pure chance, or sheer accident. However, a contributing factor was the complexity of QED, which prevented mathematical proof of the hypothesis. Another reason was that physicists were looking for a more comprehensive theory, which they hoped would unify the strong, weak, and electromagnetic forces into a single force, and that this hope made them believe that QED (which only describes the electromagnetic force) cannot function as a standalone, internally consistent theory. Maybe they also found it difficult to understand how something without energy or mass ($m_0 = 0$) could form the electron's core.
>
> If one asks what the core of the electron might look like, if it — in spite of its lack of mass and energy — is able to define the center of the electron and provide a launching pad for virtual photons, there are not many good answers from which to choose. And there is but one maximally simple answer that doesn't bring with it new complications: the center of the electron consists of *literally nothing* — it's a *hole in space*.
>
> It took me even longer to understand that Eq. (4.23) cannot provide the alternative description of the electron I had once believed it could. But then, if it doesn't picture an electron, how is it possible that the equation leads to the observed value of m_μ/m_e? The answer is that Eq. (4.23) describes an electron at the exact instant of the particle's birth, when it for the first time appears on the physical scene. Immediately when the electron attempts to perform the physically impossible three-dimensional rotation, which is mathematically described by Eq. (4.23), it disintegrates into the cloud of virtual photons with whose help it interacts with the surrounding world. Nature's first law, the law of conservation, ensures that the electron in its new, dynamical guise retains the mass (or self-energy), charge, and spin it had at its birth as a stationary particle with $\partial \boldsymbol{v}/\partial t = 0$.

Equation (4.23) answers more questions than it generates — which is something one may justifiably demand of a model contending to be physically sound. Also, the unavoidable new question:

- If f may be 3 or 2, shouldn't $f = 1$ be an option, too?

immediately finds an equally obvious answer:

- $f = 1$ characterizes a one-dimensional velocity ($\boldsymbol{v}$).

Because the point of departure is the assumption that, when applied to space, the flow equation pictures reality — and since observations show that the universe is expanding — there's only one way in which the velocity $\boldsymbol{v}$ may be interpreted: it describes the flow of space from a source supplied by the electron. So, what does this "space source" consist of? The answer is that, out of the properties of the electron (spin, charge, and energy), only energy can function as the source of new space; in the electron and generally in all types of elementary particles (spinning and non-spinning, charged and neutral, massive and massless). Therefore, the only possible conclusion is that energy creates space.

4.3 The gravitational force

The conclusion that energy creates space is supported by a simple calculation showing that the flow described by $\boldsymbol{v}$ causes an attractive force between particles. This force is proportional to the square of the distance between the particles and cannot, therefore, be identified with anything else than the force of gravitation, which is known to be proportional to the energy content of the particles it acts on.

In analogy with $w = \pm w_0 r_0^2/r^2$ for $f = 3$, one obtains for $f = 1$ and $r \gg r_0$, an outward radial flow with velocity $v = v_0 r_0^2/r^2$ (with $v_0 = c$), which decreases with the square of the distance from the source. Let r (in contrast to the microscopic radius r_0 of the electron) denote a cosmological distance. Consider a compact group of N particles with total mass m positioned at $r = 0$ and a single particle of mass m_0 at the point r, where the flow of space emanating from the group of particles has the speed $v = Ncr_0^2/r^2$. The corresponding contribution from the overall expansion of the universe is $v = cr/R$, where R is the *radius of the visible universe*. Seen from the group of particles, the total flow past the particle at r has the velocity

$$v = Nc\frac{r_0^2}{r^2} + c\frac{r}{R}. \tag{4.27}$$

When only $f = 1$ in Eq. (4.23) is considered, Eq. (4.24) is replaced with $\rho/\rho_0 = (1 - v^2/v_0^2)^{1/2}$ with $v_0 = c$. The flow past the lone particle causes a decrease in the particle's self-energy, which is proportional to the space density ρ. Seen from the group of particles, the energy of the particle at r is

$$E = m_0 c^2 \left(1 - N^2\frac{r_0^4}{r^4} - 2N\frac{r_0^2}{Rr} - \frac{r^2}{R^2}\right)^{1/2}. \tag{4.28}$$

The force acting on the particle is $F = \mathrm{d}E/\mathrm{d}r$, which means that the third term under the square root, $-2Nr_0^2/Rr$, causes an attractive, gravity-like force. The force is mutual, acting with the same strength on both m_0 and m provided that the self-energy of the particles is proportional to r_0^2. (This means that, in connection with gravity, $r_e^2/m_e = r_\mu^2/m_\mu = r_\tau^2/m_\tau$ while,
according to Eq.(4.14), $r_e m_e = r_\mu m_\mu = r_\tau m_\tau$ holds in connection with 31
electromagnetism. In the quantum world where distances are undefinable,
this is no contradiction. Compare with the discussion in subchapter 3.8 24
about *pointless space*.) In contrast, the second term under the square root is proportional to r_0^4, which means that a muon attracts an electron

stronger than the electron attracts the muon. Such a force isn't physically allowed. Therefore, Eq. (4.28) has to be modified. It's done by writing the square root as a series in which all terms containing higher powers of r_0 than r_0^2 are omitted. The result is a series, which may be summed up as

$$E = m_0c^2\left(1-\frac{r^2}{R^2}\right)^{1/2}\left[1-N\left(1-\frac{r^2}{R^2}\right)^{-1}\frac{r_0^2}{Rr}\right]. \tag{4.29}$$

Proof. Equation (4.28) gives, with $x = r^2/R^2$ and $a = Nr_0^2/Rr$ and omission of a^2 and higher powers of a,

$$\begin{aligned}
E/m_0c^2 &= [1-(a^2/x+2a+x)]^{1/2} \rightarrow [1-(x+2a)]^{1/2}\\
&= 1-\frac{1}{2}(x+2a)-\frac{1}{2\cdot 4}(x+2a)^2-\frac{1\cdot 3}{2\cdot 4\cdot 6}(x+2a)^3\\
&\quad -\frac{1\cdot 3\cdot 5}{2\cdot 4\cdot 6\cdot 8}(x+2a)^4-\cdots\\
&\rightarrow 1-\frac{1}{2}(x+2a)-\frac{1}{2\cdot 4}(x^2+2x\cdot 2a)-\frac{1\cdot 3}{2\cdot 4\cdot 6}(x^3+3x^2\cdot 2a)\\
&\quad -\frac{1\cdot 3\cdot 5}{2\cdot 4\cdot 6\cdot 8}(x^4+4x^3\cdot 2a)-\cdots\\
&= 1-\frac{1}{2}x-\frac{1}{2\cdot 4}x^2-\frac{1\cdot 3}{2\cdot 4\cdot 6}x^3-\frac{1\cdot 3\cdot 5}{2\cdot 4\cdot 6\cdot 8}x^4-\cdots\\
&\quad -a\left(1+\frac{1}{2}x+\frac{1\cdot 3}{2\cdot 4}x^2+\frac{1\cdot 3\cdot 5}{2\cdot 4\cdot 6}x^3+\cdots\right)\\
&= (1-x)^{1/2}-a(1-x)^{-1/2}\\
&= \left(1-\frac{r^2}{R^2}\right)^{1/2}-N\left(1-\frac{r^2}{R^2}\right)^{-1/2}\frac{r_0^2}{Rr}.
\end{aligned}$$

The square root in Eq. (4.29) may be written as $(1-v_{\text{exp}}^2/c^2)^{1/2}$, where v_{exp} is the universe's rate of expansion at a distance r from the observer. Now, according to the theory of special relativity, the motion of the particle away from the observer means that its rest energy m_0c^2 is replaced with $m_0c^2(1-v_{\text{exp}}^2/c^2)^{-1/2} = m_0c^2 + \frac{1}{2}m_0v_{\text{exp}}^2 + \ldots$. Consequently, Eq. (4.29) contains a factor, which cancels the kinetic energy caused by the expansion of the universe.

An alternative interpretation of the result is obtained if one leaves out the square root from Eq. (4.29) and concludes that the universe's expansion does not generate kinetic energy. This more practical interpretation means that Eq. (4.29) is replaced with

$$E = m_0c^2\left[1-N\left(1-\frac{r^2}{R^2}\right)^{-1}\frac{r_0^2}{Rr}\right], \tag{4.30}$$

whose second term gives rise to a force, $F = \mathrm{d}E/\mathrm{d}r = m_0\,\mathrm{d}U/\mathrm{d}r$, with the *gravitational potential*

$$U = -Gmr^{-1}\left(1-\frac{r^2}{R^2}\right)^{-1} \tag{4.31}$$

caused by a mass m at a distance r from m_0. The force becomes repulsive when r exceeds the distance to the *turning point*, $r_{tp} = R/\sqrt{3} = 0.577\,R$

Proof. According to Eq. (4.31), the force between the masses m and m_0 is

$$\begin{aligned}
F = m_0 \frac{\mathrm{d}U}{\mathrm{d}r} &= G\, m_0\, m \frac{\mathrm{d}}{\mathrm{d}r}\left[-r^{-1}\left(1-\frac{r^2}{R^2}\right)^{-1}\right] \\
&= G\, m_0\, m \left[r^{-2}\left(1-\frac{r^2}{R^2}\right)^{-1} + r^{-1}\left(1-\frac{r^2}{R^2}\right)^{-2}\frac{-2r}{R^2}\right] \\
&= G\, m_0\, m \left[r^{-2}\left(1-\frac{r^2}{R^2}\right) - 2R^{-2}\right]\left(1-\frac{r^2}{R^2}\right)^{-2} \\
&= G\, m_0\, m\, r^{-2}\left(1-3\frac{r^2}{R^2}\right)\left(1-\frac{r^2}{R^2}\right)^{-2},
\end{aligned}$$

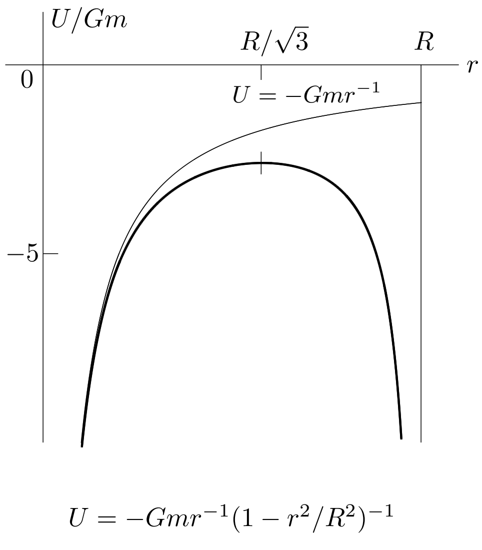
which means that $F \leq 0$ for $r \geq R/\sqrt{3}$.

In all practicable measurements of gravity's strength, r^2/R^2 in Eq. (4.31) may be set equal to zero, which leads to *Newton's gravitational potential*

$$U = -Gmr^{-1}. \tag{4.32}$$

The calculation shows that the attraction changes to repulsion over very large cosmic distances ($r > R/\sqrt{3} = 0.577\, R$, where R is the radius of the universe). This means that the particle model is internally consistent. Because the force of gravitation results from the expansion, it cannot affect the overall, large-scale expansion of the universe — globally, the force must balance itself so that the repulsion over very large distances compensates for the attraction over shorter distances.

The figure shows the gravitational potential (4.31) derived from the flow equation and, for comparison, the Newtonian potential $U = -Gm/r$:



$U = -Gmr^{-1}(1 - r^2/R^2)^{-1}$

Notice that the steeper the slope (or gradient) of U is, the stronger is the force $F = m\mathrm{d}U/\mathrm{d}r$ exerted by the potential on a mass m.

To sum things up: a very simple equation, which mathematically expresses the law of conservation of momentum, explains the origin of charge and energy, spin, gravity, and the expansion of the universe. In addition, the equation eliminates the need to introduce a fifth force at the same time as it predicts that the expansion will continue forever at a steadily decreasing rate. Thus, the first three questions in subchapter 3.1 have been answered: 18

1. *Why is there a gravitational force?*
2. *Why is the universe expanding?*
3. *What governs the expansion of the universe?*

I thought that the equation I had discovered was so interesting that it should "sell" itself. It didn't. In spite of repeated attempts over several years, I didn't find any established physicist willing to discuss it with me.

> Looking at Eq. (4.21), a new question comes to mind. Is it conceivable that the equation, in addition to describing the unobservable space, might find practical use in physics? Since the equation in its new interpretation lacks references to molecules and heat, maybe it could be useful in low-temperature physics? Perhaps it might be used to describe *superfluids* (so-called *Bose–Einstein condensates* formed by liquid helium near absolute zero or by the electrons in a superconductor) in which the "molecules" (that is, atoms or electrons) have lost their individuality? 33

On the next page, I try to briefly summarize what the flow equation can tell about nature after the pressure p has been eliminated from it and replaced by the number of degrees of freedom, f.

4.4 What the flow equation reveals about nature

$$\frac{\partial \boldsymbol{v}}{\partial t} - \boldsymbol{v} \times (\nabla \times \boldsymbol{v}) + \frac{1}{2}\nabla \boldsymbol{v}^2 + \frac{1}{\rho}\nabla p = 0$$

Flow equation for a nonviscous
fluid in the absence of external forces

$$\frac{\partial \boldsymbol{v}}{\partial t} - \boldsymbol{v} \times (\nabla \times \boldsymbol{v}) + \frac{1}{2}v_0^2\, \nabla \left(\left(\frac{\boldsymbol{v}}{v_0}\right)^2 + f\left(\frac{\rho}{\rho_0}\right)^{2/f} \right) = 0$$

The **pressureless** form of the flow equation

$$\rho = \rho_0 \left(1 - \frac{1}{f}\frac{v^2}{v_0^2}\right)^{f/2}, \quad f = 3,\, 2,\, 1$$

A pressureless **stationary** solution

characterized by

$\underline{B = 0.666\ 001\ 731\ 498}$

No pressure = no heat = no molecules = no reference points
= position, distance, and direction undefinability
= quantum indeterminacy

$f = 3$: charge e, energy $E = mc^2$
$f = 2$: spin $\frac{1}{2}\hbar$, magnetic moment
$f = 1$: expansion with $dV/dt \propto E$, gravitation with $U = -Gmr^{-1}(1 - r^2/R^2)^{-1}$

4.5 The electron-structure constant

What I managed to do over the years was to compute the electron-structure constant B with ever greater accuracy as the memory capacity of computers increased.

When the velocity v is taken into account, the equation that defines B becomes so complicated that it has to be solved numerically. This is done by transforming it into a matrix equation with the accuracy of its solution dependent on the size of the matrix.

When v is taken into account, Eq. (4.24) takes on its final form, 33

$$\rho = \rho_0 \left(1 - \frac{v^2}{v_0^2}\right)^{1/2} \left(1 - \frac{1}{2}\frac{u^2}{u_0^2}\right) \left(1 - \frac{1}{3}\frac{w^2}{w_0^2}\right)^{3/2} . \tag{4.33}$$

As before, it holds that $w = \pm w_0 r_0^2/r^2$ and $u = u_0 r_0/r \sin\theta$. In contrast, v, which describes how space is generated within the electron and flows out from it, cannot be explicitly defined. The amount of space that is continuously created is assumed to be proportional to the energy density. It means that the *equation of continuity* of vector analysis may be written as $\nabla \cdot (\rho \boldsymbol{v}) = \rho_0 A \,\mathrm{d}E/\mathrm{d}V$, where $A = 4\pi r_0^2/m_0 c$. By applying *Gauss' divergence theorem* to this equation, it can be written in the form of an elliptic partial differential equation in two dimensions. The equation determines a scalar function, f, defined via $B\boldsymbol{v} = -v_0 r_0 \nabla f$. The value of f, and thereby the value of v^2/v_0^2, is calculated numerically at a
large number of points, after which B is found from Eq. (4.11) with the ratio 30
ρ/ρ_0 given by Eq. (4.33). Using the value $B = 0.669\ 605\ 309\ 417\ 211$ obtained on 41
page 33 as the starting point, an improved value of the constant B is computed. With this value inserted into the differential equation, one obtains a further improved value of the constant. After a few iterations, B gets its final value whose accuracy depends on the number of points in which f is calculated as well as on the precision of the calculations.

In 1968, I computed B on a big computer of the time. I don't find any saved printouts from that year, but as far as I can remember the result was $B = 0.666$. Thanks to the fast development in computer technology, I had eleven years later obtained a 100 times more precise result: $B = 0.666\ 00$. Still later, I computed the constant on my own personal computer (PC). To overcome the restriction caused by the 64-kilobyte memory space of the PC, I developed a program package with the help of which I was able to perform mathematical operations on large matrices stored on the hard disk faster than would have been possible using standard software if there had been room for the same matrices in the memory space of the PC.

After acquiring a second 10-megabyte hard disk, and using all of it as work memory, I concluded in 1987 that B has the value 0.666 0017. To arrive at this value, I had to perform many runs using varying matrix sizes. Because one run typically took a week or two, the project required many months of computer time.

As the PC became faster, and the capacity of its hard disk grew, the accuracy of the result improved. In 1992 the value was 0.666 001 73(1), with the uncertainty of the last digit given in parenthesis (as is customary in physics). In 1994, it was 0.666 001 7315, and four years later I arrived at

$$B = 0.666\ 001\ 731\ 498. \tag{4.34}$$

At that time, the capacity of the hard disk of my PC had increased a thousandfold, from 10 megabyte to 10 gigabyte. I continued to use the PC's DOS operating system with its 64-kilobyte memory spaces, but in addition I now used the computer's extended memory (situated above the 1-megabyte boundary) as temporary storage when I shoveled data to and fro, between the hard disk and the central memory of the PC. Also, since the maximum DOS disk file was 2 gigabyte, I had to add code that made it possible for my band matrix to span five DOS files.

The accuracy of the value in Eq. (4.34) is a thousand times greater than it would have been if I had used the standard precision (8-byte *real*8*, or *double precision*) of the Fortran compiler. I managed to obtain the greater accuracy by writing assembler routines in which I utilized the internal *tenbyte* precision of the PC's floating-point instructions.

4.6 The muon–electron mass ratio

When v is taken into account, the theoretical ratio between the muon and electron masses increases further, and is (with recent values for B, α, and m_μ/m_e)

$$m_\mu/m_e = 1/B\alpha = 205.759\ 22, \tag{4.35}$$

or barely 0.5 percent less than the observed value of 206.768 28(1).

I found it fascinating that multiplication of the value in Eq. (4.35) by a simple series in powers of $B\alpha$ leads to a value,

$$\begin{aligned} &(1/B\alpha)[1 + B\alpha + 2(B\alpha)^2 \pm \cdots] \\ &= 1/B\alpha + 1 + 2B\alpha \pm \cdots \\ &= 206.769, \end{aligned} \tag{4.36}$$

close to the observed ratio 206.768. Still, for a long time I tried to find other explanations for the difference between the two values — without success.

In 1990, 24 years after my discovery of the pressureless space equation, I once again begin to wonder about the role of the constant B in physics. By now, physicists have already determined the experimental value of the *electron anomalous moment*, a_e, with high precision. With equally good accuracy, they have managed to compute its theoretical value in the form of a series,

$$a_e = A_2\,\alpha/\pi + A_4(\alpha/\pi)^2 + A_6(\alpha/\pi)^3 + \ldots, \tag{4.37}$$

in powers of the fine-structure constant $\alpha \approx 1/137$. Alternatively, since α is proportional to e^2, Eq. (4.37) is said to be the sum of second-order, fourth-order, sixth-order, etc. contributions to a_e.

In the series (4.37), only the values $A_2 = 1/2$ (value calculated in 1947 and published in 1948, but misprinted as $a_e = \frac{1}{2}\pi$ instead of $1/2\pi$) and $A_4 = \frac{197}{144} + \frac{1}{2}\zeta(2) + \frac{3}{4}\zeta(3) - 3\zeta(2)\log 2 = -0.328\ 478\ 966$ (value miscalculated in 1950, correct value published in 1957) are exactly (or analytically) known. The *zeta function* appearing in the expression for A_4 is the sum of an infinite series,

$\zeta(n) = 1 + 1/2^n + 1/3^n + 1/4^n + \ldots$, when n is an integer. Note that $\zeta(1) = \infty$. For even n, $\zeta(n)$ may be expressed in powers of π: $\zeta(2) = \pi^2/6$, $\zeta(4) = \pi^4/90$, $\zeta(6) = \pi^6/945$, etc.

In 1990, the coefficients A_6 and A_8 have been determined through numerical computations of integrals in up to 7 and 10 dimensions, respectively. They are said to be $A_6 = 1.176\ 11(42)$ and $A_8 = -1.434(138)$.

Not until 1996 will mathematicians and physicists by united and massive efforts manage to analytically determine the third coefficient, which turns out to be

$A6 = \frac{28259}{5184} + \frac{17101}{135}\zeta 2 + \frac{139}{18}\zeta 3 - \frac{596}{3}\zeta(2)\log 2 - \frac{239}{24}\zeta(4) + \frac{100}{3}(a_4 + \frac{1}{24}\log^4 2)$
$-\frac{25}{3}\zeta(2)\log^2 2 - \frac{215}{24}\zeta(5) + \frac{83}{12}\zeta(2)\zeta(3) = 1.181\ 241\ 457,$

where $a_4 = \sum_{k=1}^{\infty} 1/2^k k^4 = 0.517\ 479\ 061$.

The result shows that the estimated uncertainty in the 1990 value was much too small. Also the fourth coefficient will be seen to have a far too optimistic margin of error. In 2007, its value is given as $A_8 = -1.9144(35)$, at the same time as the fifth coefficient of the series is estimated to be $A_{10} = 0.0(3.8)$.

Via numerical experiments, I think I have found an alternative and very simple series for a_e in powers of $B\alpha$, which I summarize as

$$a_e = \frac{B\alpha}{\pi} - \frac{1}{4}\frac{B\alpha/\pi}{1 - B\alpha/\pi}. \tag{4.38}$$

That my guess cannot possibly be correct, I don't understand. Instead I'm fascinated by the thought that it might be true, and again start thinking about my particle model and experimenting with various equations. It's now I realize that the law of conservation of energy must have forced the two lightest particle generations (in the form of the muon and electron) to appear. Thereby, I have found the answer to the fourth question in subchapter 3.1: 18

4. *Why does the electron come in three weights?*

After new futile attempts to draw the interest of physicists to my particle model, I have to accept that no one else than I myself is interested in my discoveries. If I want to know how the world functions, I have to find it out myself. To get any further, I must on my own investigate how the pieces I have discovered fit into the big puzzle of physics. And to be able to do this, I have to learn physics.

4.7 Physics for dummies — Feynman diagrams

By now, in the year 1993, everything I learned about physics 30 years earlier has evaporated.

I begin my physics studies in a library cellar where I spend the days systematically scanning through the library's collection of physics journals from 1970 and onward. I copy everything that looks interesting from my point of view. In particular, I'm fascinated by articles describing progress made in the determination of the electron's anomalous magnetic moment, a_e, with constantly improving accuracy — a never-ending job, which had begun in 1948; continues with the help of ever more powerful super computers; and doubtless will continue for many decades to come.

The text at the beginning of the articles is often easily understood. However, the equations I seldom understand. Neither do I understand the Feynman diagrams, which illustrate the various contributions to a_e. And it will take me a few years before I learn to interpret them correctly.

Afterward, I find it hard to understand why it was so difficult. In reality, **!**
the diagrams are simple and easy to understand. In addition, they give exactly **!**
the basic knowledge of physics that everybody should have the right to learn. This is how it is:

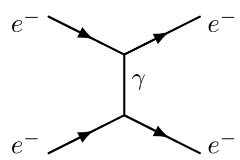
Matter — which stars, planets, and you and I consist of — is built from *atoms*. Every atom consists of a heavy *nucleus* surrounded by a *shell* of electrons. The nucleus gives the atom its weight, but is otherwise of little interest. Phenomena we experience in everyday life are almost always caused by electrons moving to and fro and sending out photons which, depending on their energy, may be used for wireless communication (such as radio, TV, and mobile telephoning); be felt as heat radiation or seen as visible light; or be used in X-ray examinations, etc.

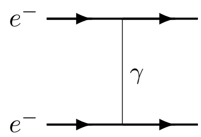
As far as I can understand, chemical reactions are caused by electrons that change their orbits in atoms and molecules. That's what my present knowledge of chemistry is restricted to.

When you fall and hurt yourself, it's gravity that does the job. But the shock you feel is caused by electrons in the molecules of the ground and your skin coming close to each other. The pain is mediated by electrons, the black and blue color of the bruises are the work of electrons, etc. However, there is one point that isn't self-evident:

electrons cannot directly collide with each other;

they never touch each other. It's because the repulsive force between (the negatively charged) electrons is mediated by unobservable, so-called *virtual photons*. This is how one may graphically describe how two electrons repel each other:



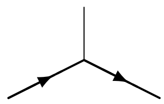


The figure to the left shows how the electrons first approach each other, and then repel each other with the aid of a photon fired from one electron to the other. To the right, the same diagram is shown without indicating the change of path of the electrons.

For simplicity, I use continuous lines for both the electron and photon instead of the wavy or dashed lines that are customarily used to denote photons. But often, as in the figure to the right, I try to distinguish the particles by using a thinner line for the massless photon.

Quantum electrodynamics, QED, is the theory of electromagnetism. In other words, QED is the part of quantum physics that describes the electron (including the electron's heavy varieties, the muon μ and tauon τ) and its interaction with the photon.

The diagrams of QED are built from a single building block — a so-called *one-photon vertex*, which looks like this:



The vertex shows an electron, which emits or absorbs a photon. By twisting and turning the vertex, it may be used to describe all imaginable electromagnetic processes. For instance:

where the two diagrams to the left show an electron, which absorbs and emits a photon, respectively, and the right diagrams correspondingly illustrate how an antielectron (a so-called positron, e^+) absorbs and emits a photon.

Note that the arrows in the figure don't show the direction of motion of the particles, but that an arrow pointing to the right denotes a particle, while a left-pointing arrow indicates an antiparticle.

> This convention results from the fact that the mathematical description of QED demonstrates that a positron may be regarded as an electron moving backward in time — a phenomenon called *CPT invariance*, where C stands for *charge*, P for *parity*, and T for *time*. It means that if one has an equation that describes an electron (e^-) in spin state $+1/2$ and replaces the time t with $-t$, then on gets an equation that describes a positron (e^+) in spin state $-1/2$.

A photon may also split into an electron pair (short for electron–antielectron, or electron–positron pair). Conversely, an electron (e^-) and a positron (e^+) may collide and *annihilate* each other, forming a massless photon:

The reason why the photon line has no arrow is that the photon doesn't have an antiparticle. Alternatively, one often says that the photon is its own antiparticle even though two photons are unable to collide and annihilate each other, which a charged particle and its antiparticle may do. (The same holds for the neutral

Higgs particle (H) and the neutral Z particle (Z^0), which have no antiparticles, and which interact with the electron in a similar manner as the photon (γ) does.)

Particles and antiparticles. The elementary particles (u and d quarks and the electron) that build up matter are (unlike bosons with integer spin) fermions with spin 1/2: u (or $u^{+2/3}_{1/2}$ — here I depart from established practice by indicating the particle's charge and spin), d (or $d^{-1/3}_{1/2}$), and e^- (or $e^-_{1/2}$). The atomic nucleus is built from protons and neutrons. Also these so-called *nucleons* are fermions. The nucleons consist of quarks, p (or $p^+_{1/2}$) $= uud$ and n (or $n^0_{1/2}$) $=$ ddu, which are held together by *gluons*.

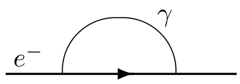
In some cases, the particle's antiparticle is denoted by a horizontal bar on top of the symbol: $\bar{u}$, $\bar{d}$, $\bar{p}$ ($\bar{u}\bar{u}\bar{d}$), and $\bar{n}$ ($\bar{d}\bar{d}\bar{u}$). For charged particles other than the proton, one indicates their charge, writing for example e^+ (instead of $\bar{e}$ — a symbol I can't recall I've seen before).

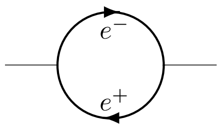
The force-mediating elementary particles, or *gauge bosons*, are $\gamma = \gamma^0_1$ (the photon), $H = H^0_0$ (the Higgs particle), $Z = Z^0_1$, $W = W^{\pm}_1$, and eight neutral massless gluons ($g_1, \ldots, g_8$) with spin 1. W^+ and W^- are the antiparticles of each other. Unlike the rest of the elementary particles, the neutral gauge bosons have no antiparticles. It may be added that some theories predict that the gravitational force is mediated by a massless gauge boson, the so-called *graviton*, $G = G^0_2$.

Spin. The electron has two spin states, $-1/2$ and $+1/2$. The heavy Z^0 particle may be regarded as a kind of massive photon. Like other massive spin-1 particles, it has three spin states: -1, 0, and $+1$. This means that the electron is able to emit a Z^0 particle in spin state $+1$ or -1 by flipping its spin from $+1/2$ to $-1/2$ or from $-1/2$ to $+1/2$, respectively. It may also emit a Z^0 particle in spin state 0 without changing its own spin state.

When it comes to the photon, the situation is more complex. Due to its lack of mass, the photon can only be in spin state -1 or $+1$. But, thanks to a property called *orbital angular momentum* (that is, rotation in an orbit instead of around a spin axis), which can "neutralize" its *spin angular momentum*, the photon is able to carry zero *total angular momentum* (its total rotation adding up to zero). Consequently, the electron can, without changing its angular momentum, emit photons as well as Z^0 and Higgs bosons. Also, it's worth noticing that the photon's spin cannot be directly observed, but that the observable property of the photon is its polarization, which is a mix between the photon's spin and its orbital angular momentum.

With the help of two building blocks, one may construct a so-called *self-mass*, or *self-energy* diagram, which illustrates how an electron (or any charged elementary particle) emits a virtual photon, which it quickly recaptures. Or, one may draw a diagram that shows how a photon forms a *vacuum-polarization (v-p) loop* consisting of an electron pair (or a pair of any charged particle and its antiparticle) of short duration:





Energy. A common misunderstanding is that energy may appear out of nowhere, exist for a short time, and then disappear. But in reality, energy is always conserved. Instead, the Heisenberg *uncertainty principle*, $\Delta E\,\Delta t \geq \frac{1}{2}\hbar$, says that a particle for a brief moment may exist with an energy that differs from its normal energy and even may be negative. For the vacuum-polarization loop, it means that if the energy of the incoming photon is vanishingly small, then one of the electrons in the pair gets positive energy and the other an equally large negative energy.

It wasn't easy for me to arrive at the above summary of the basics of elementary particle physics. It took me nearly 15 years. Above all, the photon's *spin* and its *orbital angular momentum* caused me a headache. And today I've already forgotten (if I ever learned) the answer to the question: Do photons always possess *orbital angular momentum*?

4.8 The electron anomalous magnetic moment

If one imagines the electron as an electrically charged ball rotating around its axis, it should — according to the laws of classical physics — form an electromagnet with the *gyromagnetic ratio* $\gamma_e = -e/2m_e$ between the electron's *magnetic moment* and its *spin angular momentum*.

A more realistic way of looking at the electron is to imagine it as a cloud of virtual photons surrounding a hole in space. Compare with the discussion in the deviation on page 34.

The experimentally measured value of the gyromagnetic ratio of the electron is more than twice as large as the theoretical value obtained from classical physics. The first quantum theoretical calculation of the ratio was done in 1928 and gave the value

$$\gamma_e = g_e \frac{-e}{2m_e} = \frac{-e}{m_e}, \tag{4.39}$$

where $g_e = 2$ is the *gyromagnetic factor* of the electron.

The figure to the left shows the Feynman diagram that gives the quantum mechanical *zeroth-order value* $g_e = 2$:

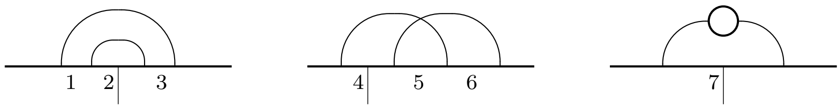
The diagram to the right corrects the value upward. This *second-order correction* turns out to be α/π. See deviation following Eq. (4.37). The correction 42
is said to be of second order because the corresponding *self-mass diagram* (diagram without incoming photon) is built from two *vertices* (see page 45), each one proportional to the electron's charge e (which is proportinal to $\sqrt{\alpha}$).

Commonly, one talks about the electron's *anomalous magnetic moment* a_e defined via

$$\gamma_e = \frac{-e}{m_e}(1 + a_e). \tag{4.40}$$

Occasionally, physicists instead use the term *electron* $(g-2)$, which is $g_e - 2 = 2a_e$. Together, the above two diagrams give $g_e = 2 + \alpha/\pi = 2.002\ 3228$, or $g_e - 2 = \alpha/\pi = 0.002\ 3228$ and $a_e = A_2\,\alpha/\pi = \alpha/2\pi = 0.001\ 1614$, respectively. Compare with Eq. (4.37), where the *fine-structure constant* α has the value 42
1/137.035 999.

The fourth-order contributions have four *vertices* in their three self-mass diagrams. These diagrams give a total of seven corrections to a_e, since in two of them the photon from the external magnetic field may hit the electron in three different points:



Note that, instead of hitting the electron line, the photon from the magnetic field may hit one of the electrons showing up in the v-p loop, but that the *Furry theorem* says that an electron loop from which an odd number of photon lines emanate does not contribute to physical processes, and may be ignored. Consequently, the first so-called *light-by-light graphs* are to be found among the 72 sixth-order diagrams that contribute to A_6.

The contributions to A_4 from the fourth-order diagrams are
$A_4^1 = A_4^3 = \frac{11}{48} - \frac{1}{6}\zeta(2) + \frac{1}{2}\log\lambda = -0.044\ 989\ 011 + \frac{1}{2}\log\lambda$,
$A_4^2 = \frac{11}{48} + \frac{1}{3}\zeta 2 = 0.777\ 478\ 022$,
$A_4^4 = A_4^6 = -\frac{67}{48} + \frac{1}{6}\zeta(2) - \frac{1}{4}\zeta(3) + \zeta(2)\log 2 - \frac{1}{2}\log\lambda = -0.282\ 010\ 471 - \frac{1}{2}\log\lambda$,
$A_4^5 = \frac{1}{6} + \frac{13}{6}\zeta(2) + \frac{5}{4}\zeta(3) - 5\zeta(2)\log 2 = -0.467\ 645\ 446$, and
$A_4^7 = \frac{119}{36} - 2\zeta(2) = 0.015\ 687\ 422$,
which sum up to $A_4 = \frac{197}{144} + \frac{1}{2}\zeta(2) + \frac{3}{4}\zeta(3) - 3\zeta(2)\log 2 = -0.328\ 478\ 966$.

The infinite terms containing $\log\lambda$ (where λ is the so-called *cut-off mass* of the photon, and $\log\lambda = \log 0 = -\infty$, since the mass of the photon is zero) cancel each other via a procedure called *renormalization*, which complicates calculations in QED.

With the help of the analytically known coefficients $A_2 = 0.5$, A_4, and $A_6 = 1.181\ 241\ 457$ (given on page 43) together with the numerically computed $A_8 = -1.9144(35)$, one gets $a_e^{(e)} = A_2\, \alpha/\pi + A_4(\alpha/\pi)^2 + A_6(\alpha/\pi)^3 + A_8(\alpha/\pi)^4 = 0.001\ 161\ 409\ 733 - 0.000\ 001\ 772\ 305 + 0.000\ 000\ 014\ 804 - 0.000\ 000\ 000\ 056 = 0.001\ 159\ 652\ 176$ (with the last digit uncertain in the first term and in the sum) when only vacuum-polarization loops formed by the light electron itself are taken into account. The same result is obtained for the two heavy electrons if only muon loops and tauon loops, respectively, are considered:

$$a_e^{(e)} = a_\mu^{(\mu)} = a_\tau^{(\tau)} = 0.001\ 159\ 652\ 176 \tag{4.41}$$

The heavier the particle pair is in a *v-p loop*, the smaller is its contribution to the electron anomalous magnetic moment. This means that the contributions to a_e from other particles than the light electron itself are very small compared to $a_e^{(e)}$. Conversely, it holds that the e^+e^- pairs give a comparatively large contribution to a_μ, and an even larger contribution to a_τ. The contributions from the $\mu^+\mu^-$ pairs to a_τ are relatively large, too.

The contributions from pairs of weakly interacting particles are small, since the H, W, and Z bosons are very heavy. The contributions from pairs of strongly interacting quarks are larger. In addition, they are very difficult to calculate because the series expansion in powers of the coupling constant that works so well in QED (*quantum electrodynamics*, which is the theory of electromagnetic interaction) doesn't work in QCD (*quantum chromodynamics*, which is the theory of strong interaction).

It is worth mentioning that the *pure QED* hypothesis says that the polarization loops, all of which contribute to the value of the anomalous magnetic moment a, do not contribute to the mass of the electron.

> Intuitively, one might think that this is self-evident. Free photons move, as we know, always with the speed of light, c. This means that the polarization loops that appear in the *propagator* of the free photon do not give the photon any mass. And, if the polarization loops in the propagator of a real photon do not create mass, why should polarization loops appearing in the propagators of virtual photons do so?

4.9 Learning physics

I began my physics studies from scratch by laboriously plowing through my old textbook in classical *theoretical physics*, a thick book of nearly 900 pages, which also introduces the reader to the mathematics behind the theories. According to my notes, it took me a little more than three months. Ten hours a day, seven days a week during 13 weeks adds up to 910 hours. That is, not much more than one hour per page.

Next, I studied selected pages of a 500-page book summarizing *particle physics and cosmology* without any ambition to understand all the details.

After that, I felt it was time to turn to quantum theory. In a university library I found a book dealing with *quantum electrodynamics* that didn't look too difficult. As a remembrance of the three months I spent working on this book, I have a bunch of pages containing handwritten notes. I weigh the notes: 560 grams at 3.5 g per page makes 160 pages. Also, the notes show that I read 299 out of the 336 pages of the book.

> I can't learn much only through listening or reading. If I want to remember what I have just read, I have to make notes and write down by hand every equation together with its detailed derivation. My working memory appears to be related to my fingers — it seems to be a kind of motoric memory.

Then, I read a book about "*diagrammatica*", after which I began to study the "QED bible" in two volumes, which I now discovered — 30 years after it was published at a time when I without success was trying to learn QED from an older book that didn't contain anything about diagrams.

> **Renormalization.** In quantum electrodynamics (that is, QED), mathematical infinities show up all the time. One gets rid of them by subtracting infinities from each other — simply and easily one would think. It's called (*renormalization*). However, to my mind, the process was neither simple nor easy. I never managed to understand neither the theory of renormalization nor the derivation of the equations used in it. Still, after a couple of years of practical (that is, numerical) work with the equations, I learned how to get rid of the infinities in practice. A series of articles published as early as 1974 described both the theory (which I despite great efforts never fully understood) and its practical use (which I, through even greater efforts, managed to learn).

Now I should have used my fresh knowledge to draw the Feynman diagram which shows how the last muon pair of phase 2 annihilates and reappears as a pair of electrons in phase 3. If I had done that, I would have discovered how the series in Eq. (4.36) continues. But I didn't see the obvious. Ten years would 42
pass before I got the bright idea to draw the diagram.

Instead, I used my knowledge to numerically, on my PC, compute the values of various integrals in QED with great precision and from the results try to conclude what the analytical value of a given integral might look like.

> It was like numerically calculating the integrals belonging to the seven diagrams that contribute to the coefficient A_4 in the series $a_e = A_2\,\alpha/\pi + A_4(\alpha/\pi)^2 + A_6(\alpha/\pi)^3 + \ldots$ for the *anomalous magnetic moment* of the electron (see the mathematical deviation on page 42) and from the resultat, $A_4 = -0.328\ 479$, infer that the exact analytical value has to be $\frac{197}{144} + \frac{1}{2}\zeta(2) + \frac{3}{4}\zeta(3) - 3\zeta(2)\log 2$.

I even got an article published in the biggest journal in theoretical physics. Naively, I figured that the article would open up the road ahead and be the first in a series of articles in which I was planning to explain my findings.

Soon after my article had been accepted for publication, I found another important piece of the puzzle. I thought that the difference, 1.009 06, between the measured value 206.768 28 and my calculated value 205.759 22 of the ratio between the muon and electron masses — see Eq. (4.35) — might be due to an 42
effect caused by weak interactions. Consequently, I decided to investigate the idea.

After my earlier attempts to understand the theory of weak interactions had failed, I didn't have much hope that I would succeed this time, either. But luckily I found textbooks of a different sort. It turned out that one and the same author had published a whole series of books, alone or in collaboration with other physicists. The books were unique in the way that they were designed so that ordinary readers like me could understand everything. When other textbooks leave out details in the derivations of equations and give exercises that no student of normal intelligence can solve without the benevolent help of his or her professor, these books are "self-contained". They help the reader overcome all difficulties by showing how every equation is derived and every exercise solved.

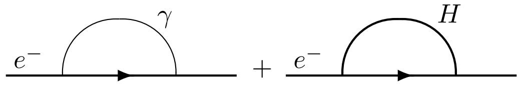
4.10 The Higgs particle

After I finally got the book about *gauge theory of weak interactions* in my hand — I had to wait some months before the coming new edition of it could be ordered from the publisher — I picked up paper and pencil and began my work. It turned out that, out of the book's 400 pages, it sufficed to read until page 178. There, I found the information I was looking for. I noted that there was but one particle that might be able to produce the mass correction I was hunting for. This was the *Higgs particle* H, which is also known as the *Higgs boson*.

> **Bosons** are particles with integer spin (0, 1, 2, ...). The Higgs particle (H) has spin 0, while the photon has spin 1. In analogy with the "Higgs boson", one might call the photon (γ) a "gamma boson", or "light boson".

A look at the Feynman diagrams, which picture how elementary particles in- 95
teract with each other, reveals that the diagrams that describe how the Higgs particle and the photon interact with the building blocks of matter — electrons and the up and down quarks of the atomic nuclei — look exactly the same. See
Appendix A.2. This means that the Higgs particle may be seen as a kind of 96
photon that, unlike the familiar photon (or light particle), has mass but lacks spin and polarization.

The *self-mass* diagrams in the figure show the main contributions from the photon and the Higgs particle to the mass (or self-energy) of the electron:



For the sum of the *bare mass* (m_0) of the electron, which is graphically described by an *undressed* straight line, and the contributions to its *self-mass* (δm) shown in the figure, I obtained the expression

$$m = m_0 + \delta m(\gamma) + \delta m(H) = m_0 + \frac{3}{2\pi}\left(\ln\frac{\Lambda}{m}\right)\left[\alpha - \frac{G_F m^2}{4\sqrt{2}\pi}\right] m, \qquad (4.42)$$

where m is the *renormalized mass* of the electron. In the equation, α is the fine-structure constant and G_F the *Fermi coupling constant*, which is a measure of the strength of the weak force in a similar way as α is a measure of the strength of the electromagnetic force. Λ (*Lambda*) is a so-called *cut-off mass*, which tends to infinity in the calculations.

> One may ask why γ and H should have the same cut-off mass, Λ. The answer is that they may well have cut-off masses that differ from each other and from Λ of Eq. (4.42) as long as all of them are proportional to each other. With, say, $\Lambda_\gamma = k_\gamma \Lambda$ and $\Lambda_H = k_H \Lambda$, the divergent factors become $\ln(k_\gamma \Lambda/m) = \ln(\Lambda/m) + \ln k_\gamma$ and $\ln(k_H \Lambda/m) = \ln(\Lambda/m) + \ln k_H$, respectively. And, since the finite terms $\ln k_\gamma$ and $\ln k_H$ are negligibly small in comparison with the infinite term $\ln(\Lambda/m)$, they fall out from the expression in Eq. (4.42), which only shows the leading, infinite self-mass contributions.

In standard QED theory, the electron's bare mass m_0 (described by a single straight line) also tends to infinity, which means that — being the sum of two infinite terms — Eq. (4.42) is totally nonsensical.

The situation changes if one reintroduces the *pure-QED* hypothesis proposed in 1963, which says that the electron's bare mass (also called *naked mass* or *mechanical mass*), is zero.

> I can't understand why, at the time, physicists didn't apply the pure-QED hypothesis to equation (4.42). If they had done that, they would have arrived at the same conclusion as I did several decades later. Compare with my discussion in the deviation beginning on page 34. 34

Setting $m_0 = 0$ in Eq. (4.42), one finds that the contributions from the Higgs particle and the photon to the electron mass are related to each other as $-G_F m^2/4\sqrt{2}\pi$ to α, or

$$\frac{\delta m(H)}{\delta m(\gamma)} = -\frac{G_F m^2}{4\sqrt{2}\pi\alpha}. \tag{4.43}$$

When I noticed that the Higgs particle gave a negative contribution to the mass of the electron, I refused to believe it at first. But when I repeated my calculation, I again arrived at the same result.

> That the Higgs particle should give a negative correction to the mass of the electron may seem odd. And, in fact, the correction isn't negative, but positive. The minus sign in Eqs. (4.42) and (4.43) should, consequently, be changed to a plus sign. However, it would take 11 years before I discovered that I had made a mistake. And in these 11 years, the minus sign played an important role by first leading me on the right track, and later contributing to a number of stupid mistakes, which it took me a long time to discover and repair.

I had hoped, and wanted to believe, that the contribution of the Higgs particle to the muon–electron mass ratio m_μ/m_e would equal the difference +1.009 06, but to my great disappointment, I found the correction to be −0.000 2076.

After reintroducing $\hbar$ and c, which I according to general practice have put equal to 1, Eq. (4.43) takes the form $\delta m(H)/\delta m(\gamma) = -G_F(\hbar c)^{-3}(mc^2)^2\alpha^{-1}/4\sqrt{2}\pi$ with $G_F(\hbar c)^{-3} = 1.166\ 37(1)\times10^{-11}$ MeV^{-2} and $\alpha^{-1} = 137.035\ 999$. The contribution to m_e is so small that it can be neglected. With $m_\mu c^2 = 105.658\ 37$ MeV, one obtains for the Higgs particle's relative contribution to m_μ the negative value $-1.004\ 05(1)\times10^{-4}$, which means that its absolute contribution to m_μ/m_e is about 206.768 times larger, or $-0.000\ 2076$.

Not only was it much too small, but it had the wrong sign, too, making the discrepancy between theory and experiment even larger than before. I tried to find the error in my calculation, but without success. With my usual quick-wittedness, I concluded after a couple of months that the minus sign might be important. And suddenly the thing seemed crystal-clear. The minus sign must indicate, I reasoned, that the photons lose some of their energy when the weak force emerges together with the strong force — that is, when the quarks appear and form the first proton. And since I already knew that the proton must have originated from the 1836.15 times lighter positron (which is what the positively charged antielectron is commonly called), I had now found how the transformation was energetically possible: the increase in self-energy of the positively charged particle is compensated for by a decrease in photon energy caused by the emergence of the weak force.

I had been looking for an explanation of why my theoretical calculation of the muon mass gave a result that differed from the measured value of the mass. To my great disappointment I had failed. But to my delight (which wasn't as great since the thing was so trivially simple), I had instead stumbled on the explanation of why the weak force originally emerged.

I had concluded that the appearance of the Higgs particle caused the three charged leptons to decrease in mass. (*Lepton* is the common name used for three *charged leptons*; *electron* e, *muon* μ, *tauon* τ and three *neutral leptons*, or *neutrinos*; *electron neutrino* ν_e, *muon neutrino* ν_μ, *tauon neutrino* ν_τ.) Since the photon forms short-lived virtual pairs of charged leptons, a sudden decrease in their mass (or self-energy) leads to a small decrease in the energy of the background photons.

Later, I have wondered why I never understood to ask the self-evident follow-up question: How is the mass lost by the charged lepton transported to the quarks that build the proton? But the fact is that I didn't. Instead, it would take 12 years before I, in a roundabout way, arrived at the equally self-evident answer: It's the Higgs particle itself that handles the mass transport.

A not quite as long time (only ten years) would pass before I made an alternative control calculation which showed that the contribution of the Higgs particle to the mass of the charged lepton in reality is positive, and that my original doubts about the correctness of the minus sign were justified.

To summarize, in 1999 I had through unsystematic but stubborn mathematical experimentation found a good explanation for how a transition from a pure-QED universe (consisting of electrons and photons) to our present universe (with its protons and strong and weak forces) was possible without violating the law of conservation of energy. Thereby, I had found the answer to the fifth question in subchapter 3.1: 18

5. *Why is there a weak force?*

4.11 Efforts to sell the model

The turn of the millennium was approaching. A few years earlier I had set up 31 December 1999 as the deadline by which my contribution to the new particle model should be finished and I would leave it to others to continue where I had stopped. It was true that many open questions remained to be answered. But physics is teamwork, people used to say. And out of the seven fundamental questions listed on page 18, my unfinished model already answered the first five:

1. *Why is there a gravitational force?*
2. *Why is the universe expanding?*
3. *What governs the expansion of the universe?*
4. *Why does the electron come in three weights?*
5. *Why is there a weak force?*

In addition, I had obtained a precise value, $H = 56.8$ km/s/Mpc, for the *Hubble expansion rate* (see Eq. (7.18) on page 19 in physicsideas.com/Paper.pdf).

Therefore, it was only a matter of time, I reasoned, before I would have persuaded the physics community to take a serious look at my results and begin developing the model further. Nine months remained of the old millennium. That should be enough, I thought. However, it would turn out that not even nine years sufficed.

I soon learned that no established physicist or science writer specializing on theoretical physics and cosmology was tempted by the thought that the big-bang theory they knew so well should be replaced by an infinitely (already one verifiable prediction versus zero predictions gives $1/0 = \infty$) much better theory.

In retrospect, it's clear as daylight (although it took me many years to see it) that researchers and writers don't want the knowledge and competence they have acquired through years of study and hard work to suddenly become outdated. Who wants to contribute to a situation where oneself and one's colleagues sit there without funding, or where the popular science journal says no thanks to the article one has written?

The years that followed were filled with frustration. I fought against editors whose job it was to stop all articles that contained ideas that might threaten the established theories.

> A few years were still to pass before I stumbled on the article that explained the behavior of the physicists. When I had read the article and

> digested its message, my anger simmered down. I realized it was little sense in moralizing against nature's second law — the law of change — that steers the world toward ever increasing complexity, causes life to appear where it's possible, and implants the law in the genes of plants and animals with the result that humans strive to make their society more and more complex, and instinctively oppose all attempts to simplify it. And simplification is what my theory implied. Consequently, it was forbidden by the second law of nature.

I had planned to write page upon page about my fight against the establishment. However, I'll refrain from carrying out my plans now when I realize that I had, in effect, been fighting against the second law. I feel that criticizing the law of nature that you have to thank for your existence, and which you can't affect in any way, is fruitless activity.

4.12 The missing piece

In the fall of 2006, the situation seems hopeless. I have managed to get in contact with a few particle physicists with whom I can discuss QED. But none of them wants to even mention the word “cosmology”. I’m pretty sure that they look with skepticism on inflationary cosmology, but that the solidarity between colleagues prevents them from encouraging opponents of the dominating mainstream theory of cosmology.

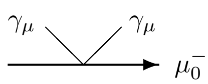
I decide to take a renewed look at my theory and once again try to get a little further on my own. Especially frustrating I find the fact that I have failed in my attempts to theoretically calculate the muon mass. The uncorrected mass ratio, $m_\mu/m_e = 1/B\alpha = 205.759\ 22$, which originally was a pure guess, I have indeed managed to derive theoretically (see Eq. (7.13) on page 17 in physicsideas.com/Paper.pdf). But its deviation, 1.009 06, from the experimentally observed value, 206.768 28, I haven’t been able to explain.

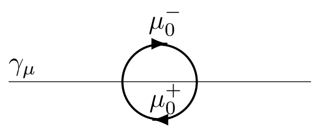
Suddenly, the idea strikes me that I should draw the diagrams that picture the phase transition in which the muon replaces the electron. Drawing diagrams is something you do all the time in elementary particle physics. It had taken me ten years to reckon that it was something I ought to do in this case, too. Talk about quick-wittedness!

I immediately realize that I’m near the answer to the puzzling question as to why the sum $m_\mu/m_e = 1/B\alpha + 1 + 2(B\alpha) = 206.768\ 94$ is so close to the experimental value. It takes me some time, maybe a month because I’ve forgotten so much, to understand the true meaning of the diagrams. After that, it’s clear that the series I’ve been looking for is $m_\mu/m_e = 1/B\alpha + 1 + 2(B\alpha) + 4(B\alpha)^2 + 8(B\alpha)^3 + \ldots$ which may be summed up in the closed form

$$m_\mu/m_e = 1/B\alpha + 1/(1 - 2B\alpha) = 206.769\ 04. \tag{4.44}$$

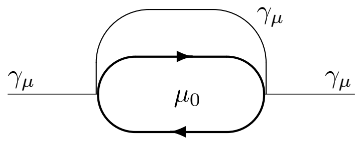
The photon (γ) and electron (e) of phase 3 are the same as today’s well-known particles, which are described by the *one-photon vertex* (page 45). In phase 2, the electron corresponds to the spinless muon (μ_0) whose purely *electric force* is mediated by a photon (γ_μ), which differs from the mediator of the electromagnetic force (the photon γ of today). The interaction between the spinless muon and the phase-2 photon is described by the basic building block shown to the left — a *two-photon vertex*, or *“seagull” diagram*:



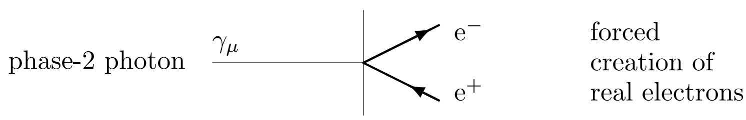


The diagram to the right shows the *“sunset” graph* obtained by coupling together two building blocks after first remodeling the seagull diagram so that the muon line becomes vertical and one of the photon lines point left, the other right. The sunset diagram (which applies in phase 2) describes how the real photon is momentarily transformed into three virtual particles: μ_0^-, γ_μ, and μ_0^+. This particle triplet corresponds to the particle pair of the *vacuum-polarization loop* existing both in phase 3 and today. 47

By letting the photon line that traverses the muon circle make a detour, one may change the appearance of the sunset diagram:

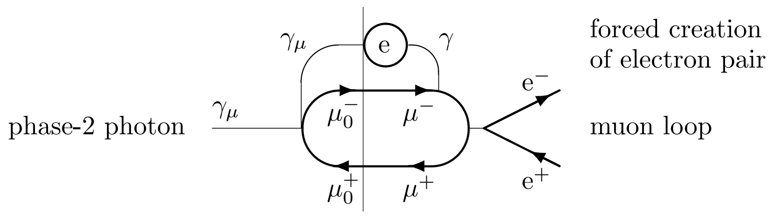


The figure below illustrates the transition from phase 2 to phase 3. The vertical line shows the exact instant when the last mass-bearing muon pair ($\mu_0^+\mu_0^-$) decays into a pair of photons, after which all photons (γ_μ) in the universe materialize as pairs (e^+e^-) of spinning electrons with mass m_e.



Note that the muons of phase 2 are pairwise entangled, and that there is no contact between the pairs. Thus, at the beginning of phase 3, the universe consists of pairwise entangled electron pairs with every pair of particle pairs ($e^+e^-\,e^+e^-$ with total mass $4m_e$) defining a world of its own, which is unaffected by external forces. An important consequence is that the gravitational force does not affect the particles of phase 3.

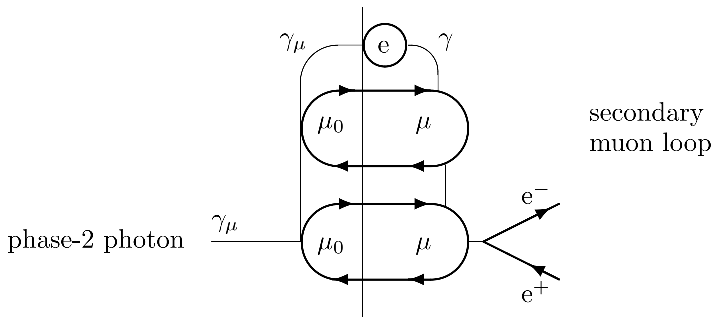
Since the photon of phase 2 doesn't always appear as a single real particle but may form a short-lived system consisting of three virtual particles (illustrated by the sunset diagram), the figure above doesn't tell the whole truth about what happens in the phase transition. In the next figure, the photon forms a three-particle state when the phase transition takes place:



In the phase transition, the muon acquires spin and gets the mass $\bar{m}_\mu$, which is the initial, uncorrected mass of the muon for which holds that $\bar{m}_\mu/m_e = 1/B\alpha$. See Eq. (4.35). Instead of recapturing the muon pair 42
emitted by the photon of phase 2, the (now virtual) photon temporarily rematerializes as a virtual electron pair with total mass $2m_e$, after which

it is absorbed by the spinning muon of phase 3, which thereby receives an additional mass of $2m_e$. Consequently, the virtual muon pair has a mass of $2\bar{m}_\mu + 2m_e$ when it transforms into a photon, which finally materializes in an electron pair of mass $2m_e$. (Remember that the muons of the diagram are virtual, and do not carry any real mass.)

In a third case, the photon emits two pairs of muons in phase 2, and becomes itself absorbed in phase 3 by the muon of the secondary loop:



The materialized mass, $2m_e$, affects the primary muon pair at the bottom of the figure in the proportion $2m_e$ to $2\bar{m}_\mu$ because it is transmitted to the pair via the secondary muon loop (with associated mass $2\bar{m}_\mu$), which transforms into a phase-3 photon (with associated mass $2m_e$). Thereby, the contribution of the diagram to the primary muon loop is $(m_e/\bar{m}_\mu)2m_e$.

Obviously, any number of muon loops may appear in diagrams of the type just described. In the *path integral formulation* of quantum theory, a particle simultaneously takes all possible paths. Therefore, by adding all contributions from the series of diagrams, one obtains $2\bar{m}_\mu + 2m_e + (m_e/\bar{m}_\mu)2m_e + (m_e/\bar{m}_\mu)^2 2m_e + \cdots$ for the mass of the primary muon pair.

(In phase 3, as well as today, α is the *probability amplitude* by which the
terms in a QED series are multiplied before the summation is performed.
Compare with Eq. (4.37). Since α essentially is a measure of the electron– 42
muon mass ratio, which is not defined in phase 2 where the electron e
doesn't exist, the natural phase-2 amplitude is 1.)

For each secondary muon loop that runs clockwise (as in the last example above), there is another loop running anticlockwise (that is, the photon γ may be absorbed by either μ^- or μ^+). Consequently, the contribution to the mass of the primary muon pair from all the diagrams is $2m_\mu = 2\bar{m}_\mu + 2m_e + 2(m_e/\bar{m}_\mu)\,2m_e + 2^2(m_e/\bar{m}_\mu)^2\,2m_e + \cdots$, which means that the mass of the muon of phase 3 (where only virtual muons without real mass exist) is $m_\mu = \bar{m}_\mu + m_e + 2(m_e/\bar{m}_\mu)m_e + 2^2(m_e/\bar{m}_\mu)^2 m_e + 2^3(m_e/\bar{m}_\mu)^3 m_e + \cdots$, or $m_\mu = \bar{m}_\mu + m_e/(1 - 2m_e/\bar{m}_\mu)$. With $\bar{m}_\mu/m_e = 1/B\alpha$, one obtains

$$\begin{aligned} m_\mu/m_e &= 1/B\alpha + 1 + 2B\alpha + 4(B\alpha)^2 + 8(B\alpha)^3 + \cdots \\ &= 1/B\alpha + 1/(1 - 2B\alpha) \\ &= 206.769\,04 \end{aligned}$$

for the QED-corrected muon–electron mass ratio.

Now the difference between the measured and theoretical values is already as low as −0.000 76. In addition, the minus sign suggests that the difference may be explained as a Higgs effect. It is true that my calculation led to a Higgs correction of only −0.000 2076, but if (as some theories predict) there exist four different Higgs particles, the correction becomes −0.000 83 and the theoretical value 206.768 21, which means that the difference between the measured value, 206.768 28, and the theoretical value now is a mere +0.000 07, or 0.3 ppm.

It will later become evident that my belief in the existence of four different Higgs particles results from a flaw in my reasoning. However, it will also be seen that there are four Higgs particles in one — that is, the neutral spinless Higgs boson may show up in four different mass states. In this respect, the Higgs resembles the neutrino which may appear in three mass states.

Experimental physicists spend large sums of money on measuring the anomalous magnetic moment of the muon, a_μ, with as high accuracy as possible. By comparing the result with the theoretically obtained value, one hopes to find hints of what is called *new physics*, small deviations from the so-called standard model of elementary particles (SM). The Higgs particle is sometimes regarded as "new physics" because many theoretical models have been proposed in which the particle differs from the single neutral boson of SM.

In the same way that a_μ gives information about new physics, my theoretical result for the muon mass m_μ yields similar information. Not only does the result indicate that the number of Higgs particles is four, but the remaining small difference ought to be of great interest to physicists doing research in weak interactions. Here they have a clue that is free of charge. However, in the long run the clue will be expensive when the experimentalists want to measure m_μ with still higher precision.

seldom the result of conscious, careful considerations.

4.13 Simulating the early universe

The relief I feel after finally having succeeded in my repeated attempts to calculate the muon mass with high accuracy doesn't last long. My theory hasn't been any easier to sell.

I decide to once again try to simulate the early phases of the universe on my PC. It's now almost 15 years since I wrote about 30 different versions of a Fortran program in which I tried to simulate the evolution of the newborn universe. At that time, my attempts were doomed to failure because a couple of critical pieces were still missing. Also, a couple of more recent attempts have failed.

This time I have better luck. None of the first nine Fortran programs I write gives any meaningful output. But the tenth program does. Suddenly it all fits together. In January 2007, I have achieved my goal.

My *simulation program* is based on the assumption that the law of conservation of energy is globally valid. The goal of the simulation is to explain how the tauon and muon of phases 1 and 2, respectively, acquire their precise masses, and why the universe contains more than a billion photons at the end of phase 3 and the beginning of phase 4, when the proton is created.

In earlier attempts, I have assumed that the speed of light c is constant while the particle mass m — and with it, the energy $E = mc^2$ — grows over time. Now, it turns out that a credible simulation (that is, a simulation without freely adjustable input parameters) is only possible if it's the other way round: m is constant while c grows in such a way that the increase in rest energy, mc^2, of the massive particles is compensated for by the decrease in photon energy, which is caused by the expansion of the universe. See Eq. (3.2) on page 22.

Thus far, everything is simple and foreseeable. The surprise comes when I discover that an additional requirement for the simulation to produce a sensible result is that the lifetimes τ (*tau*) of the particle pairs grow at the same rate as c increases; that is, τ is proportional to c ($\tau \propto c$).

Saying it differently, the simulation shows that our clocks are going slower and slower. Every tick of the atomic clock lasts a little longer than its previous tick. However, it's neither as simple nor as dramatic as it may sound.

If one views the universe from a global perspective, that is, if one studies the universe as a whole (which I am doing in the simulation program), one sees a "global" picture of the world where global timekeeping is used. The global picture shows an expanding universe, which is governed by the demand of the energy principle that the energy content of a cosmic volume expanding with the universe is constant. Among other things, this demand causes the speed of light and the decay rates of atomic nuclei to increase with the age of the universe.

It's a picture that differs from our common, "local", picture of the world. In the local picture, local timekeeping is used. The local picture shows a world governed by the demand of the energy principle that the energy content of a non-expanding volume with a fixed number of particles must be constant in time. Among other things, this demand causes the particle rest energy mc^2, the speed of light (c), and the decay rates (τ) of atomic nuclei to be constant — not varying with the age of the universe.

At first sight, the result appears paradoxical. Indeed, in a "classical" world (an imagined world ruled by classical physics) the two pictures are totally irreconcilable. However, in our real world (which is a quantum world) the pictures simply show two sides of the same coin. The pictures complement each other, and are perfectly reconcilable.

The reason for this is that position cannot be defined in empty space. Note that space is described by an equation (of which Eq. (4.23) shown on page 33 is a special case), which implies that "space molecules" don't exist, and that, consequently, there are no "space points" that could be used to define a coordinate system. Without points (or definable position), distance is of course undefinable, too. A well-known result of distance undefinability is the so-called *spooky action at a distance.* 23, 25

The discovery of the two pictures of the world, each of them with a timescale of its own, eliminates my last big stumbling-block: in my previous interpretation of it, the model led to an age of the universe of about 5.7 billion years, which is unrealistically low. Also, the model predicted that the gravitational constant G decreases faster than measurements indicate. These erroneous predictions are now explained by the existence of the two timescales, global and local. My conclusion is that, seen in both the global picture and our familiar local picture, the age of the universe is much higher than five billion years.

> My conclusions are based on the simulation of the first three phases of the universe. At this point in time, I haven't understood what a dominating role the black holes are playing in phase 4. In other words, my belief that all major pieces of the puzzle have fallen into place is premature.

It's not only the apparent time paradox that is explained by my computer simulation of the universe. All the fundamental questions listed in subchapter 3.1 18
have been answered, including

6. *Why are there so many elementary particles?*
7. *Why isn't there as much antimatter as matter?*

In addition, it is seen that the flow equation (4.1) in its prolongation: (1) 28
explains why the universe appears to be accelerating (but isn't), (2) predicts the initial so-called *photon–baryon number ratio* (the number of photons in the universe at the instant the proton — which together with the neutron belongs to the *baryons*, particles made up of three quarks — is created), and (3) gives the initial temperature of the universe's present (hot) phase.

4.14 The pion parenthesis

A couple of years after my successful computer simulation of the first three phases of the universe, I begin to ponder about the difference 0.000 76 between
the theoretical value 206.769 04 of the muon–electron mass ratio in Eq. (4.44) 56
and the experimentally observed ratio 206.768 28. What does it hint at? What is its hidden signification?

When I divide the discrepancy 0.000 76 by the Higgs particle's contribution 0.000 2076, I get the result 3.66. Why isn't it exactly 3 or 4, I wonder. If the role of the Higgs particle is to contribute the energy needed to transform a positron (or antielectron, e^+) into an antiproton ($\bar{p}$), one would expect the division to result in an integer, such as 3 or 4.

But what if the positron isn't transformed into an antiproton, but into a positively charged pion (π^+)?

It's now that I perform a mathematical calculation which sets a new record in simplicity. First, I subtract the electron mass (measured in MeV) from the pion mass and get the difference $139.570 - 0.511 = 139.059$. Next, I subtract the pion mass from the proton mass and arrive at the difference $938.272 - 139.570 = 798.702$. Then I divide (2×798.702) by (4×139.059) and get 2.872. Finally, I add 1 to 2.872, which gives

$$y = 1 + 2(m_p - m_\pi)/4(m_\pi - m_e) = 3.872. \tag{4.45}$$

This result I interpret in the following way:

The Higgs particle's first task is to contribute the mass needed by the quarks — the building blocks of both pions and protons — to transform 4 electrons (two electron pairs) into 4 pions (two pion pairs). The fulfillment of the task means that the mass of the new particle (the Higgs) becomes determined once and for all.

After one of the pion pairs has decayed into two photons, and the remaining pair — which is now the bearer of all mass remaining in the universe — is on the point of annihilating, the material universe is saved by the transformation of the pion pair ($\pi^+\pi^-$) to a proton pair ($p\bar{p}$), which requires 2.872 times as much mass as was conveyed from the background photon radiation to the quarks when the pion pairs were built.

Consequently, the value of y in Eq. (4.45) shows how many loads of Higgs mass the building of the proton pair requires in total. It also demonstrates that all the mass contributed by the fourth load isn't needed.

And now I finally understand to ask the obvious question I should have asked many years ago:

How is the mass transported from the background radiation to the quarks?

This obvious question now gets an equally obvious answer:

The Higgs particle itself transports the mass.

> Hitherto I have assumed that the appearance of the Higgs particle causes the energy of the background radiation to decrease suddenly at the same time as the energy of matter increases without any transport of energy taking place. In this way, the total energy of the universe is conserved, I must have previously thought, but without fully understanding that the law of conservation also applies to individual particles: a particle can only lose part of its mass by emitting another massive particle that carries away the mass.

Even the neutrino's previously so puzzling properties find an explanation: why the particle exists, possesses mass, appears in three mass states, and is capable of oscillating between these mass states. The role of the neutrino is simply to restore to the background radiation the mass that the quarks haven't used in their proton-building project. To be able to give over its mass to the electron, muon, and tauon, the neutrino requires help of one more not previously existing particle, namely the $W^\pm$, whose mass (80.4 GeV) is mainly generated by the Higgs particle, which this time appears in a fourth, very heavy mass state. This is the *heavy Higgs boson* that physicists have long been looking for, and which later, in 2011, will be experimentally spotted and found to have a mass of about 125 GeV.

The reason for the neutrino's *oscillation* is that the quarks supply the neutrino (ν_e, ν_μ, and ν_τ) with mass in the same proportion as they received mass from the Higgs particle (H_e, H_μ, and H_τ), and that the electron, muon, and tauon demand that the proportions be changed before they can absorb the mass being restored.

The Feynman diagrams show that the mass of the Higgs particle is proportional to the third power of the mass of the emitting particle ($m_H \propto m^3$, see, for example, Eq. (4.51) on page 72). This means that $m_{H_\mu} = (m_\mu/m_\tau)^3 m_{H_\tau}$. For the simulation to produce a value of m_μ/m_e that equals the experimental value, $m_{\nu_\mu} = (m_\mu/m_\tau)^3 log(m_\tau/m_\mu) m_{\nu_\tau}$ must hold for the muon masses being restored to the tauon and muon. Consequently, the neutrino must be capable of changing its mass in flight. That the factor $\log(m_\tau/m_\mu) = \log 16.82 = 2.82$ should be part of the expression describing the connection between m_{ν_μ} and m_{ν_τ} is a prediction of the model which still remains to be theoretically confirmed. Alternatively, the logarithm should be replaced by another, more complicated factor of about the same size. Hopefully, a future final neutrino theory will clarify the question.

4.15 Surprises afforded by the simulation

After 15 years of trials and errors, my attempts to simulate the first phases of the universe had finally born fruit.

The big surprise was that the simulation demonstrates that the universe may be viewed from different perspectives, and that both the speed of light c and particle lifetimes τ increase over time in the global perspective, where energy is conserved in an expanding universe.

Another surprise was that a successful simulation requires the universe not to pop up at time zero, but at the time t_c (where t_c denotes *time of creation*), which is seen to coincide with the lifetimes of both the D particle and the spinless-tauon pair, and which, therefore, may be regarded as nature's *basic time unit*.

The assumption that $t_c = 0$ leads to a mismatch between the simulation of the universe's first phase and the simulation of its second phase. Instead, the simulation is logically consistent if t_c is greater than zero, and both the D particle's lifetime τ_D and the tauon pair's lifetime $\tau_{2\tau}$ coincide with t_c.

How then can one explain the equality $\tau_D = t_c$? If one takes a look at the properties of the D particle, one finds a simple and logical explanation: the particle may be looked upon as an oscillator.

The D particle is described by *Dirac's equation for a neutral spin-0 particle* published in 1971 under the title *"A positive-energy relativistic wave equation"*. I cite what theoretical physicists wrote about the equation a couple of years later: *"In a very real sense, the new Dirac equation constitutes an explicit and precise solution to the relativistic harmonic oscillator."*

One may, therefore, imagine that the D particle — which at the instant it is born constitutes the entire universe — starts to build up at time $t = 0$ in an oscillation that reaches its peak at $t = t_c$ when the particle is fully developed, after which the oscillation turns downward and the particle strives to disappear in the same time (t_c) in which it built up.

And, disappear is exactly what the particle would have done if it wasn't for the fact that the particle, and thereby the universe, possessed mass and energy. As it was, the law of conservation of energy forbade the self-annihilation of the particle and the universe it formed.

But how — through which mechanism — can the law of conservation prevent the energy of the D particle from dissolving into *literally nothing*? The answer is that another property of the D particle explains how it is possible.

> I cite further: *"The new Dirac equation and its generalization may be consistently viewed as composites of two subparticles interacting via action-at-a-distance forces."* And: *Viewing the "new Dirac equation" as a "realization on two bosons", one "must assume that one or both of the two subparticles will bear electric charge."*

The conclusion is that the D particle may disintegrate into a pair consisting of charged bosons with zero spin, or spinless tauons ($D \to \tau_0^+ \tau_0^-$). The tauon pair may in its turn annihilate into a pair of photons ($\tau_0^+ \tau_0^- \to \gamma_\tau \gamma_\tau$). Naturally, the D particle may also annihilate directly ($D \to \gamma_\tau \gamma_\tau$) — but not before matter has been created in a new form; that is, in the form of tauons (τ_0).

> According to the well-known rules of quantum physics, all allowed reactions of a system in an indeterminate quantum state happen in parallel. This means that the primordial particle after its coming into being does not, like *Schrödinger's cat* is said to do, exist simultaneously in a living state and a dead state. Instead, it exists in three states: in the form of a live primordial particle (D); as a dead particle transformed into pure radiative energy ($\gamma_\tau \gamma_\tau$); and living a second life in the form of a tauon pair ($\tau_0^+ \tau_0^-$).

Finally, a third property of the D particle explains why it — after its decay into a pair of charged particles — cannot reappear even as a virtual particle; that is, why it cannot exist today:

> *It "cannot interact with the electromagnetic field without destroying the consistency of the defining structure."*

On second thought, it shouldn't have come as a surprise that the universe wasn't born at time $t = 0$. Common sense says that the universe cannot have been born in the form of a point with zero radius. Such "objects" are mathematical abstractions that have no place in the physical world. Similarly, common sense says that the particle — or universe — when it comes into being should form a kind of four-dimensional *spacetime* bubble with both the three spatial components and the temporal component of its radius greater than zero.

> The easy way to understand the details of the simulation is to take a look at the Fortran program I used citeSimul. To understand the simple logic of the program, it's enough to compile and run the first part, which is titled Phase 1. Instead of Fortran, you may use another program language, such as C. The instructions (or Fortran *statements*) I use should be easy to interpret and translate.

To me, the really big surprise is that I have managed to compute the theoretical value of the muon–electron mass ratio m_μ/m_e. It had long been my dream to calculate the fine structure constant α. That dream hasn't come true. But instead I have done something very much better, something I could never have dreamed of doing. I have calculated the *muon–electron mass ratio*

$$m_\mu/m_e = 206.768\ 283\ 185(77)(7)(5)(5). \tag{4.46}$$

> By combining the uncertainties, one obtains for the mass ratio the theoretical value 206.768 283 185(78), or 206.768 2832(1), which agrees with the less accurate experimental value 206.768 2823(52).

Why, then, is it better to calculate m_μ/m_e than α? The answer is that α is a pure constant of nature, which specifies the strength of the electromagnetic force. That's all there is to it. Compared to it, the precise value of m_μ/m_e is much more interesting, since it also contains other information than the mass of the muon relative to the mass of the electron. This can be seen from the fact that the four uncertainties in Eq. (4.46) derive from the uncertainties in the values of α, the Fermi constant G_F, the charged-pion mass m_π, and the tauon mass m_τ, respectively.

And, even more important, the simulation that leads to the value of m_μ/m_e in Eq. (4.46) explains why the weak force and the various weakly interacting particles exist.

4.16 The superweak force

The list of surprises afforded by the simulation does not end here. To be able to perform the simulation, one must know the lifetime of the electron pairs of phase 3. I have assumed it to be

$$\tau_3 = \frac{1}{8\pi}\alpha^{-2} = 743.1873. \tag{4.47}$$

> That the lifetime is proportional to α^{-2} is a conclusion I arrive at after taking a look at the theory for positronium decay (in *positronium* the proton nucleus of hydrogen has been replaced by a positron, e^+). The value of the coefficient, $1/8\pi$, remains to be verified theoretically.

But at one point, I began to doubt the correctness of my assumption. The reason was that the value of the factor $y = 1 + 2(m_p - m_\pi)/4(m_\pi - m_e) = 3.872$
in Eq. (4.45), which is calculated in the local picture where particle masses m 62
and self-energies mc^2 are constant, did not agree with the value $y = 3.844$, which the simulation (done in the global picture with increasing c and τ) produced.

Still, after analyzing the situation, I found that I could stick to my assumption in Eq. (4.47), and that the discrepancy disappears if the universe is slightly older when the proton appears than I had assumed it to be. In other words, the simulation demonstrated that the duration of the "pion parenthesis" can't be quite as short as I had thought. Slowly I began to understand how things hang together. This is how it must be:

Elementary particles have a property called *intrinsic parity*, or simply *parity*. The photon has negative parity (-1) while the quarks have positive parity $(+1)$ and the antiquarks negative parity (-1). This means that the pions (π^0, π^+, and π^-), which consist of a quark and an antiquark, have negative parity: $(+1)(-1) = -1$. Thus, both pion pairs $(\pi^+\pi^-)$ and photon pairs $(\gamma\gamma)$ have positive parity: $(-1)(-1) = +1$.

> Also the particles e^+, μ^+, τ^+, and $\bar{p}$ have negative parity while e^-, μ^-, τ^-, and p have positive parity. Parity is conserved in strong and electromagnetic reactions. Consequently, when for example an electron and a positron annihilate each other ($e^- + e^+ \rightarrow \gamma$), parity is conserved: $(+1)(-1) = -1$. In contrast, parity is not conserved in weak interactions.

Almost immediately after the first two pion pairs have formed, within about 10^{-24} s, one of the pairs annihilate via strong interaction: $\pi^+_-\pi^-_- \rightarrow \gamma_-\gamma_-$, where the minus sign denotes the (negative) parity of the particles.

Also the second pair would have met the same fate, if it wasn't for the fact that the law of conservation forbids the existence of a universe void of matter. Nature solves the problem as economically as possible by introducing the weakly interacting Z particle, which comes to the rescue and switches the parity of one of the pions ($\pi^+_-\pi^-_- \rightarrow \pi^+_+\pi^-_-$). This change of parity has the effect that the pion pair can no longer annihilate through strong interaction, since the reaction $\pi^+_+\pi^-_- \rightarrow \gamma_-\gamma_-$ would mean that the parity switches from $(+1)(-1) = -1$ before the decay, to $(-1)(-1) = +1$ after the decay.

Thus, the task of the Z particle is to save the matter of the universe from extinction. It's a task that it successfully performs. However, the pion matter only gets a short respite because now, after the appearance of the Z particle, parity is no longer universally conserved. In about 10^{-16} s, the presence of the (virtual) Z particle also makes the second pion change its parity. With both pions now possessing the same parity, the pair will renew its attempt to rapidly annihilate through strong interaction ($\pi^+_+\pi^-_+ \rightarrow \gamma_-\gamma_-$). It's at this point in time — about 10^{-16} s, or 0.1 femtosecond later than I first assumed — that a real proton pair is created from the last pion pair, and the proton replaces the charged pion as bearer of the universe's mass.

The simulation (which takes place in the global picture) shows that the time elapsing between the two parity switchings is enough for the self-energies of the particles (mc^2) to increase by about one percent and for their lifetimes τ (and the velocity of light c) to increase by 0.5 percent. This means that a small difference arises between the pion ($\pi^+ = u\bar{d}$) and its antiparticle ($\pi^- = d\bar{u}$). In other words, the perfect matter–antimatter symmetry, which prevailed in the universe's first three phases, is now broken.

Even if it's not self-evident that this asymmetry between particles and antiparticles will lead to observable physical effects, it seems probable that it's the cause of the so-called *superweak force*, which lies behind the asymmetrical behavior of the decays of the neutral K and B mesons. (The *mesons*, to which also the pions belong, are particles made up of a quark and an antiquark.)

The fact that both mesons contain a down quark ($K^0 = d\bar{s}$ and $B^0 = d\bar{b}$ with $\bar{K}^0 = s\bar{d}$ and $\bar{B}^0 = b\bar{d}$, where s and b stands for strange and bottom, respectively) suggests that the parity change of the pion is caused by a switching of the down quark's parity, and that it's only among d quarks that a particle–antiparticle asymmetry exists. Or, does an asymmetry exist between u and $\bar{u}$ as well?

My conclusion is that the small difference in properties between matter and antimatter, which some physicists believe gives the clue to why matter dominates over antimatter (that is, why there are more protons and electrons than antiprotons and antielectrons), in reality has a very simple (and therefore unwelcome) explanation.

> Maybe the observed matter–antimatter asymmetry can be explained as follows. Let E_{π^+} be the rest energy of the pion when a parity-switching force, f_{π^+}, causes it to flip its intrinsic parity ($\pi^+_- \to \pi^+_+$). Denote by E_{π^-} and f_{π^-} the corresponding rest energy and force when a little later the antipion flips its parity ($\pi^-_- \to \pi^-_+$). As just mentioned, the pion rest energy grows by about 1 % during the time interval between the two parity-switching events. Thus, $E_{\pi^-} > E_{\pi^+}$, which means that
>
> $$f_{\pi^+}/E_{\pi^+} > f_{\pi^-}/E_{\pi^-} \tag{4.48}$$
>
> holds if the force remains constant ($f_{\pi^-} = f_{\pi^+}$) or increases at a slower rate than the rest energy does. Interpreted in the local picture, where particle rest energy is constant, Eq. (4.48) implies that $f_{\pi^+} > f_{\pi^-}$. Therefore, one expects that $f_{\bar{K}^0} > f_{K^0}$, since both π^+ and $\bar{K}^0$ contain a positively charged down antiquark. Consequently, the antikaon should transform into a kaon more often than the kaon transforms into an antikaon.

4.17 The Higgs–neutrino mechanism

The simulation of the universe's first femtoseconds leads to the conclusion that the proton acquires its large mass ($m_p = 1836.15\, m_e$) via what might be called the *Higgs–neutrino (Hν) mechanism*, or more precisely, the *HZνW mechanism*, which forms the next-to-last link in the chain of changes the universe's mass-bearing particles go through:

$$D \to \tau_0^+\tau_0^- \to \underline{\mu}_0^+\underline{\mu}_0^- \to \mu_0^+\mu_0^- \to \underline{e}^+\underline{e}^- \to e^+e^- \to HZ\nu W \text{ mechanism} \to p\bar{p} \to pe^-$$

1	9	0	23	0	37 293	1000	0	∞
1	10^2	10^2	10^3	2×10^3	3×10^9			

The first row shows which particle in turn serves as bearer of the mass of the universe. An underscore indicates that the particle is in a "frozen", static state, which at the exact instant of the particle's birth is described by the stationary form of the flow equation. See last paragraph in the deviation that begins on page 34. The numbers in the second row show the duration of the states measured in units of t_c, which corresponds to about 10^{-19} seconds. The last row specifies the number of particles or particle pairs in the universe when the last massive particles in a phase annihilate. Note that the pair of spinless muons is succeeded by a pair of two electron pairs ($\mu_0^+\mu_0^- \rightarrow \gamma_\mu\gamma_\mu \rightarrow e^+e^-\,e^+e^-$). See figures illustrating the transition from phase 2 to phase 3 on pages 57–58.

The *Higgs–neutrino* mechanism may in turn be summarized in the following manner:

$$\begin{array}{ccccccccccccccc} e^+e^-e^+e^- & \rightarrow & \underline{\pi}^+\underline{\pi}^-\underline{\pi}^+\underline{\pi}^- & \overset{H}{\rightarrow} & \pi_-^+\pi_-^-\pi_-^+\pi_-^- & \rightarrow & \pi_-^+\pi_-^- & \overset{Z}{\rightarrow} & \pi_+^+\pi_-^- & \rightarrow & \pi_+^+\pi_+^- & \overset{\nu W}{\longrightarrow} & p_+\bar{p}_+ & \rightarrow & p_+e_+^- \\ & & 0 & & 10^{-5} & & 10^{-5} & & 10^3 & & 10^{-5} & & 0 & & \infty \end{array}$$

The first row shows in which reactions the weakly interacting particles H, Z^0, ν, and $W^\pm$ first appear. As in the previous figure, the last row shows the approximate duration of the particle states in units of $t_c \approx 10^{-19}$ s. The lifetime of the proton pair is zero, since the positive parity of the antiproton means that the pair is not physically viable. (The antiproton, which already exists as a virtual particle before the creation of the real proton–antiproton pair takes place, has negative parity.)

The decay of the heavy, non-physical antiproton into a light electron gives both the electron and the remaining proton kinetic energy — a property of particles that didn't exist earlier when every entangled particle pair in the universe formed its own world, unaware of the existence of other particles. The fact that the particles begin to move relative to each other means that the *law of change* takes command over the small-scale development in the world.

On the next page, I try to summarize the information about the muon mass, which is obtained from the simulation of the universe's first three phases.

4.18 Secrets revealed by the muon–electron mass ratio

Let V be an arbitrarily large volume that coexpands with the universe. Denote by E the total energy of the particles within the volume. Leaning on two assumptions,

$$\mathrm{d}V/\mathrm{d}t = \text{constant} \quad \text{and} \quad E = \text{constant},$$

the universe's evolution may be simulated. Two measured mass ratios,

$$m_\tau/m_\mu = 16.8183(27) \quad \text{and} \quad m_\mu/m_e = 206.768\ 2823(52),$$

are used to check and calibrate the simulation. With the help of data produced by the simulation, a theoretical value is obtained for the latter ratio:

$$(m_\mu/m_e)^{\mathrm{th}} = 206.768\ 283\ 185(78),$$

which is nearly two orders of magnitude more precise than the experimental value used in the calibration. The muon–electron mass ratio contains detailed information about the history of elementary particles:

$$m_\mu/m_e = 205.759\ 223 + 1.009\ 816 - 0.000\ 208 - 0.000\ 623 + 0.000\ 074 = 206.768\ 283$$

1966

$1/B\alpha = 205.759\ 223$ is the basic ratio. In it, $B = 0.666\ 001\ 731\ 498$ characterizes the simplest possible solution to the pressureless form of the momentum equation, while α is the fine-structure constant with $1/\alpha = 137.035\ 999\ 084(51)$.

2007

The contribution $1/(1-2B\alpha) = 1.009\ 816$ to the muon mass derives from photons that materialize when the spinless muon is succeeded by the spinning electron as bearer of the universe's mass.

1999

The small negative correction ($-0.000\ 2076$) to the mass ratio is a result of the Higgs appearing and conveying mass from the virtual charged leptons $\tau^\pm$, $\mu^\pm$, and $e^\pm$ (which appear in the background photon propagators) to the real quarks forming two pion pairs ($\pi^+\pi^-\ \pi^+\pi^-$) that replace the last decaying electron pairs ($e^+e^-\ e^+e^-$).

2008

The second negative correction ($-0.000\ 6228$) to the mass ratio is a result of Higgs particles conveying three times more mass from the leptons to the quarks when the last decaying pion pair ($\pi^+\pi^-$) is replaced by a proton pair ($p\bar{p}$).

2008

The mass brought by the Higgs particles is more than the quarks need to build the proton pair. The neutrino restores the excess mass to the leptons.

4.19 Observations of a light Higgs particle

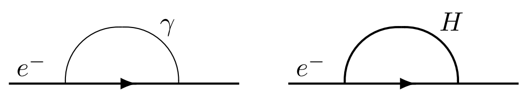
Now I have arrived at a point where the editor of a physics journal — it's the same person who is behind my textbook in weak interactions, and whom I for several years have been informing about the progress of my work — agrees to publish an article I have written.

The article drowns in the enormous number of articles in theoretical physics that are constantly being published, and doesn't draw the attention of anyone. Also, I don't make any efforts to sell it because I realize that the puzzle isn't finished — I still don't understand how the universe is evolving in its present, fourth phase.

Finally, I feel that trying to advertise my theory would be a waste of time because I'm sure that it's soon going to sell itself. The reason for my belief is that the theory, in addition to saying that the Higgs particle exists in the now experimentally observed heavy version, also predicts that it exists in three light varieties, which in the long run cannot escape detection. As I understand things, the light Higgs particle has already manifested its presence in a number of experiments, which until now have defied physicists' attempts to understand them, but which may all be explained by the existence of the light Higgs particle.

Why then do the established physicists refuse to believe in the existence of the light Higgs particle? The answer is that the mystery disappears. Human beings are fascinated by unsolved mysteries. Researchers dream of one day discovering the existence of what they call *new physics*, for example in the form of exotic dark matter. If the dreams are crushed, and it turns out that the standard model of elementary particle physics (SM) is capable of explaining all fundamental physics, the world becomes in one stroke a very much duller place than it used to be. And, worst of all, physicists will find it difficult to justify continued funding of a number of research projects currently in progress.

But, if the light Higgs particle — a kind of spinless (or polarization-free) photon — really exists, why don't we see it everywhere around us? Why is it so difficult to intercept? The answer to the question is found by placing side by side the diagrams that describe the photon's and the Higgs particle's contributions to the electron mass:



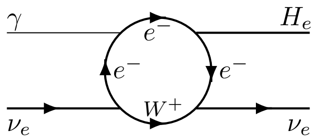
The only visible difference is that the photon is represented by a thin line, which indicates that it does not possess mass (is massless), while the line that indicates the Higgs particle is thicker to indicate that the Higgs possesses mass (is a massive particle).

> In addition, there exist a couple of differences that are not visible in the figure: the photon has spin, and mediates the electromagnetic force; the Higgs particle lacks spin, and mediates a weak force.

The fact that the photon doesn't have mass means that the electron may emit a photon without recapturing it. That's why we see the sun shine — a photon emanating from the sun may end its journey on the retina of your eye. In contrast, the electron can't emit a Higgs particle for good because then it would lose the mass that the Higgs carries with it. And such a loss of particle mass is forbidden by the law of conservation. Similarly, the law prohibits the electron from increasing in mass by absorbing and indefinitely retaining a Higgs boson coming from elsewhere. The consequence is that real (free) Higgs particles can be neither produced nor observed with the help of ordinary laboratory instruments.

> But, as we know, energy and mass are equivalent. Why can't the electron use the formula $E = mc^2$ to create a massive Higgs particle without changing its own mass? My answer is that the simulation of the early universe shows that the muon, which is a heavy electron, loses mass (the mass ratio m_μ/m_e is corrected downward) when the Higgs particle it emits is absorbed by a down or up quark instead of being recaptured by the muon (see page 69). The same observation suggests that the restriction, which applies to the (light) electron, muon, and tauon, should apply to the d and u quarks as well.

Still, this doesn't mean that real Higgs particles do not exist. The figure pictures how light Higgs particles may be produced in the sun:



The diagram shows how an incoming electron-type neutrino produced in the core of the sun splits in a particle pair ($\nu_e \to e^- + W^+$), after which the virtual electron absorbs an incoming photon and emits a Higgs particle before it rejoins the W^+ particle, and together with it forms an outgoing neutrino.

> **Comment 1.** As the right-pointing arrow indicates, the W^+ is defined as particle and W^- as antiparticle.
>
> **Comment 2.** The reaction $\nu_e + \gamma \to \nu_e + H_e$ means that the total masses of the elementary particles change ($m_{\nu_e} + 0 \to m_{\nu_e} + m_{H_e}$). However, this is what normally happens in reactions involving W or Z particles. One example is the W-mediated decay of a muon into an electron and two nearly massless neutrinos. In other words, the law of conservation does not apply to the masses of elementary particles taking part in weak reactions involving W or Z particles.

At this point, I have discovered the sign error in the contribution of the Higgs particle to the mass of the electron, and replaced Eqs. (4.42) and (4.43) with 51, 52

$$m = m_0 + \delta m(\gamma) + \delta m(H) = m_0 + \frac{3}{2\pi}\left(\ln\frac{\Lambda}{m}\right)\left[\alpha + \frac{G_F m^2}{4\sqrt{2}\pi}\right] m \qquad (4.49)$$

and

$$\frac{\delta m(H)}{\delta m(\gamma)} = \frac{G_F m^2}{4\sqrt{2}\pi\alpha}, \tag{4.50}$$

respectively. See Appendix A in physicsideas.com/Article3v2.pdf.

Also, I have understood that the Higgs mass m_H must equal its contribution, $\delta m(H)$, to the electron mass m. Since the contribution from the photon to the electron mass is much greater than all other contributions taken together, one may in addition set $\delta m(\gamma) = m$, which gives

$$m_H = \frac{G_F m^2}{4\sqrt{2}\pi\alpha} m. \tag{4.51}$$

Using the values $1/\alpha = 137.035\ 999$ and — after reintroducing $\hbar$ and c, which have been set equal to one — $G_F/(\hbar c)^3 = 1.166\ 36 \times 10^{-5}\ \text{GeV}^{-2}$, Eq. (4.51) leads to the relation

$$m_H = \frac{m^2}{11\ 118.8\ \text{GeV}^2} m \tag{4.52}$$

between the mass m of the electron and the mass m_H of the light Higgs particle.

For the mass of a Higgs particle emitted by an electron (with mass $m_e = 0.510\ 9989$ MeV), muon ($m_\mu = 105.658\ 37$ MeV), and tauon ($m_\tau = 1777$ MeV), respectively, one obtains the values

$$\begin{aligned} m_{H_e} &= 12.0006\ \mu\text{eV}, \\ m_{H_\mu} &= 106.085\ \text{eV}, \\ m_{H_\tau} &= 0.505\ \text{MeV}, \end{aligned} \tag{4.53}$$

with the masses given in electronvolts, which is customary in particle physics and simply means that c is set equal to 1 in the mass unit eV/c^2.

> The energy of a massless photon is $E = h\nu$, where $h = 4.135\ 667 \times 10^{-15}$ eV s is the *Planck constant* and ν the frequency of the photon. Similarly, the energy of a massless or massive particle of temperature T is $E = kT$, where $k = 8.6173 \times 10^{-5}$ eV K^{-1} is the *Boltzmann constant*. Consequently, the self-energy of the electron-type Higgs, $E = 12.0006\ \mu$eV, corresponds to the energy of a photon of frequency $\nu = E/h = 2.9017 \times 10^9\ \text{s}^{-1}$, or 2.9017 GHz, and temperature $T = E/k = 0.14$ K. Since this temperature is well below the 2.275 K temperature of the *cosmic microwave background*, the H_e particle always travels with relativistic speeds very close to c. That is, its mass or self-energy is negligible compared to its kinetic energy.
>
> Also compare the energies in Eq. (4.53) to the energy $E = kT = 0.0253$ eV of particles at *room temperature*, 20 °C = (273.15 + 20) K = 293.15 K.

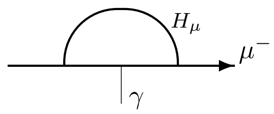
In the same way as virtual photons mediate the electromagnetic force, virtual Higgs particles mediate a weak force. As a result, the light virtual Higgs particles manifest their presence in many ways.

4.19.1 The muon $(g - 2)$ experiment

In the most expensive experiment in high-energy physics ever completed — the *"muon $(g - 2)$ experiment"* — physicists measured the muon's *anomalous magnetic moment* (a_μ), which is half of its $g - 2$: $a_\mu = (g_\mu - 2)/2$, where g_μ designates the *gyromagnetic factor* of the muon. Compare with subchapter 4.8. 47

> The planning of the experiment began before the previous series of measurements, which took place in the years 1974 to 1976, had finished. Construction of the necessary requisites (including cyclotron, magnetic storage ring, measuring instruments, and other peripheral equipment) took a long time. The measurements were performed during the years 1997 to 2001, and after five separate reports had been published, the *"Final Report of the Muon E821 Anomalous Magnetic Moment Measurement at BNL"* appeared in 2006.

The diagram in the figure shows the Higgs particle's contribution to the anomalous magnetic moment of the muon:



In the same way as Eq. (4.51) for the contribution of the Higgs particle to the electron mass is derived from basic *electroweak theory*, an elementary calculation of the Higgs particle's contribution to a_μ gives the value 72

$$a_\mu(H_\mu) = \frac{3G_F m_\mu^2}{8\sqrt{2}\pi^2} = 0.000\ 000\ 003\ 50 \quad (m_{H_\mu} \ll m_\mu) \tag{4.54}$$

in the case where the mass m_{H_μ} of the Higgs particle (H_μ) appearing in the diagram tends to zero. The general expression, which holds for all values of m_{H_μ}, shows that the contribution is vanishingly small when $m_{H_\mu} \gg m_\mu$.

The sum of the contributions to a_μ from the rest of the elementary particles of SM is found to be

$$a_\mu^{\text{th}}(\text{SM}) = 0.001\ 165\ 917\ 78(61), \tag{4.55}$$

which means that the total theoretical value is

$$a_\mu^{\text{th}} = 0.001\ 165\ 921\ 28(61) \quad (m_{H_\mu} \ll m_\mu) \tag{4.56}$$

and

$$a_\mu^{\text{th}} = 0.001\ 165\ 917\ 78(61) \quad (m_{H_\mu} \gg m_\mu), \tag{4.57}$$

respectively, in the two cases. The value obtained in the experiment was

$$a_\mu^{\text{exp}} = 0.001\ 165\ 920\ 91(63). \tag{4.58}$$

Thus, its deviation from the theoretical value in Eq. (4.56)

$$a_\mu^{\text{exp}} - a_\mu^{\text{th}} = -0.000\ 000\ 000\ 37(88) \quad (m_{H_\mu} \ll m_\mu), \tag{4.59}$$

is well within the margin of error (note that the uncertainties are added in square: $61^2 + 63^2 = 88^2$), which indicates good agreement between theory and observation. In contrast, its deviation from the value in Eq. (4.57),

$$a_\mu^{\text{exp}} - a_\mu^{\text{th}} = +0.000\ 000\ 003\ 13(88) \quad (m_{H_\mu} \gg m_\mu), \tag{4.60}$$

indicates a discrepancy between theory and observation of $313/88 = 3.5$ times the error margin.

In summary, comparison of the experimental and theoretical values of a_μ suggests that the Higgs particle (H_μ) that interacts with the muon has a mass that lies considerably below the muon mass, $m_\mu = 105.66$ MeV. Therefore, H_μ cannot possibly be identical to the heavy Higgs particle, which was found to have a mass of about 125 GeV.

> If the muon $(g-2)$ experiment had been an "ordinary" experiment, one could have dismissed the result by explaining that the large discrepancy for a heavy Higgs might well result from undetected experimental or theoretical errors. But, since it doubtless was up to then the world's most thoroughly analyzed experiment — just as the computations of a_e and a_μ are by far the most thoroughgoing theoretical determinations of physical constants ever done — the result is believed to be very solid.
>
> This conclusion is underpinned by the observation that a refined analysis made after the final report was published in 2006 didn't result in a diminishing, but in an increasing discrepancy for $m_{H_\mu} \gg m_\mu$; that is, from +0.000 000 003 02(88) in 2008 to +0.000 000 003 13(88) in 2010.
>
> But, instead of taking the result to indicate the existence of a "spinless photon" described by the standard model's Feynman diagrams, physicists have chosen to interpret it as indicating the existence of unknown *"new physics"*.
>
> It's worth mentioning that originally the so-called Higgs mechanism was introduced to explain the masses of the W and Z bosons, which are mainly generated by the heavy Higgs particle in the same way as the light Higgs particle generates small contributions to the masses of the electron, muon, and tauon. The conviction of the cosmologists that the universe had been born in the form of a tremendously hot and dense "singularity" motivated particle physicists to try to develop the Higgs mechanism into a theory explaining the creation of all particle masses apart from the mass of the neutrino, which at the time was believed to be zero. The theory they laboriously built wasn't very convincing. However, after the road ahead had been mapped out and research funding had begun to flow, it was too late to abandon the theory.

It may be mentioned that the measured value of the ordinary electron's anomalous magnetic moment, $a_e^{\text{exp}} = 0.001\ 159\ 652\ 180\ 73(28)$, has an accuracy that is

2000 times higher than the accuracy of the experimental value of a_μ. But since the contribution $a_e(H_e) = 3G_F m_e^2/8\sqrt{2}\pi^2$ is $(m_\mu/m_e)^2 = 206.768^2 \approx 40\ 000$ times less than $a_\mu(H_\mu)$, the value of a_e still isn't precise enough to give any further information about the mass of the light Higgs particle.

4.19.2 The proton's missing spin

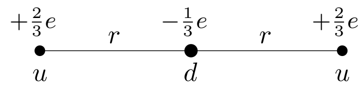
A comparison between the Feynman diagrams for the Higgs particle and the photon suggests that the Higgs-mediated force between two charged particles is repulsive, independent of the signs of the charges (while the electromagnetic force mediated by the photon is attractive or repulsive depending on whether the charges have opposite or equal signs).

The fact that no anomalous static force has been observed between charged particles must mean that the Higgs force is dynamic in its nature, perhaps resembling the magnetic force mediated by the photon.

Nuclear physicists have observed several puzzling phenomena that might be caused by a light Higgs particle that generates a force of sufficiently long range to affect the motions of the quarks relative to each other.

One puzzling observation has to do with the proton's spin, which is the sum of the *orbital angular momenta* and *spin angular momenta* of the quarks and gluons (caused by their motion in orbits around each other and their rotation around an axis, respectively). It means that experiments indicate a gap between the proton's spin of $\frac{1}{2}\hbar$ and the sum of the theoretically estimated orbital angular momenta and the measured spin angular momenta of the component particles of the proton (one d and two u quarks together with the massless gluons that mediate the strong force between the particles). A Higgs force affecting the motions of the quarks may explain the discrepancy.

Asymptotic freedom means that the strong force that holds the quarks together ceases for $r \ll r_p$, where r is the distance between the quarks and r_p the radius of the proton. The figure shows the three quarks of the proton lined up in a row with the down quark (of charge $-\frac{1}{3}e$) at the center: The electric force be-



tween one of the up quarks and the down quark is attractive and proportional to $-(+\frac{2}{3}e)(-\frac{1}{3}e)r^{-2} = +\frac{2}{9}e^2r^{-2}$, where e is the unit charge of elementary particles. The corresponding force between two up quarks is repulsive and proportional to $-(+\frac{2}{3}e)^2(2r)^{-2} = -\frac{1}{9}e^2r^{-2}$. The positive sum, $+\frac{2}{9}e^2r^{-2} - \frac{1}{9}e^2r^{-2} = +\frac{1}{9}e^2r^{-2}$, of the two forces shows that the up quarks are acted on by an inward force even when the distance r is small and the attractive strong force negligible. Therefore, the quarks tend to gather at the center of the proton, with the result that they move in narrow orbits around each other and, consequently, possess relatively small orbital angular momenta.

The situation changes if a repulsive Higgs force overcomes the electromagnetic force and causes the quarks to move in as wide orbits around each other as the strong force allows. (The strong force may be compared to a rubber band whose force increases with growing distance r.)

The conclusion is that the presence of a sufficiently light virtual Higgs particle (the range of the force mediated by the observed heavy 125-GeV particle is much too short) may signify that the angular momenta of the quarks are considerably larger than they would be in the absence of the light Higgs particle.

Consequently, the existence of the light Higgs boson provides a simple explanation for the mystery of *the proton's missing spin* within the framework of the standard model.

4.19.3 The nucleon's magnetic moment

The theoretically predicted values of the magnetic moments of the proton, neutron, and some other hadrons show an unmistakable tendency to fall below the corresponding experimentally observed values. (A particle built from two or more quarks is called a *hadron*.)

The same effect that explains the *"proton spin crisis"* — why the sum of the quarks' theoretically calculated *spatial angular momenta*, their experimentally determined *intrinsic spin angular momenta*, and the gluons' estimated *net glue polarization* is less than the spin of the proton — should explain why the magnetic moment of the hadrons is greater than what the theoretical calculations predict.

4.19.4 The proton radius

A third problem in nuclear physics is that one gets a certain result when the proton radius is measured using ordinary hydrogen, and another result when the experiment is done with the use of *muonic hydrogen* (hydrogen in which the electron orbiting the proton has been replaced with a muon): $r_p = 0.8768(69)$ fm and 0.841 84(67) fm, respectively.

A simple explanation for the difference, 0.035(7) fm, could be that the light muon-type Higgs, whose existence the E821 muon anomalous magnetic moment measurement convincingly demonstrates, causes a repulsive force between the quarks of the proton and the muon orbiting it.

Such a force counteracts the electromagnetic force of attraction between the proton and the muon, and makes the distance between the proton's "surface" and the muon slightly larger than it is assumed to be, which is interpreted to mean that the proton is smaller than it actually is.

> The *"Bohr radius"* of the hydrogen atom is $a_0 = 52\ 918$ fm, and its value for an atom with the electron replaced by a muon is $m_\mu/m_e = 206.768$ times smaller, which implies a radius of $a = a_0/206.768 = 256$ fm for *muonic hydrogen atoms.*
>
> For the repulsive force to have a sufficiently long range, the particle that mediates the force must be comparatively light. The maximum lifetime of

a particle is determined by the Heisenberg uncertainty relation $\Delta t \Delta E = \hbar$.
Using the value 106.085 eV for m_{H_μ} given in Eq. (4.53), one obtains 72
$\Delta t = \hbar / m_{H_\mu} c^2 = 6.582 \times 10^{-16}$ eV s/106.086 eV $= 6.2 \times 10^{-18}$ s. The
distance covered by a particle traveling with the speed of light, c, gives
an estimate of the upper limit of the range of the force mediated by the
particle. For H_μ, this distance is $c\Delta t = 2.998 \times 10^8$ m s$^{-1} \times 6.2 \times 10^{-18}$ s
= 1.86 nm, which is much larger than the radius 0.000 256 nm of the
muonic hydrogen atom.

For the heaviest (H_τ) of the three light Higgs particles, one finds $c\Delta t =$ 390 fm. This means that even the force mediated by the tauon-type Higgs has a sufficiently long range for the particle to play an important role in atomic nuclei (compare 390 fm with the value 0.8768(69) fm of the proton radius).

4.19.5 The Hoyle state

A puzzle that emerged some 60 years ago is the so-called Hoyle state, which current models of atomic nuclei are unable to explain. It relates to the fusion in stars of light elements into successively heavier elements — up to iron, which is element number 26 ($_{26}$Fe) and the heaviest element that can be produced without adding energy to the fusion process. The mystery is how stable carbon, $^{12}_{6}$C, an element that is crucial for life to form, can be produced in large amounts in the stars.

The sun is a nuclear reactor in which four protons, or hydrogen nuclei ($^1_1$H), fuse into an *alpha particle*, or helium nucleus ($^4_2$He). In the process, two of the protons transform to neutrons via absorption of an electron (e^-) or emission of a positron (e^+). When its hydrogen supply eventually runs short, the sun will become a *red giant*, whose energy is produced via the combination of two alpha particles (or helium-4 nuclei) into an unstable $^8_4$Be isotope (beryllium's stable isotope is $^9_4$Be). The fusion of an $^8_4$B and a $^4_2$He nucleus produces in turn the stable carbon nucleus $^{12}_{6}$C. It's the efficiency of this process that puzzles physicists.

During its short lifetime — about 10^{-16} seconds or less (depending on its mode of decay) — the beryllium isotope will in general not have time to fuse with a helium nucleus and form a stable carbon nucleus ($^8_4$B + $^4_2$He $\rightarrow$ $^{12}_{6}$C). Instead, stable carbon is produced in red giants via an intermediate state, the *Hoyle state*, which is a short-lived excited form of the carbon nucleus C-12.

Computations suggest that the carbon nucleus in its stable state exhibits a compact triangular configuration of three alpha particles (to the left in the figure), while in its unstable and highly dynamical state it also appears in an elongated *"bent-arm configuration"* (to the right):

The existence of the elongated state suggests that a repulsive dynamic force of longer range than the attractive strong force tends to prevent the three alpha particles from immediately forming a compact triangular formation.

> The strong force attempts to gather the alpha particles as close to each other as possible. It is counteracted by the repulsive electrostatic force between the positively charged alpha particles. If these two well-known forces were the only forces acting in atomic nuclei, the process should be relatively easy to calculate. The fact that, after 60 years of effort, physicists still aren't able to understand the Hoyle state with its complex dynamics, suggests that a third force plays a critical role in the formation and maintaining of the state.

The logical conclusion is that the light Higgs particle in its three mass states (H_e, H_μ, and H_τ) mediates a dynamic force that should be able to explain the properties of the excited Hoyle state.

4.20 Other possible appearances of a light Higgs particle

There are several other reported anomalies in which a low-mass, virtual or real, Higgs particle might play a role.

4.20.1 Seasonal variations in radioactive half-lives

Light Higgs particles emanating from the sun and accumulated within the earth would occasionally interact with unstable beta-decaying nuclei and trigger their decay. Early reports of comparatively large seasonal variations in radioactive half-lives have been disproved in later experiments. In other words, if light Higgs particles indeed do affect the decay of unstable nuclei, more precise experiments are needed to confirm the effect.

4.20.2 The lithium problem

In the hot interior of the stars, lithium burns to helium through a process in which a lithium nucleus absorbs a proton (${}^7_3\text{Li} + {}^1_1\text{H} \rightarrow {}^8_4\text{Be} + 17.3$ MeV), after which the beryllium nucleus that is formed decays into two helium nuclei through the reaction ${}^8_4\text{Be} \rightarrow {}^4_2\text{He} + {}^4_2\text{He} + 92$ keV. Proton–lithium fusion requires a temperature of approximately 2×10^6 K, which is less than the temperature of 2.5×10^6 K needed to maintain the hydrogen-to-helium fusion process in a star.

One may theoretically calculate how much lithium-7 is formed in *primordial nucleosynthesis*. When astrophysicists attempt to theoretically estimate how much of the isotope should remain in old, so-called *galactic halo stars*, their results are contradicted by observations showing that in reality these stars contain only one-fourth of the estimated amount.

A possible explanation for the difference between theory and observation is that H_e particles created in the sun accelerate the process of lithium burning.

For a proton to be able to penetrate the Coulomb barrier and fuse with a lithium-7 nucleus, it requires an energy of about 0.1 MeV. Neutrinos created in the core of the sun may acquire energies approaching 14 MeV. In head-on collisions between neutrinos and photons, high-energy H_e particles may be created. In collision with protons, such particles may in turn transfer to the protons energies that are high enough to make the protons penetrate the Coulomb barrier and fuse with the lithium-7 nuclei.

> A calculation shows that an H_e particle possessing an energy of 9.38 MeV (which is one percent of the proton's rest energy) may hand over two percent of its energy to the proton, or 0.19 MeV, which is more than the 0.1 MeV needed for the proton to fuse with a lithium nucleus.

4.20.3 The flyby anomaly

The *flyby anomaly* is a puzzling effect observed when spacecraft destined for the outskirts of our planetary system pass near the earth in order to change their trajectories. It manifests itself as a mysterious acceleration of the spacecraft that varies in magnitude from one flyby to another.

A possible explanation for the curious penomenon might be that virtual H_e
particles — which according to Eq. (4.53) have a mass equivalent to the energy 72
of a 2.9017 GHz photon — appear in the propagators of the photons that carry the microwave radio signal, and cause an unanticipated "Higgs delay" of the signal when it traverses the Van Allen belts with their many free protons.

4.20.4 The Pioneer anomaly

Pioneer 10 was launched in 1972 and Pioneer 11 in 1973. When the two spacecraft — after fulfilling their main missions: encounters with Jupiter and Saturn — were leaving the solar system in the early 1980s, measurements indicated that they were slightly less distant from the sun and earth than calculations suggested they should be. In other words, the spacecraft experienced a mysterious acceleration toward the sun which couldn't be explained by known effects, such as solar radiation pressure, solar wind pressure, heat radiation, or gas leaks.

More recently, it has been argued that "an anisotropic emission of thermal radiation off the vehicles" after all may explain the anomaly. Still, the data isn't precise enough to exclude the possibility that a small part of the anomaly might be due to other effects.

Now, if the flyby anomaly is caused by an unanticipated Higgs delay of the radio signals used in communication with spacecraft, the same type of "anomalous" signal delay should have affected the position determinations of Pioneer 10 and 11.

If a measurable Higgs delay does exist, the suggested notch in the curve
shown in subchapter 4.22 should be real and observable. It would be a relatively 83
simple task to verify its existence by measuring variations in speed of microwaves sent from a satellite that regularly passes above or through the Van Allen belts.

4.20.5 The neutron lifetime discrepancy

The neutron is a beta-decaying particle ($n \rightarrow p + e^- + \bar{\nu}_e$) with a presumably constant lifetime. Still, when researchers trap cold neutrons in a metal bottle and count them at regular intervals, they arrive at a value for the neutron lifetime that is one percent lower than the generally accepted value of about 888 seconds, which has been obtained through the traditional beam method.

It is conceivable that, as mentioned above in the discussion of possible seasonal variations in radioactive half-lives, that the discrepancy is caused by thermal Higgs particles accelerating beta decay. However, it may also be caused by thermal photons:

The left diagram shows what happens when a neutron (ddu) spontaneously decays into a proton (duu), an electron, and an electron antineutrino. The right diagram shows the same decay triggered by a nearly massless Higgs particle (H_e) or a massless photon (γ).

> Electrons orbiting atomic nuclei shield them from being hit by low-energy photons. Since free neutrons lack a shielding electron shell, they are constantly hit by thermal photons that, because of their short mean free path, have acquired the same temperature as the matter surrounding the neutrons, such as the inner surface of a tube or bottle enclosing them.

The magnitude of the discrepancy suggests that it is caused by photons, and that a possible additional contribution from Higgs particles would be difficult to discern. Also, it seems plausible that the effect reaches its maximum at low bottle and photon temperatures, possibly with a resonance peak in the vicinity of zero kelvin.

4.20.6 The tritium endpoint anomaly

Beta decay of tritium means that a radioactive hydrogen atom, with one proton and two neutrons in its nucleus (${}^3_1$H, or tritium), decays into a helium-3 atom (${}^3_2$He) with two protons and one neutron in its nucleus at the same time as a beta particle (e^-) and an antineutrino ($\bar{\nu}_e$) are emitted: ${}^3_1\mathrm{H} \rightarrow {}^3_2\mathrm{He} + e^- + \bar{\nu}_e$.

When physicists began to suspect that the mass of the neutrino is not zero, which it originally was assumed to be, they tried to determine the mass m_{ν_e} of the electron neutrino by measuring the energy of the outgoing electron and subtracting from it the radiation energy known to be released in a spontaneous decay of the tritium nucleus. A negative difference even in the limit of zero kinetic energy ($v_{\nu_e} = 0$) of the neutrino would indicate that the neutrino has nonzero mass.

> The radiation energy produced in the decay is the sum of the total (kinetic plus rest) energy (E_e) of the electron and the corresponding, unobservable, neutrino energy (E_ν). Let ΔE be the difference between the experimentally obtained electron energy E_e and the theoretically calculated sum, $E_e + E_\nu$. Since the neutrino possesses mass, this difference is always negative: $\Delta E = E_e^{\text{exp}} - (E_e + E_\nu)^{\text{th}} \leq -m_\nu c^2$. Thus, in the limit of zero kinetic neutrino energy, the energy difference should approach a maximum value of $\Delta E = -E_\nu^{\text{min}} = -m_\nu c^2$.

Against all expectations, the maximum difference proved to be neither negative nor zero, but positive. No explanation was found for this phenomenon, which was dubbed "the tritium endpoint anomaly". The possibility that the mysterious extra energy might derive from neutrinos captured by the tritium nuclei was soon ruled out.

An explanation of the phenomenon might be that Higgs particles with a comparatively long lifetime — that is, light particles traveling at practically the speed of light — are produced in the sun and reach the earth, where they occasionally trigger beta decay of unstable nuclei. Compare with subchapter 4.20.1. 78
This would mean that the observed additional energy is supplied by Higgs particles that are even more difficult to study than neutrinos.

However, the tritium endpoint anomaly may have a more prosaic explanation. Since tritium is an isotope of hydrogen, its shell consists of a single electron. And common sense says that the lone electron in the shell of the tritium atom cannot completely shield the quarks in its nucleus from being hit by thermal photons coming from all directions. Consequently, the tritium endpoint anomaly may have the same trivial explanation as the neutron lifetime discrepancy discussed in subchapter 4.20.5. 80

4.20.7 The sun's hot corona

The high temperature of the sun's corona is a mystery. It ranges from one to three million degrees kelvin, while the temperature of the surface of the sun is less than 6000 K.

> Astrophysicists have suggested that small but numerous so-called *nanoflares*, which cannot be directly studied, might explain the phenomenon. However, what the mechanism behind the speculative nanoflares is, they don't know.

A possible explanation of the mystery is provided by light Higgs particles. H_τ particles created in the corona through collisions between neutrinos would have a short lifetime and decay close to the place where they were created. Their comparatively large mass (0.505 MeV versus 0.511 MeV for the electron) would 72
give their annihilation products — that is, pairs of photons (or X-rays) — a very high energy, which they would pass on to the surrounding matter.

> The two photons that are created in the self-annihilation of an H_τ particle at rest get a high temperature. With $E = E_{H_\tau}$ and $T = 2T_\gamma$, the relation

$E = kT$, where k is the *Boltzmann constant*, gives $T_\gamma = 0.5 \times 0.505$ MeV/8.617 $\times$ 10^{-5} eV/K = 2.9 GK (2.9×10^9 kelvin). In other words, the energy of the photons is initially a thousand times higher than the average corona temperature of about 2 MK (where M stands for mega, or million).

It shouldn't be very difficult to estimate the amount of H_τ particles produced in the sun and calculate how much they heat the corona.

4.21 Conjectured mass of the heavy Higgs particle

Equation (4.51), which yields the masses of the light Higgs particle, may contain 72
a clue to the value of the mass of the heavy Higgs boson. For a hypothetical spin-$\frac{1}{2}$ particle lacking electromagnetic mass, the equation

$$M_H = \frac{M^2}{11\ 118.8\ \text{GeV}^2} M \tag{4.61}$$

suggests that the Higgs mass (M_H) should equal the Higgs-generated mass (M) of the neutral particle. That is, $M = M_H = 105.45$ GeV should hold.

However, the standard model's neutral particle of purely weak origin is not a spin-$\frac{1}{2}$ fermion, but the spin-1 boson called Z, or Z^0 with mass $M_Z = 91.19$ GeV. Also, the heavy Higgs mass has a value that differs from 105.45 GeV, since measurements at CERN show it to be about 125 GeV.

Therefore, Eq. (4.35) cannot be applied as such to the spin-1 Z boson. Still, it is interesting that the mass $M = 105.45$ GeV obtained from the equation is of the correct order of magnitude, and even seems to represent some kind of midpoint value between the masses $M_Z = 91.19$ GeV and $M_H \approx 125$ GeV. Tentatively assuming that there exists a simple relation between the three mass values, numerical considerations suggest that

$$M_H - M = \sqrt{2}(M - M_Z), \tag{4.62}$$

which gives $M_H = 125.62$ GeV for the Higgs mass.

4.22 Photon wavelength, frequency, and energy

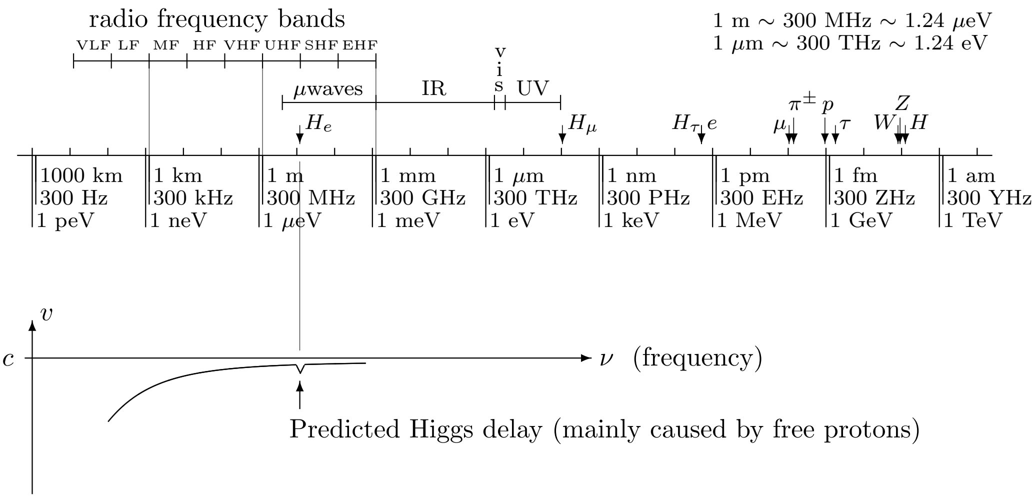
Since I didn't find any concise summation of the wavelengths and frequencies of light and radio waves and their coupling to photon energies, I have made my own summary.

The radio frequencies are: *very low, low, medium, high, very high, ultra high, super high*, and *extremely high frequency.* The abbreviations above the next line mean *microwaves*, and *infrared, visible*, and *ultraviolet light.* The prefixes of meter (m), hertz (Hz) and electronvolt (eV) are: *milli, micro, nano, pico, femto*, and *atto*; and *kilo, mega, giga, tera, peta, exa, zetta*, and *yotta.*

The relation between the photon's wavelength λ and its frequency ν follows from $\lambda = c/\nu$. Example: $\lambda = 1$ m gives $\nu = c/\lambda = 299\ 792\ 458\ \mathrm{m\,s^{-1}}/1\ \mathrm{m} = 299.792\ 458$ MHz.

The relation between the photon's energy and its frequency follows from $E = h\nu$, where h is the *Planck constant*. Example: $\nu = 300$ THz gives $E = 4.135\ 667 \times 10^{-15}\ \mathrm{eV\,s} \times 300 \times 10^{12}\ \mathrm{s^{-1}} = 1.2407$ eV.

The arrows show the self-energies (mc^2) of the three theoretically predicted *light Higgs* particles and the experimentally observed *electron, charged pion, proton, tauon, charged W* boson, *neutral Z* boson, and *heavy Higgs* boson.



In plasma, radio signals travel with speeds (v) lower than the speed of light in vacuum (c). In general, v increases with signal frequency (ν), which the arbitrarily drawn curve in the figure is meant to illustrate.

If a light Higgs particle (H_e) with mass 12 μeV exists, it will give rise to an "anomalous *Higgs delay*" and, consequently, create a notch in the curve $v(\nu)$ as indicated above. The *flyby anomaly* and the *Pioneer anomaly* discussed in subchapters 4.20.3 and 4.20.4, respectively. suggest that the Higgs delay exists 79, 79
and is measurable.

5 Black holes and dark matter

MxSM shows that the gravitational force results from the expansion of space,
which is determined by the energy content of the universe. See Eq. (3.1) and 20
subchapter 4.18. More precisely, gravity and expansion are proportional to the 69
universe's effective density, to which black holes do not contribute.

From MxSM's explanation for the origin of gravity, it follows that the gravitational force is fundamentally different from the rest of the forces acting between particles. As a result, a new and greatly simplified picture of black holes emerges. In this picture, the so-called information paradox and the singularity at the center of the hole (both of them predicted by traditional black-hole physics) are absent.

According to the new picture, time comes to a standstill for particles falling down on the surface (the so-called event horizon) of a black hole growing in size.

> The *gravitational time dilation* has the effect that — as imagined by a distant observer — processes of an object falling in toward a black hole growing in size appear to slow down until time stops ticking when the object reaches the surface, or the so-called *event horizon*, of the black hole. (Even if the particle itself can never be aware of it, outside observers know that, due to the constantly increasing radius of the growing black hole, the particle will reach the surface of the hole and disappear into its interior in a finite time.) The fact that time doesn't run on the surface of the black hole implies in turn that the energy trapped inside the hole will forever continue to affect the hole's surroundings via its "frozen" gravitational force. (In the language of general relativity: once space has become curved, it remains curved.)

With time halted, there is no motion and no exchange of photons or other force-mediating gauge particles. Consequently, there are no forces acting between particles within a black hole or on its surface. This means that the energy trapped in black holes is effectively removed from the rest of the world and doesn't contribute to the universe's expansion and the gravitational force resulting from it.

An immediate consequence of MxSM is that the "deep-frozen" particles contained in a black hole will be released when the black hole explodes, which the forever weakening gravity eventually must cause it to do.

5.1 The black holes take command

Presently, the ratio of the electric to the gravitational force between a proton and an electron separated a distance r from each other is

$$\frac{F_e}{F_g} = \frac{e^2/r^2}{Gm_e m_p/r^2} = 2.269 \times 10^{39}, \tag{5.1}$$

with the values of the physical constants obtained from Ref. [6, pp. 1587, 1588].

Details: $F_e/F_g = e^2/Gm_em_p$
$= (e^2/\hbar c)/(G/\hbar c)\, m_e^2 m_p/me$
$= (1/137.036)/6.708 \times 10^{-39}$ $(\text{GeV}/c^2)^{-2} \times (0.510\ 999\ \text{MeV}/c^2)^2 \times 1836.153$
$= (1/137.036 \times 6.708 \times 10^{-39} \times 0.510\ 999^2 \times 10^{-6} \times 1836.153$
$= 10^{45}/137.036 \times 6.708 \times 0.510\ 999^2 \times 1836.153$
$= 0.2269 \times 10^{40}$

The magnitude of the ratio suggests that the gravitational force initially must have been much stronger than today. In fact, the simulation of the universe's early evolution indicates that immediately after the appearance of the proton–electron pair, the force of gravity should have been about 4.5×10^{31} times stronger than at present.

When the proton is formed, the universe is about 4×10^{-15} s old (see subchapter 67
4.17). If one assumes that the universe continues to expand in the same manner as it did before the birth of the proton (that is, with $G \propto H \propto 1/t$), calculations using the present-day value of G lead to the value $H = 56.8$ km/s per Mpc $=$ 1/17.2 Gyr for the Hubble constant and $t = 1/3H = 5.7$ Gyr for the present age of the universe [5, p. 19]. Division of this age by the above-mentioned age, 4×10^{-15} s, gives the ratio $5.7 \times 10^9 \times 31\ 557\ 000$ s$/4 \times 10^{-15}$ s $= 4.5 \times 10^{31}$.

By capturing particles surrounding them, black holes remove from the visible universe part of the energy that feeds its expansion, thereby making H and G decrease. By later releasing particles they have swallowed at an earlier epoch, the black holes fuel the expansion with additional energy, thereby causing the expansion to accelerate and gravity to increase in strength.

The minimum mass of a *black hole* coincides with the so-called *Planck mass*

$$M = \sqrt{\hbar c/G}, \tag{5.2}$$

where $\hbar = h/2\pi$ is the *reduced Planck constant* and h the *Planck quantum of action*.

Today, $G/\hbar c = 6.708 \times 10^{-39}$ $(\text{GeV}/c^2)^{-2}$, which gives $M = 1.22 \times 10^{19}$ GeV$/c^2$ — or 2.2 μg.

The simulation shows that the photons surrounding the original proton–electron pair have a total energy of $N_\gamma E_\gamma = 2\ 786\ 000\ 000 \times 97\ 010$ eV $=$ 2.70×10^5 GeV, where N_γ is the original photon–baryon number ratio (see
subchapter 2.5) and E_γ is the energy of the background photons at the beginning 14
of universe 2.0.

Consequently, for the proton and its surrounding diphotons to be able to form a black hole, the initial force of gravity has to be $(1.22\times10^{19}$ GeV$/2.70 \times 10^5$ GeV$)^2 = (4.52 \times 10^{13})^2 = 2 \times 10^{27}$ times stronger than today. Since the force should have been 22 500 times stronger than that (4.5×10^{31} stronger than today), and since the background photons initially formed entangled pairs at rest, the conclusion can only be that the photons around the proton–electron pair immediately condense into a black hole with the proton at its center.

The black hole strives to grow and swallow as many of the photons surrounding it as possible. However, black holes cannot swallow all the particles surrounding them because the force of gravity is a by-product of the expansion of the universe. And the expansion is caused by elementary particles that continuously create space in proportion to their energy content.

Now, the particles within the *event horizon* of the black hole are cut off from the outer world and cannot, consequently, contribute to the expansion of the universe. Therefore, the more background photons the black hole swallows, the slower the expansion becomes, and the more the gravitational force weakens.

Let there be N photons outside the event horizon of the primordial black hole and $N_\gamma - N$ photons trapped inside it. It means that the gravitational force is N/N_γ times as strong as it was before the PBH was formed. After the PBH has grown to a critical point, the decrease in gravity that accompanies the
ongoing expansion will cause it to explode. According to Eq. (5.2), this happens 85
when

$$(N_\gamma - N)E_\gamma/c^2 = \sqrt{\hbar c/(N/N_\gamma)G_0}. \tag{5.3}$$

With $G_0 = 4.5 \times 10^{31}\, G$, where G is the present-day gravitational constant, this condition is fulfilled when the ratio N/N_γ has reached the value

$$N/N_\gamma = 0.000\ 045, \tag{5.4}$$

which means that the very first black hole grows until only 45 ppm (parts per million) of the photons remain in freedom outside its event horizon.

Details: Set $N/N_\gamma = x$ and $E_\gamma/c^2 = M_\gamma$, write Eq. (5.3) in the form

$$1/x = (1-x)^2(N_\gamma M_\gamma)^2 G_0/\hbar c, \quad \text{or} \tag{5.5}$$

$1/\text{x} = (1-x)^2 \times (2\ 786\ 000\ 000 \times 97\ 010 \times 10^{-9})^2 \times 4.5 \times 10^{31} \times 6.708 \times 10^{-39}$
$= (1-x)^2 \times 2.205 \times 10^4$,
and solve the equation iteratively, beginning with $1 - x = 1$:
$(1-x)^2 = 1$: $1/x = 22\ 050$, $x = 0.000\ 045$, $(1-x)^2 = 0.9999$;
$(1-x)^2 = 0.9999$: $1/x = 22\ 048$, $x = 0.000\ 045$.

However, when the first PBH has reached its maximum size, it is no longer alone in the universe. Also, the randomness caused by the interactions of electrons and photons with the now numerous black holes have had the effect that they do not explode all at the same time. Instead, one of a number of neighboring PBHs will be the first to explode.

5.2 Early inflation of the universe

The initial sharp decrease in the rate of creation of space is accompanied by an explosion — a sudden inflation — of the visible universe, which increases in size by a factor of about 10^{13}.

As mentioned in the discussion of Eq. (3.1), the Hubble expansion rate, 20
defined as $H = r^{-1}\mathrm{d}r/\mathrm{d}t$, is proportional to $r^{-3}E_V$, where r is the radius of an expanding spherical volume V with effective energy content E_V. A sudden decrease in E_V by the factor 0.000 045 given in Eq. (5.4) results in a corresponding decrease in H. Since the Hubble expansion rate is inversely

> proportional to the radius R of the visible universe (that is, $H = c/R$), R increases by a factor of about 22 000, and the universe's volume by a factor of 22 000^3, or about 10^{13}. Thus, the number of black-hole–electron pairs in the universe suddenly explodes from 1 to 10^{13}.

During the rapid inflation, very little new space is created, and the increase in the radius r of an expanding spherical volume is negligible.

5.3 Dark matter

Observations of how stars orbit galactic centers, and how galaxies orbit each other suggest that the universe contains more invisible than visible matter. The nature of the former, so-called dark matter, has remained a mystery.

According to MxSM, the only energy and mass-bearing particles that initially existed in the present universe were photons together with black-hole–electron pairs. The primordial black hole (PBH) had a proton at its center, which gave it a positive electric charge. Also, the PBHs contained most of the universe's photons, which totaled about 2.786×10^9 per black-hole–electron pair.

The natural conclusion is that one type of dark matter consists of solitary PBHs that never merged with bigger black holes.

Also, MxSM predicts the existence of large amounts of dark matter in the form of massive particles created from photons.

> Today, the observed photon–baryon number ratio is $n_\gamma/n_b \approx 1.65 \times 10^9$.
> A comparison of this value with the theoretical initial value of $n_\gamma/n_b =$ 10
> 2.786×10^9 predicted by MxSM suggests that about 40 percent of the
> original background photons have transformed into massive particles.

After its initial inflation, the universe is still small and compact with the positively charged PBHs at rest in a tranquil sea of diphotons. For each PBH, there are two high-energy photons and one electron racing through the calm photon sea. Their positive charges make the PBHs stay away from each other and interact mainly with the electrons that accompany them.

As the universe continues its expansion, H together with $G \propto H$ decrease,
with the result that the critical black-hole mass, which according to Eq. (5.2) is 85
inversely proportional to the square root of G, increases and the lightest of the PBHs explodes.

> When they first appear, the PBHs have a mass of 2.70×10^5 GeV, or
> 0.000 045 times their critical mass of today, that is $0.000\,045 \times 2\ \mu\text{g} =$
> 0.9 ng. Compare with discussions following Eqs. (5.2) and (5.4). 85, 86

The particles released in the explosion cause a small upward jump in G and nourish the remaining PBHs with fresh energy.

After the first PBH has exploded, G continues its decrease, which is caused by the steady deceleration of the expansion.

When G reaches a new low, the lightest of the remaining PBHs explodes in its turn. As a result, G again temporarily increases slightly, and particles set free in the explosion hit the remaining PBHs, and add to their energy content.

This period of constantly exploding PBHs, which very slowly grow in mass, lasts until black holes merging with each other release more energy than is trapped by solitary black holes, thus preventing G from decreasing any further.

> Some of the black holes acquire electric charge different from +1 by trapping electrons colliding with them or by swallowing protons freed in black-hole explosions. With repulsive and attractive forces of various strengths acting between them, the black holes start to slowly move relative to each other. Gradually, the dynamics of the PBHs becomes more complex, with some of them circling each other. Finally, PBHs begin to collide and merge into heavier black holes.
>
> Eventually, the period of decreasing gravity and constant clattering from exploding PBHs ends when enough of the energy freed in collisions and other interactions between black holes leads to an increase in G that outweighs the decrease, which is partly caused by the natural slowing down of the expansion, and partly by energy being trapped in black holes that are still growing in size.

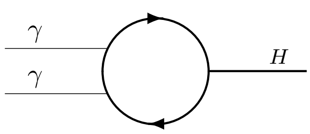
The end of the epoch of exploding PBHs — universe 2.0 — signals the beginning of the universe's present epoch of accelerating expansion — universe 2.1.

Today remaining PBHs of mass somewhat larger than two micrograms, compare with Eq. (5.2), may contribute to the indirectly observed dark matter. 85

> The observed acceleration of the expansion means that G has been increasing during billions of years. Therefore, when G reached its minimum value, the remaining PBHs must have had a mass larger than 2 μg, which is their minimum mass at present.

Consequently, solitary PBHs of critical mass should not exist today. However, a PBH circling a bigger black hole may wear down and explode before the two black holes have had time to merge. Such explosions should occur from time to time and might provide an explanation for observed cosmic radiation of "inexplicably" high energy.

Except for the proton at its center, the very first PBH contained nothing but photons. In the intense flash of light produced in the explosions of PBHs, photons colliding with each other may have produced massive particles. One such particle is the Higgs boson created from two photons through an intermediate vacuum-polarization loop formed from a pair of any charged particle (a $W^{\pm}$ boson or an electron or quark in any mass state) and its antiparticle:



In this way, Higgs particles may have been produced in a continuous range of masses, from vanishingly small to very high masses.

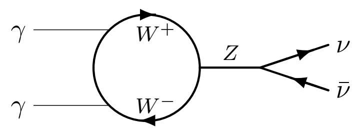
> As discussed on page 7 in chapter 1, MxSM states that particle masses are of dynamic origin, and that mass and energy are simply space in motion — space that oscillates or forms vibrating waves. Thus, the photon should be a traveling wave, while the Higgs particle (that appears to be a kind of massive, weakly interacting photon) might be visualized as a standing wave bent into a ring. In the same way as the photon is able to carry any energy given to it, the Higgs particle should be able to carry any mass it receives in the reaction creating it. 7

The lifetime (τ_H) of the Higgs depends on its mass (m_H), and for $m_H \to 0$ it holds that $\tau_H \to \infty$. Consequently, long-lived light Higgs particles, first created in photon–photon reactions in the early universe, and later in stars and galaxies, may contribute to the dark matter of the universe.

Due to their negligibly small mass, very light Higgs particles move with practically the speed of light, and their energies are determined by their temperature. They should tend to accumulate within galaxies and galaxy clusters where they interact weakly with, and take on the temperature of, the matter surrounding them.

A third dark-matter candidate is the neutrino. One possibility is that, instead of annihilating back into photons, a small part of the high-energy Higgs particles created in PBH explosions decay into Z pairs with some of the Z particles in turn decaying into pairs of neutrinos.

Another possibility is that colliding photons create neutrinos without help from intermediary Higgs particles:



MxSM suggests that not only the unstable Higgs particle, but also the stable neutrino should be able appear in a continuous mass spectrum.

> In its basic form, the neutrino might simply be a Higgs particle with the standing wave of the spin-0 Higgs transformed into a traveling wave that gives the neutrino its half-integer spin. (One may ask if the observed neutrino oscillations could be caused by traveling waves of different frequencies and speeds that are superposed on each other.)

If that is so, heavy neutrinos might be responsible for the bulk of the dark matter.

During the period of constantly ongoing explosions of PBHs that are slowly increasing in mass, the background photons are repeatedly swallowed by black holes. And every time they are released in an explosion, some of them will combine into neutrinos. In this way, a successively greater part of the massless photons are transformed into massive particles forming dark matter whose existence can only be inferred from its gravitational interaction with visible matter.

In other words, late generations of black holes grew ever larger and became constantly richer in light Higgs particles and heavy neutrinos.

Today, the heavy neutrinos created in PBH explosions have lost practically all of their original kinetic energy through redshifting caused by the expansion of the universe. Due to their low speed, they tend to accumulate in regions with high mass density: galaxy clusters, galaxies, galaxy centers, and stars — being more abundant the higher the density of the surrounding matter becomes.

5.4 Formation of large-scale structures

At the beginning of universe 2.0 characterized by exploding primordial black holes, the expansion of the universe is still comparatively fast. That is, the Hubble expansion rate H is much higher, the gravitational force (with G proportional to H) much stronger, and the visible universe (with $R = c/H$) much smaller than today.

During this period, the simultaneously (over distances $r < R/\sqrt{3} = 0.577\,R$) 37
attractive and (for $r > R/\sqrt{3}$) repulsive force renders the universe a fractal structure. The grains that form the structure continuously grow in size as the universe expands at an ever slower rate, gravity weakens, and the distance R to the horizon of the universe increases.

Toward the end of universe 2.0, distances have grown too vast for the, now relatively weak, gravity to keep the largest, previously tightly bound, structures together. Galaxy clusters begin to lose contact with each other, but as a result of the once stronger gravity, the originally tightly packed giant structures are still discernible as hyperclusters and "great walls" spanning distances up to about $0.5\,R$.

The presently observed increase in H means that the radius $R = c/H$ of the visible universe is decreasing. In other words, billions of years ago, the visible universe was larger than it is today. Its content was also much more densely packed than today, which means that galaxies that by now have disappeared far beyond the horizon were within sight of each other.

> The fact that the visible universe doesn't grow in size means that a large cosmic volume V, which is forever expanding as the energy within it continuously creates space, will eventually cover the entire visible universe and overflow the horizon of the universe.

Due to the compactness of the universe billions of years ago, the gravitational force bound together and formed, not only galaxies and galaxy clusters (as it still does), but even structures spanning the entire visible universe of today.

> An simple calculation might clarify the issue: The decoupling of radiation from matter that makes hydrogen transparent can be shown to take place at a temperature of $T_d \approx 3000$ K [7, p. 380], which corresponds to the energy $E_\gamma = k\,T_d = 0.26$ eV (where k is the Boltzmann constant with a value of $k = 8.617 \times 10^{-5}$ eV/K). After the decoupling, the energy of the cosmic microwave background radiation decreased further and is

> today about 2.725 K, or about one-thousandth of what it was at the time of decoupling. This means that the photons have been stretched and redshifted a thousandfold. In other words, creation of space has caused the radius r of an expanding spherical volume V to increase by a factor of about one thousand during the period in which light has been traveling freely in the universe.
>
> Astrophysical measurements indicate that the strength of gravity cannot have increased very much during the time the universe has been transparent. For simplicity, one may therefore assume that G, and with it H and the radius $R = c/H$ of the visible universe, are the same today as they were when the decoupling took place. Consequently, the gravitational force was (as it still is) strong enough to form structures approaching ten million light-years (10 Mly) in size. An expanding spherical volume V which, at the time of decoupling, had a radius of $r = 100$ Mly and contained tightly bound structure several millions of light-years across, as well as larger loosely bound structures, would by today have expanded into a volume of radius $r = 100$ Gly, with tightly bound structures still of sizes approaching 10 Mly, and its once loosely bound structures now discernible as giant walls spanning the entire visible universe.

In this connection, it should be pointed out that the presently advocated value of the Hubble expansion rate of $H = 1/13.8$ Gyr, which is deduced from observations, cannot be correct. The reason why it must be wrong is that its calculation is based on the assumption that G has been the same in the past as it is today,

> According to MxSM, the Hubble expansion rate H is directly related to the gravitational constant G, and is today $H = 1/17.2$ Gyr [5, p. 19]. The corresponding value deduced from observations (1/13.8 Gyr), which is 20 percent higher than the theoretical value, is obtained by measuring the brightness of so-called standard-candle type Ia supernovae formed in explosions of white dwarfs. And, since the Chandrasekhar limit, which specifies the critical mass at which white dwarfs explode, is proportional to $G^{-3/2}$, the light emitted by the "standard candles" can hardly be constant.

It shouldn't be an insurmountable task to estimate what variation in G would make the indirectly observed value of H coincide with its theoretical value.

6 Zooming in on "137.036"

As explained in subchapters 4.13 to 4.16, the simulation program [4] successfully 59, 65 describes the evolution of particles and forces in the early universe. Still, it has a couple of severe shortcomings. Thus, instead of being self-contained, the program requires input in the form of two experimentally known mass ratios (m_τ/m_μ and m_μ/m_e) for its calibration. Also, it assumes that at every point in time the number of particles in the universe, N, is a whole number (a non-negative integer), which it can hardly be in a quantum world.

Devoting recently two full months to the project, I tried to modify the original simulation program in various ways, hoping to obtain, through trial and error, an approximate value for $1/\alpha$ from scratch and gradually zoom in on its known value of 137.0360. However, my experiments didn't lead anywhere.

After finishing my experiments, I noted that my approach couldn't work because the program is based on the assumption that the universe begins in the form of a ditauon, even though it was concluded from the output of the original program that it begins in the form of a D particle.

> More precisely, the big mistake I made in my experiments was that I believed the D particle would decay into either a ditauon ($\tau_0^+\tau_0^-$) or a diphoton ($\gamma_\tau\gamma_\tau$). I didn't understand that, for such a decay to be possible, the D would have to be accompanied by virtual tauons and photons (since, without exception, unstable particles decay into other particles that already exist in virtual form). And, because the D particle cannot exist together with charged particles or particles mediating the electric force (see Ref. [2] and references therein), it cannot possibly annihilate in the way presently existing particles do. It can only attempt to disappear by reversing its clock and annihilate back into literally nothing with a lifetime of $\tau_D = 1$. Since this solution is forbidden by the law of conservation of energy, the only remaning possibility is that the D particle at time $t = 2$ makes a symmetry-breaking quantum leap into the next nearest physically allowable particle state: a massive ditauon whose component particles ($\tau_0^\pm$) possess charge and are kept together by virtual photons (γ_τ) mediating their electric force.

Even though I believe that my new insights might enable me to obtain a theoretical value for alpha, I have no ambition to perform the calculation myself. Instead, in physicsideas.com/Simulalpha.pdf [9], I try to explain how I think the "four mystery numbers" of physics might be determined.

If I am right, any teenager who knows elementary mathematics and is experienced in computer programming should be able to do the calculation.

7 Test of predictions made by MxSM

Since I myself have already stumbled upon about ten anomalies that might be explained by the existence of a light Higgs particle, I would be surprised if there are not more of them. Maybe experienced astrophysicists and nuclear physicists could add a few more puzzling anomalies to those listed in subchapters 4.19 70
and 4.20? 78

Also, I have not tried to systematically invent possible ways of testing the predictions of MxSM. However, here are a few more-or-less realistic suggestions I come to think of.

1. Improve the simulation of the first two phases of the universe. It should be possible to exactly predict the value of $1/\alpha$ (which is observed to be about 137.035 999) and in the process obtain precise values for the uncorrected m_τ/m_μ and m_μ/m_e ratios. A purely mathematical derivation of these three physical constants would prove that MxSM rests on a solid platform. Since the calculation, which is outlined in Ref. [9], relies on basic mathematics, and no previous knowledge of physics is needed, almost any one with some experience in computer programming should be able to perform the computation.

2. See if there is a correlation between the magnitudes of the flyby anoma- 79
lies and the movements of the Van Allen belts as observed from the spacecraft when they were heading toward the earth. The experiments have already been done and all the data should be available, I assume. That is, only the analysis remains to be done. Naturally, even if a clear correlation exists, it doesn't prove the existence of light Higgs particles.

3. A simple and comparatively inexpensive experiment should suffice to con-
firm or refute the prediction of a "Higgs delay" of radio signals with frequencies 83
near 2.9 GHz traveling through a plasma containing free protons. Here is an example:
Program a satellite to send, on command, three short signals with a delay of precisely one second between each of three or more consecutive signals of frequencies varying between, say, 2 GHz 4 GHz. Measure the delays at the receiving station. See if the delays change "anomalously" when the signals traverse the inner and/or outer Van Allen belts.

4. Clarify theoretically how the Higgs-mediated force between (electrons, muons, and) quarks behaves. Even if the neutral Higgs boson only comes in a single heavy (125-GeV) version and the range of the Higgs force is too short for it to be experimentally observed, the answer to the question should be of theoretical interest.

5. If the dynamic Higgs force is found to be predominantly repulsive, determine what mass a Higgs interacting with the muon should possess if it was to
explain the proton radius discrepancy. 76

6. Clarify if the small difference between the weak forces of the down quark
and the down antiquark demonstrated by the simulation program may explain
what Gerardus 't Hooft calls the superweak force, which manifests itself as a 65
difference between the decays of the neutral K and B mesons and the corre-
sponding decays of their antiparticles.

7. Confirm theoretically the simulation program's prediction $\tau_3 = 1/8\pi\alpha^2$ [5, p. 40].

8. Replace the simulation of phase 4 in Ref. [4] with a more realistic simulation that takes into account the role of the PBHs.

9. Investigate the dynamics of the black holes of MxSM, in which particles hibernate in a timeless, "frozen" state. How high does the temperature rise in an exploding black hole? How is the resulting radiation distributed spatially when a rapidly rotating black hole explodes? And how is it distributed when a small black hole orbiting a heavier black hole disintegrates? Is it possible that certain types of gamma flashes or "inexplicably" energetic cosmic radiation originate from exploding black holes?

10. What are the consequeces of MxSM's picture of gravity as a byproduct of the expansion of the universe? Does the graviton exist?

11. Should a dynamic "unified" theory of gravity and elementary particles start from the pressureless momentum equation? Should this equation be modified to take into account the quantum nature of space (undefinability of position, distance, etc.)?

12. Should one try to develop a hydrodynamic description of the quarks? Would such a description require a reformulated, multidimensional version of the "space equation"?

13. Can the laws of quantum mechanics be derived from the assumption that
space is pointless? See subchapter 3.8. 24

14. Is it conceivable that the pressureless momentum equation might find prac-
tical use in low-temperature physics? See question asked in the deviation at the
end of subchapter 4.3. 39

A Feynman diagrams

A.1 The Feynman diagrams of the standard model

The solid basis of the standard model (SM) of elementary particles is provided by its well-tested Feynman diagrams and rules. Thus, in the Introduction of his book *Diagrammatica — The Path to Feynman Diagrams* [8], Martinus Veltman writes:

> "Perturbation theory means Feynman diagrams. [. . .] Here there is a most curious situation: the resulting machinery is far better than the originating theory."

In other words, when discussing elementary particles, one should base the reasoning on their Feynman diagrams, not on experimentally unverified theoretical speculations such as the idea that all particle masses are generated through the so-called Higgs mechanism.

In particular, one should remember that the Feynman diagrams do not specify in how many mass states an elementary particle may appear, and that the theorists were unable to predict both the existence of the heavy electron (or muon, μ) first observed in 1936 and the superheavy electron (or tauon, τ) discovered in 1975.

In Appendix E of *Diagrammatica*, Martinus Veltman summarizes the "Standard Model". In Appendix E.2 (titled "Feynman rules"), he gives a complete list of the Feynman vertices appearing in SM. In the listing there are in all 92 vertices of which 47 involve ghost particles.

> On page 249, in appendix E.1 "Lagrangian", Veltman writes: "The gauge chosen is the Feynman–'t Hooft gauge. In this gauge [. . .] there are ghost fields, Higgs ghosts and Faddeev–Popov ghosts. The ghost fields must be included for internal lines, but they should not occur as external lines. They do not correspond to physical particles, but they occur in the diagrams to correct violations of unitarity that would otherwise arise due to the form of the vector boson propagators chosen here. The proof of that fact is really the central part of gauge field theory."

The standard model contains seven massive elementary particles — some of them appearing in several mass states.

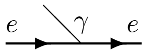
There exists one charged spin-1 boson, the W particle (or $W^{\pm}$). Also, there are three charged spin-$\frac{1}{2}$ fermions, namely the electron ($e^{\mp}$), the down quark (d, or $d^{\mp 1/3}$), and the up quark (u, or $u^{\pm 2/3}$), all of which also appear in a heavy and a superheavy version.

In addition to these four charged particles, there are three neutral elementary particles: the spin-1 Z boson (or Z^0), the spin-0 Higgs boson (or H), and the neutrino (ν), which is a spin-$\frac{1}{2}$ fermion.

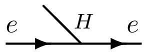
On the next page I show the 20 basic Feynman vertices through which the seven massive particles interact with each other and with the massless photon (γ) and gluon (g^a, $\alpha = 1, \ldots 8$), which are polarization-carrying spin-1 bosons. The last vertex shows gluon–gluon interaction.

A.2 Feynman vertices in the standard model

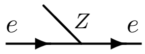
The three-legged ghost-free vertices of SM are:

1


Interaction $\propto \sqrt{\alpha} \propto e$

2


Interaction $\propto m_e$

3


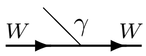
4, 5

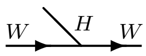

Interactions $\propto \sqrt{\alpha} \propto e$

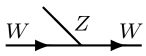
6, 7

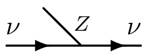

Interactions $\propto m_d,\ m_u$

8, 9


10


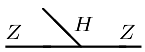
11


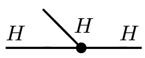
12


13


14, 15


16, 17


18


19


Non-perturbative for large M_H

20, 21


Quark–gluon, gluon–gluon interactions

Right-pointing arrows indicate particles (W^+, e^-, d, u, and ν). Similarly, left-pointing arrows are used to indicate antiparticles (W^-, e^+, $\bar{d}$, $\bar{u}$, and $\bar{\nu}$), which may be regarded as particles moving backward in time.

References

[1] James D. Bjorken and Sidney D. Drell, *Relativistic Quantum Fields*, McGraw-Hill, New York, 1965.

[2] Stig Sundman, physicsideas.com/Dparticle.pdf, 2009, and references therein.

[3] Walter Greiner and Joachim Reinhardt, *Quantum Electrodynamics*, 2nd edition, Springer, 1996.

[4] Stig Sundman, physicsideas.com/Simulation.for, 2009.

[5] Stig Sundman, physicsideas.com/Paper.pdf, 2009.

[6] Peter J. Mohr, Barry N. Taylor, and David B. Newell, *CODATA recommended values of the physical constants: 2010*, Rev. Mod. Phys. **84**, 1527, 2012.

[7] P. D. B. Collins, A. D. Martin, and E. J. Squires, *Particle Physics and Cosmology*, John Wiley & Sons, 1989.

[8] M. Veltman, *Diagrammatica: The Path to Feynman Diagrams*, Cambridge University Press, 1994.

[9] Stig Sundman, physicsideas.com/Simulalpha.pdf, 2016.

Index

1 A simple history . . . , **5**, **12**
2 The universe's mysteries . . . , **18**
3 A particle model takes form, **26**
3.19 Observations of Higgs, **70**
4 Black holes and dark matter, **84**
α (alpha), *see* fine-structure constant
β (beta), *see* beta particle
Γ (Gamma), *see* decay width
γ (gamma), *see* photon
Λ (Lambda), *see* cosmological constant
λ (lambda), *see* photon wavelength
μ (mu), *see* muon
ν (nu), *see* neutrino
π (pi), *see* pion
τ (tau), *see* lifetime; tauon
ζ (zeta), *see* zeta function

accelerating universe, *19*
alpha particle, *12*, *77*
angular momentum, *46*
  orbital, *46, 47*
  spin, *46, 47*
antiparticle, *15*
antiparticles, *46*
asymptotic freedom, *75*
atom, *44*

baryon, *61*
Bernoulli equation, *28*
beta particle (β), *13*
big bang, *19*
big rip, *19*
black hole, *85*
  event horizon, *84*, *86*
  primordial, *17*, *21*
Boltzmann constant, k, *72*, *82*, *90*
boson, *51*
bosons, *see* gauge bosons

charge, *13*, *45*
classical electron radius, *21*
conservation
  momentum, *28*
cosmic microwave background, *72*, *90*
cosmological radius, *34*
cosmological redshift, *14*
CPT invariance, *45*
cut-off mass, *48*, *52*

D particle, *14*, *63, 64*
dark energy, *19*
decoupling, *90*
degrees of freedom, *24*, *33*
Dirac's equation for a neutral spin-0 particle, *63*
Dirac's large-number hypothesis (LNH), *21*
Dirac's primordial particle, *see* D particle
divergence theorem, *41*

electric force, *56*
electron, *13*, *16*, *53*
  anomalous magnetic moment, a_e, *42, 43*, *47, 48*, *50*
  bare mass, m_0, *34*, *51, 52*
  dressed mass, m, *34*
  $(g - 2)$, *48*
  gyromagnetic factor, g_e, *47*
  gyromagnetic ratio, γ_e, *47*
  heavy, *see* muon
  magnetic moment, *47*
  renormalized mass, m, *52*
  self-mass, δm, *34*
  shell, *44*
  spin angular momentum, *47*
  structure constant, B, *31*, *41*
  superheavy, *see* tauon
electroweak theory, *73*
equation of continuity, *41*

Fermi constant, G_F, *9*, *52*, *65*
Feynman diagrams, *43, 44*, *48*, *50, 51*

fine-structure constant α, *31*, *42*, *48*, *52*
finite-QED, *see* pure QED
flow equation, *19, 20*, *28*, *40*
flyby anomaly, *79*, *83*
fundamental hydrodynamic equation, *28*
fundamental questions, *18*
Furry theorem, *48*

g, *see* gyromagnetic factor
gauge bosons, *13*, *46*
general relativity, GR, *22*
generation, *16*
global picture, *22*, *60*
gluon, *46*, *75*
gravitational constant, G, *21*, *61*, *86, 87*
gravitational force, *20*, *36*, *46*
gravitational potential, *37, 38*
gravitational time dilation, *84*
graviton, *46*
gyromagnetic factor, g, *47*, *73*

hadron, *76*
Higgs
  boson, H, *16*, *51*
  delay, *83*
  force, *75, 76*
  heavy, *16*, *62*
  light, *16*
  mass, *72*
  mechanism, *74*
  particle, H, *51*
Higgs–neutrino mechanism, *67*
hole in space, *34, 35*
hot big bang, *13*
Hoyle state, *77*
Hubble expansion rate, H, *20*, *54*, *86*
hydrodynamic equation, *28*
hydrogen atom, *15*

indeterminate quantum state, *16, 17*
inflationary phase, *19*
irrotational flow, *28*

JBW hypothesis, *see* pure QED

kinetic energy, *12*

law of change, *16*, *18*, *55*, *68*
law of conservation, *14*, *18*
lepton, *53*
  charged, *53*
  neutral, *53*
lifetime, τ, *23*
literally nothing, *12–14*, *35*, *64*
LNH, *see* Drac's large-number hypothesis21
local picture, *22*, *60*

maximally simple model, *see* MxSM
meson, *67*
momentum equation, *28*
muon, μ, *15, 16*, *53*
  anomalous magnetic moment, a_μ, *73*
  $(g-2)$ experiment, *73*
muon neutrino, ν_μ, *53*
muon–electron mass ratio, *42*, *65*, *69*
muonic hydrogen, *76*
MxSP, maximum-simplicity principle, *18*, *34*

Navier–Stokes equation, *28*
neutrino, *16*, *53*
  mass states, *62*
  oscillation, *62, 63*
neutron, *17*
  lifetime, *80*
new physics, *59*, *70*, *74*
nucleon, *12*, *46*
nucleosynthesis, *78*
nucleus, *44*

Occam's razor, *19*, *24*
orbital angular momentum, *75*

parity, *45*, *66*
path integral, *58*
photon, γ, *22*

orbital angular momentum, *46, 47*
propagator, *49*
spin, *46, 47*
virtual, *44*
wavelength, λ, *22*
photon–baryon number ratio, *15*, *61*, *85*
pion
charged, $\pi^{\pm}$, *15*, *61*
neutral, π^{0}, *15*
Pioneer anomaly, *83*
Planck constant, h, *22*, *72*, *83*
Planck mass, *85*
Planck quantum of action, h, *85*
pointless space, *24*, *36*
positron, *15*, *45*
positronium, *65*
potential flow, *28*
ppm (parts per million), *86*
principle of maximum simplicity, *see* MxSP
probability amplitude, *58*
proton, *17*
proton decay, *16*
pure QED, *34*, *49*, *52*

QCD, *49*
QED, *34*, *45*, *49*
quantum chromodynamics, *see* QCD
quantum electrodynamics, *see* QED
quantum leap, *12*
quantum universe, *13*
quark, *16*
questions being answered:
What governs the expansion, *18*, *39*, *54*
Why are there so many elementary particles, *18*, *61*
Why does matter dominate over antimatter, *18*, *61*
Why does the electron come in 3 weights, *18*, *43*, *54*
Why is the universe expanding, *18*, *39*, *54*
Why is there a gravitational force, *18*, *39*, *54*
Why is there a weak force, *18*, *54*

red giant, *77*
redshift, *14*
reduced Planck constant, $\hbar$, *85*
relativity
special, *37*
relativity theory
general, GR, *18*
special, *18*
renormalization, *48*, *50*
room temperature, *72*

self-mass, *47, 48*, *51*
simplicity, *see* principle of maximum simplicity
simulation program, *60*, *65*
space, *21*
space equation, *32*
spacetime, *34*, *64*
spin, *13*
spin angular momentum, *75*
spooky action at a distance, *23*, *25*, *60*
stationary flow, *24*
string theory, *34*
superposition principle, *33*
superweak force, *67*

tauon, τ, *15, 16*, *53*
tauon neutrino, ν_τ, *53*
time, t, *45*
basic unit, t_c, *63*
of creation, t_c, *63*
tritium endpoint anomaly, *81*
turning point, *37*

uncertainty principle, *47*, *77*
universe
radius, R, *36*
rate of expansion, *37*

vacuum-polarization loop, *35*, *47*, *49*, *57*

vertex
    one-photon, *45*, *56*
    two-photon, *56*
virtual photon, *see* photon

W particle, $W^{\pm}$, *16*, *46*, *62*, *71*, *74*
    mass 80.4 GeV, *62*

Z particle, Z^0, *16*, *46*, *66*, *71*, *74*, *82*
    mass 91.19 GeV, *82*
zeta (ζ) function, *42*