Abstract

My essay contains three main chapters (2-4). In chapter 2, I put forward a row of questions to which I (an amateur theoretical physicist) haven’t found – or understood – the answers. In chapter 3, I explain my doubts about the (self)sufficiency of mathematics in theoretical physics. Hasn’t there been comparably too little conceptual reflection and too much calculation since the mid seventies? A similar question might be asked – but on completely different grounds – about the use of mathematics and language in quantum mechanics, which I discuss in chapter 4.

Every why hath a wherefore

I write this essay for the fun of learning and writing about a subject that interests me deeply and challenges my curiosity. The question behind it is: How far is it possible for a fairly well-read lay(wo)man like me to understand the problems and stumble stones at the front of research in theoretical physics – without being a skilled mathematician? The essay gives a picture of my understandings and miss-understandings. Its title is a suitable quotation from Shakespeare’s *The comedy of errors*.

1. A somewhat unhappy love

Once upon a time, when I was a wannabe doctoral student in theoretical physics at the University of Lund, I tried to combine cooking with solving the Schrödinger equation. My casserole contained pea soup – simple Swedish farm food. The Schrödinger equation was equally simple. Yet I had to concentrate hard not to make any mistakes with the differentials.

I forgot about the soup. Two hours later it had burned into something that looked like asphalt and smelled like hell. The Schrödinger equation remained unsolved. From then on my love for theoretical physics became somewhat unhappy. I saw that I wouldn’t become a skilled enough mathematician to handle the equations effortlessly. Never the less, I kept on, following the research from a distance. During the last few years I have intensified my studies, not only reading popular scientific books and articles, but also trying to read scientific text-books and articles as well – between the equations.

Late in life I earned my PhD in a completely different subject area at the Royal Institute of Technology in Stockholm. My doctoral thesis is based on knowledge philosophy and knowledge theory. It deals with artificial intelligence, knowledge-based systems, professional skill, and how we can – and cannot – use language (be it literal, metaphorical or analogical) to transfer our knowing to other people. Key concepts are tacit knowing, creativity and intuition – the hallmarks of true professional skill, whether you are a theoretical physicist, an artist, or a carpenter.

2. Wouldst I make a good fool?

The best way to find the right answer is to ask the right question. But to ask the right question you need to be fairly close to the answer already. Otherwise you have to reflect upon a chain of questions before (if ever) you arrive at the final one; every why hath a wherefore. Since I am not a professional theoretical physicist, I feel free to ask as many silly questions as I like – and make a fool of myself repeatedly, if needed.

2.1 Can something come of nothing?

Perhaps, like King Lear, I “wouldst make a good fool”? But I hope not to ask the silliest question of all, as King Lear did, when offering the best part of his kingdom to the one of his daughters who loved him most. They were expected to explicitly answer his question. Two of them did greedily, whilst the youngest one kept silent. When the king asked her what she had to say, she couldn’t “put her heart into her mouth”. Her only answer was: “Nothing.” The king burst out in fury: “Nothing can come of nothing!”

Was he wrong? Can something come of nothing? Whatever caused the big bang also caused the creation of primordial matter/force(s) and a dynamical space-time, where both gravitational and quantum effects were vividly present. When, in 1977, I read Steven Weinberg’s *The first three minutes* I wondered (and still wonder): What “ticked” these first minutes, seconds and fractions of seconds? How long were they really? Was there no gravitational time dilation? At least before inflation set in and flattened it all. If it did.

2.2 Inflation – sweeping what under the carpet?

Alan Guth didn't invent inflation to explain the uniformity of the Cosmic Background Radiation, CBR, but to explain the non-existence of magnetic monopoles (predicted by P. A. M. Dirac in 1931) that would otherwise still be abundant in the Universe. The inflation was conjectured to have blown them away, beyond the boundaries of the primordial Universe.

But why would there be any magnetic monopoles at all from the start? Some like it hot, but wouldn't magnetic monopoles rather prefer it cold? If the Grand Unifying Theory, GUT, is true, the colour force and the electroweak force were united in the very hot and young Universe. When it cooled, spontaneous symmetry breaking differed the colour force from the electroweak. After further cooling the weak force differed from electromagnetism.

But electricity and magnetism are still united at the low temperature we experience on the Earth. Therefore (to my mind) there must come a symmetry breaking between them at an even lower temperature. Perhaps then magnetic monopoles would emerge? Recent experimental results seem to partly verify this idea. Not that magnetic monopoles have been detected as real particles, but as quasi-particles in spin-ice at temperatures below 2ºK (*Signature of Magnetic Monopoles and Dirac String Dynamics in Spin Ice*, L. D. C. Jaubert and P. C. W. Holdsworth, arXiv:093.1074v3, 2010).

2.3 Is there any need for dark matter?

The 8th of December in 2011, I went to the beautiful Aula Magna at the University of Stockholm to listen to the Nobel lectures about the accelerating expansion of the Universe. The dark energy that drives this acceleration is the cosmological constant or vacuum energy, according to Lewis Carrol (*From eternity to here*, 2010): "Some people may try to convince you that there is some difference between vacuum energy and the cosmological constant – don't fall for it."

Is the vacuum energy equal to quantum vacuum fluctuations? How could it be – if the predicted energy from quantum fluctuations is 10^{120} times larger than the measured value of the cosmological constant? This is said to be the biggest disagreement in science between theoretical expectation and experimental reality. But Gregory Volovik has other thoughts in *Vacuum Energy: Myths and Reality* (arXiv:gr-qc/0604062v2 10 Jul, 2006). So does Emilio Santos in *Quantum vacuum fluctuations and dark energy* (2010).

After all, dark energy might be equal to quantum vacuum fluctuations. But what is expanding? Space between galaxies? Or might the expansion also influence their stars – at least the outer ones? If so, I wonder about the whereabouts of the limit between the expanding and the non-expanding parts of a galaxy. Might it be where Newton's law of gravitation seems to fail? That is, where there is a choice between conjecturing either Modified Newtonian Dynamics (MOND) or the existence of dark matter, to explain why stars outside a certain distance from the galactic centre rotate differently from what Newton's law allows them to do.

Should it be that dark energy influences the stars of the galaxies in a way that makes up for dark matter – is there any need assume the existence of dark matter at all?

2.4 How stubbornly stable are the protons?

GUT conjectures that there is an extremely high temperature at which the strengths and ranges of the colour force, the weak force and electromagnetism are equal; the forces are one and the same. But this temperature is so high that it is beyond the limit of conceivable experiments to verify the GUT. However, GUT also conjectures the unification of quarks and leptons – i.e. there is a process in which quarks can change into leptons. For example, the quarks in free protons can change into electrons and neutrinos.

But free protons seem stubbornly stable. No observation of a decaying free proton has ever been made since the formulation of GUT some thirty years ago. Does this disqualify GUT? If the unification of the forces demands an extremely high temperature, wouldn't the same temperature also be required to unify quarks and leptons? Could it be that proton decay requires a much higher level of energy than the free protons that come in naturally from the outer space have? This question seems so self-evident that it ought to have been asked long ago, should it be meaningful. What have I missed?

2.5 How elementary are the elementary particles?

If super symmetry – the unification of force particles (bosons) and matter particles (fermions) – is true, the boundaries between matter and forces are kind of blurred. Every fermion has a bosonic super-partner, and vice versa. No such has ever been observed. But who says that the particles that we call elementary today need to have super-partners? Even though the fermions and bosons in the standard model of particle physics are the most elementary we know of, are they really primordial? If there might be some kind of preon, wouldn't there be a spreon as well?

2.6 Is there a need to review the basic natural forces?

What can be learnt from the differences between the basic forces? For example, might the refusal of gravity to join in with the other ones be a sign that it is not a force at all, but the form of the curved and dynamical space-time itself? Leaving gravity out, are the remaining forces thoroughly understood? Not completely, according to B. M. Martin (*Nuclear and Particle Physics*, 2009): "Even the basic strong nucleon-nucleon force is not fully understood at a phenomenological level, let alone in terms of the fundamental quark-gluon strong interaction."

Leaving gravity out once more, how many basic forces are there? The colour force that glues the quarks together to form nucleons and mesons. The (semi-basic) residual strong force that pulls nucleons together to form nuclei. The weak and the electromagnetic forces that cause beta- and alfa decay, preventing the nuclei from growing too large.

The electromagnetic force is, of course, active throughout the whole atom, from within the nucleons through to keeping the electrons connected to the nucleus. Due to Pauli, the electrons (as fermions in general) in identical states are prohibited to come too close to each other. I wonder: How come that the exclusion principle is not interpreted as a repulsive force between identical fermions? And analogously – might the love of bosons in identical states to pile up close be interpreted as an attractive force?

2.7 How are the strong and the weak forces related?

The residual strong force that keeps the atomic nuclei together was predicted in 1937 by Hideki Yukawa. The picture of it was a particle (later called pi-meson, a combined boson consisting of a quark-anti-quark pair) that was "thrown" between the nucleons so as to keep them together. The year before Yukawa's prediction it had been shown that the seemingly most near-at-hand conjecture – that the Fermi-interaction might be responsible for the residual strong force – was false. Fermi's force was far too weak and hence was called the weak force.

However, the resemblance between pi-mesons and weak bosons seems a bit too close to be wholly haphazard. There are three pi-mesons (neutral, negative, and positive) and three weak bosons with the same set of electric charges. They decay in similar ways. For example, the negative W-boson decays into an electron and an antineutrino, and the negative pi-meson sometimes do (even though it prefers to decay into a muon and an anti-muon-neutrino).

Trying to understand the relation between the residual strong force and the weak force, I imagine Yukawa's model as a couple of school-children (nucleons) throwing balls (pi-mesons) between them. The play keeps the group together. But at times a ball escapes, especially from a large enough group. The ball/pi-meson escapes the nucleus as the carrier of the residual strong force and decays weakly into an electron and an anti-neutrino.

This seems to me as a rather straightforward picture of the relation between the strong residual force and the weak force. Yet it is faulty. Martinus Veltman (*Facts and Mysteries in Elementary Particle Physics*, 2003) describes beta-decay as follows. First a down quark in a neutron decays into a W-boson and an up quark, then the W-boson decays into an electron and an antineutrino. Where does my analogy go wrong?

2.8 From where does the God particle get its own mass?

Let there be light… Or at least quantum fluctuations, where virtual photons can produce particle and anti-particle pairs, e.g. electrons and positrons or quarks and anti-quarks. If these pairs succeed in not immediately annihilating each other, they might escape each other. If so, mustn't there be some potential (i.e. negative) energy to make up for the energy needed to create the particles' mass? If so, doesn't this potential energy demand space; create space; add distance to space – make it expand?

This is one side of the question. The other side is how the particles gain their mass. As I happen to be writing this part of my essay the 4th of July, when traces of the Higgs boson are reported at the LHC, this is a question of immediate interest. The Higgs particle is conjectured to transfer mass to other particles. But from where does the God particle get its own mass? Form the Holy Ghost?

2.9 Might Planck length/time be the lower limit of space-time curvature?

Mathematics (at least infinitesimal calculus) prescribes zero-dimensional points and continuous space-time. What if nature does not? The picture of zero-dimensional point particles was never but an idealization and simplification to facilitate calculation. From this aspect one-dimensional strings mean one step forward.

Be that as it may. If matter and energy are quantized – why not also space and time? How small would the tiniest parts of space-time be? Planck length-time? In Doubly (or Deformed) Special Relativity, DSR, both the velocity of light and the Planck-length are independent of the velocities of different observers. If there is no Lorenz contraction of the Planck-length, it is reasonable to ascribe a similar independence to Planck-time (no dilation).

Should there be a space-time atom whose dimensions are of Planck length/time, is it not reasonable to assume that space-time cannot be curved across its dimensions? Otherwise, this atom could not be the tiniest possible piece of space-time. I have found no reference that describes Planck-length/time as the lower limit of space-time curvature. Have I done some original thinking – or am I simply wrong?

2.10 Which ailment is renormalisation a remedy for?

With a possible space-time atom at hand, which would be the closest simile to the singularity of e.g. a black hole? A space-time atom loaded with Planck mass/energy? The gravitational force would be enormous – however finite and non-singular. It seems to me that Gerard ‘t Hooft has a similar idea (*The fundamental nature of space and time* in *Approaches to Quantum Gravity*, ed. Daniele Oriti, 2009).

If the singularities in today’s mathematical models of physics are caused by the assumption of a continuous space-time and the existence of point-particles, would the need for renormalization still be there in a theory based on quantized space-time and non-point particles? I am suspicious about renormalization – and in good company too. In a radio interview (part of a CBC radio documentary series *Physics and Beyond*, David Peat and Paul Buckley, in the early seventies) Dirac says: “It’s just a stop-gap procedure. … When you get a number turning out to be infinite when it ought to be finite, you should admit that there is something wrong with your equations, and not hope to get a good theory just by doctoring up that number.” Is this an out-dated point of view or is it perhaps taken even more seriously today?

2.11 Is there a need for another kind of mathematics?

What would the space-time of quantum gravity be like? Dynamical, curved, discrete, and non-Abelian? Is there, for example, a need for a mathematical operation somewhere in between Σ and ∫ – that is where the neither-sum-nor-integral is carried out across intervals of Planck length? This idea came to me on a (b)rainy day at a rural bus stop. Since then I believe that I have found some support for it in the literature, e.g. in *The Shape of Inner Space*, Shing-Tung Yau and Steve Nadis (2010), *Time in Quantum Gravity*, Claus Kiefer in *The Oxford Handbook of Philosophy of Time* (ed. Craig Callender, 2011), and *The fundamental nature of space and time*, Gerard t'Hooft in *Approaches to Quantum Gravity* (ed. Daniele Oriti, 2009).

3. Is "shut up and calculate" the best thing to do?

Shut up and calculate is the headline of a paper of Max Tegmark (2007). The first sentence reads: "I advocate an extreme 'shut up and calculate' approach to physics, where our external physical reality is assumed to be purely mathematical." Max Tegmark also says: "…the holy grail of theoretical physics is a theory of everything – a complete description of reality. … Put differently, such a description must be expressible in a form that is devoid of any human baggage like "particle", "observation" or other English words. … in principle everything could be calculated without this baggage."

Of course it's self-evident to accept "calculate" as a proposition from a theoretical physicist. But what does "shut up" imply? Does it imply the worthlessness of words as media to confine and convey scientific meaning? Does it imply that our reality is out of reach from human thought? If you accept the standpoint of Karl Kraus (publicist in the fin de siéclè Vienna) that language is the mother of thought and not its chambermaid, you cannot help to interpret Max Tegmark otherwise than that he regards mathematics to be the master of though, whilst language doesn't even suffice as a lackey.

Even though I'm not able to question the "shut up and calculate" strategy scientifically, I can question it out of my work life experience. In the late seventies I was responsible for analyzing the reliability performance of the combat leading centrals of the Swedish Air Defence. If I had just shut up and calculated – and not travelled around the country to ask operators and maintenance people about their reasoning when reporting the down times – I had delivered completely misleading statistics to my clients.

Behold that I don't question the necessity of mathematics in theoretical physics, only its (self)sufficiency. My point against the "shut up and calculate" promoters is that when you retreat from human language it becomes hard to build mental pictures of what the equations are based on, what goes on within them and what they have to say about the world. Which are the simplifications behind the physical models? Which further simplifications are required in order to fit a physical model to a suitable mathematical method? And which approximations must be accepted when using a numerical method to facilitate calculation? These questions cannot be answered by calculation alone, but require conceptual reasoning as well.

Not with malicious pleasure – yet with some kind of pleasure – I wonder: How come that the ability to create substantial predictions in theoretical physics have decreased during the same time as calculation capacity has increased exponentially, to levels that were unbelievable in the mid seventies?

Steven Weinberg (*The dreams of a final theory*, 1993) says: “Often we have felt as did Siegfried after he tasted the dragon’s blood, when he found to his surprise that he could understand the language of birds. But now we are stuck. The years since the mid-seventies have been the most frustrating in the history of elementary particle physics.” Kerson Huang (*Fundamental Forces of Nature*, 2007) says: “In contrast to experiment, theory went into a depression after the blinding success of QED.”

I agree with Lee Smolin (*The trouble with Physics*, 2006): “It should not just be math – my very conception of nature should change.” Here is the proper place for an additional quotation, originally from Fortun and Bernstein (1998) related in *Unification and Emergence in Physics: The problem of articulation* (Ian T. Durham, 2009): “Language matters. Language is essential to reason and can’t be gotten rid of so easily with a few machines. Somewhere along the line – no matter how long that line is – every experiment, every mathematical equation, every pure numerical value will have to find its way into words.”

Has there been comparably too little conceptual reflection and too much calculation in theoretical physics since the mid-seventies? Even though the human language lacks the logical exactness of mathematics, and even though scientific intuition and creativity is the kind of tacit knowledge that can only partly be explicitly expressed in words… Not even trying! Just shut up and calculate? I helvete, Max Tegmark.

4. Is the need to understand needless?

In an interview with Werner Heisenberg (conducted by David Peat and Paul Buckley in the CBC radio documentary series *Physics and Beyond*) there is an interesting discussion about the use of language in theoretical physics. Heisenberg refers to Ludwig Wittgenstein’s late philosophy of language, which (simply put) tells that the meaning of words is rooted in practice; the meaning of words comes from our use of them; there is no unambiguous meaning of a word and consequently no unambiguous meaning of language.

Heisenberg was talking about the difficulty to put the interpretation of quantum mechanics into words. There was no lack of trying – most of the leading scientists at the time (plus Schrödinger’s cat) were involved in the discussions. No doubt that quantum mechanics was (and still is) very hard to catch within the classical framework of experience and terminology.

Louis de Broigle, who proposed the generalisation of the particle-wave duality 20 years after Einstein’s first published paper on the photoelectric effect, was vague about the physical nature of the particle-waves. He meant that the waves were in some way guiding the particles. Shortly after de Broigle’s publication, Erwin Schrödinger and Werner Heisenberg independently published their path-breaking works on quantum mechanics.

Different to Schrödinger, Heisenberg based his matrix version solely on experiments, without using de Broigle's particle-wave duality. Still, whether you follow Heisenberg or Schrödinger – and even though their starting points and mathematical methods were very different – Dirac showed that their theories were equivalent and lead to identical predictions.

Did matrix mechanics and wave mechanics also lead to identical interpretations of quantum mechanics? According the radio interview, Heisenberg and Niels Bohr had a different point of view from Schrödinger: "He [Schrödinger] agreed about the experimental tests of quantum mechanics, but he disliked the interpretation." So, the inner circle of the founders of quantum mechanics did not agree about the Copenhagen interpretation. Neither did, among many others, de Broigle – and least of all Einstein. Quantum mechanics is still an ambiguous theory, open to different interpretations. Few scientists claim to understand it, even though none denies its elegance, and (different from string theory) its never-ending success in correctly predicting the outcome of experiments.

Ever since the mid twenties quantum mechanics has been developed as a background dependent theory, without regard to the background independence of the general theory of relativity. How come that the background dependence of was not questioned much earlier, as it could have been already in Copenhagen at the time – at least in principle? A simple answer is that the time was not ripe to try to unite quantum mechanics and general relativity – not until the ideas of black holes and the big bang had come up and matured. Then it was no longer possible to keep cosmology and elementary particle physics apart. But not even then was the background dependence seriously questioned.

And the question still remains: What is waving? Could it be that the Copenhagen (non?)interpretation of quantum mechanics postponed a deeper conceptual interpretation, partly due to the difficulty to put the theory into words, but perhaps most of all due to the grand success of the equations to predict the outcome of experiments? Did quantum mechanics work too well to be questioned? Was the need to understand needless, as Niels Bohr put it in the old hey-days? Is the need to understand still needless?

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