

The Universe's Balance on a Razor's Edge

In de serie 'Students on Science' presenteren we Engelstalige artikelen die zijn geschreven door studenten van het vak Wetenschapscommunicatie aan de UvA. Vandaag beschrijft Mike Keizer het hiërarchieprobleem: de verbazende balans tussen verschillende krachten in de natuur.



Nature's balance. The forces of nature show a delicate balance expressed in the hierarchy problem. Image via [Goodfon.com](https://www.goodfon.com).

The Universe's Balance on a Razor's Edge

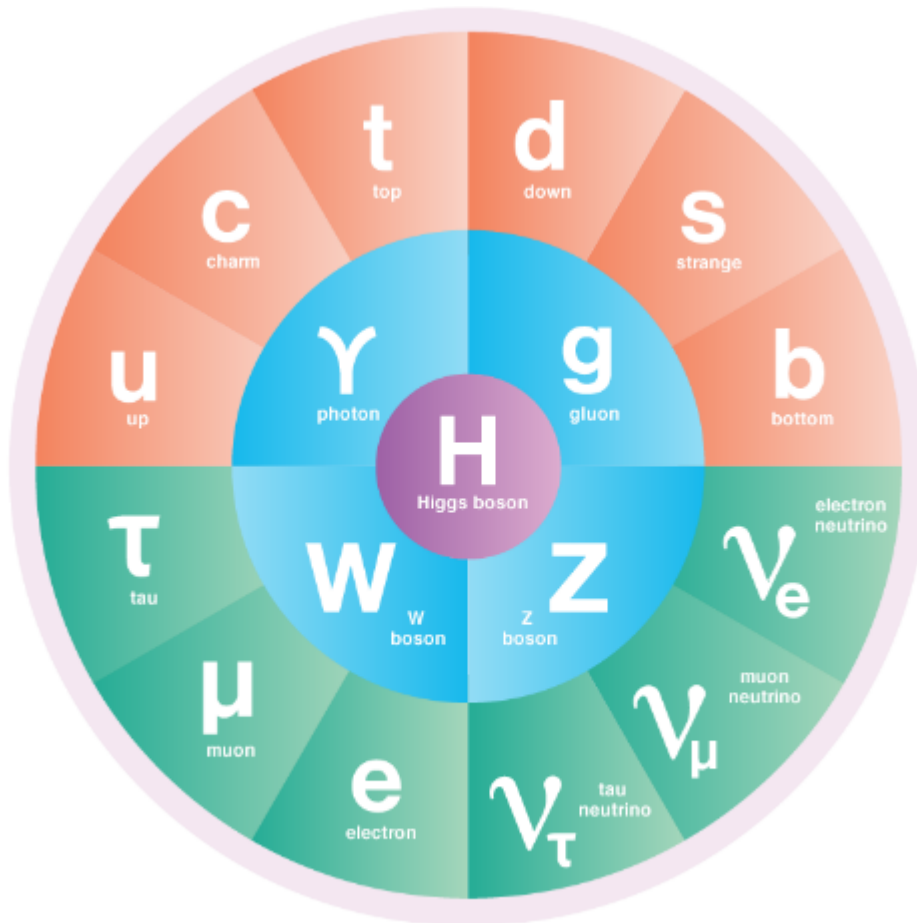
It's a sunny Thursday afternoon. You and a colleague are having a drink after work when a friend of your colleague walks in. They greet each other with a warm hug,

so naturally, you get up to introduce yourself. But before you know it, you lean in for a hug instead of offering a handshake. Awkward!

That small moment of confusion, where you have to choose between a handshake and a hug, might feel purely human. However, something similar happens in the world of particles. In their own strange quantum way, particles also “greet” one another with different strengths of interaction. Most of these greetings are familiar; we know them as the strong, electromagnetic and weak forces. But there is also one outlier that joins the party: gravity. Compared to the others, it greets with a whisper rather than a hug, and is thus far weaker than expected.

A kiss, a hug and a handshake

The “greeting mechanism” of particles is captured by a grand framework that physicists call the [*Standard Model of Elementary Particles*](#). It lists all known particles of nature: quarks and leptons, which make up the matter of the universe, and force carriers (gauge bosons), which are the messengers between the quarks and leptons and carry the forces. Finally, there is the famous [*Higgs boson*](#), which provides mass to all of the particles. It should be noted that every particle is tied to an underlying field filling up all of space. The particle is then an excitation or tiny ripple of that field, for example the Higgs boson is a ripple of the Higgs field.



● QUARKS ● LEPTONS ● BOSONS ● HIGGS BOSON

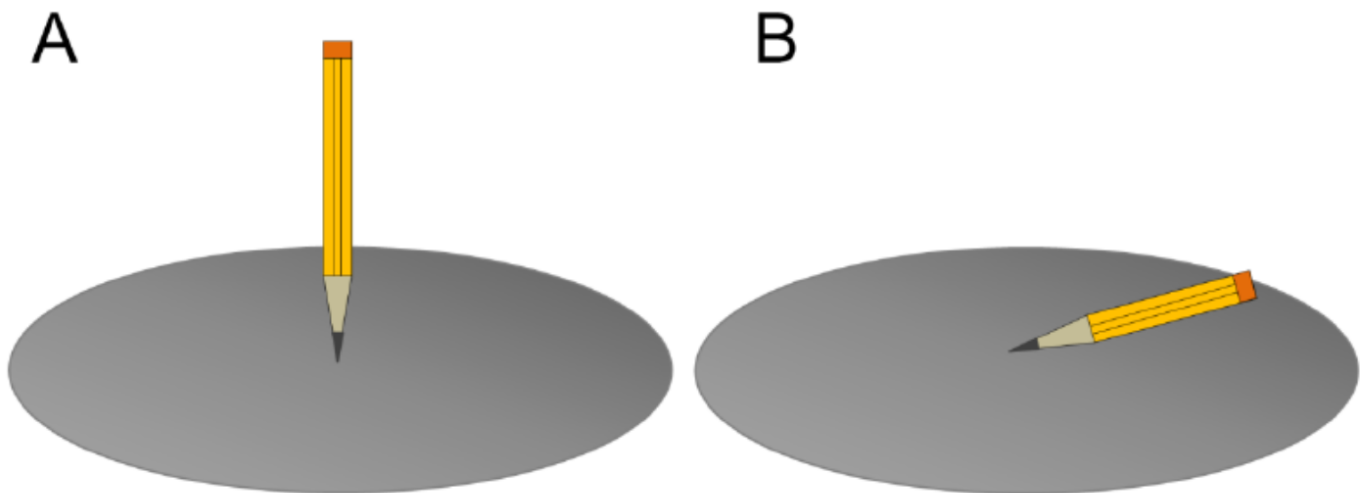
The Standard Model. A visual representation of the particles in the Standard Model. Via energy.gov.

Each force can be identified by its own personality. The strong force acts like a tight kiss, since it glues quarks together inside protons and neutrons. The electromagnetic force is more like a friendly hug, gently pulling and pushing charged particles. The weak force acts as a polite handshake, and is weaker than the other two.

However, there is one force that does not quite fit in: [gravity](#). Compared to the others, it barely even whispers. It is so weak that we only notice it when huge amounts of matter are involved, like stars and their planets. In the world of all the particles, gravity's voice is almost silent. So why is this whisper so much softer than all the other greetings? This is the heart of the great puzzle called the *hierarchy problem*.

The tipping point of mass

To see how the Higgs boson is related to this problem, we first dive into its strange nature. Imagine trying to balance a perfectly sharp pencil on its tip. For a brief moment, it stands completely straight on the table. At that moment it is almost perfectly *symmetric*, meaning that it is the same in every single direction. However, a tiny vibration can make it fall in any single direction. The pencil has to “choose” this direction, breaking its perfect symmetry.



Symmetry breaking. Cartoon demonstration of symmetry breaking: A) a perfectly symmetric pencil balancing on a table, B) the pencil “choosing” its direction and thus breaking its symmetry. Image from [Chung et al.](#)

The Higgs field in our universe went through something very similar. Right after the Big Bang, it was still like the symmetric pencil balancing on the table. As the universe cooled down however, the symmetry of the Higgs field broke and it chose a particular “direction” or state to stay in. This did not only have an effect on the Higgs field itself; it also caused the particles in our universe that interact with the Higgs field to gain a certain and definite mass. Without this cosmic tipping point, you and I would not have any weight at all.

In addition, the symmetry breaking also set the strength of the weak force, defining it for all of eternity. The result of the falling of the “Higgs pencil” was the weak force as we know it today; a force that greets by a polite handshake.

The quantum mood

Now comes the real strangeness of our universe. When viewed from up close, the world we

know behaves very differently. When we zoom into the smallest scales of reality, the so-called [quantum world](#) takes over, a place full of randomness.

Imagine giving a firm handshake, your bare interaction. But just as you do, you notice your friend's piercing blue eyes, or you remember you're late for a meeting. Suddenly your grip slightly changes without your intention to do so. Those tiny changes are like *quantum fluctuations*: unpredictable effects that slightly disturb your original perfect handshake.

The same thing happens to the Higgs field. Its "bare" strength gets disturbed by quantum effects. Physicists do an immense amount of calculations to see those tiny corrections to its original value, and find that it should add up to something enormous. The tiny changes do not seem so tiny anymore, and we expect the change to be huge. However, the actual strength that we measure is very small. Where did the large disturbances go?

Think of it as two huge numbers, the original value and the quantum corrections, that cancel each other almost perfectly. What is left behind is just a tiny number. Physicists call this process *fine-tuning*. It is very *unnatural*, as if nature had to adjust its settings with absurd precision just to make the universe work. This strange mismatch between the expected and the observed value is the core of the hierarchy problem.



Fine-tuning. Cartoon demonstration of the difference between a natural and a fine-tuned, unnatural event. Image: [Matt Strassler](#).

Conclusion

At last, let us step back to see the full picture and combine everything we know. In the Standard Model, the three main forces explain almost everything we see in the universe. Gravity stands apart, and it is billions of times weaker, so faint that it barely belongs with the other forces.

The Higgs field defined the strength of the weak force, by falling in a random direction after the Big Bang. But quantum corrections should have pushed that value to something enormously larger. Only a delicate cancellation between the bare strength of the Higgs field and those quantum corrections keeps the weak force at the modest strength we observe today. That balancing act is what puzzles physicists: why does this perfect fine-tuning exist at all?

Thus instead of asking why gravity is so weak, we should ask why the weak force is so precisely balanced, or why this fine-tuning does not apply to gravity. Perhaps there is still hidden physics behind the curtain, like new particles or new symmetries. Whatever the answer to the hierarchy problem, it reminds us how finely balanced our universe really is. Even the smallest “adjustment” in this grand cosmic handshake could have made our world a very different place.