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News

Two constants to rule us all

Physicists whittle down the number of truly fundamental constants.

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What units are needed to describe all this...?

NASA

How many physical constants does it take to describe the Universe? The answer, according to a team of physicists in Brazil, is just two.

The two can be chosen, according to taste, from a list of three: the speed of light, the strength of gravity, and Planck's constant, which relates the energy to the frequency of a particle of light, say George Matsas of the São Paulo State University and his colleagues.

Once two constants have been chosen from that list, they say, those are the only parameters that need have units of measurement ascribed to them. Everything else — for example, the charge or the mass of an electron, or the strength of nuclear forces — can be described in relation to these two 'dimensional' constants.

"Their argument is very interesting and perhaps even profound in what it implies about the natural world," says Richard Davis of the Bureau International des Poids et Mesures at Sèvres in France, which establishes international standards for fundamental units.

Four, three, two, none

The minimum number of dimensional fundamental constants has been debated for over a century. In 1899, Max Planck argued that four constants were needed to describe all phenomena. He didn't know what they were, but labelled them a, b, c and f.

Planck's four constants were later identified. His 'f' is Isaac Newton's gravitational constant G, which describes the relationship between the strength of gravity exerted by one body on another, and their masses and separation. Planck's 'b' is the constant he later called h, which describes the proportionality of the energy of a photon to its frequency. Planck's h is very small and only comes into play at the 'quantum' scale of very small things. Planck's 'c' turns out to be the speed of light, and has kept that symbol ever since, most notably in Einstein's $E = mc^2$.

Constant 'a' turned out to be equivalent to the Boltzmann constant, which relates energy to temperature. It later became clear that this one isn't strictly needed, as it can be described using the others. Many physicists have long believed that three constants — c, h and G — suffice.

But there is still no consensus. Some think that two should be enough, while others have even argued that none are needed: that the universe can be described using ratios alone, so that there are no 'natural' units.

Constant relations

Matsas and his colleagues start by noting that all measurements obviously happen in time and space. Might these two quantities, then, be all we ultimately need to measure? That's clearly enough for the speed of light, c (measured in distance per time). But what about h and G?

The Brazilian group notes that a common way of measuring mass is to measure the movement of a set of scales. Converting that to mass in kilograms depends on knowing the gravitational constant G. But why convert to kilograms, except because of convention (which Newton, in effect, followed)?

In fact you could eliminate units of mass from everything by multiplying every unit in which the kg appears by the factor G. That would include Planck's constant h (which can be written as 6.6×10^{-34} $m^2 kg/s$), which would become redefined as a new constant Gh, denoted $h^{(G)}$.

In this sense, the reseachers say, G was never really needed in the first place[1].

Indispensible

So it is enough to have just c and $h^{(G)}$. Or, if you choose your system another way, just c and $G^{(h)}$, where every unit that currently features kg is multiplied by h to some appropriate power.

Matsas and his colleagues say that the nice thing about using c and $h^{(G)}$ is that they set the scales at which relativity and quantum physics — the two fundamental descriptions of nature — manifest themselves. The speed of light, being very large, is the 'natural' speed scale for relativity, and $h^{(G)}$ being very small, is the 'natural' size scale for quantum physics. Our everyday world operates in between.

The search for a minimal set of fundamental physical constants may sound like something of a game, but it has something profound to say about what a 'theory of everything' could tell us. Matsas explains that such a theory could never account for the magnitude of the fundamental physical constants, but could only explain all other quantities and physical laws in terms of them. So the fewer such constants there are, the more, in a sense, such a theory can tell us.

It won't have much practical impact on how we measure things in the everyday world though, says Davis, since scientific units generally strive not for minimalism but for greatest practical utility. But the work shows nicely how "some constants are more fundamental than others", he says – some are merely useful, whereas perhaps precisely two are indispensable.

References

1. Matsas, G. E. A. et al. Preprint http://xxx.arxiv.org/abs/0711.4276

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