AN ASIDE: JIU-JITSU PHYSICS AND THE ANTHROPIC PRINCIPLE

Just as economists have invented the Efficient Market Hypothesis to account for the failure of their models to predict the future of stock prices, so physicists have invented The Anthropic Principle to account for their failure to derive the values of certain fundamental constants of nature.

The Rydberg Constant

The clinching triumph of Bohr's 1912 planetary model of the atom was the formula he derived to explain and predict the series of discrete wavelengths of light emitted by heated hydrogen gas, the so-called spectral lines.

At that time, physicists were aware of the so-called *Rydberg formula*, the following elegant empirical equation discovered years earlier that fit the wavelengths λ of all the spectral lines of hydrogen:

$$\frac{1}{\lambda} = R\left(\frac{1}{n^2} - \frac{1}{m^2}\right)$$

In this formula, λ is one of the many wavelengths of the light emitted by hydrogen, n is an integer greater than or equal to 1, and m is another integer greater than n. Each possible set of values of n and m correspond to one possible wavelength of emitted light. The coefficient R is the Rydberg constant whose value, approximately 1.1×10^7 inverse meters, was measured experimentally.

Once measured and inserted into the simple formula above, it could account for all the lines. So, for example, for $n = 1$ and $m = 2$, the formula predicted that hydrogen should emit light of a wavelength λ given by

$$\frac{1}{\lambda} = 1.1 \times 10^7 \times \left(\frac{1}{1^2} - \frac{1}{2^2}\right) = 1.1 \times 10^7 \times \left(1 - \frac{1}{4}\right) = 1.1 \times 10^7 \times \frac{3}{4}$$

that is, a wavelength of approximately 1.212×10^{-7} meters.

Physicists before Bohr knew the Rydberg formula, but had no idea where it came from. In particular, they assumed that the Rydberg constant was a fundamental quantity whose value, 1.1×10^7, could be obtained only by measurement, much like the speed of light or the charge of an electron. Bohr's model treated the hydrogen atom as composite made out of an electron and a proton and calculated their quantized energies, as described in Chapter 5. He then derived the Rydberg formula from the differences in energies between planetary electron orbits in the model, discovering that n and m in the formula are the numbers corresponding to the discrete sequence of orbits.

His model produced a formula for R itself that was a simple product of powers of the electron mass m, its charge e, the speed of light in a vacuum c, and Planck's constant h, given, to be specific, by

$$R = \frac{2me^4\pi^2}{h^3c}$$

The values of all the fundamental constants on the right hand side were known. The computed value of R on the left hand side agreed with its experimentally measured value. Bohr had shown that the mysterious Rydberg constant was not at all fundamental, but depended on other quantities already known; it was, in a sense, a derivative, a contingent quantity. This discovery provoked a kind of Spinozan (anti-)Wonder. *Anti* because Wonder is the feeling you get when contemplating something magnificently unconnected to everything else you understand; the calculation of the Rydberg constant provokes Wonder at the magnificent connection.

Ever since, buoyed by this triumph, physicists deep in their hearts hope to find a theory that will explain the values of other apparently fundamental constants too. If R is a derivative quantity that can be explained in terms of m, e, c, h, then why shouldn't m, e, c, h, the gravitational coupling constant *G*, and so on be explained in terms of other more primitive quantities?

Occasionally the community of physicists has become excited about a new formula, often discovered by chance or by mathematical tinkering, that seem to derive a value for some of the dimensionless constants of physics. Dimensionless constants are pure numbers that have no units, are not measurable in feet or seconds or kilograms. They are numbers with no scale. Perhaps the most famous is the fine structure constant α, called so by Sommerfeld because of the way it appears in an extension of Bohr's planetary atomic model that he developed in order to take account of the fact that an electron cannot move faster than the speed of light. Sommerfeld's formula was able to explain some of the finer details of the structure of atomic spectral lines.

The fine structure constant α defined as $\alpha = 2\pi\frac{e^2}{hc}$, and is dimensionless. Its measured value is about $\frac{1}{137.035999084}$, measured nowadays to an astonishing accuracy of more than ten significant figures. Although it was first used by Sommerfeld to derive merely small corrections to the formulas for spectral lines, the fine structure constant represents the essential strength of the electromagnetic force. Since α is a pure number with no scale, it reminds physicists of the purely mathematical numbers π, and so they dream of finding a formula for its value from pure mathematics.

Here is what Feynman* had to say about α in 1985:

> "There is a most profound and beautiful question associated with the observed coupling constant, *e*, the amplitude for a real electron to emit or absorb a real photon. It is a simple number that has been experimentally determined to be close to –0.08542455. (My physicist friends won't recognize this number, because they like to remember it as the inverse of its square: about 137.03597 with about an uncertainty of about 2 in the last decimal place. It has been a mystery ever since it was discovered more than fifty years ago, and all good theoretical physicists put this number up on their wall and worry about it.) Immediately you would like to know where this number for a coupling comes from: is it related to π or perhaps to the base of natural logarithms? Nobody knows. It's one of the greatest damn mysteries of physics: a magic number that comes to us with no understanding by man. You might say the "hand of God" wrote that number, and "we don't know how He pushed his pencil." We know what kind of a dance to do experimentally to measure this number very accurately, but we don't know what kind of dance to do on the computer to make this number come out, without putting it in secretly!"

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* QED: The Strange Theory of Light and Matter, Princeton University Press, p. 129, ISBN 0691083886

Respectable physicists with mystical leanings (Wolfgang Pauli and Arthur Eddington among others) as well as psychologists (Carl Jung, who treated Pauli) have speculated on the significance of the value of the fine structure constant, and tried to find formulas for calculating α or $1/\alpha$. One simple and elegant formula, accurate to several decimal places is

$$\frac{1}{\alpha} \approx 4\pi^3 + \pi^2 + \pi \approx 137.0363037...$$

There are others that do even better.

When you then see a simple formula like this for α, your romantic heart leaps. Though many formulas of this kind have been derived, some more accurate and some less so, none of them have had proofs that physicists find convincing or acceptable. I remember several exciting mini-sensations in the physics community during the time I was a graduate student about near incomprehensible formal "derivations" of the value of α.

Faced with these failures, physicists over the past thirty years have adopted their own jiu-jitsu approach to "explain" the values of fundamental constants such as α: they invented the anthropic principle. The anthropic principle states that fundamental constants are what they are because if they were different we wouldn't be here to measure them. For example, some physicists argue that if α and/or various other fundamental constants had even slightly different values, our carbon-molecule-based life would not have been possible. The value of α we find in the universe, they claim, is what it is. If it weren't, we wouldn't be here to measure it. In some versions of string theory there is in fact room for many universes (multiverses, as they are fashionably called by physicists progressively excising any residual notion that we, our earth, our solar system, or our universe are central), each with their own values for the fundamental constants. As Nabokov wrote in *Lolita*, "You can always count on a murderer for a fancy prose style."

The anthropic principle disguises the failure of physicists to find a theory for the value of α. As with the EMH, there are “weak” and “strong” formulations of the anthropic principle too, but these are nitpicking distinctions.

This seems to me more metaphysics than physics.

Very recently, some astronomical experiments have very tentatively indicated that α varies ever so slightly across the visible universe. If that were so – if the strength of the electromagntic interaction is different in different places – the fundamental constant wouldn’t be constant, and ambitious idealistic physicists would try to find a formula for its variation.