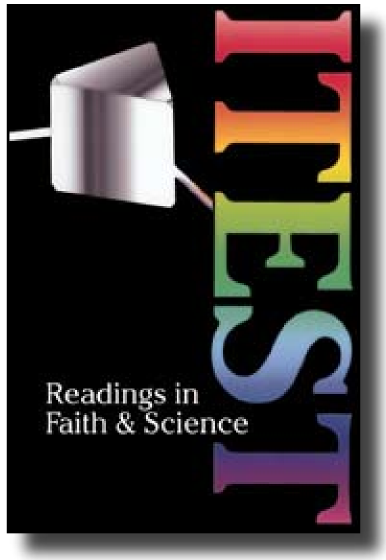

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Six Magic Numbers in Physics

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Six Magic Numbers in Physics

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For most people, their introduction to physics deals with Newton's laws, energy, momentum, sound, light and *maybe* a little atomic physics. Quantum Mechanics opens up an almost mystical wonderland of strange phenomena, and leads various people off into philosophical speculation of one kind or another.

One very essential fact is that everything we deal with is made of atoms -- every cell in every body, every neuron in the brain, and so forth. Through the use of intellect, we are able to discern order in nature, and that order is rooted in mathematical laws that govern the behavior of atoms.

The "advance" of science is the discovery of patterns and regularities that display order. To "study" science means to inquire into the organized body of knowledge about order.

In basic physics, we learn about certain numerical values, like the temperature at which water boils, the speed of light, the charge on the electron, the acceleration of gravity, and many more. Each of these *physical constants* has some dimensions, or units, like meters per second or miles per hour. Only a few of these are worth memorizing, since their numerical values change whenever the units change.

Dimensionless Numbers

However, it is possible to construct *dimensionless ratios* by comparing two numbers that have the same dimensional units. For example, the speed of sound (C_s) and the speed of light (C_L) both are measured in the dimensions of meters/second, and so their ratio is a pure number without any dimensions at all. (No matter what units you use, $C_L/C_s = 875{,}000$). Another dimensionless number is the ratio of the mass of the proton divided by the mass of the electron: $M_p/m_e = 1836$. There is a very long list of dimensionless numbers that can be constructed this way. You might think all these numbers are of no special significance, just a coincidence. For most of them, you would be right.

However, here's what is really interesting: There are six very special dimensionless numbers which, if their numerical values had been different by even very small percentages, the universe as we know it today could never have come to be. These numbers pertain to the basic forces that govern the universe, the size and time scale of the universe, and the structure of everything. They appear in physics at a very rudimentary level. Coincidences? Actually, they reveal the exquisite *engineering* that went into giving us the universe we live in.

The British Royal Astronomer Martin Rees has written a book, *Just Six Numbers* (1), that devotes one chapter apiece to explaining the significance of each of these very special numbers. Here I follow Rees' notation and descriptions, but there is only space enough to synopsize very briefly the key interesting facts about each.

Let's examine each of these numbers in turn:

The Special Numbers

1. Ratio of the Electromagnetic Force to the Gravitational Force:

Gravity is a *lot* weaker than electromagnetism. It may not feel like it when you fall out of a tree and hit the ground, but it is. The extremely weak force of gravity only builds up to real strength when a *lot* of mass is present, such as in a planet. In stars and galaxies, there is so much mass that the force of gravity dominates.

However, both gravity and electromagnetism vary in strength via an "inverse square" law. As electric charges get farther away from each other (distance r), the force between them diminishes; similarly, as planetary bodies get farther away, the force diminishes; The "inverse square" law says both kinds of forces fall off as $1/r^2$. Consequently, a ratio can be formed of the strength of the two forces, and the $1/r^2$ dependence cancels out.

The ratio of the electromagnetic force to the gravitational force is about 10^{36} (= 1 with 36 zeroes behind it). Martin Rees' book denotes this ratio by the letter N.

The extreme weakness of gravity is what gives the universe enough time to "get its act together." If gravity were stronger, gases would coalesce into much smaller stars much quicker, and those stars would burn out more rapidly -- in about 10 thousand years instead of 10 billion years. The formation of planets takes longer than that, and the development of life longer still. If gravity were stronger, stars wouldn't last for enough time for us to be here.

2. Efficiency of the Strong interaction, E :

The process that takes place inside a star is that hydrogen is "burned" by nuclear fusion into helium. The interactions between nucleons is governed by the Strong Force, a type of force different from electromagnetism. As hydrogen nuclei combine, a certain amount of mass is converted into energy, according to the famous formula $E = mc^2$. The amount of mass converted is E = 0.007 (= 7/10 of one percent). Some of that energy is released as starlight, some energy is carried away by neutrinos, but most sticks around the star as heat, and regulates the speed at which burning takes place and hydrogen is used up.

Now, what's interesting is that if this conversion efficiency were E = .008, the early protons from the Big Bang would have combined too quickly, and stars wouldn't even have formed. If E = .006, protons wouldn't bind to neutrons, and thus there would be no stellar process to produce helium. Either way, no stars as we know them.

Moreover, another process taking place inside stars produces carbon by the combination of three helium nuclei. A chance combination of three things is much too rare to depend on to produce much of anything, but it seems there is a "resonance" -- a very precise matching of energy levels -- that allows this process to happen, forming carbon from helium. Without the fine-tuning of the strength of the *Strong Force*, that resonance would vanish. Needless to say, without carbon, again no biology as we know it. The value of E has to be quite close to 0.007.

3. Cosmic Density:

For centuries astronomers have looked at stars, but only in the 20th century was it discovered that the stars cluster together in galaxies. By the late 20th century, it became clear that the rotating motions within galaxies would cause them to fly apart, unless there is a lot of additional unseen mass out there exerting the gravitational pull necessary to hold things together. This unseen mass is termed *Dark Matter*. This idea is fully accepted by astrophysicists, because it is based upon a very sound theoretical basis. Our current understanding is that we see very little of the mass in the universe; about 90% of the mass is actually dark. It is probable that most of this mass is neutrinos, but other contestants have not been ruled out.

What is important, though, is that the universe has some average density, customarily denoted by p. If we take all that can be seen and spread it out uniformly over all space, that density seems to be about p = 0.1 atoms/m^3; and if we add interstellar dust, it becomes p = 0.2 atoms/m^3. The presence of dark matter runs it up to around p = 2 atoms/m^3.

If the density exceeded 5 atoms/m^3, the strength of gravitational attraction would be so great as to pull everything back together again in a giant collapse. That is called the "critical density." The ratio of the *actual* density to the *critical* density is denoted by Ω and is another of the six special numbers.

It is not hard to do calculations to show the importance of this density ratio. Starting off from the Big Bang, the expansion of the universe can be traced in space and time, depending on various choices for the parameter Ω. Basically, the computational process diverges. If the density were slightly low ($\Omega < 1$), expansion would proceed rapidly, and density would become lower still; in that case, stars and galaxies would never form, and the universe would simply fly apart. If the density were slightly high ($\Omega > 1$), gravity would halt expansion, the universe would re-collapse, and there would be insufficient time for stellar evolution. The range of permissible values of Ω is very narrow -- and sure enough, we're in that range. The actual expansion rate of the universe is an observable, measurable quantity, known as the *Hubble Constant*. We observe that, in over 10 billion years, Ω has stayed remarkably close to one. For that to be true today, it must have been the case that at one second after the Big Bang, $\Omega = 1$ had to hold within one part in 10^{15}. It is plausible to argue that Ω has to be exactly one, for reasons not yet discovered.

4. Smoothness and Ripples:

Any theory of cosmology has to match the observations from astronomy. One problem is that the observable universe is certainly non-uniform. If one imagines a "Big Bang" followed by expansion, at first it would be plausible to suppose that the expansion proceeded uniformly; in which case, there would be no particular reason for stars and galaxies to coalesce.

The most convincing observational evidence we have that a big bang did occur is the *Cosmic Background Radiation*, which shows that the universe is filled with radiation corresponding to a temperature of about 3°K (2.7°K to be precise). That radiation, leftover from a very hot Big Bang about 14 billion years ago, was first discovered in 1963, and seemed to be coming uniformly from all directions. However, in recent years, the NASA *Cosmic Background Experiment* (COBE) showed that there were small fluctuations ("ripples") in this radiation, and those irregularities are enough to trigger the formation of galaxies: denser regions led to galaxies, and sparser regions led to voids. The magnitude of the initial fluctuations are very small: about one part in 10^5 (1/100,000). But slight density fluctuations are magnified over time, such that stars and galaxies coalesce.

Separately, the gravitational "binding energy" of a galaxy, divided by the energy of its rest mass ($E = mc^2$) is denoted by Q, and is about 10^{-5}. This number Q provides an estimate of the size of "ripples" in the density of space. The fact that it comes out about the same as the "ripples" in cosmic background radiation confirms the relation between the two -- the primordial fluctuations of radiation density probably led to the observed density variations across intergalactic space.

Since $Q = 10^{-5}$, it means that gravity is weak in a galaxy (or even in a cluster of galaxies), so Newton's laws are applicable. That in turn allows machine computations to be done on an expanding universe subject to its own gravity, and the results simulate how gravitation leads to clusters of galaxies. The numerical outcome is statistical, of course, but not in disagreement with what is observed.

However, if Q were significantly smaller than 10^{-5}, galaxies would coalesce much slower and looser, star formation would be much slower, and the heavy elements formed in a supernova would easily go away, so that planets could not condense around stars. If Q were significantly larger than 10^{-5} (large ripples), very large galaxies would coalesce quickly and collapse into black holes. Stars (if any) would be so close-packed that they could not have planets. Either way, Q has to be close to 10^{-5} or else no planets form, and once again, we're not here.

5. The Cosmological Constant:

When Einstein first proposed the General Theory of Relativity, he introduced a term (λ) known as the

Cosmological Constant, whose role was to provide a balancing force that opposed gravity and kept everything from collapsing. It was to represent a force even weaker than gravity, one that would only have effects on a galactic scale, undetectable on our planetary scale. This force created a “cosmic repulsion.” This factor λ didn’t enhance the beauty of Einstein’s equations, and he was unhappy with it. It became unnecessary several years later when the universe was observed to be expanding. So theorists set $\lambda = 0$, and put it aside. Some years later Einstein called it his “greatest blunder.”

Many decades later, λ is making a comeback. There is reason to believe that there may be energy-fluctuations in a vacuum, and there are irregularities in the observed primordial background radiation. Recent astronomical observations of red-shifts from distant supernovae tell how fast they are receding, and hence give a measure of the expansion rate.

But still λ must be a very small number. If $\lambda = 0$, then the expansion of the universe is decelerating. On the other hand, with a finite λ there would be an anti-gravity effect that actually accelerates the expansion. Thus, the fine-tuning of λ affects the predictions of the long-term future of the universe.

6. Dimensionality, D:

The sixth number that Rees takes note of is the dimensionality of space, denoted by D. This equals 3, and thanks to the theory of relativity, the space-time continuum is taken as 4 dimensional. The connection of time to the 3 space dimensions is easy to do mathematically, by associating an imaginary number with time; and the equations of physics take on a symmetry and beauty when this is done. However, in human thoughts and human language, the connection has never been successfully made.

Nevertheless, it is easy to show that a universe having 2 or 4 (or more) spatial dimensions doesn’t work. The electromagnetic and gravitational forces only fall off as $1/r^2$ in a system having 3 spatial dimensions. That means that atoms wouldn’t form, and the orbits of planets would be unstable, if there were other than 3 spatial dimensions. In fact, Martin Rees has some kind words to say (p. 136) about William Paley, a theologian-scientist circa 1800 who first stressed the importance of this dimensional requirement. Again, the significance is that we wouldn’t be here unless $D = 3$.

In the relatively new physics research category of *String Theory*, quarks are treated as excitations upon a string, and the whole theory takes place in a manifold of extra spatial dimensions (usually 10), most of which are “compactified” or “rolled up.” The mathematics is sound, but the links to ordinary language are awkward and contrived, and so the non-specialist listener is often mystified by presentations attempting to explain string theory. For example, the analog of a membrane (familiar to us as a 2-dimensional surface) is termed a “d-brane” in higher dimensions, and quantum gravity is then said to project downward from higher dimensions to become the gravity that we observe in the real universe. It’s very difficult to form an image of what this means.

It is important to note here only that string theory does not predict any changes in 3dimensional physics. Electromagnetism and gravity do not change. For everyday purposes, the sixth number has the single value $D = 3$.

What Does it All Mean?

So what are we to make of these remarkably fine-tuned numbers? Are they all just coincidences, even the one (OMEGA that must be precise to the 15th decimal place?)

A lot of people would call this very clear evidence for design -- the numbers seem to point out clearly that the Creator of the universe was awfully smart, thought way ahead, and had perfect control. Of course, the phrase “thought way ahead” gives an image of God acting within time, rather than being exempt from time and simply present to all times; but that’s another story entirely. Still, the impact of the numbers is to inspire in mankind both awe and humility.

We know that God has a habit of never forcing anyone to believe in Him. There is a “bail out” path for those who insist that our universe must be due just to random chance alone. That bail-out route requires the notion of a “Multiverse.”

The idea is as follows: in the “Multiverse”, there are an infinite number of universes, and most of them are uninteresting, just random chaos. All the others (except ours) are going nowhere fast. This way, we just so happen to be in the only universe that could accommodate us. With an infinite number of possibilities, of course one would turn out just right.

Just one thing, though: It is impossible for us to detect or observe any of those other universes in any way. There is absolutely no connection between our universe and all those others. If you can agree with the “Multiverse”idea, then you can accept that our universe was just dumb luck, the one-in-a-gazillion event that led to something meaningful.

This is the point where a lot of scientists part company. In particular, Martin Rees, author of *Just Six Numbers* whom I have quoted so extensively above, prefers the idea of a “Multiverse.” I find this surprising, since on page 68 in the same book he writes: “A `bad’ theory, in this sense, is one that is so flexible that it can be adjusted to account for any data.”

I prefer this approach: Many centuries ago, scientists adopted a principle that has become known as “Occam’s Razor.” You limit your theories to the simplest possible combination of hypotheses that can explain the observed data. That’s how real science is done. You don’t think up extraneous stuff that is unobservable and call that “science.” In fact, you really can’t call yourself a scientist if you don’t accept this basic principle of thinking and reasoning known as “Occam’s Razor.”

Thus, there is quite a high price to be paid if you want to believe in the “Multiverse”and say that all these very precise dimensionless numbers have no significance -- you have to abandon a basic cornerstone of science!

How can anyone go for the “Multiverse” and still call themselves a scientist? Cognitive Dissonance is the only way I can explain that behavior. My view is a very harsh one: the “Multiverse” is the last refuge of the atheist who is so totally committed to his position that he will give up everything else to hold onto it.

For the rest of us, the message that stands out from the exceptional precision of the dimensionless ratios is that our universe was designed by an intelligence far superior to our own, who wanted things to come out in a very special way, and wanted us to be here eventually.

Endnote

1. M. Rees, *Just Six Numbers*, (Basic Books: 2000)

Questions

Is an argument derived from the existence of “these six numbers) really a sneaky way of bringing in “intelligent design”?

What is it about the “argument from design” that so many scientists (and philosophers) rush to deny it? What would the admission of such an idea add to the area of faith/science work? What subtract? Discuss this.

Is it merely a coincidence that the values of these numbers are so close to what they have to be to produce the universe as we know it? Or is it merely redundant to say that these numbers correspond to those which control the workings of the universe that is?

What about the statement against the notion of “multiverses”?

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