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You've heard it claimed that a picture is worth a thousand words, but, to our astonishment, we humans have discovered that an **equation** is worth a thousand *pictures* --- hey, *at least* a thousand! HOW can that possibly BE? An EQUATION? Surely you jest!

Hi, I'm Dick Henry, and I'm Director of NASA's Maryland Space Grant Consortium, and I'm also an Academy Professor at the Johns Hopkins University in Baltimore, Maryland. My PhD is in Astronomy, but, I've also taught PHYSICS for **decades**, endlessly trying to understand that mysterious subject!

When I finally DID understand (well, at least I *think* I understand!) I *wrote it up* as an essay, and I submitted it to the famous international journal NATURE; and, by gum, it was published: **The Mental Universe**. Just google it! <https://www.nature.com/articles/436029a>

You see, while I'd always found mathematics easy and interesting, physics was, to me, incomprehensible! It didn't seem to fit the world I actually lived in! Equations, BOO! But, then, I was incredibly lucky: I was hired as an assistant professor in a PHYSICS department! Hey: they hired me because they needed an **astronomer**! But! that gave me the chance to TEACH physics, and with wonderful results. It did take a long time: decades! but, **I got there!**

So, what is the result? I can share it with you all very easily indeed, because it turns out to be simple after you've gotten there: the universe is intrinsically mathematical in its very bones: if you understand math, which is easy, you can understand the universe.

So, exactly where do you start?

You start with the Pythagorean theorem, which is the most important single result in all of mathematics AND as it has turned out, the most important single result in **all of physics** as well.

You do all **KNOW** the theorem – heck, EVERYBODY knows the theorem: “the square on the hypotenuse is equal to the sum of the squares on the other two sides.” Even the Straw Man knew a (well, somewhat garbled) version of **THAT!**

So, **why** is the Pythagorean theorem so important? It is because that theorem miraculously turned out to be the gateway to our understanding the nature of **TIME**.

TIME, which is by far the most mysterious feature of our universe—and of our own existence.

Well! Who was it that discovered **that** about the ancient **Pythagorean theorem**?

No, it wasn't Albert Einstein. It was one of Albert Einstein's former **teachers** in Switzerland, Hermann Minkowski. Yes, yes, it is true: precocious young Einstein **had**, in 1905, discovered his Special Relativity – WOW indeed – **but**, just three years later, it was Hermann Minkowski, a former teacher of Einstein, who discovered just *what* special relativity **really meant**: relativity, Minkowski discovered, is nothing but a mathematically-trivial extension of **the famous Pythagorean theorem**, to include **TIME** as a fourth dimension! I consider that to be the biggest human discovery: **EVER!**

You can write the 3-D Pythagorean theorem as **an algebraic equation**: the sum of three squared terms. Why three? Three, because space has three dimensions. You would add one more term wouldn't you, if it had turned out that space had four dimensions? Of course you would! And parking would have been much easier! But, space **doesn't** have four dimensions: it has only three. Well, here's the enormous, yet **trivial**, secret: instead of **adding** one more term, you use, for time (that fourth term), a **MINUS** sign, instead of a **PLUS** sign! **That's it!** The greatest discovery in the history of physics!

Well, that's the end of the story! The most important discovery about the nature of the universe EVER MADE. Mathematically trivial, yet incredibly consequential for physics; for engineering; for philosophy; perhaps even for religion! The nature of **TIME!**

Simply a minus sign in the Pythagorean theorem!

So what great **difference** did Einstein and Minkowski's discovery make?

For one thing, it is what allowed us to actually **understand**, at long last, what underlies the **incredibly important** earlier physics discoveries that had been made by **Sir Isaac Newton!**

Just think what Newton had accomplished! He, and his followers, **had** discovered **wonderful** things, **yes, but**, all of them were things that they could **not actually understand** at all:

conservation of energy, conservation of momentum, conservation of angular momentum, **and** Newton's famous law of gravitation! Yes, **but**: where did these wonders *come from*? **WHY** were they true? Experimental test, plus extremely detailed observations, showed all these to be TRUE: **but** no one knew **WHY** they were true! Indeed, Newton was deeply embarrassed by his inability to **explain** the wonders that he had uncovered.

Well, Hermann Minkowski's brilliant re-interpretation of Einstein's new special relativity, as being nothing but an extension of the **Pythagorean theorem** to include time as an additional dimension – but with a minus sign, not a plus sign — allowed immediate re-writing of all of physics to include time, finally in its actual and proper role. Nothing **hard** about it, just a great long bunch of mathematics! You don't even need to go through it all; you can just **use** the wonderful results!

HOLD IT! Just a bunch of mathematics? Algebra? Let's pause: and **think** a bit about **that!**

How can the universe possibly **understand OUR** mathematics; **OUR algebra**; much less *use* it, when algebra didn't even **exist** until we humans thought it up!

And, wait a minute: how the heck **could** naked apes like **US**, *think up algebra*?

Well, let's take a serious **pause** now, and go back and review: **all of ancient human history!**

The naked apes, our ancestors, had been around for a long, long, time: but, until about 50,000 years ago **we homo sapiens did not; could not; TALK**. But, at that point, the FOX-P2 gene appeared, just in a small group of about 50,000 of us, in East Africa. We were not the only

people on Earth: there were a couple of million people. But every single person on Earth **today** is descended **just** from those particular 50,000 people — and **not** from **all** those others, simply **because our** ancestors were the people that acquired **SPEECH**.

A click-language! There are still, today, in Africa peoples who speak click-languages, *including* a language that may be the **original** click language!

Oh, just imagine you were THAT child, the first child to, say, pick up a stone and think to say “click-click” while pointing to the stone. Another child mimics you! It’s a fun game! Another child picks up a stick, and says “CLICK-click-CLICK.” The game continues, day after day, and the first human language **has appeared!** Among the kids, is my bet! A turning point in human destiny!

Not all the kids were able to keep up; but, those that DID become **fluent**, had hugely successful hunting parties, because they could plan and coordinate and communicate! Within some generations that whole tribe of humans had become **talkers**.

Hey! We’ve never stopped talking since! I’m doing it right now!

Fast forward to ancient Greece! All Greeks talked, obviously, **but** a few **also** developed something totally new: **geometry!** Diagrams! Brilliant geometry, over some hundreds of years! But **none** of them thought up what we now call **algebra**, to **represent** that geometry with abstract and arbitrary symbols. Even so, one brilliant Greek, Pythagoras, in addition to creating his famous theorem, recognized that “**number is all things,**” which is what we, finally, are realizing today! For Pythagoras seemed to know, that hiding within the wonderful geometry: lurk **numbers**.

Algebra, once **finally** discovered: and it **did** take a long long time, meant that you could write the Pythagorean theorem **without drawing** any triangles!

Algebra was **essential** in allowing that extension to the Pythagorean theorem that we, today, call Einstein’s Theory of Relativity, because only very clumsy diagrams could sorta sorta sorta include time, and really only in a **fake** manner: **BUT algebra** includes time **easily**, without missing a beat! Just that simple **MINUS** sign! For there are **NO** minus signs in diagrams! There **CAN BE** in **equations!** It’s as simple as that!

Victory!

But wait, there’s MORE!

Recall that Newton, and his followers, did find **conservation laws** (energy, momentum, angular momentum); yes! **But** no one had any idea **WHY** these laws held true!

Do any of you know who it was that made the crucial discovery as to **WHY** these laws are true?

You don’t know? **Then ONE GUESS as to the gender of the person who made this second-most fundamental discovery ever in the history of physics.**

The person who **found out WHY**, was an American mathematician named Emmy Noether. After Pythagoras himself, she is the greatest contributor to our understanding of the nature of the

universe, for Emmy discovered **WHY** there **ARE** conservation laws: and, it is utterly simple: each conservation law exists **only** because there is a particular **symmetry** present (for unknown reasons) in our universe. And, all it takes is simple algebra to show that what Emmy discovered, is true: that **THAT** is why conservation laws exist, and **must** exist. Here is **her** result in **words**:

- 1) If you do an experiment of any kind and you repeat it LATER, you get the SAME result, and **THAT** is **why energy** is conserved.
- 2) If you do an experiment of any kind and you also do it across the room, you get the SAME result there, and **THAT** is **why linear momentum** is conserved.
- 3) If you repeat an experiment, but ROTATING it some, you get the SAME result ROTATED, and **THAT** is **why angular momentum** is conserved.

Well, wow! We now know **WHY!**

(Even today we don't know **why** the universe **HAS** those symmetries. Except that **if** it did **not**, we ourselves could not exist.)

Now, to make this **even BETTER**: suppose you try one more thing: instead of waiting, or shifting, or rotating, your experiment, you create a MIRROR IMAGE version of your experiment.

Well, I guess you expect that you'll get the same result, but mirror imaged: hey, let's give that hypothesis a name: we'll label it (oh, we do love obscure terminology!) "conservation of **parity**" *if* it turns out, by experiment, to be true." Like, the other ones **did** turn out to be true.

And YES indeed! for experiments that involve the **gravitational** force or the **nuclear** force or the **electromagnetic** force, **YUP!** same-old same-old! Conservation, this time, of parity as it is called in the jargon! It is just a word, but it is a real symmetry: **by experiment!**

BUT if your experiment involves the **fourth** of the four forces, the so-called 'weak' interaction (for example, as seen in neutron decay) you get a **DIFFERENT** result: **NON-conservation of parity! Nobel prizes! WOW!** Our universe has a very peculiar structure embedded in its mathematical bones! **There are NO right-handed neutrinos! This is a fact!**

Now let's go back to Einstein-&-Minkowski's great discovery of the geometrical nature of **TIME**. That minus sign! Well, Albert Einstein, bless the poor fellow, for about one year, **he resisted** his teacher Hermann Minkowski's re-interpretation of Einstein's already famous relativity as being merely a trivial extension of the Pythagorean theorem!

But, finally, fortunately, good old Albert **did see the light**; and indeed, he saw it **so clearly** that it was what led (in 1917) directly to Einstein's greatest accomplishment, his experimentally-verified theory of gravitation, called for some reason **General Relativity**.

Now, remember how embarrassed Newton was about his hugely successful theory of gravitation? He couldn't explain why it worked? Well, a light bulb had gone off in Albert Einstein's head: maybe spacetime is not FLAT, but is CURVED: THEN, if a great mass, such as our Sun, was

(somehow! We still don't know *why!*) the *cause* of that curvature, the planets would naturally follow **curved** paths: orbits!

OK, sounded like an idea at least worth trying. Just a bunch of math to work it all out, and hey! the heavy lifting had already been done by the pure mathematicians Gauss and Riemann. Well, by gum, just a few years of effort by Albert, during World War I, and **bingo**: Einstein's crowning achievement, his famous theory of General Relativity!

The equations are extremely simple: here it is, in words; curvature = mass/energy

OK, but wait a minute! Take a look at that! Careful! Mass/energy is conserved; but curvature (it turns out) is **not**. (That is, its derivative with time is not zero.)

Shucks! But, Einstein **persisted**: he said, OK, let me **tweak** curvature, to get something that **IS** conserved.

Well, would **you** have bet on **that**? I wouldn't! **I'd have given up!**

But by gum it worked!

WONDERFUL! And that's when the story gets incredibly exciting! For World War I was on! Einstein (auf Deutschland) published his equations; equations that he, Einstein, never could solve, other than numerically (which Einstein **had** done, to verify that they worked by showing that they explained perfectly the mysterious observed precession of the perihelion of the planet Mercury, the only deviation that had EVER been found from Newton's **problematic** law of gravitation). (Well, apart from what led to the discovery of Neptune by Leverrier!)

Well, then a miracle happened: on the German World War I Eastern Front, physicist-soldier Karl Schwarzschild received his copy of the journal in which Einstein's General Relativity was published, and: **KARL SOLVED THE EQUATIONS, AND ... THEY PREDICTED BLACK HOLES!**

The rest is history.

And guess what! You'll never ever guess!

Schwarzschild's solution that predicted black holes was:

A SLIGHT MODIFICATION OF THE PYTHAGOREAN THEOREM!

OMG! I'll stop there; I can't take it any more; its too exciting for me!

NO, wait:

I've just realized that I have not yet mentioned **quantum mechanics**, and that might seem to you to be derelict of me! So, let me deal with quantum mechanics, which, most unfortunately, is what almost everyone thinks is the most mysterious thing in all of physics.

Oh yes, I myself certainly did feel that exact same way, at one time! But, fortunately, it dawned on me that surely quantum mechanics must be the result of the same symmetries that produced the conservation laws. And so it turned out. I spend a summer at Los Alamos National Laboratory starting from scratch to see if I could produce QM from nothing: and: I succeeded! “Quantum Mechanics Made Transparent,” published, after thorough peer review, in the American Journal of Physics. Hey, no joke: **four** referees: ALL four supportive!

Well, that was long ago: 1990! That paper has only been referenced (in more recent papers) one single time: but that one reference was by: brace yourself! Isaac Newton, no less!

Now, you may think that that is impossible, but I assure you that it is true, for; I should know: I was Isaac’s co-author!

[And I am **very** happy indeed to be able to report that there is a later paper, by a different author, establishing the exact same thing: namely, that QM is a just a simple product of the (mysterious) presence of symmetries in the universe. That paper is by the late Moshe Shapiro: J. Phys. A: Math. Theor. 41 (2008) 175303 (9pp)]

Wow! At that point, I, of course, entirely lost all interest in quantum mechanics! I had turned Quantum Mechanics into a dull subject! And I must say, to me, it is bizarre that so many people, even physicists, still think that QM is mysterious.

Well, that’s physics. Now for the big question: what does it all mean?

My answer: Sorry, I haven’t **any** really defensible idea as to what it **DOES** all mean!

HOWEVER!

I do assert that I DO know FOR SURE what it does **NOT** mean! Experiment has shown that there IS NO UNIVERSE “out there,” in the conventional sense. **Bishop Berkeley was correct!** There’s NOTHING ‘OUT THERE’ despite all our observations!

Yes, of course we “make observations:” you’re making them now! But they are not observations **of** anything, as in “any-thing.” By experiment, we know that there are no ‘things.’ What there are, are observations, and those observations are of course in our minds: they are purely mental. Looked at closely, and we HAVE looked at them closely, there is NOTHING THERE, as in “NO-THING THERE.” There are no THINGS: there are only observations. I like to call them “records.” The universe is clearly, and **most definitely**, NOT material, since there IS NO material; so, they must be mental, because my mind, and, you will agree, your mind, do vividly perceive them!

What are we to make of that? What I make of it, is that you and I are incredibly; indeed almost inconceivably, fortunate to exist; to experience the magic of life! I am so grateful!

Whatever the universe actually is, in actual practice the astronomer’s universe out there is utterly **hostile** to life of any kind. Our planet, Earth, is a lifeboat, in an ocean of destructive high-energy

radiation: particles, accelerated from our own Sun, and also particles accelerated by the magnetic fields out in the Galaxy of stars where our Sun enjoys its existence.

So: do take care of planet Earth, and do learn physics: the key to understanding the beautiful world that you are enjoying this very day.

Oh yes, my own **research**: I have published dozens of investigations of the cosmic diffuse ultraviolet background radiation from our universe. My interest in it, today centers on the possibility that a component of it originates in the very slow decay of the dark matter particles, with the emission of ultraviolet photons that are capable of ionizing hydrogen. The idea is, that **THAT** is how the universe managed to achieve its present extremely high degree of ionization, following the universe's recombination, just 380,000 years after the big bang.

Next up on this, I hope to make observations using an instrument that is on board the New Horizons mission, which is now well beyond Pluto. We'll see!

That's me. Who are YOU? You are a **THING**, just like a **stone** is a thing: both are made of nothing but up-quarks, down-quarks, and electrons! By the way, those quarks of yours are only a **bit** heavier than your electrons: when you stand on the scales, to weigh yourself, 98% of what you "weigh" is due to the **kinetic energy** of all the **MASSLESS** gluons that hold your quarks together. **Physically, that's ALL that you are: a stone!**

But the **arrangement** of all of that, into **complex molecules**, produces, somehow, your hopes and your dreams; your knowledge and your understanding; your loves and your fears. **You** are the **most complex entity**, in the entire universe.

So, do you have any questions?
