LITTLE *Ways* to LIVE *a* BIG LIFE

HOW TO UNDERSTAND $E=mc^2$

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Foreword

$E = mc^2$.

E is for Energy.

The same kind of energy that makes your car run, your light bulbs shine, your fridge hum.

m is for mass.

The same kind of mass you and I, the air, the seas, mountains and clouds and all the known matter in our universe, are made of.

And c^2 is the square of the speed of light.

A huge number by all means.

$E = mc^2$ says that energy can become mass. And mass can be turned into energy. An awesome lot of it. It tells us why we can split the atom and how stars shine, and even how nature can create particles out of nothing. But that is not all.

$E = mc^2$ is a beacon of sorts, a signpost indicating the entrance into a new reality where not only mass and energy, but also space and time have meanings that are not the expected ones. It has implications in the realm of the very small, and the very big. So much so that it shaped pretty much all of the twentieth century, including how we think about ourselves, leading to the world we live in today.

PART I: Light

Chapter 1

Historical Introduction

Around the beginning of the twentieth century, almost everything that was scientifically known about reality was based on what Newton had summed up from past knowledge, and discovered himself, some 180 years earlier. It corresponded to how our intuition tells us nature behaves.

But this was about to change radically.

After all, for the past ten thousand years, our bodies have hardly evolved. We've had pretty much the same eyes, ears, fingers, tongues and noses in all that time. That makes us all equal at birth, throughout the ages, when faced with trying to understand what is happening around us.

Thanks to centuries of questioning, wondering and technological improvements, the beginning of the last century saw our species reach a new level of awareness. We realized that the laws of nature we intuitively believed to be true everywhere, throughout space and time, were not the ones we thought.

Compared to the immensity of our universe, we are tiny.

Compared to the minuteness of fundamental particles and their quantum world, we are huge.

We float in between these two infinities, one large and one small, and our senses only allow us to probe what is around us in a limited way.

About 100 years ago, we saw that as one drifts away from the safety of our scale of reference, the laws of nature begin to change – drastically. What we experience on a daily basis is but an approximation of realities our senses are not made to detect. This knowledge is what makes us different from all the humans who have lived before us.

As of today, we know of three paths that lead to unforeseen aspects of reality. One is the big. One is the small. And the last one is the fast – the realm of high velocities.

Just as it is true that we are neither large (compared to the universe) nor small (compared to particles), it is also the case that we never move fast. Even the fastest rocket ever launched is pretty much a slug in comparison with whatever flies at the speed of light.

But wait, doesn't light travel instantaneously?

I know you know it doesn't. It travels at a particular velocity which we call the speed of light. Scientists refer to it as the letter 'c', for celerity, which means swiftness. And if it has been granted the honour of a letter, which neither your velocity nor mine will ever achieve, it is because there is something really peculiar about it: in a vacuum, light always travels at the same speed.

Always. Independently of who is measuring it.

This is half the reason why $E = mc^2$.

And to see how this was understood, we need to begin by measuring the speed of light.

Chapter 2

The Speed of Light

Picture yourself in a dark room.

Your hand is on the light switch.

You are totally focused, because you are about to figure out the time it takes for light to travel from the bulb to your eye.

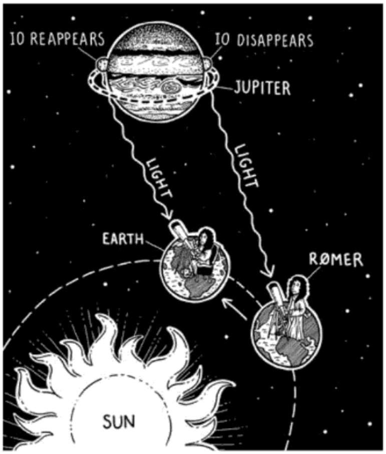
You turn the lights on.

But you don't detect any delay.

As far as your senses are concerned, the room was lit instantaneously.

Galileo tried such a trick as far back as 500 years ago with a source of light about a mile away from where he stood, and wasn't able to notice any delay either. Yet there is one. Around Galileo's time, no device was precise enough to detect it. To be able to see anything at all, our ancestors would have needed light to travel through much, much greater distances than anything that can be found on Earth.

And in 1676, that is exactly what Danish astronomer Ole Rømer did. He studied Io, one of Jupiter's largest moons.[1] Like most planets, Jupiter does not shine on its own. It is lit by the Sun. So there is a shadow behind it. Io moves in and out of this shadow on a very regular basis, making it pop in and out of the darkness. Thanks to Galileo's newly invented telescope, Rømer noticed that it took more time for Io to disappear and reappear when the Earth was moving away from Jupiter than when it was moving towards it. For Rømer, that was it. A telltale sign that light did not travel instantaneously. He even estimated how fast it was to within about 20 per cent of today's value. Not bad at all for a first attempt.



About 200 years later, around 1860, the physicist James Clerk Maxwell, from Scotland, started a series of scientific revolutions which led to no less than the science of the twentieth century. In a time when people rode horses to travel around and used candles to work at night, Maxwell discovered that electricity and magnetism were two aspects of the same phenomenon – electromagnetism – which, when perturbed, gave birth to a wave.

Just as a moving buoy on a lake creates waves on the surface that move away from the buoy at a certain speed, if you move a magnet around, you get a wave – an electromagnetic wave. That is what Maxwell's equations implied. And he, of course, wondered how fast these waves travelled. Experiments told him: at the speed Rømer had found. The speed of light. Maxwell did not believe this was a coincidence. As strange as it may sound, he had discovered that light was an electromagnetic wave.

But this led to a new puzzle.

A wave on the surface of the ocean travels on water; a sound wave travels through matter.[2] But what does a wave of light travel through? In a room, we do see a candle burning on a table and we do see faraway stars in the night sky. In a room, there is air. In space, there is nothing. Nothing that can be seen, anyway. And yet, light travels through both. Following Maxwell's discovery, scientists imagined there had to actually be something out there in outer space, and here on Earth, that we could not see. Some sort of medium that would fill