The Story Behind Einstein's Immortal Equation

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It has been more than a century ago that Albert Einstein arrived at his immortal equation $latex E=mc^2$. It can rightly be said that a new age in modern physics started with Albert Einstein whose legacy will stay with us for a long time to come. The equation that bears his name is as famous as Einstein himself. Indeed, the equation has been immortalized by its utter simplicity and its profound meaning and impact in our civilization. The energy E of a body (at rest) is equal to its mass 'm' multiplied by $latex c^2$ (that is $latex c\times c$), where 'c' equals the speed of light (in vacuum). The equation's message is that the mass and energy of a body are convertible, and the mass of a body measures its energy content.

We can do some simple computation by using the SI system where m = mass in kg, c = speed of light 300,000,000 (approx) (that is $latex 3 \times 10^8$) meter per sec, and E = the energy in Joules (3.6 million Joules equals one kilowatt-hour, kWh). Taking 'm' as 1 kg, we can calculate the energy content of 1 kg of matter (any matter) as $latex E= mc^2 =1 \times c^2 = 1 \times (3 \times 10^8)^2 = 9 \times 1016$ Joules = $latex 25 \times10^9$ kWh, that is 25.0 billion kilowatt-hours.

How much energy is that? If we consider 10,000 kWh to be the average annual power consumption (833 kWh per month) of a modern household, this one kg equivalent energy will give enough energy for 2,500,000 years that is 2.5 million years.

The equation $latex E=mc^2$ becomes more fundamental if we consider the unit of c, the speed of light, as 'one light year per year' in which case $latex c^2$ converts to I, and the equation becomes just E=m, meaning energy and mass are equal and the same. This is the most simple, fundamental and most profound equation ever evolved by humanity.

When the full meaning of the equation was known by the general public with the equivalence of mass and energy, someone asked Einstein, how come this fact was not known to us before? The answer given by Einstein was very simple but at the same time very profound. He said, consider a rich man who has not spent a single penny all his life. How you would know that he is rich? In case of matter, the situation is like that. We never knew that matter possesses so much energy. His answer reads like a Buddhist Jataka story of 'Hidden Treasure' where the poor monk had an invaluable gem sewn in his garment all his life which he did not know.

Einstein formulated this equation in 1905. The question is how Einstein has arrived at this equation? How and why others could not? Many would think that being a mathematical genius, Einstein, might have evolved the equation after intense mathematical analysis. In fact nothing is further from the truth. As a matter of fact, Einstein was neither the first person to consider the equivalence of mass and energy, nor did he actually prove it. He just proposed the equation. In order to understand how he evolved the equation, and how and why he received all the credit and fame for $latex E=mc^2$, we will have understand a bit of history of science of his time as well as a bit of the life of Albert Einstein.

Albert Einstein was born in 1879 in Germany of a Jewish family, and as a child he grew up in the city of Munich. When Albert was a child, he had a remarkable experience of his first 'wonder' of nature. When little Albert was just five years old, his father gave him a pocket compass. The compass with its needle moving in a determined way by an unknown force, made a lasting and profound impression on the future theoretical physicist. This was one of the things that drove him to study science.

When he was twelve, he experienced his second joy and 'wonder' of a different kind when somebody gave him a little book dealing with Euclidian plane geometry. The theorems like "The theorems like 'three altitudes of a triangle are concurrent', the Pythagoras theorem and others gave him so much joy and wonder, that he remembered this all his life and wrote about it in his autobiographical notes years later.

As an youth, Einstein was a discontented and an independent thinker. At home he was stimulated more by a free exchange of ideas with his liberal parents. At sixteen, he told his father that he no longer wished to be German and at the same time announced that while he loved the Jewish culture, he was severing all formal connections with the Jewish faith. His independent readings included many and was especially thrilled with natural sciences, geometry, philosophy (Spinoza, Buddhism etc), history, music and all. He was also playing the Violin. He was inquisitive and interested to know everything. However, at the advice of his father, he decided to focus on something which will assure him a job - especially important for a Jewish boy. Otherwise, according to his own admission, he might have ended up being a musician.

However, he was also good in science. While studying in high school, Einstein familiarized himself with the elements of mathematics. By the time he was seventeen and ready to go to college, he also studied quite a bit of college physics. A number of scientific theories and mathematical equations had been worked out by the physicists at that time. There were however a few situations where these theories couldn't satisfactorily explain. Einstein was interested to study these riddles on his own and to offer explanations. When there were no riddles, he used to create his own riddle. When he was sixteen (1895), one such riddle that he created for himself was this: He used to imagine what would happen if he would fly with a beam of light. If he would move at the same speed of light, would he see the light waves as frozen? Would he see himself in a mirror if he would carry a mirror with him? That was a riddle none of the physicists were interested to bother. They had too many other important issues to bother. But Einstein was not a professional physicist, he was just a college student studying physics and mathematics. For Einstein, the riddle was very intriguing, and he became passionately inquisitive about it. During these ten years, there was probably not a single day when he was not thinking about the problem and probably not a single night when he was not going to bed with the problem in his head. The problem remained in his conscious and subconscious mind everyday of his life till he could solve the riddle in 1905.

During these ten years, he graduated from the Polytechnic in 1900 with a diploma to teach to math and physics. However, he could not find any job and he remained unemployed for quite some time. Finally, he could land up a job as a clerk in the Patent office. This however become a blessing in disguise for Einstein. Working in the Patent office required less demands of his time. He soon discovered that he could go back to his 'Gedanken experiments,' or 'thought experiments' (meditations) that had tantalized him so far to concentrate on solving such scientific riddles. During this time he also met a girl named Mileva, a class mate, with whom he fell in love and they got married.

Einstein had studied Maxwell's equations of electromagnetic waves which predicted that the electromagnetic waves travel at a constant speed c, the same speed as light. Sharp Einstein could immediately guessed that light must be a kind of electromagnetic wave. Concentrating on his riddle with his deep 'thought experiments', he could solve one part of the problem: that is no one can fly at that speed of light because it does not make sense. As he recounted later: “If I pursue a beam of light with the velocity c, I should observe such a beam of light as a spatially oscillatory electromagnetic field at rest. However, there seems to be no such thing, whether on the basis of experience or according to Maxwell's equation.”

Now he need to figure out why, and what happens if one travels at high speed near c, the the speed of light. Suddenly the riddle which seemed hopeless and impossible before, became very intriguing and exciting for him. He used his imagination and 'thought experiments' to solve the problem. He found some additional clues. There were many attempts by eminent scientists like J.J. Thomson (1881) and others to understand how the mass of a charged object depends on the electrostatic field. This concept was called electromagnetic mass, and was considered as being dependent on velocity and direction as well. For this some physicists have postulated different equations showing how mass increases inversely with the square of c when energy is imparted to it. All of these developments may not be fully known to Einstein at that time as he was not associated with any professional physicists and was working on his own in isolation. The research scientist, Marie Curie had another riddle of her own. While working on radioactive materials, she observed that these materials were transmitting huge amount of radio active energy, the source of which remained a mystery. Was it possible that the radioactive energy was obtained at the expense of tiny bit of the radio active materials?

There were also other clues. Since light was believed to be wave, it was believed that light needed some kind of media (like the media water and air for sound waves). For this, the scientists believed that some media was all around us at absolute rest and that it also filled the vacuum of space through which light flows. They named that media "aether," after the Greek god of light. In 1881, two American scientists, Michelson and Morley, created an experiment and tried to prove the theory that aether existed. Their experiment was quite simple. Since, the earth travels around the Sun at a speed of more than 100,000 km per hour apparently through aether, it would cause an “wind of eather" in the same way that there seems to be a “wind of air” outside a moving car. They tried to measure the relative speed of the earth in this “aether wind” at various directions and at various times of the year in order to determine the relative speed of light. But they simply could not detect the relative speed of the earth against this aether (at rest) and could not find the slightest difference of speed of light. The result was very puzzling to the scientific community, and nobody had any explanation. One explanation was offered by Fitzgerald and Lorentz who proposed the hypothesis that a body in motion is actually shortened in the direction of motion by a certain proportion depending on the velocity. Te amount of contraction was to be just enough to account for the negative results of the Michelson-Morley experiment. Of course this shortening could never be detected, even if it actually occurs, because any rod of measurement would also be shortened proportionately. All the Michelson-Morley experiment has proved was that relative to the earth the velocity of light is same in all direction, and that there is nothing called 'absolute rest' as proposed by Newton.

Considering all these available data, Einstein tried to come up with a theory which will answer all these riddles. However, there was another big puzzle to solve. Maxwell has proposed constant velocity c for electromagnetic waves. However the problem was, speed always had to be measured relative to something. But what was this speed relative to in vacuum, in empty space, that is? That remained an unanswered question. Recalling his mental experiment of the railway carriage traveling at a speed of v and the passenger moving inside with a velocity w, Einstein tried to do 'thought experiments' by replacing the man (with velocity w) with a ray of light (with constant velocity c). He found that it becomes incompatible with the Galilean relativity unless he considers the velocity of light same relative to the railway carriage and the railway station at the same time. By this time, it became clear to Einstein that the speed of light must be independent of the speed of the observer as well as of the speed of the source of the light. That would also mean that everyone in the universe, no matter how fast they were moving, would always observe the speed of light as constant c. That goes against all normal Newtonian logic, but that must be true as otherwise you cannot solve the problem.

Confident of his logic, he boldly proposed that the velocity of light c must be constant 'relative to everything'. They asked, what do you mean by 'relative to everything?' He said, it means exactly that, it is 'relative to everything'; c is a true universal constant. And that assumption basically solved the whole problem. Because once we accept this hypothesis, and are willing to discard just about everything else to make sure it holds true, we can end up with 'special theory of relativity' without a whole lot of mathematics, that is, if we know what we are doing. And that is what Einstein did.

The year 1905 is known as the ‘Miracle Year’ of Einstein. That year he submitted his Doctorate thesis and 4 of his major papers which eventually altered the very fabric of modern physics. The paper dealing with the famous equation was his last paper, titled 'Does the Inertia of a Body Depend Upon its Energy Content?' The paper was submitted in September 1905 as a follow up paper of his 'Special Theory of Relativity' submitted earlier in June 1905.

It may be noted that Einstein did not actually formulate exactly the formula $latex E=mc^2$ in his paper. He even did not use the term E for energy, he used term L instead. In the paper he stated that if a body gives off the energy L in the form of radiation, its mass diminishes by $latex L/c^2$ and that the inertia of a body represents its energy content. This is of course is another way of saying the same thing, and the equation $latex E=mc^2$ can easily be deduced from Einstein's prophetic statement. Importantly, Einstein was the first to have correctly deduced the mass–energy equivalence formula for the entire universe. Instead of proof, he made the statement that the validity of the equation may be tested by experiments.

Nearly all previous authors thought that the energy that contributes to mass comes only from electromagnetic fields. It may be said that while others were trying to write papers based on their mathematical derivations, Einstein was trying to find a natural law for the universe. That is where his greatness lies.

In this proposal, we see that Einstein's solution to the problem was simple and at the same time very profound. More than a mathematical genius, it shows his courage of imagination and the purity of thought.

What may be the secret of his great success? When asked, he used to say, "I have no special talents. I am only passionately curious". While it shows his humility, it also show a truth about what his being passionately curious. He was indeed passionately curious about solving the problem. He was not concerned about time. His chasing the riddle of light for ten years proves that. As we see, Einstein used imaginative 'thought experiments' and was working all by himself in isolation to other professional physicists. In this case, we may say that he could solve the problem because he already sensed the answer through his imagination. He was just looking for the process that will give him the answer. And the process told him that in order to find the answer he was looking for, he must take the velocity of light c as a universal constant . Einstein himself often used to say that "Imagination is more important than knowledge. For knowledge is limited, whereas imagination embraces the entire world, stimulating progress, giving birth to evolution." In his evolution of the mass and energy equivalence, we clearly see how this is true. While the knowledge was available to all the scientists, it was only Einstein who could solve the puzzle with his imagination. As we see, his hypothesis that the speed of light is constant relative to everything was evolved not out of intense mathematical analysis but it came out of his his strength of imagination and his courage to think against the flow.