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The Consequences of Einstein's Theory of General Relativity

Science has progressed and advanced through human history by the power of the scientific method. You must observe the world around you, formulate a hypothesis to fit your observation, develop unbiased tests, and refine your hypothesis to form general theories. This method, which is naturally intuitive to most but crucial to science, is the backbone to every major advancement. Until the beginning of the 20th century, Newtonian physics was the well-tested and approved background to scientific thinking. "In Newton's laws of motion there appears a quantity called the mass, which determines how easily an object accelerates when a force is applied. But Newton also discovered a law governing those forces, the force of gravity. In that law there appears another quantity which determines the amount of gravitational pull an object exerts, and the amount of gravitational pull it feels when in the presence of another object. That quantity is also called mass. (Einstein IX)" Albert Einstein wondered how these two could be equivalent? The combination of Einstein's brilliance and that question "led to his realization that the scaffolding of space and time reacts to the presence of matter and energy" (Einstein X). General relativity's postulates include that the laws of physics are the same for every observer and that the speed of light appears the same to every observer. This implicates that the speed of light is the universe's 'speed limit.' "As a result of these principals, Einstein deduced that there is no fixed frame of reference in the universe. Everything is moving relative to everything else, hence Einstein's Theory of Relativity" (Nola).

As the scientific method suggests, tests must be made to gain approval from the rest of the scientific community. "The first prediction put to a test was the apparent bending of light as it passes near a massive body. This effect was conclusively observed during the solar eclipse of 1919, when the Sun was silhouetted against the Hyades star cluster, for which the positions were well known" (Putting Relativity to the Test). This test gave Einstein's theory credibility but still needed to survive countless more tests. "Since almost two centuries earlier astronomers had been aware of a small flaw in Mercury's orbit around the Sun, as predicted by Newton's laws. As the closest planet to the Sun, Mercury orbits a region in the solar system where spacetime is disturbed by the Sun's mass. Mercury's elliptical path around the Sun shifts slightly with each orbit such that its closest point to the Sun (or "perihelion") shifts forward with each pass. Newton's theory had predicted an advance only half as large as the one actually observed. Einstein's predictions exactly matched the observation" (Putting Relativity to the Test). When astronomers began to accept general relativity as a possible solution to many current issues with Newtonian physics, major consequences arose outside of the known and observed flaws. The first consequence to explore is time dilation, both from the effect of a gravity well and a moving object.

A gravity well is a warp in space-time from an object with huge mass. This will be the basis of understanding gravitational time dilation. "Light sent down into a gravity well is blueshifted, whereas light sent in the opposite direction (i.e., climbing out of the gravity well) is redshifted; collectively, these two effects are known as the gravitational frequency shift" (General Relativity). This means that light is affected by the gravitational field from an object with mass. Before the 20th century, this was not a concept ever proposed before. The doppler effect, which was a phenomenon known due to its impact on a moving objects sound, can now be applied to light. "Known as the Doppler Effect, the same phenomena occurs with waves of light at all frequencies. In 1959, two physicists, Robert Pound and Glen Rebka, shot gamma-rays of radioactive iron up the side of a tower at Harvard University and found them to be minutely less than their natural frequency due to distortions caused by gravity" (Nola). With the idea of light being affected by an extreme gravity well helps convince us that as an object falls into the gravity well, a viewer outside of the well will see the objects 'time clock' slow down, and even stop in extreme cases. "General relativity predicts that the path of light will follow the curvature of spacetime as it passes near a star. This effect was initially confirmed by observing the light of stars or distant quasars being deflected as it passes the Sun" (General Relativity). Light follows the curve of space-time, so as an object travels closer to an object with extreme mass, the ‘light clock’ takes longer to ‘tick,’ appearing slower to viewers outside of the well. Since the "higher" observer measures the same light wave to have a lower frequency than the "lower" observer, time must be passing faster for the higher observer. Thus, time runs more slowly for observers who are lower in a gravitational field” (Introduction to General Relativity). This suggests that the ‘higher observer,’ which is the observer outside of the gravity well, must experience time moving faster for him. This will show the ‘lower observer’ moving slower in time in relation to him. But, for both of the observers, their perception of time seems the same. The ‘lower observer’ won’t take longer to itch his nose, but to the higher observer looking in, it could take the lower observer much longer to finish the task.

Time dilation also occurs from objects moving. This consequence can be directly derived from the postulate that states that the speed of light is constant to all viewers, no matter how fast you are already moving. Let us imagine a situation where we have two ‘light clocks.’ Each light clock has a beam bouncing between two mirrors three feet away from each other. We know that the universal speed limit, or the speed of light, is 300,000 km/s, or just 1 foot per nanosecond. The only difference with the clocks is that the second one is set in motion at 80 percent the speed of light. From both view points, it takes 3 nanoseconds for a light beam to travel between the mirrors. Each ‘tick’ represents 3 nanoseconds of time passing. But, as the viewer holding the stationary light clock looks at the light clock rushing past him at 80 percent of the speed of light, it takes 5 nanoseconds for the light beam to transverse across the mirrors and ultimately ‘tick.’ As the moving light clock travels the 3 feet towards the mirror, it has moved 4 feet to the right in the direction of motion. Therefore, from the viewpoint of the stationary clock, the beam seemed to have traveled 5 feet in a diagonal following Pythagorean’s Theorem. So, from the viewpoint of the stationary clock, in the time it takes the stationary clock to ‘tick,’ which is still 3 nanoseconds, it takes the moving clock 5 nanoseconds because the speed of light is the same from all viewpoints. From the viewpoint of the moving ‘light clock,’ it transposes as you would think. “Time does not pass at the same rate for everyone. A fast-moving observer measures time passing more slowly than a (relatively) stationary observer would. This phenomenon is called time dilation” (Nola). This is where it becomes very interesting. Not only is the moving ‘light clock’ ‘ticking slower from the viewpoint of the stationary 'light clock,' but everything with the moving 'light clock' moves slower. The astronaut holding the light clock in his spaceship moves slower. The astronauts air molecules from his breath move slower. His heart beats slower. From the viewpoint of the moving astronaut, nothing is wrong. He is living his life just like the astronaut inside the stationary spaceship is. But, time dilation occurs and has an impact on even the aging of the astronaut. Because the moving astronaut is affected by a different time scale, he ages slower than the stationary astronaut. This points to the famous 'Twin Paradox' that details if someone travels at near the speed of light away from you and returns, he would have aged less than the other person remaining on earth. Einstein's theory of relativity predicts this with his postulates. As we begin to understand time dilation, both with gravitational effects and a moving body, we can begin to explore the most baffling, unique and mysterious objects in the universe, black holes.

If enough mass in concentrated into a single region, its escape velocity at the surface can become greater than the speed of light. When this happens, it is known as a black hole. Newtonian physics simply does not work in situations where the mass of an object is so extreme. "Because the gravitational field around a black hole is so strong, we must use general relativity to understand the properties of black holes; indeed, most of what we know about black holes comes from theoretical studies based on general relativity" (Heckert). What is so peculiar about the study of a black hole is that we cannot see it. We can detect its influences on other objects, but we have never been able to look at it. This makes sense though, because light cannot escape and travel to us to be analyzed. To achieve the mass and radius combination of a black hole, the escape velocity at the surface must be greater than the speed of light. So, if Earth's mass was compacted to achieve this escape velocity, it would have to be crunched into a sphere the size of a small marble (Tyson). It is quite hard to imagine. The primary way of a black hole forming is from the supernova of a massive star. As Einstein's theory of relativity predicts, the presence of extreme mass can warm space-time. Time is no longer seen as absolute, but a malleable quantity. It can be slowed and sped up depending on the scenario. Black holes are a perfect example of gravitational time dilation. Picture you are watching your buddy (perhaps someone who wronged you recently) falling towards a black hole. You know that this adventure is deadly, so you stay back in a spaceship just enough to not be affected by the blackholes tidal forces. As your buddy falls in, he continues to send a steady beep every second he experiences. As he falls closer and closer to the event horizon, which is the point where the escape velocity equals the speed of light, you see his movement slow down. The second interval quickly turn into minutes, then hours, then even years. As he nears the last second of his final adventure and sends the last signal at the event horizon, that 'beep' remains still, forever locked at the surface of the black hole (Tyson). The theory of relativity provides a rulebook to analyzing some of the most immense objects in the universe, but we still don't really know what happens inside of the event horizon. It is merely speculation. Another significant result of the theory of relativity is the existence of gravitational waves, which has recently first been discovered last year in 2016 since its prediction in 1916.

Einstein's theory of relativity predicts the existence of gravitational waves. "Just as sound waves disturb the air to make noise, gravitational waves disturb the fabric of spacetime to push and pull matter as if it existed in a funhouse mirror. If a gravitational wave passed through you, you'd see one of your arms grow longer than the other. If you were wearing a watch on each wrist, you'd see them tick out of sync" (Resnick). Of course, we do not see this in our daily lives at all. The reason for this is that the events that take place near us do not produce a gravitational wave that is at all noticeable, even with the most sensitive instruments. "It is only with two super-massive objects colliding that we get significant waves produced in the fabric of space-time. Two black holes colliding unleash a loud thunderclap of gravity. If you were near the black holes when they collided, you'd see the universe expand and contract like you were living inside a funhouse mirror. But by the time they reach the Earth — like ripples nearing the edge of a pond — they grew faint" (Resnick). So, with our most precise instruments, we have recently detected a collision of two black holes that have travelled through space. The waves that reached us were incredibly smaller then what they were if we were at the location of the collision. Gravity is an interesting thing to measure because it is not opaque to anything like how light can be opaque. The LIGO, which is the instrument that is capable of detecting the faintest of gravitational waves across the universe, has the potential to look back further in time then the light we currently see. Almost nothing is opaque to gravity.

With LIGO, we could potentially listen in on the gravitational waves emanating from the early universe, or even the Big Bang, and gain a better understand of how it formed (Resnick). Gravitational waves can provide us with a better understand of where we are and why we are here.

With the many consequences of Einstein's theory of relativity, there are also a great deal of applications. One of the most interesting applications is the idea of time travel. "Kurt Gödel showed that solutions to Einstein's equations exist that contain closed timelike curves (CTCs), which allow for loops in time. The solutions require extreme physical conditions unlikely ever to occur in practice, and it remains an open question whether further laws of physics will eliminate them completely" (General Relativity). These loops in time could be used to allow people to travel through time. Although the conditions for these results are extremely rare and deadly, humans could one day develop the technology to harness the power of the most mysterious and immense objects in the universe. As we look to become a multi-planetary species, space travel becomes a necessity. With that, we must understand the effects of traveling at speeds that begin to approach the speed of light. "As a result of Energy being proportional to its mass, as an object gains kinetic energy, it gains mass. This makes an object harder and harder to accelerate as it approaches the speed of light" (Nola). Referencing Newton's 2nd law, we understand that as mass becomes bigger, it naturally takes more force to accelerate it. Although Einstein's theory of relativity is now over 100 years old, research is more active than ever. As we continue to develop better technology for space research and exploration, we will delve deeper into the mysteries of what lies before us. The only thing in our way is time.

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