DOWNLOAD PDF ALBERT EINSTEINS THEORY OF GENERAL RELATIVITY

Chapter 1 : Albert Einstein's General Theory of Relativity

Einstein's theory of general relativity predicted that the space-time around Earth would be not only warped but also twisted by the planet's rotation. Gravity Probe B showed this to be correct.

Theory Of Relativity Theory of Relativity â€” A Brief History The Theory of Relativity, proposed by the Jewish physicist Albert Einstein in the early part of the 20th century, is one of the most significant scientific advances of our time. Although the concept of relativity was not introduced by Einstein, his major contribution was the recognition that the speed of light in a vacuum is constant and an absolute physical boundary for motion. For objects travelling near light speed, however, the theory of relativity states that objects will move slower and shorten in length from the point of view of an observer on Earth. When Einstein applied his theory to gravitational fields, he derived the "curved space-time continuum" which depicts the dimensions of space and time as a two-dimensional surface where massive objects create valleys and dips in the surface. This aspect of relativity explained the phenomena of light bending around the sun, predicted black holes as well as the Cosmic Microwave Background Radiation CMB -- a discovery rendering fundamental anomalies in the classic Steady-State hypothesis. For his work on relativity, the photoelectric effect and blackbody radiation, Einstein received the Nobel Prize in Newtonian physics had previously hypothesised that gravity operated through empty space, but the theory lacked explanatory power as far as how the distance and mass of a given object could be transmitted through space. General relativity irons out this paradox, for it shows that objects continue to move in a straight line in space-time, but we observe the motion as acceleration because of the curved nature of space-time. The total solar eclipse allowed astronomers to -- for the first time -- analyse starlight near the edge of the sun, which had been previously inaccessible to observers due to the intense brightness of the sun. It also predicted the rate at which two neutron stars orbiting one another will move toward each other. When this phenomenon was first documented, general relativity proved itself accurate to better than a trillionth of a percent precision, thus making it one of the best confirmed principles in all of physics. Applying the principle of general relativity to our cosmos reveals that it is not static. Edwin Hubble demonstrated in that the Universe is expanding, showing beyond reasonable doubt that the Universe sprang into being a finite time ago. The most common contemporary interpretation of this expansion is that this began to exist from the moment of the Big Bang some However this is not the only plausible cosmological model which exists in academia, and many creation physicists such as Russell Humphreys and John Hartnett have devised models operating with a biblical framework, which -- to date -- have withstood the test of criticism from the most vehement of opponents. Theory of Relativity â€” A Testament to Creation Using the observed cosmic expansion conjunctively with the general theory of relativity, we can infer from the data that the further back into time one looks, the universe ought to diminish in size accordingly. However, this cannot be extrapolated indefinitely. This is referred to as the Cosmological arrow of time, and implies that the future is -- by definition -- the direction towards which the universe increases in size. The expansion of the universe also gives rise to the second law of thermodynamics, which states that the overall entropy or disorder in the Universe can only increase with time because the amount of energy available for work deteriorates with time. If the universe was eternal, therefore, the amount of usable energy available for work would have already been exhausted. This has profound theological implications, for it shows that time itself is necessarily finite. If the universe were eternal, the thermal energy in the universe would have been evenly distributed throughout the cosmos, leaving each region of the cosmos at uniform temperature at very close to absolute 0 , rendering no further work possible. The General Theory of Relativity demonstrates that time is linked, or related, to matter and space, and thus the dimensions of time, space, and matter constitute what we would call a continuum. They must come into being at precisely the same instant. Time itself cannot exist in the absence of matter and space. From this, we can infer that the uncaused first cause must exist outside of the four dimensions of space and time, and possess eternal, personal, and intelligent qualities in order to possess the capabilities of intentionally space, matter -- and indeed even time itself -- into being. Moreover, the very physical nature of time and space also suggest a Creator, for infinity and eternity must necessarily exist from a logical perspective. The existence of time implies eternity as time has a beginning and an end , and the existence of space implies infinity. The very concepts of infinity and eternity infer a Creator because they find their very state of being in God, who transcends both and simply is.

Chapter 2 : Einstein's Theory of Relativity Explained (Infographic)

Albert Einstein's Theory of General Relativity. When forced to summarize the general theory of relativity in one sentence: Time and space and gravitation have no separate existence from matter.

November 7, Gravity Probe B showed this to be correct. NASA In , Albert Einstein determined that the laws of physics are the same for all non-accelerating observers, and that the speed of light in a vacuum was independent of the motion of all observers. This was the theory of special relativity. It introduced a new framework for all of physics and proposed new concepts of space and time. Einstein then spent 10 years trying to include acceleration in the theory and published his theory of general relativity in In it, he determined that massive objects cause a distortion in space-time, which is felt as gravity. The tug of gravity Two objects exert a force of attraction on one another known as "gravity. The force tugging between two bodies depends on how massive each one is and how far apart the two lie. Even as the center of the Earth is pulling you toward it keeping you firmly lodged on the ground , your center of mass is pulling back at the Earth. But the more massive body barely feels the tug from you, while with your much smaller mass you find yourself firmly rooted thanks to that same force. Albert Einstein , in his theory of special relativity , determined that the laws of physics are the same for all non-accelerating observers, and he showed that the speed of light within a vacuum is the same no matter the speed at which an observer travels. As a result, he found that space and time were interwoven into a single continuum known as space-time. Events that occur at the same time for one observer could occur at different times for another. As he worked out the equations for his general theory of relativity, Einstein realized that massive objects caused a distortion in space-time. Imagine setting a large body in the center of a trampoline. The body would press down into the fabric, causing it to dimple. A marble rolled around the edge would spiral inward toward the body, pulled in much the same way that the gravity of a planet pulls at rocks in space. How To See Spacetime Stretch] Experimental evidence Although instruments can neither see nor measure space-time, several of the phenomena predicted by its warping have been confirmed. Light around a massive object, such as a black hole, is bent, causing it to act as a lens for the things that lie behind it. Astronomers routinely use this method to study stars and galaxies behind massive objects. The quasar is about 8 billion light-years from Earth, and sits behind a galaxy that is million light-years away. Four images of the quasar appear around the galaxy because the intense gravity of the galaxy bends the light coming from the quasar. Gravitational lensing can allow scientists to see some pretty cool things, but until recently, what they spotted around the lens has remained fairly static. However, since the light traveling around the lens takes a different path, each traveling over a different amount of time, scientists were able to observe a supernova occur four different times as it was magnified by a massive galaxy. Although the white dwarf is more massive, it has a far smaller radius than its companion. Changes in the orbit of Mercury: The orbit of Mercury is shifting very gradually over time, due to the curvature of space-time around the massive sun. In a few billion years, it could even collide with Earth. Frame-dragging of space-time around rotating bodies: The spin of a heavy object, such as Earth, should twist and distort the space-time around it. The electromagnetic radiation of an object is stretched out slightly inside a gravitational field. Think of the sound waves that emanate from a siren on an emergency vehicle; as the vehicle moves toward an observer, sound waves are compressed, but as it moves away, they are stretched out, or redshifted. Known as the Doppler Effect, the same phenomena occurs with waves of light at all frequencies. In , 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. Violent events, such as the collision of two black holes, are thought to be able to create ripples in space-time known as gravitational waves. It is thought that such waves are embedded in the cosmic microwave background. However, further research revealed that their data was contaminated by dust in the line of sight. LIGO spotted the first confirmed gravitational wave on September 14, The pair of instruments, based out of Louisiana and

Washington, had recently been upgraded, and were in the process of being calibrated before they went online. The first detection was so large that, according to LIGO spokesperson Gabriela Gonzalez, it took the team several months of analyzation to convince themselves that it was a real signal and not a glitch. A second signal was spotted on December 26 of the same year, and a third candidate was mentioned along with it. While the first two signals are almost definitively astrophysicalâ€”Gonzalez said there was less than one part in a million of them being something elseâ€”the third candidate has only an 85 percent probability of being a gravitational wave. Together, the two firm detections provide evidence for pairs of black holes spiraling inward and colliding. As time passes, Gonzalez anticipates that more gravitational waves will be detected by LIGO and other upcoming instruments, such as the one planned by India.

Chapter 3 : General relativity - Wikipedia

Formulated by Albert Einstein in , the theory of relativity is the notion that the laws of physics are the same The Evidence for Einstein's Theory. human health and general science.

Albert Einstein published the theory of special relativity in , building on many theoretical results and empirical findings obtained by Albert A. Max Planck , Hermann Minkowski and others did subsequent work. Einstein developed general relativity between and , with contributions by many others after The final form of general relativity was published in Relativtheorie used in by Planck, who emphasized how the theory uses the principle of relativity. In the discussion section of the same paper, Alfred Bucherer used for the first time the expression "theory of relativity" German: By comparison, general relativity did not appear to be as useful, beyond making minor corrections to predictions of Newtonian gravitation theory. Its mathematics seemed difficult and fully understandable only by a small number of people. Around , general relativity became central to physics and astronomy. New mathematical techniques to apply to general relativity streamlined calculations and made its concepts more easily visualized. As astronomical phenomena were discovered, such as quasars , the 3-kelvin microwave background radiation , pulsars , and the first black hole candidates , [3] the theory explained their attributes, and measurement of them further confirmed the theory. Special relativity Main article: Special relativity Special relativity is a theory of the structure of spacetime. Special relativity is based on two postulates which are contradictory in classical mechanics: The laws of physics are the same for all observers in uniform motion relative to one another principle of relativity. The speed of light in a vacuum is the same for all observers, regardless of their relative motion or of the motion of the light source. The resultant theory copes with experiment better than classical mechanics. For instance, postulate 2 explains the results of the Michelsonâ€"Morley experiment. Moreover, the theory has many surprising and counterintuitive consequences. Some of these are: Two events, simultaneous for one observer, may not be simultaneous for another observer if the observers are in relative motion. Objects are measured to be shortened in the direction that they are moving with respect to the observer. Maximum speed is finite: No physical object, message or field line can travel faster than the speed of light in a vacuum. The effect of Gravity can only travel through space at the speed of light, not faster or instantaneously. Relativistic mass , idea used by some researchers. General relativity Main articles: General relativity and Introduction to general relativity General relativity is a theory of gravitation developed by Einstein in the years â€" The development of general relativity began with the equivalence principle , under which the states of accelerated motion and being at rest in a gravitational field for example, when standing on the surface of the Earth are physically identical. The upshot of this is that free fall is inertial motion: This is incompatible with classical mechanics and special relativity because in those theories inertially moving objects cannot accelerate with respect to each other, but objects in free fall do so. To resolve this difficulty Einstein first proposed that spacetime is curved. In , he devised the Einstein field equations which relate the curvature of spacetime with the mass, energy, and any momentum within it. Some of the consequences of general relativity are: Clocks run slower in deeper gravitational wells. This has been observed in the orbit of Mercury and in binary pulsars. Rays of light bend in the presence of a gravitational field. Rotating masses "drag along" the spacetime around them; a phenomenon termed " frame-dragging ". The universe is expanding , and the far parts of it are moving away from us faster than the speed of light. Technically, general relativity is a theory of gravitation whose defining feature is its use of the Einstein field equations. The solutions of the field equations are metric tensors which define the topology of the spacetime and how objects move inertially. Experimental evidence Einstein stated that the theory of relativity belongs to a class of "principle-theories". As such, it employs an analytic method, which means that the elements of this theory are not based on hypothesis but on empirical discovery. By observing natural processes, we understand their general characteristics, devise mathematical models to describe what we observed, and by analytical means we deduce the necessary conditions that have to be satisfied. It makes predictions that can be tested by experiment. In the case of special relativity, these include the principle of relativity, the constancy of the speed of light, and time dilation. Einstein derived the Lorentz transformations from first principles in , but these three experiments allow the transformations to be induced from experimental evidence. The modern view is that light needs no medium of transmission, but Maxwell and his contemporaries were convinced that light waves were propagated in a medium, analogous to sound propagating in air, and ripples propagating on the surface of a pond. This hypothetical medium was called the luminiferous aether , at rest relative to the "fixed stars" and through which the Earth moves. Michelson designed an instrument called the Michelson interferometer to accomplish this. The apparatus was more than accurate enough to detect the expected effects, but he obtained a null result when the first experiment was conducted in , [14] and again in The interpretation of the null result of the Michelsonâ€"Morley experiment is that the round-trip travel time for light is isotropic independent of direction , but the result alone is not enough to discount the theory of the aether or validate the predictions of special relativity. While the Michelsonâ€"Morley experiment showed that the velocity of light is isotropic, it said nothing about how the magnitude of the velocity changed if at all in different inertial frames. The Kennedyâ€"Thorndike experiment was designed to do that, and was first performed in by Roy Kennedy and Edward Thorndike. Stilwell first in [21] and with better accuracy in The strategy was to compare observed Doppler shifts with what was predicted by classical theory, and look for a Lorentz factor correction. Such a correction was observed, from which was concluded that the frequency of a moving atomic clock is altered according to special relativity. Other experiments include, for instance, relativistic energy and momentum increase at high velocities, experimental testing of time dilation , and modern searches for Lorentz violations. Tests of general relativity Main article: Other tests confirmed the equivalence principle and frame dragging. Modern applications Far from being simply of theoretical interest, relativitistic effects are important practical engineering concerns. Satellite-based measurement needs to take into account relativistic effects, as each satellite is in motion relative to an Earth-bound user and is thus in a different frame of reference under the theory of relativity.

Chapter 4 : Albert Einstein and the Theory of Relativity

General relativity (GR, also known as the general theory of relativity or GTR) is the geometric theory of gravitation published by Albert Einstein in and the current description of gravitation in modern physics.

An inertial reference frame is a body that is either at rest or that moves with a constant velocity. In contrast, his general theory of relativity accounts not only for these, but also for bodies that accelerate i. Einstein began his theory with a thought experiment--that is, an experiment carried out only in the mind of the experimenter. This experiment imagines a physicist in a room on Earth dropping a ball to the ground. The ball falls to the floor at an accelerating rate because of the force of gravity. To the physicist inside the ship, however, the ball would appear to "fall" toward the floor exactly as it did in the room on earth. Thus, it would be impossible for the physicist inside the spaceship to distinguish between gravitation and any other acceleration. Based on this principle, Einstein formulated the principle of general covariance, which forms the basis of his general theory of relativity. This maxim states that the laws of physics are the same in all i. This extends the first postulate of special relativity to include accelerating frames of reference as well. Basically, with his general covariance principle, Einstein applied the equivalence principle to special relativity: One consequence of this principle is that space-time in the presence of matter is curved. Space-time is the four-dimensional continuum of time and space in which any event or physical object is located. This can be understood by imagining a spaceship accelerating upward through space. If a light ray enters the ship through a window, a person inside the ship will see the light ray bend downward, because by the time the light reaches the other wall of the spaceship, that wall will have accelerated upward; thus the ray of light enters through the window at one height, and hits the opposite wall at a height closer to the floor of the space ship. Yet because nothing can travel faster than light, we know that light must always travel the shortest distance between two points; and since the shortest distance between two points in an accelerating spaceship is curved, space-time itself must be curved. As Einstein demonstrated, mass causes a curvature in space-time in much the same way as a bowling ball will deform the shape of a stretched rubber sheet on which it rests. Rather than speaking in terms of mysterious forces of attraction, as Newton did, Einstein understood gravitation as pure geometry. With the help of his mathematician friends Minkowski and Grossman, he was able to quantify the extent to which a body warps its surrounding space-time. After completing the general theory of relativity, Einstein began working on a clear and comprehensive presentation of it. Until this point, most of his publications were provisional reports on the state of his research, comprehensible only to those physicists who had been following his work all along. In , he published a treatise entitled "Foundations of the General Theory of Relativity," in which he established the terminology of "special" and "general" relativity and presented his theory formally. Then, at the end of , he published a small book entitled On the Special and the General Theory of Relativity, Generally Comprehensible. This work was written with as little mathematics as possible and was designed to appeal to an even broader readership, albeit one still somewhat educated in mathematics or physics. After arriving at the final form of his theory of general relativity in November , Einstein proposed three possible tests for his theory. These involved the orbit of the planet Mercury, the bending of starlight near the sun, and the redshift of light. On November 6, , a team of British astronomers led by Arthur Eddington reported to the Royal Society of London that during a recent total eclipse of the sun, they had observed that the positions of the stars near the sun appeared to have shifted slightly from their proper positions. The publication of this finding in newspapers across the world made Einstein an immediate celebrity. However, not all the response to his theory was positive. Unfortunately, this was not the last of the anti-Semitism that Einstein would encounter during his tenure at the University of Berlin.

DOWNLOAD PDF ALBERT EINSTEINS THEORY OF GENERAL RELATIVITY

Chapter 5 : SparkNotes: Albert Einstein: General Relativity

Albert Einstein's general theory of relativity is one of the towering achievements of 20th-century physics. Published in , it explains that what we perceive as the force of gravity in fact.

Special Relativity As a patent clerk in Switzerland, Einstein began to think about how moving observers see events differently from stationary observers. This is part of our common experience. When you sit in a train waiting for it to go, and the train on the adjacent track starts to move, there are sometimes a few moments when you are not sure which train is moving. It is only after you see your absence of motion with respect to background objects that you realize the other train is moving. But if you are at rest or your are moving at a constant velocity in deep space and you see another space ship pass you by moving at a constant velocity, you would not be able to tell which spaceship is really moving. I leave it as a homework problem for you to do the samejust kidding! Part of the reason for this result is that if a massive object is moving from the point of view of one observer, but at rest as seen by another observer, then one observer would seem to measure zero energy of the object while the other observer would measure a finite energy. It turns out that for the laws of physics to be consistent in the two "reference frames" of two observers moving with constant speed with respect to each other the has to be an energy associated with a body at rest, not just a body in motion. All of these effects are only when the velocity of objects approach the speed of light. The effects are hard to understand and feel in our daily lives because we are always experiencing much smaller velocities at which Newtonian physics dominates. General Relativity The General Theory of Relativity is even more subtle and even farther beyond the scope of this course. Nevertheless, some of the basic ideas can be described. He then realized that it is impossible for an observer to distinguish between freely falling in a gravitational field, and some other mechanism of uniform acceleration such as a rocket. This turned out to be a profound insight. A physical picture of what is going on is something like the following: Consider a very large trampoline with nothing on the trampoline pad. The trampoline pad remains flat and parallel to the ground. Now place a heavy bowling ball at the center of the trampoline pad. The center of the pad will sag downward. If we assume the analogy that the trampoline pad represents space-time, and the bowling ball a gravitating object, then the sagging of the trampoline represents the curvature of space time under the influence of gravity. We can now see that if we take a lighter ball, and place it at the edge of the trampoline bad, it will roll down toward the bowling ball. This attraction to the bowling ball is because the path toward the bowling ball through space is favorably curved. In general relativity, however, it is not only balls that would follow that curved path but light as well. Consequences of the Principle of Equivalence Said another way, as light passes a massive object, the path of light is actually bent by a gravitational field. This effect is even measurable during a solar eclipse. Stars whose locations we know to be behind the position of the sun are actually observable during a solar eclipse because the light is bent around on a curved path! They make essentially identical predictions as long as the strength of the gravitational field is weak, which is our usual experience. However, there are crucial predictions where the two theories diverge, and thus can be tested with careful experiments. This is commonly called the "precession of the perihelion", because it causes the position of the perihelion to move. This effect is extremely small, but the measurements are very precise and can detect such small effects very well. Precise observations indicate that Einstein is right, both about the effect and its magnitude. A striking consequence is gravitational lensing. The Modern Theory of Gravitation And there is stands to the present day. Our best current theory of gravitation is the General Theory of Relativity. We shall return to this issue in our subsequent discussion of cosmology. For interested students, more about Einstein and his work see Albert Einstein Online.

Chapter 6 : Theory of relativity - Wikipedia

The theory of relativity usually encompasses two interrelated theories by Albert Einstein: special relativity and general relativity. Special relativity applies to elementary particles and their interactions, describing all their physical phenomena except gravity.

Albert Einstein Biography General Theory of Relativity Although Einstein had changed the face of modern physics with the release of his paper on Special Relativity, he was not satisfied with the theory. He wanted to build a more general theory that would include and explain gravity. He realized that a person falling in freefall would not feel their own weight. If the person was in an enclosed chamber while falling, they would have the same experience as someone floating weightless in outer space at least until they hit the ground. What this meant to Einstein was that gravitation did not exist to the observer. The Equivalence Principle Einstein used his "falling man" thought experiment to develop the equivalence principle. This principle said that the affects of gravity and the affects of acceleration were both produced by the same structure. He published his ideas at the end of a article published by the Yearbook of Radioactivity and Electronics. Although it would take several more years, the concept of the equivalence principle would serve as an important step in the road to general relativity. Early Predictions In addition to coming up with the equivalence principle, Einstein used this idea to make some important real world predictions. First, he demonstrated that clocks would actually run slower the more intense the gravitational field. In other words, clocks on Jupiter would run more slowly than clocks on Earth. This is now known as gravitational time dilation. Einstein also predicted that gravity would cause light to curve, a prediction that could be proven through experiment. Strategies Over the next several years Einstein would pursue a solution to general relativity using two different strategies: His early attempts in at the mathematical solution can be seen in a notebook called the Zurich Notebook. However, Einstein abandoned the mathematical strategy after a year feeling that his final equations did not meet the necessary conditions. He then turned his effort fully to the physical strategy and released a paper that became known as the Entwurf on the subject. Success and the General Theory of Relativity Einstein was only somewhat satisfied with the Entwurf paper and, by , he had come to the realization that the Entwurf theory was flawed. Ever persistent, Einstein returned to a mathematical strategy. By the end of , Einstein had begun to form equations that would explain his idea of general relativity. It was the result of years of hard work. He then refined his equations and presented them in a lecture at the Prussian Academy called "The Field Equations of Gravitation. In , his theory was confirmed when it correctly predicted the deflection of starlight by the sun during a solar eclipse. The confirmation of his theory brought Einstein worldwide fame. Interesting Facts When discussing his success at finding a solution to general relativity Einstein said "My boldest dreams have now come true.

Chapter 7 : Theory Of Relativity

The theories of relativity by Albert Einstein revolutionized how the world thinks about space, time, mass, energy and gravity.. FULL STORY: General Relativity at Einstein's Famous Theory Has.

March 5, By Karl Tate, Infographics Artist The theories of relativity by Albert Einstein revolutionized how the world thinks about space, time, mass, energy and gravity. General Relativity at In , Newton wrote that gravity affects everything in the universe. The same force of gravity that pulled an apple down from a tree kept the Earth in motion around the sun. But Newton never puzzled out the source of gravity. Hume was an empiricist and skeptic, believing that scientific concepts must be based on experience and evidence, not reason alone. He also held that time did not exist separately from the movement of objects. In , Albert Einstein based a new theory on two principles. First, the laws of physics appear the same to all observers. Second, he calculated that the speed of light â€" , miles per second , kilometers per second â€" is unchanging. Prior to Einstein, scientists believed that space was filled with luminiferous aether that would cause the speed of light to change depending on the relative motion of the source and the observer. As a result of these principles, Einstein deduced that there is no fixed frame of reference in the universe. It is known as special relativity because it applies only to special cases: In , Einstein published the general theory of relativity, which applies to frames that are accelerating with regard to each other. 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. A fast-moving object appears shorter along the direction of motion, relative to a slow-moving one. This effect is very subtle until the object travels close to the speed of light. Mass and energy are different manifestations of the same thing. The increase in mass is the reason that Einstein says that matter cannot travel faster than light. The mass increases with velocity until the mass becomes infinite when it reaches light speed. An infinite mass would require infinite energy to move, so this is impossible. Space and time are part of one continuum, called space-time. More recent theories presume extra dimensions that we do not perceive. Space-time can be thought of as a grid or fabric. The presence of mass distorts space-time, so the rubber sheet model is a popular visualization. Relativity explains where gravity comes from. The rubber sheet model shows that gravity results from massive objects warping space-time. The warp is called a gravity well. Orbiting objects follow the path that is shortest and requires the least amount of energy. The planets move in ellipses, the most energy-efficient path in the gravity well of the sun. This phenomenon is called gravitational lensing. When we observe a distant galaxy, the gravity of matter between Earth and the galaxy causes light rays to be bent into different paths. When the light reaches the telescope , multiple images of the same galaxy appear.

Chapter 8 : 6 Things You Might Not Know About Einsteinâ€™s General Theory of Relativity - HISTORY

Success and the General Theory of Relativity Einstein was only somewhat satisfied with the Entwurf paper and, by , he had come to the realization that the Entwurf theory was flawed. Ever persistent, Einstein returned to a mathematical strategy.

History of general relativity and Classical theories of gravitation Soon after publishing the special theory of relativity in , Einstein started thinking about how to incorporate gravity into his new relativistic framework. In , beginning with a simple thought experiment involving an observer in free fall, he embarked on what would be an eight-year search for a relativistic theory of gravity. After numerous detours and false starts, his work culminated in the presentation to the Prussian Academy of Science in November of what are now known as the Einstein field equations. Einstein used approximation methods in working out initial predictions of the theory. But as early as , the astrophysicist Karl Schwarzschild found the first non-trivial exact solution to the Einstein field equations, the Schwarzschild metric. This solution laid the groundwork for the description of the final stages of gravitational collapse, and the objects known today as black holes. In line with contemporary thinking, he assumed a static universe, adding a new parameter to his original field equationsâ€"the cosmological constant â€"to match that observational presumption. This is readily described by the expanding cosmological solutions found by Friedmann in , which do not require a cosmological constant. It was clearly superior to Newtonian gravity , being consistent with special relativity and accounting for several effects unexplained by the Newtonian theory. Einstein himself had shown in how his theory explained the anomalous perihelion advance of the planet Mercury without any arbitrary parameters " fudge factors ". It juxtaposes fundamental concepts space and time versus matter and motion which had previously been considered as entirely independent. The combination of this description with the laws of special relativity results in a heuristic derivation of general relativity. For example, an observer will see a ball fall the same way in a rocket left as it does on Earth right , provided that the acceleration of the rocket is equal to 9. In modern parlance, their paths are geodesics , straight world lines in curved spacetime. However, there is an ambiguity once gravity comes into play. This suggests the definition of a new class of inertial motion, namely that of objects in free fall under the influence of gravity. This new class of preferred motions, too, defines a geometry of space and timeâ€"in mathematical terms, it is the geodesic motion associated with a specific connection which depends on the gradient of the gravitational potential. Space, in this construction, still has the ordinary Euclidean geometry. However, spacetime as a whole is more complicated. From this, one can deduce that spacetime is curved. The resulting Newtonâ€"Cartan theory is a geometric formulation of Newtonian gravity using only covariant concepts, i. The differences between the two become significant when dealing with speeds approaching the speed of light , and with high-energy phenomena. They are defined by the set of light cones see image. The light-cones define a causal structure: These sets are observer-independent. In mathematical terms, this defines a conformal structure [30] or conformal geometry. Special relativity is defined in the absence of gravity, so for practical applications, it is a suitable model whenever gravity can be neglected. Bringing gravity into play, and assuming the universality of free fall, an analogous reasoning as in the previous section applies: Instead there are approximate inertial frames moving alongside freely falling particles. Translated into the language of spacetime: But using different assumptions about the special-relativistic frames such as their being earth-fixed, or in free fall , one can derive different predictions for the gravitational redshift, that is, the way in which the frequency of light shifts as the light propagates through a gravitational field cf. The actual measurements show that free-falling frames are the ones in which light propagates as it does in special relativity. In the language of spacetime geometry, it is not measured by the Minkowski metric. As in the Newtonian case, this is suggestive of a more general geometry. At small scales, all reference frames that are in free fall are equivalent, and approximately Minkowskian. Consequently, we are now dealing with a curved generalization of Minkowski space. The metric tensor that defines the geometryâ€"in particular, how lengths and angles are measuredâ€"is not the Minkowski metric of special relativity, it is a generalization known as a semi- or pseudo-Riemannian metric. Furthermore, each Riemannian metric is naturally associated with one particular kind of connection, the Levi-Civita connection , and this is, in fact, the connection that satisfies the equivalence principle and makes space locally Minkowskian that is, in suitable locally inertial coordinates , the metric is Minkowskian, and its first partial derivatives and the connection coefficients vanish. In Newtonian gravity, the source is mass. In special relativity, mass turns out to be part of a more general quantity called the energyâ€"momentum tensor , which includes both energy and momentum densities as well as stress: Drawing further upon the analogy with geometric Newtonian gravity, it is natural to assume that the field equation for gravity relates this tensor and the Ricci tensor , which describes a particular class of tidal effects: In special relativity, conservation of energy â€"momentum corresponds to the statement that the energyâ€"momentum tensor is divergence -free. This formula, too, is readily generalized to curved spacetime by replacing partial derivatives with their curved-manifold counterparts, covariant derivatives studied in differential geometry.

Chapter 9 : Einstein's Theory of General Relativity: A Simplified Explanation

Albert Einstein is famous for his theory of relativity, and GPS navigation and nuclear energy would be impossible without the equation e=mc2. In the first major test of general relativity.