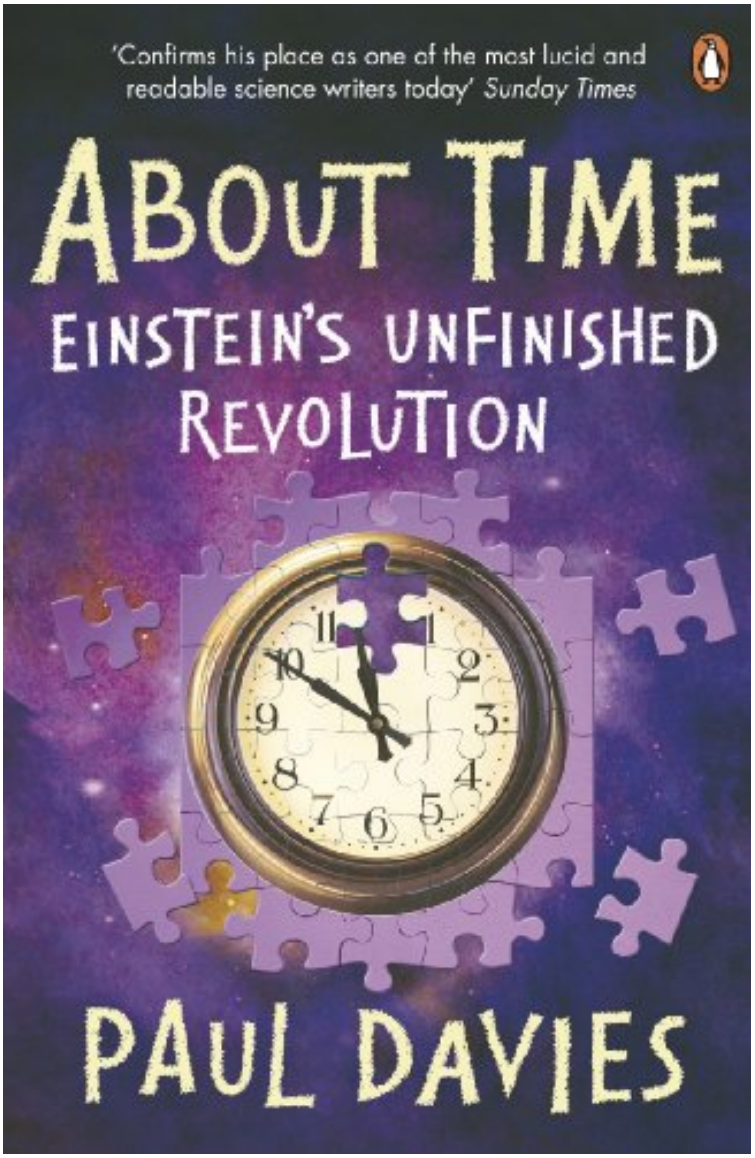
About Time: Einstein's Unfinished Revolution



Par Paul Davies
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Description :

Prsentation de l'diteurThis is a book about the meaning of time, what it is, when it has started, how it flows and where to. It examines the consequences of Einstein's theory of relativity and offers startling suggestions about what recent research may reveal.ExtraitCHAPTER 1A VERY BRIEF HISTORY OF TIMETime is at the heart of all that is important to human beings.Bernard d'EspagnatWHOSE TIME IS IT ANYWAY?Time must never be thought of as pre-existing in any sense; it is a manufactured quantity.Hermann BondiIn a dingy laboratory in Bonn lies a submarine-shaped metal cylinder. It is about three meters long, and rests comfortably in a steel frame surrounded by wires, pipes and dials. At first glance, the entire contraption looks like the inside of a giant car engine. In fact, it is a clock -- or, rather, the clock. The Bonn device, and a

network of similar instruments across the world, together constitute "the standard clock." The individual instruments, of which the German model is currently the most accurate, are cesium-beam atomic clocks. They are continually monitored, compared, tweaked and refined via radio signals from satellites and television stations, to cajole them into near-perfect step. At the International Bureau of Weights and Measures at Svres, not far from Paris, the data are collected, analyzed and broadcast to a time-obsessed world. Thus originates the famous pips, the radio time signals by which we set our watches.So, as we go about our daily toil, the Bonn cesium-beam clock keeps the time. It is, so to speak, a custodian of Earth time. The trouble is, the Earth itself doesn't always keep good time. Occasionally our clocks, all supposedly linked to the master system in France like a retinue of obedient slaves, must be adjusted by a second to track changes in the Earth's rotation rate. The last such "leap second" was added on 30 June 1994. The planet's spin, accurate enough to serve as a perfectly suitable clock for a thousand generations, is now defunct as a reliable chronometer. In this age of high-precision timekeeping, poor old Earth doesn't make the grade. Only an atomic clock, man-made and mysterious, serves to deliver those all-important tick-tocks with the precision demanded by navigators, astronomers and airline pilots. One second is no longer defined to be 1/86,400 of a day: it is 9,192,631,770 beats of a cesium atom.But whose time is the Bonn clock telling anyway? Your time? My time? God's time? Are the scientists in that cluttered laboratory monitoring the pulse of the universe, fastidiously tracking some abstract cosmic time with atomic fidelity? Might there be another clock, perhaps on another planet somewhere, faithfully ticking out another time altogether, to the joy of its makers?We know clocks need not agree: the Earth clock gets out of sync with the Bonn clock. So which one is right? Well, presumably the Bonn clock, because it's more accurate. But accurate relative to what? To us? After all, clocks were invented to tell the time for entirely human purposes. Are all humans "on" the same time, however? The patient in the dentist's chair and the audience listening to a Beethoven symphony experience the same atomically tagged duration in quite different ways.So much of what we believe about time is a result of cultural conditioning. I once met a mystic in Bombay who claimed he could alter his state of consciousness through meditation and so suspend the flow of time altogether; he was unimpressed with talk of atomic clocks. In a lecture in London some years ago, I found myself sharing the platform improbably with the Dalai Lama. Our task was to compare and contrast time as it enters into Western scientific thinking and Eastern philosophy. The Lama spoke with quiet assurance, but unfortunately in Tibetan. Though I tried to follow the translation for enlightenment, I didn't receive much, regrettably. Culture clash, I suppose.After my lecture, we had a tea break, and the Dalai Lama took my hand as we walked out of the building into the sunshine. Someone dropped to his knees and presented His Holiness with a daffodil, which he graciously accepted. I had the overwhelming impression of a gentle and intelligent man with insights of value to us all, but prevented by the trappings of his office from effectively communicating them to the assembled Western scientists. I came away from the occasion with a deep sense of missed opportunity.THE QUEST FOR ETERNITYEternity? thou pleasing, dreadful thought?Joseph AddisonIn the madcap world of modern Western society, where time is money, railways, airline schedules, television programs, even cooking are subject to the tyranny of the clock. Our hectic lives are firmly bolted to the treadmill of time. We are slaves of our past and hostages to the future. But was it always thus? Running like a common thread through the history of human thought, East and West, North and South, is a belief that the entire paradigm of human temporality is rooted in some sort of monstrous illusion; it is but an elaborate product of the human mind:And likewise time cannot itself exist,But from the flight of things we get a sense of time....No man, we must confess, feels time itself,But only knows of time from flight or rest of things.Thus wrote the Roman poet-philosopher Lucretius in his first-century epic De Rerum Natura. From such unsettling ideas it is but a small step to believe that the passage of time can be controlled or even suspended by mental power, as we discover in the following haunting words of the sixteenth-century mystical poet Angelus Silesius:Time is of your own making,its clock ticks in your head.The moment you stop thoughttime too stops dead.For such temporal relativists, true reality is vested in a realm that transcends time: the Land Beyond Time. Europeans call it "eternity," Hindus refer to it as "moksha" and Buddhists as "nirvana." For the Australian aborigines it is the Dream Time. Angelus Silesius again:Do not compute eternityas light-year after yearOne step acrossthat line called TimeEternity is here.In our struggle to come to terms with mental and physical reality, nothing vexes us more than the nature of time. The paradoxical conjunction of temporality and eternity has troubled Man through the ages. Plato concluded that the fleeting world of daily experience is only half real, an ephemeral reflection of a timeless domain of pure and perfect Forms, which occupy the realm of eternity. Time itself is but an imperfect "moving image of Eternity which

remains forever at one," but which we human beings incorrigibly reify: "The past and future are created species of time, which we unconsciously but wrongly transfer to the eternal essence.The abiding tension between the temporal and the eternal pervades the world's great religions, and has led to generations of heated and sometimes violent theological debate. Is God inside or outside of time? Temporal or eternal? Process or Being? According to Plotinus, a third-century pagan, to exist in time is to exist imperfectly. Pure Being (i.e., God) must therefore be characterized by the utter absence of any relation to time. For Plotinus, time represents a prison for human beings, separating us from the divine realm -- the true and absolute reality.Belief that God lies outside of time altogether also became the established doctrine among many early Christian thinkers, such as Augustine, Boethius and Anselm, starting a tradition that continues to the present day. Like Plato and Plotinus before him, Augustine places God in the realm of eternity, "supreme above time because it is a never-ending present." In this existence, time does not pass; rather, God perceives all times at once:Your years are completely present to you all at one because they are at a permanent standstill. They do not move on, forced to give way before the advance of others, because they never pass at all...Your today is eternity.Thus, the God of classical Christianity not only exists outside of time, but also knows the future as well as the past and present. These farreaching ideas have been subjected to detailed analysis and received some sharp criticism by the medieval church, as well as by modern theologians and philosophers. The core of the debate is the daunting problem of how to build a bridge between God's presumed eternity on the one hand and the manifest temporality of the physical universe on the other. Can a god who is completely atemporal logically relate in any way at all to a changing world, to human time? Surely it is impossible for God to exist both within and outside of time? After centuries of bitter debate, there is still no consensus among theologians about the solution to this profound conundrum. These tangled issues are reviewed in greater depth in my book The Mind of God, for those readers who are interested.ESCAPE FROM TIMEThe great thing about time is that it goes on.Arthur EddingtonAlthough theologians and philosophers wrangle over the technicalities of the logical relationship between time and eternity, many religious people believe that the most powerful insights into the subject are provided, not by academic debate, but by direct revelation:I remember that I was going to bathe from a stretch of shingle to which the few people who stayed in the village seldom went. Suddenly the noise of the insects was hushed. Time seemed to stop. A sense of infinite power and peace came upon me. I can best liken the combination of timelessness with amazing fullness of existence to the feeling one gets in watching the rim of a great silent fly-wheel or the unmoving surface of a deep, strongly-flowing river. Nothing happened: yet existence was completely full. All was clear.This personal story, recounted by the physicist and Anglican bishop Ernest Barnes in his 1929 Gifford Lectures, eloquently captures the combination of timelessness and clarity so often said to be associated with mystical or religious experiences. Can a human being really escape time and glimpse eternity? In Barnes's case, as happens so often in reports from Westerners, the experience came totally out of the blue. But Eastern mystics have perfected special techniques that allegedly can induce such timeless rapture. The Tibetan monk Lama Govinda describes his own experiences thus:The temporal sequence is converted into a simultaneous co-existence, the side-by-side existence of things into a state of mutual interpenetration...a living continuum in which time and space are integrated.Many similar descriptions have been published of deep meditation, or even drug-induced mental states, in which human consciousness apparently escapes the confines of time, and reality appears as a timeless continuum.The Indian philosopher Ruth Reyna believes the Vedic sages "had cosmic insights which modern man lacks...Theirs was the vision not of the present, but of the past, present, future, simultaneity, and No-Time." Sankara, the eighth-century exponent of Advaita Vedanta, taught that Brahma -- the Absolute -- is perfect and eternal in the sense of absolute timelessness, and thus the temporal, though real within the world of human experience, has no ultimate reality. By following the path of Self-Realization through Advaita, a truly timeless reality may be attained: "timeless not in the sense of endless duration, but in the sense of completeness, requiring neither a before nor an after," according to Reyna. "It is this astounding truth that time evaporates into unreality and Timelessness may be envisioned as the Real...that spells the uniqueness of Advaita."The yearning for an escape from time need not involve refined meditative practices. In many cultures it is merely a pervasive yet subconscious influence -- a "terror of history," as anthropologist Mircea Eliade expresses it -- which manifests itself as a compulsive search for the Land Beyond Time. Indeed, this search is the founding myth of almost all human cultures. The deep human need to account for the origin of things draws us irresistibly back to a time before time, a mythical realm of timeless temporality, a Garden of Eden, a primordial paradise, its potent creativity springing from its very temporal contradictions. Whether it is Athena leaping from the head of Zeus or

Mithras slaying the Bull, we encounter the same heady symbolism of a lost, timeless, perfect realm that somehow -- paradoxically, timelessly -- stands in creative relation to the immediate world of the temporal and the mortal.This paradoxical conjunction is captured in its most developed form in the "Dreaming" concept of the Australian aborigines, sometimes referred to as the Eternal Dream Time. According to the anthropologist W. E. H. Stanner:A central meaning of The Dreaming is that of a sacred, heroic time long, long ago when man and nature came to be as they are; but neither "time" nor "history" as we understand them is involved in this meaning. I have never been able to discover any aboriginal word for time as an abstract concept. And the sense of "history" is wholly alien here. We shall not understand The Dreaming fully except as a complex of meanings.Although the Dream Time carries connotations of a heroic past age, it is wrong to think of that age as now over. "One cannot 'fix' The Dreaming in time," observes Stanner. "It was, and is, everywhen." Thus the Dreaming retains a relevance in contemporary aboriginal affairs, because it is part of the present reality; the "creator beings" are still active today. What Europeans call "the past" is, for many aboriginal people, both past and present. Stories of creation are often cast in what Europeans would call the recent past, even as recent as the era of white settlement. No incongruity is felt, because, for the Australian aborigine, events are more important than dates. This subtlety is lost on most European minds; we have become obsessed with rationalizing and measuring time in our everyday lives. Stanner quotes an old Australian black man who expressed this cultural gulf lyrically:White man got no dreamingHim go 'nother way.White man, him go different,Him got road belong himself.The concept of "white man's time" as a "road" down which he marches single-mindedly is an especially apt description, I think, of Western linear time. It is a road that may perhaps lead to progress, but the psychological price we pay for embarking upon it is a heavy one. Fear of death lies at the root of so much we do and think, and with it the desperate desire to optimize the precious duration we have been allotted, to lead life to the full and accomplish something of enduring value. Modern man, wrote J. B. Priestley,...feels himself fastened to a hawser that is pulling him inexorably toward the silence and darkness of the grave...But no idea of an "eternal dream time," where gods and heroes (from whom he is not separated for ever) have their being, comes shining through to make modern man forget his calendars and clocks, the sands of his time running out.But even those of us who are trapped within Western culture, for whom a magical, mystical escape route from time is unavailable, can still discern the powerful ancient symbols at work in art and literature, reverberating down the ages. From Paradise Lost to Narnia, from King Arthur's Avalon to that distant galaxy far away and long ago where the Star Wars were fought and won, the realm of eternity has never been very far from the surface. The evocative emblems of eternity now lay shadowy and indistinct in our culture, serving merely as a seductive distraction from the commonsense "reality" of ruthless, passing time. Yet, Priestley assures us, they live on:Among the ideas that haunt us -- ideas we may laugh at but that will not leave us, ideas that often promise a mysterious happiness when all else seems to fail us -- is this one of the Great Time, the mythological dream time, that is behind and above and altogether qualitatively different from ordinary time. We no longer create any grand central system out of it. We do not let it shape and guide our lives. It has dwindled and now looks small and shabby, rather laughable; but it cannot be laughed out of existence, it refuses to go away.CYCLIC WORLDS AND THE ETERNAL RETURNAll things from eternity are of like forms and come round in a circle.Marcus Aurelius AntoniusIn ancient cultures, contact with eternity was kept alive by introducing cyclicity in the world. In his classic text The Myth of the Eternal Return, Mircea Eliade describes how traditional societies habitually rebel against the historical notion of time, and yearn instead "for a periodical return to the mythical time of the beginning of things, to the 'Great Time.'" He maintains that the symbols and rituals of ancient cultures represent an attempt to escape from historical, linear, "profane" time, to a mythical or sacred epoch, believing that the suspension of profane time "answers to a profound need on the part of primitive man." Walter Ong, an expert on temporal symbolism, also finds evidence in mythology and folklore for a longing to throw off the trappings of time:Time poses many problems for man, not the least of which is that of irresistibility and irreversibility: man in time is moved willy-nilly and cannot recover a moment of the past. He is caught, carried on despite himself; and hence not a little terrified. Resort to mythologies, which associate temporal events with the atemporal, in effect disarms time, affording relief from its threat. This mythological flight from the ravages of time may at a later date be rationalized by various cyclic theories, which have haunted man's philosophizing from antiquity to the present.Release from historical time may be sought by religious rites, such as the ritual repetition of phrases or gestures that symbolically re-create the original events. Contact with sacred time is often identified with regeneration and renewal. The ancient Festival of New Year, common to both traditional and modern

cultures, symbolizes the periodic regeneration or rebirth of nature. In some instances, it represents a repetition of the creation event itself -- the mythical transition from chaos to cosmos.The symbolism underlying these widespread folk practices stems from the ancient belief in temporal cyclicity. Many annual rituals in the Western world have pagan origins that predate Christianity, yet they have been tolerated for centuries by the church. Indeed, cyclic rituals play an important role in the church too, in spite of Christianity's implacable opposition to cyclic time.Western art, poetry and literature, despite being strongly influenced by the dominance of linear time, nevertheless betrays much hidden and occasionally overt cyclicity. The deep preoccupation with the natural cycle of the seasons, the use of repetitious style, and the liberal employment by writers of a nothing-new-under-the-sun philosophy suggest a fantasized retreat from time's relentless arrow. In some extreme examples, the text itself is structured in a temporally distorting manner, as in James Joyce's Finnegans Wake, where the last words of the book run onto the opening passage, or Martin Amis's The Arrow of Time, where the entire narrative runs backwards.Cyclicity retains a deep appeal for some people, yet is abhorrent to others. As we shall see, there is a modern variant of Einstein's cosmology that suggests a cyclic universe, and whenever I give public lectures on cosmology and fail to mention it, somebody inevitably asks me about it. Perhaps the attraction of the model is the prospect of resurrection in subsequent cycles. There is a world of difference, however, between a general sort of cosmic regeneration, and a universe that endlessly repeats itself in precise detail. Plato's assertion of cosmic cyclicity exercised a strong influence on Greek, and later Roman thought. It was taken to the logical extreme by the Stoics, who believed in the concept of palingenesia -- the literal reappearance of the same people and events in cycle after cycle, an idea that strikes most people today as utterly sterile and repugnant.NEWTON'S TIME AND THE CLOCKWORK UNIVERSEI cannot believe that medieval man ever felt trapped in some vast machinery of time.J. B. PriestleyThe association of time with the mystical, the mental and the organic, fascinating and compelling though it may be, undoubtedly served to hinder a proper scientific study of time for many centuries. Whereas the Greek philosophers developed systematic geometry, and elevated it to a philosophical world view, time remained for them something vague and mysterious, a matter for mythology rather than mathematics. In most ancient cultures, the notion of timekeeping cropped up in just a few contexts: in music, in the rhythmic pattern of the seasons and the motions of the heavenly bodies, and in the menstrual cycle. All these topics were overlaid with deep mystical and occult qualities in a way that properties like mass, speed and volume were not.Aristotle's study of the motion of bodies led him to appreciate the fundamental importance of time, yet he fell short of introducing the notion of time as an abstract mathematical parameter. For Aristotle, time was motion. This is hardly revolutionary: we perceive time through motion, whether the movement of the sun across the sky or the hands around a clock face. The concept of time as an independently existing thing, an entity in its own right, did not emerge until the European medieval age. The existence of an order in nature has been recognized by all cultures, but it was only with the rise of modern science that a precise and objective meaning could be given to that order. In this quantification, the role of time turned out to be crucial.On 8 July 1714, the government of Queen Anne determined "That a Reward be settled by Parliament upon such Person or Persons as shall discover a more certain and practicable Method of Ascertaining Longitude than any yet in practice." The prize on offer was the princely sum of 20,000, to be awarded for the construction of a chronometer that was capable of determining longitude at sea to within thirty miles after a six-week voyage. No event better symbolizes the transition from the organic, rhythmic time of traditional folklore to the modern notion of time as a functional parameter with economic and scientific value.The challenge was taken up by a Yorkshireman named John Harrison, who designed several clocks capable of working at sea. Harrison's fourth instrument, which incorporated a refinement that compensated for temperature changes, was completed in 1759 and submitted for trial two years later. It was conveyed on the ship Deptford to Jamaica, where, some two months later, it was found to have accumulated an error of just five seconds. The Admiralty was a bit sticky coming up with the prize money, and by 1765 Harrison had collected only half his reward. He eventually appealed to the King and Parliament, but had turned eighty before he received the balance. Even in the eighteenth century, research funding was tight.History records that it was Galileo who was foremost in establishing time as a fundamental measurable quantity in the lawlike activity of the cosmos. By measuring the swing of a lamp against the pulse of his wrist while sitting in church, he discovered the basic law of the pendulum -- that its period is independent of the amplitude of the swing. Soon the era of precision clockwork was to sweep through Europe, with craftsmen designing ever more accurate timepieces. The push for greater precision in measuring time was not motivated by lofty philosophical or scientific considerations, but by the very

practical matter of navigation and trade: sailors need to know the time accurately to be able to compute their longitude from the positions of the stars; the discovery of America, necessitating several weeks of east-west travel, spurred the development of shipborne chronometers.The crucial position that time occupies in the laws of the universe was not made fully manifest until the work of Newton, in the late seventeenth century. Newton prefaced his presentation with a famous definition of "absolute, true and mathematical time, [which] of itself, and from its own nature, flows equably without relation to anything external." Central to Newton's entire scheme was the hypothesis that material bodies move through space along predictable paths, subject to forces which accelerate them, in accordance with strict mathematical laws. Having discovered what these laws were, Newton was able to calculate the motion of the moon and planets, as well as the paths of projectiles and other earthly bodies. This represented a giant advance in human understanding of the physical world, and the beginning of scientific theory as we now understand it.So successful did Newton's laws of mechanics prove to be that many people assumed they would apply to literally every physical process in the universe. From this belief emerged the picture of the cosmos as a gigantic clockwork mechanism, predictable in its every detail. The clockwork universe enshrined time as a fundamental parameter in the workings of the physical world. This universal, absolute and completely dependable time was the time that entered into the laws of mechanics, and was faithfully kept by the cosmic clockwork. It encapsulated the rule of cause and effect, and epitomized the very rationality of the cosmos. And it gave the world the powerful image of God the Watchmaker.The great French mathematical physicist Pierre de Laplace, the man who told Napoleon that he "had no need of this hypothesis" when discussing God's action in the Newtonian universe, realized that, if all motion is mathematically determined, then the present state of motion of the universe suffices to fix its future (and past) for all time. In this case, time becomes virtually redundant, for the future is already contained in the present, in the sense that all the information needed to create the future states of the universe resides in the present state. As the Belgian chemist Ilya Prigogine once poetically remarked, God the Watchmaker is reduced to a mere archivist turning the pages of a cosmic history book that is already written. Whereas most ancient cultures viewed the cosmos as a capricious living organism, subject to subtle cycles and rhythms, Newton gave us rigid determinism, a world of inert particles and forces locked in the embrace of infinitely precise lawlike principles.Newtonian time is in its very essence mathematical. Indeed, starting with the idea of a universal flux of time, Newton developed his "theory of fluxions" -- a branch of mathematics better known as the calculus. Our preoccupation with precision timekeeping can be traced to the Newtonian concept of a mathematically precise, continuous flux of time. After Newton, the passage of time became more than merely our stream of consciousness; it began to play a fundamental role in our description of the physical world, something that could be analyzed with unlimited accuracy. Newton did for time what the Greek geometers did for space: idealized it into an exactly measurable dimension. No longer could it be convincingly argued that time is an illusion, a mental construct created by mortal beings from their failure to grasp eternity, because time enters deeply into the very laws of the cosmos, the bedrock of physical reality.EINSTEIN'S TIMEIt was into this world of rigid temporality that Albert Einstein was born. Newton's time had endured for two centuries and was scarcely questioned by Westerners, though it has always rested uneasily alongside Eastern thought, and is alien to the minds of indigenous peoples in America, Africa and Australia. Yet Newton's time is the time of "common sense" (Western style). It is also easy to understand. For Newton, there is but one all-embracing universal time. It is simply there. Time cannot be affected by anything; it just goes on flowing at a uniform rate. Any impression of a variation in the rate of time is treated as misperception. Wherever and whenever you are, however you are moving, whatever you are doing, time just marches on reliably at the same pace for everybody, unerringly marking out the successive moments of reality throughout the cosmos.Among other things, Newton's concept of time invites us to chop it up into past, present and future in an absolute and universal manner. Because the whole universe shares a common time and a common "now," then every observer everywhere, including any little green men on Mars or beyond, would concur with what is deemed to have passed, and what is yet to be. This tidy image of time as defining a succession of universal present moments has important implications for the nature of reality, for in the Newtonian world view only that which happens now can be said to be truly real. This is indeed how many nonscientists unquestioningly perceive reality. The future is regarded as "not yet in existence," and perhaps not even decided, while the past has slipped away into a shadowy state of half-reality, possibly remembered but forever lost. "Act, act in the living present!" wrote Longfellow, for it is only the physical state of the world now that seems to be concretely real.But this simple view of time as rigid and absolute -- powerful and commonsensical though it

may be -- is fundamentally flawed. Around the turn of the twentieth century, the Newtonian concept of universal time began yielding absurd or paradoxical conclusions concerning the behavior of light signals and the motion of material bodies. Within a few short years, the Newtonian world view had spectacularly collapsed, taking with it the commonsense notion of time. This profound and far-reaching transformation was primarily due to the work of Einstein.Einstein's theory of relativity introduced into physics a notion of time that is intrinsically flexible. Although it did not quite restore the ancient mystical ideas of time as essentially personal and subjective, it did tie the experience of time firmly to the individual observer. No longer could one talk of the time -- only my time and your time, depending on how we are moving. To use the catch phrase: time is relative.Although Einstein's time remained subject to the strictures of physical law and mathematical regulation, the psychological effect of abolishing a universal time was dramatic. In the decades that followed Einstein's original work, scientists probed deeper and deeper into time's mysteries. Might different sorts of clocks measure different sorts of time? Is there a natural clock, or a measure of time, for the universe as a whole? Was there a beginning of time, and will there be an end? What is it that imprints on time a distinct directionality, a lopsidedness between past and future? What is the origin of our sense of the flux of time? Is time travel possible, and if so, how can the paradoxes associated with travel into the past be resolved? Remarkably, in spite of nearly a century of investigation, many of these questions have yet to be satisfactorily answered: the revolution started by Einstein remains unfinished. We still await a complete understanding of the nature of time.IS THE UNIVERSE DYING?And so some day,The mighty ramparts of the mighty universeRinged round with hostile force,Will yield and face decay and come crumbling to ruin.LucretiusIt is impossible to separate scientific images of time from the cultural background that pervaded Europe during the Renaissance and the modern scientific era. European culture has been strongly influenced by Greek philosophy and the religious systems of Judaism, Islam and Christianity. The Greek legacy was the assumption that the world is ordered and rational, and can be understood through human reasoning: if so, then the nature of time can, in principle, be grasped by mortals. From Judaism came the Western concept of time so central to the scientific world view. In contrast to the pervasive notion of time as cyclic, the Jews came to believe in linear time. A central tenet of the Jewish faith, subsequently inherited by both Christianity and Islam, was that of the historical process, whereby God's plan for the universe unfolds according to a definite temporal sequence. In this system of belief, the universe was created by God at a definite moment in the past, in a very different state from the one that exists today. The theological succession of events -- creation, fall, redemption, judgment, resurrection -- is paralleled by a divinely directed sequence of physical events -- order out of primeval chaos, origin of the Earth, origin of life, origin of mankind, destruction and decay.The concept of linear time carries with it the implication of an arrow of time, pointing from past to future and indicating the directionality of sequences of events. The origin of time's arrow as a physical principle is still a curiously contentious scientific mystery, to which I shall return in Chapter 9. Scientists and philosophers have been sharply divided over the significance of the arrow of time. The conundrum, put crudely, boils down to this: is the universe getting better or worse? The Bible tells the story of a world that starts in a state of perfection -- the Garden of Eden -- and degenerates as a result of man's sin. However, a basic component of Judaism, Christianity and Islam is a message of hope, of belief in personal betterment and the eventual salvation of mankind.In the middle of the nineteenth century, physicists discovered the laws of thermodynamics, and it was soon realized that these implied a universal principle of degeneration. The so-called second law of thermodynamics is often phrased by saying that every closed system tends towards a state of total disorder or chaos. In daily life we encounter the second law in many familiar contexts, well captured by familiar sayings: It's easier to break it than make it; There's no such thing as a free lunch; Sod's Law, Parkinson's Law, etc. When applied to the universe as a whole, the second law implies that the entire cosmos is stuck fast on a one-way slide towards a final condition of total degeneration -- i.e., maximum disorder -- which is identified with the state of thermodynamic equilibrium.One measure of the remorseless rise of chaos uses a quantity called "entropy," which is defined to be, roughly speaking, the degree of disorder in a system. The second law then states that in a closed system the total entropy can never decrease; at best it remains the same. Almost all natural changes tend to increase the entropy, and we see the second law at work all around us in nature. One of the most conspicuous examples is in the way that the sun slowly burns up its nuclear fuel, spewing heat and light irretrievably into the depths of space, and raising the entropy of the cosmos with each liberated photon. Eventually the sun will run out of fuel and cease to shine. The same slow degeneration afflicts all the stars in the universe. In the mid-nineteenth century, this dismal fate came to be known as the "cosmic heat death."

The thermodynamic "running down" of the cosmos represented a significant break with the concept of the Newtonian clockwork universe. Instead of regarding the universe as a perfect machine, physicists now saw it as a gigantic heat engine slowly running out of fuel. Perpetual-motion machines were found to be unrealistic idealizations, and the alarming conclusion was drawn that the universe is slowly dying. Science had discovered pessimistic time, and a new generation of atheistic philosophers, led by Bertrand Russell, wallowed in the depressing inevitability of cosmic doom.The second law of thermodynamics introduces an arrow of time into the world because the rise of entropy seems to be an irreversible, "downhill" process. By an odd coincidence, just as the bad news about the dying universe was sinking in among physicists, Charles Darwin published his famous book On the Origin of Species. Although the theory of evolution shocked people far more than the prediction of a cosmic heat death, the central message of Darwin's book was basically optimistic. Biological evolution also introduces an arrow of time into nature, but it points in the opposite direction to that of the second law of thermodynamics -- evolution seems to be an "uphill" process. Life on Earth began in the form of primitive micro-organisms; over time, it has advanced to produce a biosphere of staggering organizational complexity, with millions of intricately structured organisms superbly adapted to their ecological niches. Whereas thermodynamics predicts degeneration and chaos, biological processes tend to be progressive, producing order out of chaos. Here was optimistic time, popping up in science just as pessimistic time was about to sow its seeds of despair.Darwin himself clearly believed that there is an innate drive in nature towards improvement. "As natural selection works solely by and for the good of each being, all corporeal and mental endowments will tend to progress towards perfection," he wrote. Biologists began to speak about a "ladder of progress," with microbes at the bottom and man at the top. So, although the theory of evolution rejected the idea that God had carefully designed and created each species separately, it left room for a designer God to act in a more subtle way, by directing or guiding the course of evolution over billions of years upwards towards man and maybe beyond.This progressive philosophy was enthusiastically embraced by several leading European thinkers, such as Henri Bergson, Herbert Spencer, Friedrich Engels, Teilhard de Chardin and Alfred North Whitehead. All saw evidence in the universe as a whole, not just in the Earth's biosphere, of an intrinsic ability for nature to produce order out of chaos. The linear time of these philosophers and scientists was one of faltering, yet ultimately assured, advancement.Unfortunately, progress in nature did not mesh well with either blind thermodynamic chaos, or the purposeless chaos that supposedly underlies Darwinian evolution. Tension between the concept of a progressive biosphere on the one hand and a universe destined for a heat death on the other produced some confused responses. Some biologists, especially in France, downplayed Darwin's central thesis of random mutations in favor of a mysterious quality called lan vital, or life force, responsible for driving organisms in the direction of progress, against the chaotic tendencies of inanimate processes. Belief in such a life force persists in certain nonscientific circles even today. Some philosophers and scientists, worried about the overall fate of the universe, asserted that the second law of thermodynamics could be circumvented under certain circumstances, or should not be applied to the universe as a whole.The argument still rages. Biologists have long since abandoned the life force, and many argue strenuously that any impression of progress in biological evolution is simply the result of wishful thinking and cultural conditioning. The path of evolutionary change, they claim, is essentially random -- "chance caught on the wing," to use Jacques Monod's evocative phrase. Other scientists, many of whom have been influenced by the work of Ilya Prigogine, acknowledge the existence of self-organizing processes in nature, and maintain that advancement towards greater organizational complexity is a universal lawlike tendency. Spontaneous self-organization need not conflict with the second law of thermodynamics: such processes always generate entropy as a by-product, so there is a price to be paid to achieve order out of chaos. As far as the ultimate fate of the universe is concerned, which of these counterdirected tendencies -- advancing complexity or rising entropy -- will win in the end depends crucially on the cosmological model adopted. Those readers with an interest in these eschatological matters may like to read my book The Last Three Minutes.THE RETURN OF THE ETERNAL RETURNHistory always repeats itself.ProverbEven as the optimists and pessimists squabbled at the turn of the century about which way the cosmic arrow of time was pointing, the concept of cyclicity made an astonishing entrance into Western science. Physicists were struggling to understand the origin of the laws of thermodynamics in terms of the atomic theory of matter. The most basic thermodynamic process is the flow of heat from hot to cold, a one-way process that epitomizes the second law. In Vienna, Ludwig Boltzmann set out to discover a way of explaining this flow mathematically in terms of molecular motion. He envisaged a vast assemblage of microscopic molecules confined inside a rigid box, rushing about

chaotically, colliding with each other and bouncing off the walls of the box.Boltzmann intended his model to represent a gas. He realized that the random motions of molecules would tend to break up any order, and serve to mix the population of particles very efficiently. For example, the temperature of the gas is determined by the average speed of the molecules, so if at some moment the gas were hotter in a certain region the molecules there would on average move faster than the rest. But this state of affairs would not last for long. Soon the high-speed molecules would collide with the slower-moving particles around them and give up some of their kinetic energy. The excess energy of the molecules from the hot region would diffuse through the entire population until a uniform temperature was reached and the average molecular speed in each region became the same throughout the gas.Boltzmann backed this plausible physical picture with a detailed calculation in which he applied Newton's laws of motion to the molecules and then used statistical techniques to deduce the collective behavior of large numbers of molecules. He discovered a quantity, defined in terms of the motions of the molecules, that provided a measure of the degree of chaos in the gas. This quantity, Boltzmann proved, always increases in magnitude as a result of the molecular collisions, suggesting it be identified with thermodynamic entropy. If so, Boltzmann's calculation amounted to a derivation of the second law of thermodynamics from Newton's laws.Shortly after this triumph, a huge hole was knocked in Boltzmann's argument by the French mathematical physicist Henri Poincar, who rigorously proved that a finite collection of particles confined to a box and subject to Newton's laws of motion must always return to its initial state (or at least very close thereto) after a sufficiently long period of time. The state of the gas therefore undergoes "recurrences." Poincar's theorem carries the obvious implication that if the entropy of the gas goes up at some stage then it eventually has to come down again so the gas can return to its initial state. Whatever set of molecular motions may increase the entropy, or chaos, of the gas, there must be another set that decreases it. In other words, the behavior of the gas over a long time scale is cyclic. This cyclicity in the state of the gas can be traced to the underlying time symmetry in Newton's laws, which do not distinguish past from future.The length of Poincar's cycles are truly enormous -- roughly 10N seconds, where N is the number of molecules (about a trillion trillion in 40 liters of air). The age of the universe is a mere 1017 seconds, so the duration of the cycles is huge, even for a handful of molecules. In the case of a macroscopic system, the length of the Poincar cycles dwarfs all other known time scales. Nevertheless, the cycles are finite in duration, so the possibility of an entropy decrease at some stage in the very far future cannot be denied. Boltzmann's conclusion that entropy can rise only as a result of molecular collisions was therefore shown to be wrong. It was soon to be replaced by a less clear-cut, statistical claim: that the entropy of the gas will very probably rise. Decreases in entropy are possible, as a result of statistical fluctuations. However, the chances of an entropy-decreasing fluctuation fall off very sharply with the size of the fluctuation, implying that large decreases in entropy are exceedingly improbable -- but still technically possible. Boltzmann himself went on to suggest that maybe the universe as a whole undergoes Poincar cycles of immense duration, and that the present relatively ordered state of the universe came about as a result of a fantastically rare decrease in entropy. For almost all the time, the state of the universe would be very close to equilibrium -- i.e., the heat-death state. What these ideas suggested is that cosmic heat death was not forever, and resurrection was possible, given long enough.With the discovery of Poincar's recurrences, the concept of the eternal return became part of scientific discourse, but in a rather different guise from the folklore version. First, the world takes unimaginably long to return to its present state. Second, the cyclicity involved is not an exact periodicity but merely a statistical recurrence. The situation can be envisaged in terms of card shuffling. If a pack of cards arranged in suit and numerical order is shuffled, then it will almost certainly be in a less ordered state after the shuffling process. However, because the pack has only a finite number of states, continued random shuffling must cause any given state to appear and reappear, infinitely often. Simply by chance, the original suit and numerical order will eventually be restored. The state of the cards can be regarded as analogous to the states of the gas, and the shuffling process plays the role of chaotic molecular collisions.The foregoing argument was seized upon by the German philosopher Friedrich Nietzsche, who concluded that cosmic recurrences robbed human life of any ultimate purpose. The senselessness of endless cycles rendered the universe absurd, he opined. His despairing philosophy of "nihilism" rubbished the concept of progress, whether human or cosmic. Clearly, if the universe is one day to return to its initial state, all progress must eventually be reversed. This conclusion provoked Nietzsche's most famous aphorism: "God is dead!"THE START OF IT ALLEinstein was fully aware of the conflicting ideas concerning the arrow of time. Indeed, in the very year he formulated his theory of relativity, he also made a major contribution to the statistical mechanics of molecular motions. Yet,

despite this awareness, his first attempt to construct a model of the universe was based on the assumption that it was static and unchanging. In this he was not alone. Most nineteenth-century astronomers believed that the universe remained on average much the same from epoch to epoch. The belief in a stable, eternal cosmos in which degenerative processes are continuously balanced by regeneration dates from the time of ancient Greece. Such models survive to the present day, in the guise of the so-called steady-state theory and its variants.Cosmologies can thus be divided into four classes. First is the orthodox scientific model of a universe that comes into existence at a finite time in the past and slowly degenerates towards a heat death. Second is a universe that has a definite origin but progresses in spite of the second law of thermodynamics. Third is the cyclic universe with no overall beginning or end, involving either strict repetition or statistical recurrences. Finally there is the static or steady-state universe, in which local processes may be degenerative or progressive but the universe as a whole remains more or less the same forever.There is no doubt that the widespread acceptance of the first of these cosmological models owes much to Western culture and centuries of entrenched belief in a created universe. This belief brought with it the notion of a universal time -- God's time -- from which it followed that there must be a definite date for the creation. Attempts to deduce the date from an examination of the Bible inevitably gave an answer of a few thousand years B.C. In Renaissance Europe such a figure was not unreasonable. Little was known about geological processes or biological change, still less about the true astronomical arrangement of the universe. It was possible to believe that the universe was just a few millennia old. When the geologists of the nineteenth century pointed to fossils as evidence of Earth's vast age, some churchmen replied that these images were deliberately created by the devil to confuse us. There are religious zealots to this day who declare that we cannot trust our clocks or our senses. They firmly believe the universe was created by God just a few thousand years ago, and merely looks old.Might they be right? Can we be certain the universe really is old? Consider this. The star Sanduleak 69 202 blew up 160,000 years ago, Earth time. Nobody knew this until a technical assistant working at Las Campa~as Observatory in Chile saw it happen on the night of 23-24 February 1987. The explosion was clearly visible to the unaided eye in the dark night sky. The news took so long to reach us because Sanduleak 69 202 lies about 1 1/2 billion billion kilometers away, in the nearby mini-galaxy known as the Large Magellanic Cloud, and the light from the explosion travels at a finite speed.If the universe was created a few thousand years ago, it must have been made with Sanduleak 69 202 already in an exploded condition -- a star created dead. But that would not be all. In the space between the stricken star and Earth lies a light beam, stretching back from our eyes continuously to the star. And down that beam, marching inexorably towards us, is the record of events which befell the star. Imagine that beam, 160,000 light-years long, on the day of creation. The starbeam, which must have been brought into being intact along with everything else, carries, for the greater part of its length, the image of a dead star, blown to bits, debris flying. But for a short distance near Earth, along a segment just a few thousand light-years long, the beam encodes a curious fiction -- images of a living star that never was. The whole contrivance is made simply to look as if there was once a living star, whereas in fact God created a dead star.But how do we know that this bizarre and contrived act of creation happened as long ago as a few thousand years? If God can create a young universe looking old, how can we be sure he did not create it, say, two thousand years ago, perhaps to coincide with the birth of Jesus? This would have meant creating some human records, such as the Old Testament, as well as fossil records such as dinosaurs, and stellar records such as the curiously fixed-up light beam from Sanduleak 69 202. But so what? A Being who can make dead stars can surely fake a few manuscripts. In fact, how can we be sure that the universe wasn't created a hundred years ago, with everything arranged to appear as if it were much older? Or, for that matter, perhaps the world started five minutes ago, and we were all made with consistent memories of our earlier activities already in our brains. (Even more interesting would be if our memories varied a bit, to inflame controversies like the number of gunmen who assassinated President Kennedy.)IT HAPPENS WHEN IT HAPPENSTime is just one damn thing after another.AnonymousWhen I was a child, I often used to lie awake at night, in fearful anticipation of some unpleasant event the following day, such as a visit to the dentist, and wish I could press some sort of button that would have the effect of instantly transporting me twenty-four hours into the future. The following night, I would wonder whether that magic button was in fact real, and that the trick had indeed worked. After all, it was twenty-four hours later, and though I could remember the visit to the dentist, it was, at that time, only a memory of an experience, not an experience.Another button would also send me backwards in time, of course. This button would restore my brain state and memory to what they were at that earlier date. One press, and I could be back at my early childhood, experiencing once again, for the first

time, my fourth birthday....With these buttons, gone would be the orderly procession of events that apparently constitutes my life. I could simply jump hither and thither at random, back and forth in time, rapidly moving on from any unpleasant episodes, frequently repeating the good times, always avoiding death, of course, and continuing ad infinitum. I would have no subjective impression of randomness, because at each stage the state of my brain would encode a consistent sequence of events.It is but a small step from this wild fantasy to the suspicion that maybe someone else -- a demon or fundamentalist-style deity perhaps -- is pressing those buttons in my behalf, and I, poor fool, am totally oblivious to the trickery. On the other hand, so long as the mysterious button-pusher keeps at it, it seems as if I will enjoy some sort of immortality, though one restricted to a fixed set of events. Still, perhaps this is better than mortality? "In eternity there is nothing past and nothing future, but only present," wrote Philo Judaeus. But that was in the first century. We have to be cautious; times have changed since then.The striking thing about the above "thought experiments" is, how would my life seem any different if this button-pushing business really was going on? What does it even mean to say that I am experiencing my life in a jumpy, random sort of manner? Each instant of my experience is that experience, whatever its temporal relation to other experiences. So long as the memories are consistent, what meaning can be attached to the claim that my life happens in a jumbled sequence? In his novel October the First Is Too Late, the British astronomer and science fiction writer Fred Hoyle also imagined some sort of cosmic button-pusher, but one who fouled things up and got different bits of the world out of temporal kilter. People crossed "time zones" and were bewildered to encounter communities living at different historical periods. Hoyle's fictional scientist caught up in this nightmare has no truck with the notion of time as "an ever-rolling stream," dismissing it as "a grotesque and absurd illusion." He says: "If there's one thing we can be sure enough of in physics it is that all times exist with equal reality." We are invited to think about events in the universe in terms of an unusual metaphor: a series of numbered pigeonholes containing messages about neighboring pigeonholes. The messages accurately describe the contents of the holes with smaller numbers ("the past"), but are vague about those with bigger numbers ("the future"). This mimics causality and the asymmetry between our secure knowledge of the past and woolly predictions of the future. But there is no "flow" of time. Instead there is a metaphorical clerk who inspects the pigeonholes one by one. Each act of inspection creates a moment of consciousness in the world: "As soon as a particular state is chosen, as soon as an imaginary office worker takes a look at the contents of a particular pigeon hole, you have the subjective consciousness of a particular moment, of what you call the present," explains the scientist.The curious feature of this imagery is that the clerk doesn't need to sample the pigeonholes in numerical sequence. He could capriciously hop about all over the place, even at random, and we wouldn't notice; we would all still have the impression of time as a continuous, ever-rolling stream. Each clerk-activated moment of human consciousness involves a memory-experience of the "pigeonhole contents" further down the numerical sequence, even if the clerk hadn't inspected those pigeonholes for a while. Furthermore, there is nothing to stop the clerk from resampling the same pigeonhole a million times. From the subjective standpoint of the consciousness attached to that pigeonhole, the world appears the same on each go. "It doesn't matter what order you take the pigeonholes," says the scientist, "it doesn't matter if you choose some or all of them a million times, you'd never know anything different from the simple sequential order."It gets worse. The scientist envisages two rows of pigeonholes. One is for you (i.e., the pigeonholes contain events pertaining to your consciousness), the other me. The clerk gets replaced at this stage in Hoyle's narrative by a less anthropomorphic moving spot of light. "Our consciousness corresponds to just where the light falls, as it dances among the pigeon holes," we are told. But the light does not have to sample (i.e., spotlight) pairs of pigeonholes, one from each row, simultaneously. It could flit back and forth between the rows. There would really be only one consciousness, but two rows of pigeonholes, so the activated consciousness in one row would feel different -- and regard itself as a different person -- from that in the other row. By extension, all conscious beings in the universe, human, animal and alien, could actually be the same consciousness, but activated in different contexts at different times. Even if the process was totally random, it would create the impression of an orderly sequence of events being experienced by myriads of distinct minds.Back in the real world, Pope Gregory XIII pushed a metaphorical button (i.e., issued a decree) in 1582 and the date jumped from 4 October to 15 October overnight. At least it did in Catholic countries. Protestants were suspicious of this Roman sleight-of-hand. Might they be robbed of ten days of their lives? Some confused folk couldn't distinguish dates from times. Britain and America did not adopt the Gregorian calendar until the eighteenth century; the Russians held out, astonishingly, until 1917. The Pope's adjustment was needed because the Earth does not obligingly

circle the sun in an exact number of days; hence the need for leap years. The old Roman calendar did not take accurate enough account of leap years, and the Easter Festival was getting warmer and warmer as the calendar year gradually slid out of synchrony with the seasons. Pope Gregory decreed that century years should not be leap years unless divisible by 400. This rule fixes things up for 3,300 years. More recent refinements to the rule have put us right for another 44,000 years. Rumor has it, though, that the inhabitants of an island in the Outer Hebrides still have no intention of adopting the newfangled Gregorian calendar.I shall sidestep the issue of psychological pigeonhole time for the moment, and deal with physical, measurable time as if it is real. For that is the founding assumption of science -- that there is a real world out there that we can make sense of. And that world includes time. Given a rational universe, we can seek answers to rational questions about time, such as the source of the arrow of time, and the date on which the universe began, if indeed it had a beginning. However, the rational clockwork cosmology of Newton, and the dying thermodynamic cosmology that came after it, were based on a highly simplistic view of time. Though adequate for two hundred years, Newton's conception of time was fundamentally flawed. It took someone of the genius of Albert Einstein to expose its defects.Revue de presseLos Angeles Times Elegantly written and comprehensible, full of wonder and lucid explanation.Frederic Golden San Francisco Chronicle A stimulating -- indeed, timely -- read.Michio Kaku author of Hyperspace: A Scientific Odyssey Through Parallel Universes, Time Warps, and the 10th Dimension It's about time someone wrote the definitive history of time...I can think of no one better than Paul Davies...Einstein himself would have been pleased.Will St. John Detroit Free Press The fun here is in the journey and Davies is an entertaining guide.