Appendix A
Old Friends Across Time (A Story)[1]

As I sit here in my study, with the photographic evidence spread before me, I can barely comprehend what my eyes tell me must be so. The evidence is incontestable. And yet—I still struggle to believe. Let me try to explain—possibly in the process I will manage to put my tumbling mind to rest.

For as long as I can recall, old photographs have fascinated me. To page slowly through collections of historical pictures, no matter what the theme, was consummate joy. Even when I was quite a small boy I used them as my time machine into the past. They took me up and away from the problems every youngster has while growing up, and let me wonder of people and places long since returned to dust. Matthew Brady's Civil War photos had a particularly strong attraction for me, with the horror (and yes, I will admit it, the *fascination*) of war frozen in the images of young men dead before life had really begun. To look at the fallen youth of more than a century before, and to wonder who they were, and what they had felt and thought—it all sent shivers through my romantic mind.

I suppose I might have become a professional photographer. But somewhere along in the process of looking at pictures, I became aware of the miracle of the *technology* of picture taking. That led me to chemistry and optics, and finally by some wondrous route, I became an electrical engineer. I never lost my love for old pictures, though, but merely turned my interest in them to the photographic history of electrical physics.

To search out and acquire (for by now I had started my own collection) a photograph of Steinmetz, smoldering cigar clamped in his mouth, giving a lecture on AC circuit analysis using the then still mysterious square root of minus one made my heart beat faster. To find a faded picture of Einstein at a long forgotten

[1]P. J. Nahin, "Old Friends Across Time," *Analog Science Fiction Magazine*, May 1979. This tale was written with the specific goal of illustrating how a trip into the past *yet to be initiated* could logically influence events in the time traveler's present and future. The story reproduced here is, with only a few very minor alterations, as it originally appeared in *Analog*.

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conference, caught forever in time with his quiet, gentle eyes looking into mine, would send me to the heights of ecstasy.[2]

But it was Maxwell that led me to my incredible discovery. There is no doubt but that James Maxwell was the greatest theoretical physicist of the nineteenth century. Together with Einstein, he was the best of *any* century. Could it possibly be more than mere chance that the same year saw the death of one and the birth of the other? It was Maxwell who gathered together all the then known, but fragmented, experimental bits and pieces of knowledge about electricity and magnetism, and stirred in his own contribution of the displacement current. There was no physical evidence then to justify that last step, but the genius of Maxwell knew it *had* to be. And then, from his soaring mathematical insight and physical intuition, he took it all and wrote down the four magnificent equations for the electromagnetic field![3]

No one who has seen and understood those beautiful equations can come away without a quickening of the pulse and a flush of the blood. They're not long—you can write all four vector differential equations on the back of a postcard, but oh, what they tell us! With them, Maxwell, showed light was electrical in nature, predicted radio waves *two decades* before Hertz discovered them in the lab, explained energy propagation in space, and radiation pressure, and laid the scientific basis for today's television, radar, lasers, giant electric motors, generators, transmission lines and—well, why go on? The equations are the work of a level of genius we may not see again for a millennium. We have hardly begun to discover the marvels wrapped inside the electromagnetic field equations. With their aid, and that of quantum mechanics, the very secret of life, itself, may someday be unraveled.

And so I searched for old photographs of Maxwell. He died at his family's Scottish home in 1879, before the art of picture taking was barely 40 years old. But I knew in my heart that somewhere there *must* be photographs, yet undiscovered, of such a great man. Anyone who has seen the best examples of prints from wet glass collodion negatives knows they are, in the faithfulness of their rendition of detail, better than what we commonly expect today. Working against me was the fact that the process was slow, laborious, and unforgiving of mistakes. The taking of a picture was not a minor decision in Maxwell's time. But still I searched.

I searched for one photo, in particular. When Einstein died, a famous picture was taken of his office, just the way he left it for the last time. On the blackboard behind his desk are the last thoughts he had in his long quest for a Unified Field Theory,

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[2]The first reference is to Charles Steinmetz (1865–1923), the German-born American electrical engineer and mathematician who became the wunderkind of General Electric. Einstein, of course, needs no introduction!

[3]I wrote this for story effect, but it's not really *quite* true. When Maxwell wrote his theory in mathematical form, he did so using *twenty* (!) equations in as many variables. The equations, as physicists and electrical engineers use them today, were first written in 1885 by the English self-taught eccentric Oliver Heaviside, who considered Maxwell to be his hero (see note 6 in Chap. 6). Modern electrical engineers and physicists write the Maxwell equations as *four* partial differential *vector* equations.

a ‘theory of everything.’ The writing on the papers covering the desk is clearly legible, and with modern blowup methods, easily readable.

At the time of his death, Maxwell was the Einstein of his times. Surely, I reasoned, a similar photograph of Maxwell’s study must have been taken. Even though none has come down through the decades to us, it *must* exist! Gathering dust in an old trunk, or buried in a long forgotten album, it had to be somewhere. I vowed to find it.

I began by writing to all of Maxwell’s living descendants, asking that they search through family holdings for any pictures concerning Maxwell that they might possess. For the most part all were cooperative, even though more than just a few thought I was somewhat deranged. Still, it was in vain. I did receive a few old pictures never before seen by other than the family, including a poignant one taken in 1901, showing Maxwell’s grave in Parton Churchyard at Glenlair, Scotland. A forlorn, wintry scene, with only what seemed to be three men in the far distance, it brought tears to my eyes. Alas, there were no photos of Maxwell’s study.

But then late last year, while on a business trip to London, I stopped off for a few hours at the historical archives maintained by the British Institute of Electrical Engineers. On a chance, I looked through their massive files on Maxwell and was rewarded within the hour! What I found will haunt me throughout the remainder of my life.

There it was, stuck through its border with a rusty pin, between two pieces of yellowed paper covered with what appeared to be some simple, rough lecture notes. An ordinary looking photo of a study. Obviously overlooked through the years, or at best unappreciated for what it was, it was the almost illegible, penciled notation on the back that convinced me of my find—just a date: November 9, 1879. Exactly 4 days after Maxwell’s death, precisely when some unknown, yet inspired person (a family member, a neighbor, a local scientist?) would take such a picture!

I am ashamed to admit it, but there was no hope the Institute would let me have the picture. And there was no time to copy it, for I was to return home to America that very night. No, that’s not true. The *real* reason for what I did was simply that I *had* to have that original, *old* photo. I took it! It was my undoing, for that dishonorable act destroyed the picture’s tie to verified, legitimate historical records. But *I* know what I found is true.

I could barely control my wild emotions on the flight home. Several times I removed the picture from my briefcase, and looked with fascination at the papers lying on Maxwell’s desk, and at the tightly written lines of mathematics on the blackboard in the background. My hands trembled with what can only be called lust—once home, reunited with my well-equipped photo lab, I would learn every secret hidden in that picture.

There are no words I know that can convey the thrill I felt as I began the processing of that priceless photo. Alone in my lab, with all the modern equipment a well-off amateur can buy (a Caesar Saltzman 8×10 enlarger with mercury vapor point light source and a $10\times$ Plan Achromat Nikon enlarging lens), I carefully cropped and blew up selected views of the blackboard and desk. Printing the enlargements on ultra-fine grain AGFA Brovira paper, I could scarcely restrain myself from peering at them with a magnifying glass while I waited for them to dry.

Then, at last, I had them spread out across my study desk. I tried to force myself to examine each slowly, carefully, in turn, and not to skip from one to another like a child let loose in a candy store with a dollar. The first three were of the desk papers, including what seemed to be a diary. It must have been lost after Maxwell's death since no trace of it exists in the historical records. I experienced a stunning thrill as I gazed upon the scrawled words, but as they were not easily read at once, I moved on. It was the sixth enlargement, of the upper right corner of the blackboard that sent me reeling back to my chair. An equation that shouldn't, no, *couldn't*, be there. But it was.

To understand my reaction, there is one astounding thing you must realize about Maxwell's field equations. When Einstein turned the world of physics on its head in 1905 with his famous paper, "On the Electrodynamics of Moving Bodies," all the old ideas about absolute motion and simultaneity of events went out the window. Even Newton's laws of mechanics had to be modified. But *not* Maxwell's! His equations, just the way he published them in 1873, are the same ones studied today[4]—they need *no* relativistic corrections.

How can that be, you wonder, as they predate Einstein's by 32 years? The mystery of this has bedeviled the experts down through the years. Oh, they have an explanation, alright. They say that all of electromagnetics is actually relativistic phenomena to begin with, and the laboratory work of Faraday, Ampere, Henry, and the other great experimentalists were studies of relativistic electron interactions in matter (although they, of course, didn't know that). Thus, it is only 'natural' that Maxwell's equations need no correction. So goes the 'expert' explanation, but it isn't right![5] I know Maxwell knew about relativity, and understood it perfectly. He knew all about time paradoxes and the equivalence of mass and energy.

Because how else can you explain the equation visible in my enlargement: $E = mc^2$!

Why, you must wonder (just as I did), didn't Maxwell publish this remarkable result? At first, I believed it was because of a lack of faith in his results. Who would have believed any of it in those Victorian times, so sure of its absolute view of nature? I thought of how Newton, 200 years before Maxwell, had suffered from a similar hesitancy when he wrote the *Principia*. There, when explaining his theory of gravitation, Newton did *not* employ his new invention of the calculus (which he *had used* to make his discoveries), but instead fell back on laborious arguments based on the accepted mathematics of algebra and geometry. Who would have believed him, otherwise?

But then I realized that couldn't be right. Maxwell was a strong man intellectually and he wouldn't have held back for fear of disbelief. No, it had to be that he

[4]Don't forget note 3.

[5]Alas, I think it *is* right. Don't forget, this is science *fiction*. When there is a conflict between the needs of a story, and a rigid adherence to physics, the 'needs' wins!

discovered relativity and the mass-energy law just before his death, with no time to make his work known. I was still wrong.

It was later, when I returned to the enlargement of Maxwell's lost diary and read those painfully cramped notes, that I learned the truth. What I saw there showed me Maxwell had thought long and hard about his final discoveries and had purposely withheld them. For clearly visible, after I had slowly deciphered the writing, were the following words:

> *I have seen monstrous events. My blood has run cold at the sight of two great cities leveled to the ground, their inhabitants cruelly put to death instantly, or left to die slowly from a strange, lingering disease. Other trips, further on, have shown me the root of all these evils is the mass-energy equation, a result I at first believed to be my crowning glory. It will be my crown of thorns unless I ban it from my very being. Another will discover it for himself, but* my *soul shall be free! I have dismantled my machine, and shall never look upon or think of those horrible scenes again.*

This passage was dated just 1 month before Maxwell died a savage death from cancer. The reference to 'two cities' can only be that of Hiroshima and Nagasaki. His own death was surely caused by lingering too long among their atomic ruins.

Think of what this *means*. Quite simply, Maxwell knew the secret of time travel! But even more incredible is that it must be *easy*, if one only knows how, to build a time machine! Think about it—Maxwell had no gigawatt power stations at his disposal, no high technology machine shops, or nanosecond computers. He was not a gifted experimentalist, and once he had predicted radio waves, for example, it took others 20 years to finally generate them. And yet, *he* built a time machine. Somehow, with just the puny power sources available to him, and a limited mechanical capability, he wrested free the *simple* implementation of a time machine from his dynamical field equations.

Yes, yes, I know what you must be thinking. How can I really conclude such an incredible thing from a single equation on a blackboard, and a few words written by a man dying a painful death? A man, clearly suffering dearly, and possibly not in complete possession of his once marvelous mind.

This very evening the last bolt of evidence slid into place. Attempting to escape from the emotional maelstrom into which I had fallen, I turned to my old love of picture gazing. I took down from my library shelf a tattered yet cherished volume of the Meserve Collection of Lincoln pictures. My slow paging through the images stopped when I came to the famous photograph by Alexander Gardner of Lincoln's second inauguration. This incredible picture shows John Wilkes Booth looking down on Lincoln from behind a buttress high on the steps of the Capitol, while below in the crowd are the five men who, 41 days later, conspired with him in the assassination.

The following page demonstrated the extraordinary quality of Gardner's work, as it showed an enlargement of Booth's face in which the circular line between the pupil and the white of each eye is sharp and crisp! This impressive picture fascinated me, and I wondered if I could create a similar enlargement. It was then I remembered the old picture of Maxwell's grave, sent to me from Scotland, and the three distant figures in the background. They would present my photo-lab skills with a challenge, and the effort would distract my mind.

I finished the enlargement just 20 min ago. Those faces! Two of them I can now finally accept as being there—it must have been a pilgrimage for one, and for the other, it couldn't have been anything but a mocking, ironic gesture. But I wonder if the youngest one really knew who his two companions were? I don't know the answer to that—yet. But there they are, two men with faces my years of study have made as familiar to me as my own. One is a youthful Albert Einstein. The other, with the signs of death clearly written across his features, is James Clerk Maxwell. The face of the third man is familiar, too, for the third man is me!

Oh, I'm a bit older in the photo than I am now. But it's me, alright. A distinctive, jagged scar across the left cheek, a mark from a childhood accident, is sharply visible, and I can run a finger over my face and match it perfectly with the image in the enlargement. I'd say I'm about 45 or so in the image, no more than 10 years older than I am now. That doesn't leave me much time to keep my appointment, does it? I don't know, right now, how I'm going to do it, but I've got to rediscover Maxwell's secret of time travel. I'm sure I'll succeed—after all, there I am in the picture. Somehow, I'll be going back to pick James and Albert up so we can have our picture taken. Ten years—not much time.

I'm really looking forward to meeting my two new friends from across time.

For Further Discussion

When "Old Friends Across Time" originally appeared in *Analog*, it opened with a quotation from Richard Feynman's famous 1961–1963 Caltech undergraduate course (published in 1964 as *The Feynman Lectures on Physics*): "Ten thousand years from now, there can be little doubt that the most significant event of the nineteenth century will be judged as Maxwell's discovery of the laws of electrodynamics. The American Civil War will pale into provincial insignificance in comparison." This is almost certainly true, but could Maxwell *really* have built a time machine from just a knowledge of electromagnetic theory and special relativity (which is all that is needed to derive $E = mc^2$), if he didn't also have a deep understanding of general relativity (and probably of quantum mechanics, too)? How likely do you think *that* is?

The narrator in “Old Friends Across Time” knows he is going to live long enough to eventually build a time machine; discuss the implications of this knowledge. For example, is he at least *temporarily* invulnerable to committing suicide (or, for that matter, to any other variation of dying?) That is, do we have a ‘future’ version of the grandfather paradox? This issue has never (to my knowledge) been considered by physicists, and not by philosophers either until recently. See, for example, S. Keller and M. Nelson, “Presentists Should Believe in Time-Travel,” *Australasian Journal of Philosophy*, September 2001, pp. 333–345, and M. H. Slater, “The Necessity of Time Travel (On Pain of Indeterminacy),” *The Monist*, July 2005, pp. 362–369. More generally, if we assume that the past is unchangeable then the scenario in “Old Friends Across Time” seems to force at least some level of inevitability on the future as well. Or does it? In the 2007 story by Ted Chiang, “The Merchant and the Alchemist’s Gate,” that you were asked to read in a *For Further Discussion* at the end of Chap. 4, there is the following exchange between the narrator and the inventor of “the Gate” (a wormhole): “So if you learn that you are dead 20 years from now, there is nothing you can do to avoid your death?” He nodded. This seemed to me very disheartening, but then I wondered if it could not also provide a guarantee. I said, “Suppose you learn that you are alive 20 years from now. Then nothing could kill you in the next 20 years. You could then fight in battles without a care, because your survival is assured.” “That is possible,” he said. “It is also possible that a man who would make use of such a guarantee would not find his older self alive when he first used the Gate.” “Ah,” I said, “Is it then the case that only the prudent meet their older selves?” Comment on this issue, with particular attention to free-will.

Appendix B
Newton's Gift (A Story)[6]

Wallace John Steinhope was a sensitive human being, a person deeply concerned about the welfare of his fellow creatures. Any act of injustice, however slight, made his breast pound with righteous indignation. He was a champion of fair play, and his motto in life was taken from the ancient English rule of law—'Let right be done!'

Even while still a lonely, reclusive child, Wallace's heart ached mightly when he read of the laborious, boring, mind-dulling calculations endured by the great mathematicians of old. Just knowing, *thinking*, of Gauss's marvelous mind wasting literally months of its precious existence grinding out tedious mathematics that even a present-day dullard could do in a minute, on a home computer, was sheer agony for Wallace. Contemplation of the God-like Newton suffering endless delays in his gravity research, all because of a simple miscalculation of the length of a degree of longitude, was almost unbearable.

Indeed, Newton played a special role in Wallace's life (and he in Newton's, as we shall soon see). While the other great mathematical physicists had merely been hindered in their work by the lack of modern computational aids, Newton had squandered so much valuable time in other, nonscientific pursuits! His quasireligious writings alone, over half a million words, exceeded his scientific writings. What a waste! Wallace wondered endlessly over the reason for this strange misdirection of talent and bored his friends to the edge of endurance with his constant brooding on the mystery. Still, they all liked and admired Wallace enormously and so put up with it. But more than one of them had sworn to throw up the next time Wallace mentioned Newton during a wedding (but that's another story).

So deep was Wallace's anguish for his predecessors that even as he grew older and his own tremendous talents as a mathematical physicist (the result of a lucky

[6]P. J. Nahin, "Newton's Gift," *Omni*, January 1979. This tale was written with the specific goal of illustrating casual loop time paradoxes. The story reproduced here is, with only a few very minor alterations, as it originally appeared in *Omni*.

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genetic mutation induced in a male ancestor some centuries earlier) gained him an international reputation, thoughts of the unmeasurable misery of his scientific ancestors were never far from his mind. It was most appropriate, then, that his greatest discovery gave him an opportunity to *do* something! And Wallace John Steinhope vowed to *help*. He became convinced that it was his purpose on earth—he could not, he *would* not hesitate. As he strapped the knapsack-size time machine to his chest, his excitement was, therefore, easy to understand.

"It is done! And I am ready. I will travel back and bestow this gift of appreciation, this key to mental relief, on the great Newton himself!" Wallace cradled a small, yet powerful hand-calculator in his palm. It was a marvel of modern electronics. Incorporating large-scale integrated circuitry and a Z-8000 microprocessor solid-state chip, the calculator required only a small, self-contained nuclear battery for its power. It could add, subtract, multiply, divide, do square and cubic roots, trig and hyperbolic functions, take powers, find logarithms, all in mere microseconds. It was programmable, too, able to store up to 500 instructions in its micro-memory. The answers it displayed on its red, light-emitting diode readouts would liberate young Isaac from the chains of his impoverished heritage of mathematical calculation. No more Napier's bones for Newton!

But Wallace John Steinhope was no fool. He understood, indeed feared, time paradoxes. He knew Newton could be trusted with the secret, but it wouldn't do for the calculator to survive Newton's time. So Wallace had incorporated a small, self-destructing heat mechanism into it. After 5 years of use, it would automatically melt itself into an unrecognizable, charred slag mass. But that would be enough time for its task to be completed. The emancipation of Newton's mighty brain from tedium! Pleased enormously at the thought of the great good he was about to confer, Wallace set the time and space coordinates for merry old England, flipped the power switch on, and vanished.

Materializing in the Lincolnshire countryside in the spring of 1666, he began his rendezvous with destiny. It was the second and final year of the great bubonic plague, and Newton, seeking refuge from the agony and death plundering London and threatening his college of Trinity at Cambridge, had returned home to work in seclusion. The years of the Black Death were Newton's golden years, when the essentials of calculus would be worked out, when the colored spectrum of white light would be explained, and when the principle of the law of gravitation would be grasped. But how much easier it would be if Newton were released from the binding chains of dreary calculation. Wallace's gift would slip the lock on those chains! Accelerate genius!

It was early evening when, guided by a map of the area prepared by a friend who was both a cartographer and amateur historian, Wallace reached the quiet little town of Woolsthrope-by-Colsterworth. It was here, in a small farmhouse, that Wallace would meet his hero of the ages. A cold, gentle rain was falling as he approached the door. The soft, hazy light of an oil lamp glowed inside, revealing through the translucent glass the form of a man bent over a table. The fragrant smoke of well-dried wood curled from the chimney, announcing a warm fire within.

With his heart about to burst from excitement, Wallace rapped upon the door. After a pause, the shadow rose and moved away from the window. The door opened, and there stood Isaac Newton, a young man of 23 with an intellect that Hume and Voltaire considered "the greatest and rarest genius that ever rose for adornment and instruction of the species." But for the importance of his self-appointed mission, Wallace would have fainted dead away from the thrill of it all. "Is this the home of Isaac Newton?" he asked in a voice quavering with the trembling tones normally used by lovers about to reveal their deepest feelings.

The young man, of medium height and thick hair already showing signs of gray, swung open the door and replied, "My home it is, indeed, stranger. Come into the parlor, please, before the wetness takes you ill."

Isaac followed Wallace into the room and stood quietly watching as his visitor removed his soaked coat and hat. The portable time machine was gently placed on the floor next to a wall. The calculator was snug and safe in its plastic case in Wallace's shirt pocket. "Thank you, Master Newton. May we sit while we talk? I am afraid you may wish to take some time to consider my words." Motioning to a chair near the table, Isaac pulled a second chair from a darkened corner and joined Wallace. "You have a strange sound to your speech, stranger. Are you from hereabouts, or have you traveled far? Please commence slowly your tale."

Wallace laughed aloud at this question, a response prompted by his nervous excitement, and it quite surprised him. "Please forgive me. It is just that I *have* traveled so very, *very* far to see you. You see, I am from the future." Wallace was not one to play his cards close to his chest. Now it was Isaac's turn to laugh. "Oh, this is most ridiculous. Are you a friend of Barrow's at Trinity? It would be so like him to play such a trick.[7] From the future, indeed!"

Wallace's eyes ached at the sight of the papers on the table where Isaac had been working. What wonders must be there about to be born! In any other situation, Wallace would have asked their contents, but the die had been cast. He had to convince Isaac of the truth of his tale. But he had to walk a tight line, too. It just wouldn't do to misdirect Isaac's interest away from the calculator and toward the time machine itself! He must do something dramatic, something that would rivet his idol's attention and hold it.

"Yes, yes, I understand your reluctance to believe me. But, look here. This will convince you of the honesty of my words." Wallace pulled the shiny black plastic-cased calculator from his shirt pocket and flipped the power switch on. The array of LEDs glowed bright in the gloomy room as they flashed on in a random, sparkling red burst. Isaac's eyes widened, and he pushed his chair back. Was he frightened?

"As the Lord is my Savior, is it a creation of Lucifer? The eyes of it shine with the color of his domain. Are you one of his earthly agents?"

[7]The reference is to Isaac Barrow (1630–1677), who was the first Lucasian Professor of Mathematics at Cambridge. Barrow resigned that position to allow it to pass to Newton. Centuries later, Hawking became the 17th Lucasian Professor.

"Oh my, no! Look here, Master Newton, let me show you that there is no black magic or chicanery involved. It is all perfectly understandable in terms of the laws of Nature. What I have here is an automatic calculator, a device to perform all of your laborious mathematical labors."

So saying, Wallace squeezed the sides of the calculator case together, releasing pressure snap-fittings, and flipped the case open on a hinge at the top. Revealed to Isaac were the innards of the electronic marvel—a tightly packed interior of printed circuit boards, a mass of integrated circuitry, the small LED display, and the sealed nuclear battery. Isaac stared intently at the sight, and Wallace could see the natural curiosity of Newton's great mind begin to drive away the initial apprehension.

"But where are the gears, levers, springs, and ratchets to carry out the calculations? All I see is a black box with lights that glow red—how is *that* done; where is the lamp or candle to provide the light!—and many little isolated fragments of strange shapes. There is clearly nothing in your box that moves!"

"Oh, it is all done with electronics, Master Newton! The central processing unit has access to a solid-state memory that contains the decoding logic necessary to implement the appropriate algorithmic processes to provide the answers to the specific requests entered through these buttons. The actual performance of the box is achieved by the controlled motion of electrons and holes in suitably doped semiconductor material under the influence of electric fields induced—" Wallace, still overcome by his excitement, had rambled on wildly without thought of the essentially infinite technological gap that separated himself from Newton.

"Stop, stop," cried Isaac. "I understand only a few of the words you use and nothing at all of their meaning! But it is obvious that for calculations to be performed, mechanical work must be done, and that implies motion. Pascal's adding machine has shown the veracity of that. I say again, nothing moves in the box. How *can* it work?"

Wallace was embarrassed. The mistake of overlooking the hundreds of years of progress after Newton's time was one a child might make. "I am sorry, Master Newton. I'm going too fast for you." Isaac looked at Wallace with a frown, but Wallace failed to see the pricked vanity of the proud Newton. Going too fast, indeed!

Wallace prepared to lay a firmer technological foundation for Newton, but then he froze. It couldn't be done! Newton was a genius, certainly, but the task was still impossible. Wallace would have to tell him all about Maxwell's equations, Boolean algebra and computer structure, electronics, and solid-state device fabrication technology. It was just too much, and besides, there was the danger! The potential time paradoxes of all that knowledge out of its proper time sequence! What if Newton, in innocence, revealed some critical bit of knowledge out of its natural place in history? So, Wallace hesitated, but seeing the suspicion grow again in Isaac's eyes, he realized he had to do something, *anything*, immediately.

"You cannot deny your own eyes," answered Wallace. "Let me *show* you how it works. I'll divide two numbers for you with just the punch of a few buttons. Watch this." And, at random, he entered 81,918 divided by 123. Poor Wallace, of all the numbers to use, they were the worst. Within milliseconds the answer glowed brightly in fiery red characters. Wallace looked with pride at the result and then, already enjoying in his mind what he knew would be Isaac's amazement, he turned his eyes to the great man. What he saw made his spine tingle, and the gooseflesh stand high on his neck. Newton had fallen to his knees, with eyes bulging and hands raised as if in prayer.

"The mark of the Beast, it is the mark of the Beast! It is so written in the Book of Revelations—Here is wisdom. Let him that hath understanding count the number of the beast; for it is the number of man; and his number is six hundred three-score and six!" Rising to his feet, Newton fell back into his chair. "Your cursed box bears the brand of its master. There can be no doubt now, it *is* the creation of the fallen archangel!" Wallace was aghast at Isaac's violent reaction. The seventeenth century genius had now stumbled backward from his chair and had grasped a poker from the hot coals of the fireplace.

"Wait, please wait! Watch this; I'll multiply two other numbers together for you, watch!" Wallace quickly punched in the data, and then the answer gleamed steadily in burning red characters on the LEDs. Isaac's eyes first went wide with fear as he again saw the wizard electronics do their marvelous assignment, and then he shut them tight. Wallace was becoming desperate—this wasn't the way it was supposed to be! "Don't you see—imagine the tedious work, the mind-deadening labor this machine will save you from. And it is yours."

"Yes? But only for the exchange of my soul! That is always the Devil's price for his seductive gifts from Hell!" As Isaac shrieked these last words at Wallace, he raised the poker over his head. "Begone, you emissary of the Dark World! I know now you must be in the employ of the Father of the Antichrist, but the Lord God Almighty will protect me if I do not waver in my resolve. Begone, or I'll strike your brains out on the floor where you stand!"

Isaac's eyes were wide with fear, nearly rolling back to show all white spittle sprayed from his mouth as he yelled at Wallace, who stared in shock at the wild man who threatened him with death. "Please, please, *listen* to me, please! I beg you to understand—I am a scientist, just like you. The concept of the devil, and all it stands for, is contrary to everything I believe. How *could* I be in the devil's employ, when I don't even accept his existence? You *must* believe me!"

"Blasphemy!" screamed Isaac. "Your own words condemn you. To deny the reality of Satan in a sinful world is to deny that of God, too. Now leave my home, you dark beast from hell, or by the heavens above, *I shall destroy you*!" As he shrilled these words, Isaac brought the poker down in a wild swing that barely missed Wallace's head.

Struck dumb with confusion at the uncontrolled outburst, Wallace stuffed the calculator into his shirt, grabbed his hat, coat, and time machine and rushed from the house. As he hurried into the cold, wet night, he turned back, just once, to see Isaac Newton framed in the light of the open door. "Go, go, you foul messenger from the Lord of Evil! Back to your stinking pit of burning hell-fire! This is a house that honors the Divine Trinity and is no haven for the likes of you!"

Wallace rushed away into the blackness, the time machine bouncing unheeded upon his chest.

He ran, for how long he couldn't recall, until he fell exhausted next to a stream running heavy with the rain. Tears of rage, frustration, and shock streamed from his eyes. Rejected by the great Newton! Well, damn him! Wallace flung the calculator into the stream in his terrible anger and activated the return coordinates. He faded from Newton's world as quickly and quietly as he had come.

As for Isaac Newton, after having chased the Devil's messenger from his house, he returned on shaking legs to his desk. Pushing aside his rough calculations on the orbit of the moon around the earth, he swore to redeem himself in the eyes of the Savior. Somehow, he had been found lacking and had been tested. And the test was surely not over! He began to reapply his marvelous mind to determine the origin of his failure before the Lord God Jehovah. Taking quill in hand, he wrote the first of the many hundreds of thousands of words that his numerous religious tracts would devour from his allotted time.

Five years later, long after Newton had returned to Cambridge, a group of picnicking children were frightened when a nearby stream suddenly erupted into a geyser of steam. Moments later, the bravest (or most foolhardy) of the boys—who, by an astonishing coincidence that befits any good time travel paradox, would be Wallace's great-grandfather nine times removed—cautiously examined the streambed. All he found were some twisted, hot pieces of what he thought was a hard, black rock, and he tossed them back. They were all that was left of the calculator's nuclear battery. He did receive a tiny radiation dose from them, which caused a recessive genetic mutation that centuries later would suddenly appear as the cause of Wallace's genius, but otherwise the lad was unaffected. The incident was soon forgotten.

Well over 300 years later, Wallace John Steinhope reappeared in his own time. He was essentially the same man as before he left—kind, generous, and sensitive, and ready to come to the aid of any man or beast that might need help. As far as his friends were concerned, in fact, he was even improved (naturally, they didn't know what had brought about the welcome change but, if they had, they would have applauded it).

Wallace John Steinhope, you see, never again had another kind word for Newton, or for that matter, any words for him at all.

For Further Discussion

In his book *Travels in Four Dimensions: the enigmas of space and time* (Oxford 2003), the philosopher Robin Le Poidevin writes (p. 176) "But, as everybody knows, when a time machine leaves for another time it *disappears*." This is, indeed, how the time machine in "Newton's Gift" works; however, after reading *Time Machine Tales* do you think such behavior is in agreement or in conflict with general relativity? Defend your position.

"Newton's Gift" contains causal loops. Identify two of them, and discuss their role in the story (that is, are they central to the story or merely incidental?).

The idea of a time traveler visiting famous people in the past occurs fairly frequently in science fiction. In Ian Watson's "Ghost Lecturer" (*Isaac Asimov's Science Fiction Magazine*, March 1964), for example, the inventor of the "Roseberry Field" uses it to yank geniuses out of time to supposedly honor them, to let them know their lives had been worthwhile in the eyes of the future. But then he goes on to tell them—oh so kindly—where they had gone wrong or had fallen short of the mark, and of how much more we know nowadays. "You almost got it right, boy! You were on the right track, and no mistake. Bravo! *But* ..." Watson makes the interesting observation that one can easily imagine playing this pathetic game of 'second-guessing' history with scientists, but what could even the most talented modern do to upstage a Mozart or a Shakespeare? Most similar to "Newton's Gift," however, are (for example) Gregory Benford's "In the Dark Backward" (*Science Fiction Age*, June 1994) where Shakespeare and Hemingway are visited, and Jack McDevitt's "The Fort Moxie Branch" (*Full Spectrum*, October 1988) where Hemingway and Thomas Wolfe appear. Read these stories, and then compare/contrast their descriptions of how story characters react to the appearances of time travelers, to Newton's behavior in "Newton's Gift."

Appendix C
Computer Simulation of the Entropic Gas Clock

```
%gasclock.m/created by PJNahin for TIME MACHINE TALES(6/27/2015)
%This MATLAB m-file simulates the diffusion of gas molecules in a
sealed
%container by using the Ehrenfest ball exchange rules. The
simulation
%starts with n molecules (i.e., balls) of one type (i.e., black)
on
%one side of the container, and n more molecules of another type
(i.e.,
%white balls) on the other side. The two urns play the roles of the
%two sides of the container. To simulate the ball (molecule)
%movements, the program selects two random numbers from 0 to
1, which
%are then compared to the current probabilities of selecting a
black
%ball from urn I and a white ball from urn II. If BOTH random
numbers
%are greater than these two probabilities then a white ball has
been
%selected from urn I and a black ball has been selected from urn
II,
%and so the number black balls in urn I is increased by one while
the
%number of white balls in urn II is increased by one. If BOTH
random
%numbers are less than or equal to these two probabilities then a
%black ball has been selected from urn I and a white ball has been
%selected from urn II and so the number of black balls in urn I is
```


P.J. Nahin, *Time Machine Tales*, Science and Fiction,
DOI 10.1007/978-3-319-48864-6

```
%decreased by one while the number of white balls in urn II is
decreased
%by one. If one of the random numbers is greater than its
corresponding
%probability while the other random number is less than its
%corresponding probability, then no action is taken because then a
%white (black) ball moves from urn I to urn II at the same time a
white
%(black) ball moves in the opposite direction. That is, there is
no
%net change. Then, the ball selection probabilities are recalcu-
lated and
%another ball exchange is simulated.
rand('state',100*sum(clock))     %new seed for the random number
generator;
n=100;                           %number of balls in each urn;
nb1=n;                           %number of black balls INITIALLY
in urn I;
nw2=n;                           %number of white balls INITIALLY
in urn II;
pb1=nb1/n;                       %probability of selecting a black
ball from urn I;
pw2=nw2/n;                       %probability of selecting a white
ball from urn II;
for trials =1:1000;
   system(trials)=pb1;
   ball1=rand;
   ball2=rand;
   if(ball1>pb1&ball2>pw2)         %white ball selected from urn I
      nb1=nb1+1;                   %and black ball selected from
      nw2=nw2+1;                   %urn II;
   elseif(ball1<=pb1&ball2<=pw2)  %black ball selected from urn I
      nb1=nb1-1;                   %and white ball selected from
      nw2=nw2-1;                   %urn II;
   end
   pb1=nb1/n;
   pw2=nw2/n;
end
plot(system)
axis([1 trials 0 1])
grid
xlabel('time, in arbitrary units')
ylabel('fraction of balls in urn I that are black')
figure(1)
```

Epilogue

> [Science fiction] cannot be good without respect for good science . . . This does not include time machines, space warps and the fifth dimension; they will continue to exist in the hazy borderland between [science fiction] and fantasy.[8]

> In many science-fiction stories, the trip into the past is by way of some futuristic machine that can take you through time at will . . . That, however, is totally impossible on theoretical grounds. It can't and won't be done.[9]

The opening quotations, particularly the second one from Asimov who was one of the great modern writers of science fiction, is a gloomy one indeed for fans of time travel, but it is not difficult to find inconsistency in Asimov's own tales dealing with the concept. Asimov is famous, in particular, for his stories of robots, and the very last such tale that he wrote combines robotics with time travel, with a robot sent two centuries into the future.[10] At the start of the story, the narrator tells us that time travel to the past is impossible because the past is unchangeable and (of course) a time traveler would necessarily disturb history. (That is (of course) simply a failure to distinguish between the difference of *changing* the past and *affecting* the past, as well as a failure to see how the principle of self-consistency negates the issue of paradoxes.) Then, when the robot returns from the future (and so backward time travel is *not* impossible!), he reports that his arrival had been expected, that history had recorded that he would appear. At the end of the story we learn how the future knew this—it had read "Robot Visions"! So now Asimov *uses*

8Harry Harrison, in his essay "With a Piece of Twisted Wire . . .," *SF Horizons* (no. 2), 1965. Harrison (1925–2012) was a well-known (if little appreciated outside the SF community) writer, whose 1966 novel *Make Room! Make Room!* was the inspiration for the excellent (if somewhat depressing) 1973 film *Soylent Green* (a movie about future over-population of the Earth that will make you think twice about ever eating a cookie again).

9From an essay Isaac Asimov wrote on the time travel movie *Peggy Sue Got Married* for the *New York Times*, October 5, 1986.

10I. Asimov, "Robot Visions," *Isaac Asimov's Science Fiction Magazine*, April 1991.

P.J. Nahin, *Time Machine Tales*, Science and Fiction,
DOI 10.1007/978-3-319-48864-6

the principle of self-consistency, with the narrator realizing that he *must* preserve his story so the future can read it.

Not a very consistent story! Asimov, was, of course, writing a story for entertainment's sake, so perhaps it's unreasonable to hold him *scientifically* accountable (although logic wouldn't seem to be too much to ask for).

In any case, was Asimov right? Lots of his fellow science fiction writers certainly thought so. One, for example, bluntly asserted that

> Time travel is inconceivable.[11]

Other critics agreed:

> In science fiction we find the lunatic fringe more often than not trying to perfect time-travel mechanisms.[12]

and

> Scientifically, time travel can't stand inspection.[13]

and

> Time travel is . . . scientific nonsense.[14]

and

> It would be untrue . . . to present the idea of a time machine as anything but what it is, an intriguing literary device, part of the bag of tricks of the science fiction writer . . . There is no such thing as a 'science' of time travel.[15]

You'll notice that these pronouncements are from decades ago: Conklin (1904–1968), Gold (1914–1996), and Oliver all wrote just 3 years after Gödel, and so perhaps it was simply too soon for his work to be widely known outside of the physics community. But physicists have learned a lot since 1952! Have they learned enough to make Asimov and his fellow SF skeptics (if they were still alive) change their minds, or at least reconsider? I suspect not.

I say that because, even 25 years after Conklin, Gold, and Oliver wrote, while we do find an awareness of Gödel starting to appear in the science fiction world, a feeling of skepticism was still in the air. In a fascinating analysis[16] of the first half-century of the science fiction magazines, Paul Carter admitted that there *is* a rationality to time travel because of Gödel but, nonetheless, the conventional view remained that backward time travel is simply impossible. Then, citing the work of Tipler, Carter wrote "Only as recently as 1974 (see note 130 in Chap. 1), in

[11]Kingsley Amis, *New Maps of Hell*, Harcourt 1960.

[12]Groff Conklin, *Science Fiction Adventures in Dimension*, Vanguard 1953.

[13]H. L. Gold, *The Galaxy Reader of Science Fiction*, Crown 1952.

[14]Alexei Panshin, *The Mirror of Infinity*, Canfield 1970.

[15]Chad Oliver, "The Science of Man," a non-fiction essay included in Oliver's 1952 time machine novel *Mists of Time*. Chad Oliver (1928–1993) was a scientist by profession (anthropology), and his opinion carried weight among SF writers *and* (non-physicist) scientists.

[16]P. A. Carter, *The Creation of Tomorrow*, Columbia University Press 1977.

the sober pages of the *Physical Review*, has a physicist been more bold ... For 70 years in the meantime, however, without waiting for Professor Tipler to solve his equations ... writers had happily helped themselves to Mr. Wells' invention and sent their characters through time in every direction, forward, backward, and sideways."[17]

In the 1980s writers were apparently just as unaware of Gödel's time travel analyses (and of the much later ones of Tipler) as had been the 1950s commentators. In his marvelous 1985 book *The Past Is a Foreign Country*, for example, David Lowenthal repeatedly refers to time travel as "fantasy" and to science fiction stories about time travel as "unbridled by common sense." And for another example from the start of the 1980s, consider the case of James Gunn (born 1923), professor of English at the University of Kansas, past president of both the Science Fiction Writers of America and the Science Fiction Research Association, author of *The Immortals* (inspiration for the 1970–1971 TV series of the same name), and eminent scholar (see his 1975 book *Alternate Worlds*). His literary credentials are impeccable and his critical influence profound. And yet, 30 years after Gödel and 5 years after Tipler, Professor Gunn wrote in *The Road to Science Fiction*, "Time travel has been an anomaly in science fiction. Clearly fantastic—there is no evidence that anyone has ever traveled in time and *no theoretical basis for believing that anyone ever will* [my emphasis]." If you've read this book carefully, however, of the analyses by Gott, Krasnikov, Thorne, Alcubierre, Novikov, Natário, and others, you know that what Gunn claims in those last words is actually not necessarily so.

The British-born American theoretical physicist Freeman Dyson of the Institute for Advanced Study has commented[18] on that sort of narrow mindset, with words quoted from the 1979 physics Nobel prize winner Steven Weinberg, words reminding us that rigidity concerning time travel is not limited to science fiction writers: "This is often the way it is in physics—our mistake is not that we take our theories too seriously, but that we do not take them seriously enough. It is always hard to realize that these numbers and equations we play with at our desks have something to do with the real world. Even worse, there often seems to be a general agreement that certain phenomena are just not fit subjects for respectable theoretical and experimental effort." The words *time travel* and *time machine* are never mentioned, but could they have been far from either Weinberg's or Dyson's thoughts?

All through this book we have seen how people have argued against time travel to the past (Tipler's cylinder is unphysically long, Gödel's universe requires an unphysical rotation, wormholes and warps require unphysical energy conditions, what about all those paradoxes ... and on and on). These arguments remind me of

[17]Given that *The Time Machine* was published in 1895, it is not clear how Carter arrived at the value of 70 until Tipler's work (he should have written 79), and of course it was only 54 years between Wells' time travel fiction and Gödel's time travel mathematical physics.

[18]F. J. Dyson, "Time Without End: Physics and Biology in an Open Universe," *Reviews of Modern Physics*, July 1979, pp. 447–460.

the debate in the 1930s between the illustrious British astrophysicist Sir Arthur Eddington and the young Indian astrophysicist Subrahmanyar Chandrasekhar (1910–1995), winner of the 1983 Nobel prize in physics. In his analyses of the life history of stars, Chandrasekhar had arrived at an astonishing conclusion, one that Eddington simply could not accept. As Eddington sarcastically explained in an address at Harvard University in the summer of 1936, "Above a certain critical mass (two or three times that of the sun), the star could never cool down, but must go on radiating and contracting until heaven knows what becomes of it. That did not worry Chandrasekhar, he seemed to like the stars to behave that way, and believes that is what really happens."[19] Eddington then went on to declare such 'unbelievable' behavior to be nothing less than "stellar buffoonery."

As far as Eddington was concerned, Chandrasekhar had simply made an error in combining relativity theory with non-relativistic quantum theory. Indeed, so appalled was Eddington at the thought of a star contracting "until heaven knows what becomes of it" (that is, until it gravitationally collapses into a black hole) that he had earlier, in 1935, stated "There should be a law of nature to prevent a star from behaving in this absurd way!" Today, of course, no astrophysicist feels the need for a 'star protection conjecture'—which perhaps reminds you of another, more recent 'protection conjecture.'

What can one conclude from all the similar controversy concerning time travel, time machines, and spacetime warps? Not much, I think, except that these are open issues and will remain the subjects of on-going study for a long time yet to come. The one thing I am fairly certain of is that if time travel is ever achieved, it will be by means that we cannot today even begin to guess. It will almost certainly require *at least* a mutant child genius with an IQ of 270 to fix the slightly broken time machine found abandoned in a cellar![20] But that view isn't uniformly shared across all of science fiction. I very much doubt, for example, that things will be quite so elementary as depicted in the story[21] where the time machine was so simple that "If it were taken apart or put together before you, your wife, or the man across the street, you would wonder why you didn't think of it yourselves." Not only that, but its power source was just two dry cell batteries!

The time machine in an earlier story is almost as simple, requiring (besides a piece of strange crystal) only a "little stack of dry cells, a Ford [automotive ignition] coil, a small brass switch, a radio 'B' battery, an electron tube, and a rheostat."[22] Even Wells' *Time Machine* couldn't resist making it all look easy: as one critic put it, "The time machine, like all products of supreme inventive genius, was a

[19]See S. Chandrasekhar, *Eddington: The Most Distinguished Astrophysicist of His Time*, Cambridge University Press 1983, p. 48.

[20]F. B. Long, "A Guest in the House," *Astounding Science Fiction*, March 1946.

[21]R. Abernathy, "Heritage," *Astounding Science Fiction*, June 1947.

[22]J. Williamson, "In the Scarlet Star," *Amazing Stories*, March 1933.

remarkably simple affair. A few rods, wires, some odd glass knobs—nothing more!"[23] That sort of simplistic fictional description of a time machine reminds me of the reaction of the great Polish science fiction writer Stanislaw Lem to the general treatment of time travel in the genre: "There have been mountains of nonsense written about traveling in time, just as previously there were about astronautics—you know, how some scientist, with the backing of a wealthy businessman, goes off in a corner and slaps together a rocket, which the two of them—and in the company of their lady friends, yet—then take to the far end of the Galaxy. Chronomotion, no less than Astronautics, is a colossal enterprise, requiring tremendous investments, expenditures, planning . . ."[24]

An example of what Lem was talking about is the 1956 novella *Arcturus Landing* by Gordon R. Dickson (1923–2001). There we read of aliens who have confined humans to the solar system—until (if) Earth scientists discover the secret of FTL travel. So, a genius physicist does just that (with no mention of spacetime engineering, but rather we encounter a lot of mumbo-jumbo gibberish as the 'explanation'), and uses it to instantly transport himself and some friends to a planet orbiting Arcturus.[25] And when they get there the friendly aliens speak perfect English.

Lem would have snorted in derision, too, at this statement made to a prospective graduate student by the head of a college physics department, that the college "has been awarded a million dollars to build [a time machine]. It means . . . a raise for me and maybe a doctorate for you, so we'll build one and have some fun doing it."[26] Is it any wonder that Lem so readily dismissed stories that reduce space (and time) travel to weekend adventures in a home laboratory? As Lem wrote in another essay, time travel and its close relation, FTL space travel, have reduced much of science fiction to "a bastard of myths gone to the dogs."[27] Because of precisely that, Harry Harrison wrote (note 1) of the early science fiction magazines that published so much nonsense, "I used to moan over the fact that pulp magazines were printed on pulp paper and steadily decompose back towards the primordial from which they sprang. I am beginning to feel that this is a bit of a good thing."

I don't know whether time travel to the past can actually be accomplished, but I do know that speculations once thought to be as outlandish as finding the Philosopher's Stone for turning base elements into gold, *have* eventually been realized (and, come to think of it, with modern nuclear physics we *have* learned how to turn lead into gold, if only a few atoms at a time). Television, nuclear power, home computers that run at multi-gigahertz clock rates in the bedrooms of high school

[23]W. B. Pitkin, "Time and Pure Activity," *Journal of Philosophy, Psychology and Scientific Methods*, August 27, 1914, pp. 521–526.

[24]S. Lem, "The Twentieth Voyage of Ijon Tichy," in *The Star Diaries*, Seabury Press 1976.

[25]A journey incorrectly given in the story as 120 light years, when in fact it is less than 40 light years.

[26]W. West, *River of Time*, Avalon Books 1963.

[27]S. Lem, "Cosmology and Science Fiction," *Science-Fiction Studies*, July 1977, pp. 107–110.

students, even faster computers that animate our movies and simulate the formation of black holes and galaxies, voyages to the Moon and back—all these amazing developments would be pure magic to nineteenth century science. The ghosts of not just a few Victorian scientists who had poo-pooed the possibility of such things, have watched their reputations eat a lot of posthumous crow during the last 150 years.

My personal position on the question of time travel leans towards the rejoinder made to the skeptic in one science fiction story who, even after having done some time traveling, *still* argues against it by invoking paradoxes. He is sharply rebuked with "Oh, for heaven's sake, shut up, will you? You remind me of the mathematician who proved that airplanes couldn't fly."[28] I subscribe to the optimistic philosophy of the British writer Eden Phillpotts (1862–1960), who wrote in his 1934 novel *A Shadow Passes* "The Universe is full of magical things, patiently waiting for our wits to grow sharper." Perhaps he had a famous saying by the British-born Indian scientist J. B. S. Haldane (1892–1964) in mind, words from his 1928 *Possible Worlds*: "Now my suspicion is that the universe is not only queerer than we suppose, but queerer than we can suppose."

Still, even if time travel is possible, the engineering phase will surely be tough going. I am certain that before we see a working time machine, there will be many, *many* episodes like the one described in a very funny, novel-length spoof of academic research.[29] All physicists and engineers who have tried to get some stubborn piece of apparatus to work, apparatus that *should* work and simply won't, will appreciate Professor Demetrious Demopoulos' frustration and will, I am sure, forgive him his intemperate language:

> . . . the distinguished physicist took a step back and, arms akimbo, surveyed the complex and sophisticated machine that was the culmination of years of dedicated scientific research and pains-taking technological development.
>
> "What a pile of ****," he said.
> "Oh, no, Dr. Demopoulos, don't say that!"
> "Well, it is." A sneer formed on the professor's thin lips. "Time machine, my ****. This thing couldn't give you the time much less travel in it."
> "But we haven't incorporated all our latest test data yet," the pretty research assistant reminded him. "These last few adjustments might do it, Professor."
> "Hell, we've been tinkering with it for 2 years," Demopoulos complained.
>
> "We've tried everything and it's all come to dog ****."

[28]R. Heinlein, "By His Bootstraps," *Astounding Science Fiction*, October 1941. As discussed at the end of Chap. 1 (in "For Further Discussion") the mathematician was the American astronomer Simon Newcomb.

[29]J. DeChancie and D. Bischoff, *Dr. Dimension*, ROC 1993.

That scene probably won't actually happen for a long time to come but, even before the practical nuts-and-bolts bugs in the Professor's time machine are worked out, I think some adjustments are called for in our thinking about time travel. I believe that present-day philosophers and science fiction writers are going to have to become knowledgeable about the work by physicists on time travel. It simply won't do any longer for Philosophy Professor X to invoke the grandfather paradox during a discussion of causality and free will and then airily declare them to be 'obviously' incompatible with time travel to the past. And it simply won't do any longer for Famous SF Writer Y to send his hero into the past to kill Hitler as a baby and thereby change recorded history. One might as well keep watching a video recording of the 9/11 destruction of the World Trade Center, in the vain hope that maybe, on the next viewing, the planes will miss.

The principle of self-consistency around closed timelike curves is going to have to become as much a part of the science fiction writer's craft (or else she will be a writer of fantasy) as it will have to become part of the fundamental philosophical axioms.[30] The 'time police,' like the "operatives of the Bureau of Time Exploration and Manipulation" that appeared in the science fiction of Andre Norton (1912–2005), will have to be put out to pasture with the unicorns and telepathic dragons of fantasy fiction. Just as the recent physics literature on time machines has displayed a growing awareness of what science fiction writers and philosophers have had to say on the subject of time travel, so too are writers and philosophers going to have to learn some more physics. Most people can enjoy a good fantasy tale now and then, but the use of 'magic mirrors' to see through time is *not* physics. Such devices were popular and acceptable in medieval times—see "The Squire's Tale" in Chaucer's *The Canterbury Tales*, and later (see Act IV of *Macbeth*)—but good science fiction needs much more than that today.

Time travel to the past is a beautiful, romantic idea, and some words written by two physicists in a technical paper—words embedded in the midst of swirls of tensor equations—show that even hard-nosed physicists can share this dream: "In truth, it is difficult to resist the appealing idea of traveling into one's own past . . ."[31] The appeal of that dream is explained in Ray Bradbury's Foreword to a beautiful little 1989 book by Charles Champlin (*Back There Where the Past Was*). In it Bradbury clearly illuminated *why* we want to go back into the past. It is for the same reason that we go, time and again, to see *Hamlet*, *Othello*, and *Richard III*: "We don't give a hoot in hell who poisoned the King of Denmark's semicircular canal.

[30]Bud Foote (1930–2005), late professor of English at Georgia Tech, wrote (in his book *The Connecticut Yankee in the Twentieth Century: Travel to the Past in Science Fiction*, Greenwood Press 1991) that consistency is simply a well-used plot device: "The attempt of the time traveler to prevent something or take advantage of it [and so causing] the event in question, is so popular and so ubiquitous that it seems to be about worn out." Worn out or not, I believe that plot device to be correct science.

[31]A. J. Accioly and G. E. A. Matsas, "Are There Causal Vacuum Solutions with the Symmetries of the Gödel Universe in Higher-Derivative Gravity?" *Physical Review D*, August 15, 1988, pp. 1083–1086.

We already know where Désdemona lies smothered in bedclothes and that Richard goes headless at his finale. We attend them to toss pebbles in ponds, not to see the stones strike, but the ripples spread."

That's why a visit to the past is so mysteriously and marvelously fascinating. It would let us watch ripples spread through time. Our own visit to the past, in fact, might even be the pebble in the pond of history that starts an interesting ripple or two that will one day sweep over—us! (Take a look at Appendices A and B) Who would want to miss that? Indeed, if modern philosophers are right, if the analyses discussed earlier in this book are correct, you *can't* (didn't/won't) miss it.

I think time travel appeals, irresistibly, to the romantic in the soul of anyone who is human.[32] A time traveler does not exist either *here* or *then*, but rather *everywhen*. For a time traveler passing back and forth through the ages, history would be the ultimate puzzle, a chronicle described in one novel as beginning "not in one place, but everywhere at once ... It might be begun at any point along the infinite, infinitely broken coastline of time."[33] Romanticism doesn't preclude there also being a dark side to visiting the past, of course, as one time traveler from 1989 learns when he takes up residence in 1962. Falling asleep on a hot summer night in that long-ago year, he thinks "JFK slept. Oswald slept. Martin Luther King slept. [I sleep and dream] of Chernobyl ... *I am a cold wind from the land of your children*."[34]

But, I must admit, I personally am more attracted by happier descriptions of time travel. In his marvelous 1996 book *1939: The Lost World of the Fair*—which is proof that there are not enough Pulitzers to go to all the books that deserve one—Yale professor David Gelernter caught just the right spirit in his Prologue: "The best of all reasons to return to the fair is that travel is broadening, and time travel most of all ... The 1939 New York World's Fair is one amazing show. It still stands, undisturbed on Flushing Meadow, just over the edge of time; it would be an unforgivable shame to miss it." Trust me—if you read Gelernter's book, you'll come as close as you can in today's world to taking a ride in a 'time machine'!

The eminent philosopher Sir Karl Popper opens his biography with a wonderful story about his apprenticeship as a young man in 1920s Vienna to a master cabinetmaker.[35] After winning the old man's confidence, the student learned his mentor's great, secret desire: For years the master had been looking for the solution to perpetual motion. He knew what physicists thought of such machines, but nonetheless he had never given up his dream: "They say you can't make it; but

[32]How else to explain the pleasure, for modern children *and* adults too, in watching rebroadcasts of the 1960s animated TV cartoon program 'starring' Mr. Peabody, a nice but slightly stuffy, professorial white beagle. (Don't all dogs wear glasses and a bow tie?) Mr. Peabody, with his brainy adopted son Sherman, routinely travels into the past in the "Way-Bac" machine to see what *really* happened in history.

[33]John Crowley, *Great Work of Time*, Bantam 1991.

[34]R. C. Wilson, *A Bridge of Years*, Doubleday 1991.

[35]See volume 1 of *The Philosophy of Karl Popper* (P. A. Schilpp, editor), The Library of Living Philosophers, Open Court 1974, p. 3.

once it's been made they'll talk differently." Popper's master sounds just a bit like the American writer Gertrude Stein (1874–1946) in her 1938 essay "Picasso," where she writes "It is strange about everything, it is strange about pictures, a picture may seem extraordinarily strange to you and after some time not only it does not seem strange but it is impossible to find what there was in it that was strange." Might we one day say the same thing about time travel?

An alternative point of view can be found in a discussion of time travel via cosmic strings that makes this assessment: "While there is still hope that one day a sufficiently clever design may make building a time machine possible, it is beginning to seem more and more improbable. Like the perpetual motion machines of the nineteenth century, the designs have an elegant simplicity (as well as enormous commercial potential), but it seems that Nature also may abhor them just as much."[36] Of course, at one time it was thought that Nature abhorred a vacuum, but then we learned that she must actually love a vacuum because else why did she make so much of it?!

The theoretical basis for time travel is very different from that of perpetual motion (there is *more* reason to accept time travel as a plausible possibility). And so maybe one day, *just maybe*, the first time traveler will receive a toast such as the one in a story telling us about the arrival of the inventor of the first time machine and his no longer skeptical friend in the Civil War past:

"To you, Mac," I said.

McHugh loosened his tie. "To the Creator," he said, "who has given us a Universe with such marvelous possibilities."[37]

[36]B. Allen and J. Simon, "Time Travel on a String," *Nature*, May 7, 1992, pp. 19–21.

[37]J. McDevitt, "Time's Arrow," *Isaac Asimov's Science Fiction Magazine*, November 1991.

Glossary[38]

Action the integral over a **world line** of a quantity called the *Lagrangian*. When a massive particle is moving at non-relativistic speed through a gravitational field, for example, the instantaneous value of the Lagrangian is the difference between the kinetic and potential energies of the particle. For other types of fields (such as the electromagnetic) and/or relativistic motion in any type of field, the Lagrangian is different. In any case, however, the actual world line of the particle is the one for which the integrated Lagrangian, that is, the action, is minimized. See **least action**.

Action at a distance the direct interaction of two separated objects, without concern for the details of what (if anything) occurs in the region between the objects (see also **field**). Newton's theory of gravity is action at a distance, whereas Einstein's theory of gravity is a *field* theory.

Advanced solution the prediction, by Maxwell's electromagnetic field equations, of radio waves that travel into the past (see also **Dirac radio**).

Anti-matter quantum mechanical prediction (experimentally verified) that all fundamental particles of matter come in two forms (the 'normal' version and the 'anti-matter' version). The positron, for example, is the anti-matter version of the electron, differing only in the sign of its electric charge. The photon, on the other hand, is its own anti-particle. A **subluminal** anti-particle traveling forward in time can be thought of as its 'normal' version traveling backward in time.

Arbitrarily advanced civilization for time travel discussions, a civilization with a technology sophisticated enough to construct a traversable **wormhole** in spacetime. More generally, Types I, II, and III of such civilizations are, respectively, those that can control 10^{13} W, 10^{27} W (the total power output of their home star), and 10^{38} W (the total power output of their home galaxy).

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[38] "I hate definitions." (Usually attributed to writer and British Prime Minister Benjamin Disraeli (1804–1881) but, more precisely, they are the words of one of the characters in his 1826 novel *Vivian Grey*.)

—but they *can* be useful

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Arrow of time the statement the time appears to have a direction, that there is a difference between the past and the future. There are several different arrows: the psychological (we remember the past, we anticipate the future), the thermodynamic (organized systems evolve toward disorganization, that is, **entropy** increases as time increases), the electromagnetic (radio waves propagate *away* from their generators), and the cosmological (the expansion of the universe is directed toward the future).

Asymptotically flat if the geometry of a curved spacetime is such that, as one moves ever further away from all matter and energy, the spacetime **metric** becomes that of flat **Minkowski spacetime**, then the curved spacetime is said to be *asymptotically flat*. As a counter-example, the spacetime of a **Tipler cylinder** time machine is *not asymptotically flat*.

Autoinfanticide paradox see **grandfather paradox**.

Averaged null energy condition the claim that the *averaged* value of the observed mass-energy density along the entirety of any **null geodesic** is non-negative.

Averaged weak energy condition the claim that the *averaged* value of the observed mass-energy density along the entirety of any **timelike world line** is non-negative.

Back reaction the tendency of spacetime to resist the formation of **closed timelike lines** (see also **stress-energy divergence**).

Bell's theorem an inequality that either holds or does not hold, depending on whether quantum mechanics is non-local or local, respectively.

Big Bang the singular beginning of spacetime.

Big Crunch the singular end of spacetime.

Bilking paradox what would happen if a **causal loop** were disrupted. For example, suppose a time traveler builds a time machine using plans he received years earlier from a mysterious stranger. He now realizes that the stranger was himself, using the time machine to travel back into the past to give his younger self the plans. A bilking paradox would be created if the time traveler builds the time machine, verifies that it works, and then decides *not* to visit his younger self to hand over the plans. See also **bootstrap paradox**.

Black hole a region of spacetime where gravity is so strong that nothing can escape, including light. Black holes are thought to be created when sufficiently massive stars burn out (see **white dwarf** and **neutron star**) and undergo *gravitational collapse*. A black hole of ten solar masses would have a radius of about twenty miles. Black holes might have been created at the Big Bang singularity and, if so, could theoretically come in any mass and size (a black hole with the mass of the Earth would have a diameter of less than half an inch).

Block universe a spacetime in which all world lines are completely determined from beginning to end (a fatalistic universe). There is no free will in such a spacetime.

Boost matrix matrix formulation of the **Lorentz transformation**.

Bootstrap paradox the puzzle of the origin of *information* on a closed loop in time. The classic example is that of a time traveler from the future giving his younger-self the plans for the time machine the time traveler has just used to visit the past so that he can then build the time machine to visit the past. The time machine plans appear not to have been *created* by anyone! The plans just *are*. See also **bilking paradox**.

Cauchy horizon a **spacelike** hypersurface in spacetime that intersects, exactly once, every **timelike** world line that has no end point. Knowledge of the conditions on such a surface uniquely determines the spacetime at all other points.

Causal loop a time loop containing an event caused by a *later* event that, itself, is caused by the earlier event (see the example in **bilking paradox**).

Causality the metaphysical claim that every event is caused by a prior event. Time travel to the past inherently violates causality.

Chronal regions those parts of spacetime that have no closed timelike curves.

Chronology horizon a (hyper)surface in spacetime that separates **chronal** and non-chronal regions. It is a special case of a **Cauchy horizon**.

Chronology protection the claim, as yet unproved, that time machines and time travel to the past are impossible because of the **back reaction** of spacetime will lead to **stress-energy divergence**. Popularized among physicists as the *Hawking chronology protection conjecture* (1992), Hawking has since admitted that stress-energy divergence is *not* sufficient to enforce his conjecture.

Chronon science fiction name for **Planck time**.

Closed timelike line (or curve) a **timelike** world line of finite length that has no ends, i.e., that forms a *closed loop* in spacetime. A region of spacetime containing closed timelike lines is said to be a **time machine**.

Conservation law physical quantities in interacting systems that remain unchanged are said to be conserved. Total energy, total momentum (linear and angular), and electric charge are conserved quantities.

Cosmic string hypothetical, threadlike spacetime structures with enormous mass-energy and density that may have formed during the **Big Bang**. Cosmic strings may have been initially formed either as infinitely long, or as closed loops, and it is the former that are thought to be physically meaningful in the present-day universe. Cosmic strings do not violate the **weak energy condition** (as do **wormholes**), and they can theoretically create **closed timelike lines**.

Cosmological constant an extra term specifically added by Einstein to the general theory of relativity to keep that theory from predicting the expansion of the universe (which was later observationally found to actually be the case). Einstein subsequently said that his failure to believe the general theory's original prediction of the expansion of the universe was the greatest mistake of his life. The constant (which today is believed to be almost zero, if not exactly zero) appears in Gödel's rotating time travel spacetime as a determining factor in the minimum radius of a **closed timelike line**.

Determinism the metaphysical belief that effects are uniquely determined by causes (this is *not* **fatalism**).

Dirac radio science fiction gadget for sending information at infinite speed, which thus travels backward in time (see also **ultraluminal**).

Dominant energy condition the **weak energy condition** *plus* the claim that the observed energy flux is never **superluminal**.

Electron fundamental particle of mass that possesses one quantum of negative electric charge. *Bound* electrons orbit the nuclei of atoms and plays a central role in determining the chemical properties of the elements and of their compounds. *Free* electrons carry electric current, either in conductors (wires) or through space.

Elsewhen the collection of spactime events that cannot be reached from the **here-now** with a **timelike world line**.

Entropy a measure of the randomness of a system that plays a central role in the thermodynamic **arrow of time**.

Ether a substance once thought to fill all space to allow radiation 'something to propagate through' (as opposed to simply a vacuum). The special theory of relativity showed that the ether is an unnecessary concept because it has no observable effects (physicists argue that if something is impossible to detect, then it is meaningless to talk about it being part of *science*).

Event a point in spacetime.

Event horizon the spacetime surface of a black hole or of a non-traversable wormhole, at which light can *just* escape to the outside universe. It is called a *horizon* because, by definition, an external observer can't see beyond it and into the interior of the hole. To see the inside of a hole you must enter the hole by crossing the horizon (but then you can't get out).

Exotic matter matter that violates one or both of the **weak/strong energy conditions**. Exotic matter appears in the theories of wormholes and warp drives.

Fatalism the metaphysical belief that all events have been *pre*determined from the beginning of time.

Field the concept that if a physical law is local, then it is describable by differential equations that relate what is 'happening' at every point in spacetime to what is 'happening' at its closely located neighboring points. Electromagnetism and general relativity are field theories, for example, described by sets of partial differential equations called *Maxwell's equations* and *Einstein's gravitational field equations*, respectively.

Fourth dimension either time or a fourth spatial dimension.

Frame of reference a spacetime coordinate system.

Free will the condition that prevails when we can *choose* to do what we do. There is no free will in a **block universe**.

Future the collection of spacetime events that can be reached from the **here-now** via a **timelike world line** directed toward a later time (for each individual, the future is what hasn't yet been experienced).

Gamma ray very high-energy, very high-frequency electromagnetic radiation. Gamma rays have frequencies on the order of *ten trillion* (10^{13}) times greater than those of AM radio broadcast radio waves.

General theory of relativity Einstein's theory of curved spacetime, which explains gravity in terms of nothing but geometry. Its fundamental premise is that *all* the laws of physics should appear the same to all observers in *any* **frame of reference**. It is believed the theory will fail when the local mass-energy density reaches a level of about 10^{94} g/cm^3, a density so enormous (the density of water is just 1 g/cm^3) that there is no known mechanism for achieving it anywhere in the universe except in another **Big Bang**. See also **Planck density**.

Geodesic the shortest path connecting two points in space (if the space is spacetime, the world line of a particle in free-fall).

Global in the large.

Gödel universe a spacetime that, unlike the one we live in, is rotating so fast that it automatically generates *closed timelike lines* and thus constitutes a weak **time machine**. In such a universe, time travel to the past would be a natural phenomenon.

Grandfather paradox *the* classic time travel paradox, of a time-traveler killing, while in the past and *before* the time traveler has been conceived, an ancestor directly linked to the future birth of the time traveler. A more direct form of this sort of paradox is simply the time traveler killing his own younger self (called the **autoinfanticide paradox**).

Gravitational field equations a set of coupled, partial differential, non-linear tensor equations, considered to be the most complicated equations in all of mathematical physics. They show how the local curvature of spacetime depends on the local mass-energy of spacetime. The equations are independent of the **topology** of spacetime.

Gravitational lensing the ability of gravitational fields to bend and focus light.

Graviton the quantum particle of gravity.

Hawking radiation the emission of particles (energy) by a **black hole** into the region *outside* its **event horizon**, which results in the eventual evaporation of the hole. This is a quantum mechanical effect.

Here-now the point or **event** (for each observer) in spacetime that separates the **past**, the **future**, and **elsewhen**.

Hyperspace any space of four or more dimensions (for example, four-dimensional spacetime is a hyperspace).

Inertial frame any frame of reference in which Newton's laws of mechanics are true (there are no *acceleration forces* in inertial frames, and so *rotating* or 'merry-go-round' frames are not inertial).

Invariance a quantity that remains the same in any frame of reference is an invariant. Two examples are the distance between any two points on a piece of paper (because it is independent of any particular coordinate system), and the speed of light.

Kerr-Newman black hole a *rotating* black hole, which may (or may not) be electrically charged.

Krasnikov tube a particular spacetime **metric** (or *warp*) allowing **superluminal** travel, with the great difficulty of requiring *enormous* negative energy. Two Krasnikov tubes can be made into a time machine. Named after its Russian inventor.

Least action general principle in physics that asserts the world line of a particle is the one that *minimizes* the **action**.

Light cone the **lightlike** surface in spacetime that, at each point in spacetime, separates the **past** from the **future** from **else-when** from the **here-now**.

Lightlike the world line of a photon (or of any other form of mass-energy traveling *at* the speed of light).

Li mirror a perfectly reflecting, spherical surface that can be used to stabilize a wormhole against energy loops circulating through a **wormhole** time machine (thus creating unbounded energy levels that destroy the time machine). Named after its Chinese inventor.

Local in the small.

Lorentz factor the ubiquitous square-root expression that appears in so many relativistic calculations, such as time dilation, length contraction, and the variation of mass with speed. For example, the mass m of a moving body is not independent of it speed v but rather varies as $m = \frac{m_0}{\sqrt{1-\left(\frac{v}{c}\right)^2}}$, where m_0 is the rest mass (that is, the mass when $v = 0$) and c denotes the speed of light (186,210 miles per second). The denominator is the Lorentz factor.

Lorentz-FitzGerald contraction the conclusion from special relativity that the appearance (to a stationary observer) of a moving object will be shortened in length along the direction of motion. Many years after Einstein's work, it was shown that the object will also appear to be *rotated*.

Lorentz transformation equations from the special theory of relativity that describe how the space and time measurements of two relatively moving observers are related.

Many-worlds interpretation quantum mechanical view of splitting universes.

Mass-energy the famous $E = mc^2$, the equation behind atomic fission and nuclear fusion weapons.

Metric the measure of the separation between any two events in a spacetime.

Minkowski spacetime the flat spacetime of the special theory of relativity. In this spacetime there is no gravity, no spacetime curvature (hence it is *flat*) and no backward time travel.

Neutron star the end state of a star with one to three solar masses that has collapsed to a density of up to 10^{17} g/cm^2.

Non-Euclidean geometry the geometry of spacetime, whether curved or flat. Spacetime is non-intuitive precisely because it is always hard to resist thinking in terms of high school Euclidean geometry, which is simply the *wrong* geometry.

Null geodesic the world line of a photon in spacetime.

Observer physicist's term for 'somebody' equipped with recording instruments (such as a clock, a pencil and notepad, and the like).

Parallel transport a procedure for moving a vector around any closed curve in a space to determine whether that space is flat or curved.

Parallel worlds simultaneous existence of multiple (perhaps) infinite versions of reality.

Past the collection of spacetime events that can reach the **here-now** via timelike world lines directed from an earlier time (for each individual, the past is what has already been experienced).

Photon the quantum particle of electromagnetism. A photon of frequency f has energy hf, where h is **Planck's constant**.

Planck density the density of mass-energy that distinguishes classical from quantum spacetimes; about 10^{94} g/cm^3, equal to the **Planck mass** divided by the cube of the **Planck length**.

Planck length the non-zero length in quantum theory (about 1.6×10^{-33} cm) below which quantum gravity effects will become important.

Planck mass the fundamental mass in quantum theory (about 22×10^{-6} g), but *not* the smallest non-zero mass in quantum theory.

Planck's constant fundamental constant in quantum theory, h, associated with the discrete nature of quantum effects. (If h had the value of zero, rather than its actual value of about 6.6×10^{-34} joule-seconds, then the microworld would appear to be continuous.)

Planck time the time interval in quantum theory (about 5.3×10^{-44} s) below which quantum gravity effects become important. The time required to travel the **Planck length** at the speed of light.

Positron the electron's anti-particle (see **anti-matter**).

Proper time the timekeeping of an observer's clock.

Pulps the old science fiction magazines, through the 1940s and into the early 1950s or so, published on inexpensive, wood-pulp paper.

Quantum foam see **topology**.

Quantum gravity the yet-to-be-discovered theory that unifies quantum field theory with the curved spacetime of general relativity.

Quantum mechanics the exact physics of the very small (atoms and things smaller).

Quantum theory any theory in which physical quantities are not continuous but rather assume their values in discrete jumps (the size of the jump is the *quantum*).

Recurrence paradox the claim that if you wait long enough, then every system will return to every previous state infinitely often.

Red dwarf small (less than about half a solar mass) star with a very long life (hundreds of times that of the Sun). They are 'cool' stars, with a surface temperature less than 4000 °C, and are thought to be the most common type of star in the universe.

Red shift the *down* shift in frequency of light received from all distant stars due to the Doppler effect induced by the expansion of the universe. The opposite effect is called a *blue shift*.

Reinterpretation principle asserts that negative mass-energy traveling forward in time is positive mass-energy traveling backward in time, and vice-versa.

Reissner-Nordström black hole a spherically symmetric, non-rotating electrically charged black hole.

Reversibility paradox based on the fact that the equations of physics contain no **arrow of time**; that is, they work equally well with time running forward or backward.

Roman ring a time machine made of two or more traversable wormholes connected in a closed sequence.

Schwarzschild black hole a spherically symmetric, non-rotating, uncharged black hole.

Self-consistency the assertion that the events on a closed **timelike** line must never be in contradiction; generally attributed to the Russian physicist Igor Novikov, who with his colleagues showed that it is not an independent assumption but rather an implication of the principle of **least action**.

Sexual paradox a special type of causal loop, where the connected events on a time loop are 'coupled' (pun intended!) through reproductive sex. An example is a time traveler to the past who becomes her own ancestor.

Singularity either a region in spacetime where the curvature becomes infinite and the laws of physics fail, or a point in spacetime beyond which world lines cannot be extended. Singularities of the first kind are called *curvature* or *crushing* singularities, and those of the second kind are called incomplete singularities. The **Big Bang** was a curvature singularity, as is the center of a black hole. In a **Schwarzchild black hole** the curvature singularity is a point, whereas in a **Kerr-Newman black hole** it is an extended region in the form of a ring.

Spacelike a world line on which propagating mass-energy would exceed the speed of light.

Spacetime the 'stuff' out of which reality is built. Everything there is—the universe—is the total collection of events in spacetime. A *flat* spacetime has no gravity, whereas a curved spacetime is the *origin* of gravity.

Special theory of relativity Einstein's theory of *flat* spacetime, which assumes that gravity is absent (gravity is the result of the geometry of *curved* spacetime). Its fundamental premise is that the laws of physics should appear the same to observers in different **inertial frames**.

Splitting universes the idea that every decision causes reality to split into separate copies, identical in every respect except for each of the different possible results of the decision.

Stargate science fiction name for the mouth of a traversable **wormhole**.

Stress-energy divergence the unbounded growth of the **general theory of relativity**'s measure of the density of mass-energy in spacetime.

Strong energy condition the claim that gravity is always (that is, locally) attractive. A traversable **wormhole** violates this condition.

Subluminal slower than light.

Superluminal faster than light.

Tachyon a particle (hypothetical, so far) that always travels faster than light, so its **world line** is always spacelike.

Temporally orientable spacetime any spacetime in which the direction of time at every point agrees with the direction of time at its local neighboring points.

Tensor mathematical generalization of the scalar and vector concepts. Einstein's **gravitational field equations** are tensor-differential equations (for example, the metric tensor contains information about the curvature of spacetime), whereas Newton's and Maxwell's equations are vastly less complex vector-differential equations.

Tidal force force experienced by a non-point mass (one with spatial extension) in a non-uniform gravitational field. Such forces tend simultaneously to compress and stretch spatially extended masses. Black holes and wormhole mouths can generate enormous tidal forces on extended masses as small as a human body. Interestingly, the *more* massive a black hole, the *less* severe its tidal forces are at distances outside the **event horizon**. However, no matter what the black hole mass is, the tidal forces are infinite at the central curvature **singularity**.

Time dilation the altering of the rate of timekeeping by a clock, either by motion or by gravity.

Time machine (in the weak sense) a machine able to traverse **closed timelike world lines** inherent in a spacetime (e.g., a rocket in Gödel spacetime) but unable to *create* such world lines; (in the strong sense) a machine able to manipulate mass-energy in a finite or compact region of spacetime in such a way as to *create* closed timelike world lines.

Time police story characters in science fiction charged with the (unnecessary!) job of preventing time travelers from changing the past.

Time warp science fiction name for a **time machine**.

Tipler cylinder an infinitely long cylinder, made of super-dense matter, rotating so fast around its long axis that it warps spacetime enough to create closed timelike lines that encircle the cylinder. It can be used as a strong sense time machine to travel both into the future and into the past (but *not* to a time before the creation of the cylinder).

Topology the structure of a *space* (including *spacetime*) without regard to a metric. That is, topology is concerned only with how a space is connected together and not with how far apart points in the space are. Topologists consider stretching or compressing a space to be irrelevant, just as long as one doesn't *tear* it and so put holes in the space. The simplest topology is that of a *simply connected* space, in which if you construct any closed surface that lies totally in the space around any point in the space, then every other point inside the surface is also in the space. A space with a hole in it fails this test, and so is said to be *multiply connected*. A *quantum foam* spacetime has a multiply connected topology. The classical spacetime of general relativity is simply connected *until* the appearance of wormholes.

Twin paradox the conclusion from special relativity that a clock's rate of time keeping slows with motion.

Ultraluminal motion sufficiently **superluminal** that mass-energy appears to travel backward in time (see also **Dirac radio**).

Uncertainty principle the statement in quantum mechanics that says certain pairs of quantities cannot simultaneously be measured with arbitrarily small error. The position and momentum of a particle are one such pair, and energy and time are another.

Vacuum fluctuation the particle/anti-particle creation and annihilation processes allowed, even empty space, by the **uncertainty principle** of quantum mechanics.

Warp drive science fiction name for the propulsion mechanism of a faster-than-light spaceship, now commonly used by physicists, too.

Weak energy condition the claim that the observed mass-energy density is always (locally) non-negative. Quantum mechanics predicts (and it has been experimentally confirmed) that there are exceptions.

White dwarf a burnt-out star with a mass less than 1.4 solar masses, of planetary size with a density up to 10^7 g/cm^3. The ultimate fate of our Sun.

World line the trajectory of mass-energy in spacetime.

Wormhole a spacetime structure (violating the **weak and strong energy conditions**, if traversable) connecting two points of the same spacetime (or even two *different* spacetimes) with a timelike path that requires less time to travel along than does a photon traveling *outside* the wormhole between the two points. A wormhole is *traversable* if it has no **event horizons**, and such wormholes can apparently be made into a **time machine** (sometimes called a *time tunnel*) using a time shift (see **time dilation**) between the two mouths of the wormhole *unless* quantum effects forbid time machines (still an open question).

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