The Physics of Time Travel

by Dr. Michio Kaku

In H.G. Wells' novel, The Time Machine, our protagonist jumped into a special chair with blinking lights, spun a few dials, and found himself catapulted several hundred thousand years into the future, where England has long disappeared and is now inhabited by strange creatures called the Morlocks and Eloi. That may have made great fiction, but physicists have always scoffed at the idea of time travel, considering it to be the realm of cranks, mystics, and charlatans, and with good reason. However, rather remarkable advances in quantum gravity are reviving the theory; it has now become fair game for theoretical physicists writing in the pages of Physical Review magazine. One stubborn problem with time travel is that it is riddled with several types of paradoxes. For example, there is the paradox of the man with no parents, i.e. what happens when you go back in time and kill your parents before you are born? Question: if your parents died before you were born, then how could you have been born to kill them in the first place? There is also the paradox of the man with no past. For example, let's say that a young inventor is trying futilely to build a time machine in his garage. Suddenly, an elderly man appears from nowhere and gives the youth the secret of building a time machine. The young man then becomes enormously rich playing the stock market, race tracks, and sporting events because he knows the future. Then, as an old man, he decides to make his final trip back to the past and give the secret of time travel to his youthful self. Question: where did the idea of the time machine come from?

There is also the paradox of the man who is own mother. (My apologies to Heinlein.) "Jane" is left at an orphanage as a foundling. When "Jane" is a teenager, she falls in love with a drifter, who abandons her but leaves her pregnant. Then disaster strikes. She almost dies giving birth to a baby girl, who is then mysteriously kidnapped. The doctors find that Jane is bleeding badly, but, oddly enough, has both sex organs. So, to save her life, the doctors convert "Jane" to "Jim."

"Jim" subsequently becomes a roaring drunk, until he meets a friendly bartender (actually a time traveler in disguise) who wisks "Jim" back way into the past. "Jim" meets a beautiful teenage girl, accidentally gets her pregnant with a baby girl. Out of guilt, he kidnaps the baby girl and drops her off at the orphanage. Later, "Jim" joins the time travelers corps, leads a distinguished life, and has one last dream: to disguise himself as a bartender to meet a certain drunk named "Jim" in the past. Question: who is "Jane's" mother, father, brother, sister, grand- father, grandmother, and grandchild?

Not surprisingly, time travel has always been considered impossible. After all, Newton believed that time was like an arrow; once fired, it soared in a straight, undeviating line. One second on the earth was one second on Mars. Clocks scattered throughout the universe beat at the same rate. Einstein gave us a much more radical picture. According to Einstein, time was more like a river, which meandered around stars and galaxies, speeding up and slowing down as it passed around massive bodies. One second on the earth was Not one second on Mars. Clocks scattered throughout the universe beat to their own distant drummer. However, before Einstein died, he was faced with an embarrassing problem. Einstein's neighbor at Princeton, Kurt Goedel, perhaps the greatest mathematical logician of the past 500 years, found a new solution to Einstein's own equations which allowed for time travel! The "river of time" now had whirlpools in which time could wrap itself into a circle. Goedel's solution was quite ingenious: it postulated a universe filled with a rotating fluid. Anyone walking along the direction of rotation would find themselves back at the starting point, but backwards in time!

In his memoirs, Einstein wrote that he was disturbed that his equations contained solutions that allowed for time travel. But he finally concluded: the universe does not rotate, it ex- pands (i.e. as in the Big Bang theory) and hence Goedel's solution could be thrown out for "physical reasons." (Apparently, if the Big Bang was rotating, then time travel would be possible throughout the universe!)

Then in 1963, Roy Kerr, a New Zealand mathematician, found a solution of Einstein's equations for a rotating black hole, which had bizarre properties. The black hole would not collapse to a point (as previously thought) but into a spinning ring (of neu- trons). The ring would be circulating so rapidly that centrifugal force would keep the ring from collapsing under gravity. The ring, in turn, acts like the Looking Glass of Alice. Anyone walking through the ring would not die, but could pass through the ring into an alternate universe. Since then, hundreds of other "wormhole" solutions have been found to Einstein's equations. These wormholes connect not only two regions of space (hence the name) but also two regions of time as well. In principle, they can be used as time machines. Recently, attempts to add the quantum theory to gravity (and hence create a "theory of everything") have given us some insight into the paradox problem. In the quantum theory, we can have multiple states of any object. For example, an electron can exist simultaneously in different orbits (a fact which is responsible for giving us the laws of chemistry). Similarly, Schrodinger's famous cat can exist simultaneously in two possible states: dead and alive. So by going back in time and altering the past, we merely create a parallel universe. So we are changing someone ELSE's past by saving, say, Abraham Lincoln from being assassinated at the Ford Theater, but our Lincoln is still dead. In this way, the river of time forks into two separate rivers. But does this mean that we will be able to jump into H.G. Wells' machine, spin a dial, and soar several hundred thousand years into England's future? No. There are a number of difficult hurdles to overcome.

First, the main problem is one of energy. In the same way that a car needs gasoline, a time machine needs to have fabulous amounts of energy. One either has to harness the power of a star, or to find something called "exotic" matter (which falls up, rather than down) or find a source of negative energy. (Physicists once thought that negative energy was impossible. But tiny amounts of negative energy have been experimentally verified for something called the Casimir effect, i.e. the energy created by two parallel plates). All of these are exceedingly difficult to obtain in large quantities, at least for several more centuries! Then there is the problem of stability. The Kerr black hole, for example, may be unstable if one falls through it. Similarly, quantum effects may build up and destroy the wormhole before you enter it. Unfortunately, our mathematics is not powerful enough to answer the question of stability because you need a "theory of everything" which combines both quantum forces and gravity. At present, superstring theory is the leading candidate for such a theory (in fact, it is the ONLY candidate; it really has no rivals at all). But superstring theory, which happens to be my specialty, is still to difficult to solve completely. The theory is well-defined, but no one on earth is smart enough to solve it.

Interestingly enough, Stephen Hawking once opposed the idea of time travel. He even claimed he had "empirical" evidence against it. If time travel existed, he said, then we would have been visited by tourists from the future. Since we see no tourists from the future, ergo: time travel is not possible. Because of the enormous amount of work done by theoretical physicists within the last 5 years or so, Hawking has since changed his mind, and now believes that time travel is possible (although not necessarily practical). (Furthermore, perhaps we are simply not very interesting to these tourists from the future. Anyone who can harness the power of a star would consider us to be very primitive. Imagine your friends coming across an ant hill. Would they bend down to the ants and give them trinkets, books, medicine, and power? Or would some of your friends have the strange urge to step on a few of them?)

In conclusion, don't turn someone away who knocks at your door one day and claims to be your future great-great-great grandchild. They may be right.