CHAPTER 10

WORMHOLES AND TIME TRAVEL

The last chapter discussed why we see time go forward: why disorder increases and why we remember the past but not the future. Time was treated as if it were a straight railway line on which one could only go one way or the other.

But what if the railway line had loops and branches so that a train could keep going forward but come back to a station it had already passed? In other words, might it be possible for someone to travel into the future or the past?

H. G. Wells in *The Time Machine* explored these possibilities as have countless other writers of science fiction. Yet many of the ideas of science fiction, like submarines and travel to the moon, have become matters of science fact. So what are the prospects for time travel?

The first indication that the laws of physics might really allow people to travel in time came in 1949 when Kurt Godel discovered a new space-time allowed by general relativity. Godel was a mathematician who was famous for proving that it is impossible to prove all true statements, even if you limit yourself to trying to prove all the true statements in a subject as apparently cut and dried as arithmetic. Like the uncertainty principle, Godel's incompleteness theorem may be a fundamental limitation on our ability to understand and predict the universe, but so far at least it hasn't seemed to be an obstacle in our search for a complete unified theory.

Godel got to know about general relativity when he and Einstein spent their later years at the Institute for Advanced Study in Princeton. His space-time had the curious property that the whole universe was rotating. One might ask: "Rotating with respect to what?" The answer is that distant matter would be rotating with respect to directions that little tops or gyroscopes point in.

This had the side effect that it would be possible for someone to go off in a rocket ship and return to earth before he set out. This property really upset Einstein, who had thought that general relativity wouldn't allow time travel. However, given Einstein's record of ill-founded opposition to gravitational collapse and the uncertainty principle, maybe this was an encouraging sign. The solution Godel found doesn't correspond to the universe we live in because we can show that the universe is not rotating. It also had a non-zero value of the cosmological constant that Einstein introduced when he thought the universe was unchanging. After Hubble discovered the expansion of the universe, there was no need for a cosmological constant and it is now generally believed to be zero. However, other more reasonable space-times that are allowed by general relativity and which permit travel into the past have since been found. One is in the interior of a rotating black hole. Another is a space-time that contains two cosmic strings moving past each other at high speed. As their name suggests, cosmic strings are objects that are like string in that they have length but a tiny cross section. Actually, they are more like rubber bands because they are under enormous tension, something like a million million million million tons. A cosmic string attached to the earth could accelerate it from 0 to 60 mph in 1/30th of a second. Cosmic strings may sound like pure science fiction but there are reasons to believe they could have formed in the early universe as a result of symmetry-breaking of the kind discussed in Chapter 5. Because they would be under enormous tension and could start in any configuration, they might accelerate to very high speeds when they straighten out.

The Godel solution and the cosmic string space-time start out so distorted that travel into the past was always possible. God might have created such a warped universe but we have no reason to believe he did. Observations of the microwave background and of the abundances of the light elements indicate that the early universe did not have the kind of curvature required to allow time travel. The same conclusion follows on theoretical grounds if the no boundary proposal is correct. So the question is: if the universe starts out without the kind of curvature required for time travel, can we subsequently warp local regions of space-time sufficiently to allow it?

A closely related problem that is also of concern to writers of science fiction is rapid interstellar or intergalactic travel. According to relativity, nothing can travel faster than light. If we therefore sent a spaceship to our nearest neighboring star, Alpha Centauri, which is about four light-years away, it would take at least eight years before we could expect the travelers to return and tell us what they had found. If the expedition were to the center of our galaxy, it would be at least a hundred thousand years before it came back. The theory of relativity does allow one consolation. This is the so-called twins paradox mentioned in Chapter 2.

Because there is no unique standard of time, but rather observers each have their own time as measured by clocks that they carry with them, it is possible for the journey to seem to be much shorter for the space travelers than for those who remain on earth. But there would not be much joy in returning from a space voyage a few years older to find that everyone you had left behind was dead and gone thousands of years ago. So in order to have any human interest in their stories, science fiction writers had to suppose that we would one day discover how to travel faster than light. What most of thee authors don't seem to have realized is that if you can travel faster than light, the theory of relativity implies you can also travel back in the, as the following limerick says:

There was a young lady of Wight
Who traveled much faster than light.
She departed one day,
In a relative way,
And arrived on the previous night

The point is that the theory of relativity says hat there is no unique measure of time that all observers will agree on Rather, each observer has his or her own measure of time. If it is possible for a rocket traveling below the speed of light to get from event A (say, the final of the 100-meter race of the Olympic Games in 202) to event B (say, the opening of the 100,004th meeting of the Congress of Alpha Centauri), then all observers will agree that event A happened before event B according to their times. Suppose, however, that the spaceship would have to travel faster than light to carry the news of the race to the Congress. Then observers moving at different speeds can disagree about whether event A occurred before B or vice versa. According to the time of an observer who is at rest with respect to the earth, it may be that the Congress opened after the race. Thus this observer would think that a spaceship could get from A to B in time if only it could ignore the speed-of-light speed limit. However, to an observer at Alpha Centauri moving away from the earth at nearly the speed of light, it would appear that event B, the opening of the Congress, would occur before event A, the 100-meter race. The theory of relativity says that the laws of physics appear the same to observers moving at different speeds.

This has been well tested by experiment and is likely to remain a feature even if we find a more advanced theory to replace relativity Thus the moving observer would say that if faster-than-light travel is possible, it should be possible to get from event B, the opening of the Congress, to event A, the 100-meter race. If one went slightly faster, one could even get back before the race and place a bet on it in the sure knowledge that one would win.

There is a problem with breaking the speed-of-light barrier. The theory of relativity says that the rocket power needed to accelerate a spaceship gets greater and greater the nearer it gets to the speed of light. We have experimental evidence for this, not with spaceships but with elementary particles in particle accelerators like those at Fermilab or CERN (European Centre for Nuclear Research). We can accelerate particles to 99.99 percent of the speed of light, but however much power we feed in, we can't get them beyond the speed-of-light barrier. Similarly with spaceships: no matter how much rocket power they have, they can't accelerate beyond the speed of light.

That might seem to rule out both rapid space travel and travel back in time. However, there is a possible way out. It might be that one could warp space-time so that there was a shortcut between A and B One way of doing this would be to create a wormhole between A and B. As its name suggests, a wormhole is a thin tube of space-time which can connect two nearly flat regions far apart.

There need be no relation between the distance through the wormhole and the separation of its ends in the nearly Hat background. Thus one could imagine that one could create or find a wormhole that world lead from the vicinity of the Solar System to Alpha Centauri. The distance through the wormhole might be only a few million miles even though earth and Alpha Centauri are twenty million million miles apart in ordinary space. This would allow news of the 100-meter race to reach the opening of the Congress. But then an observer moving toward 6e earth should also be able to find another wormhole that would enable him to get from the opening of the Congress on Alpha Centauri back to earth before the start of the race. So wormholes, like any other possible form of travel faster than light, would allow one to travel into the past.

The idea of wormholes between different regions of space-time was not an invention of science fiction writers but came from a very respectable source.

In 1935, Einstein and Nathan Rosen wrote a paper in which they showed that general relativity allowed what they called “bridges,” but which are now known as wormholes. The Einstein-Rosen bridges didn’t last long enough for a spaceship to get through: the ship would run into a singularity as the wormhole pinched off. However, it has been suggested that it might be possible for an advanced civilization to keep a wormhole open. To do this, or to warp space-time in any other way so as to permit time travel, one can show that one needs a region of space-time with negative curvature, like the surface of a saddle. Ordi-nary matter, which has a positive energy density, gives space-time a positive curvature, like the surface of a sphere. So what one needs, in order to warp space-time in a way that will allow travel into the past, is matter with negative energy density.

Energy is a bit like money: if you have a positive balance, you can distribute it in various ways, but according to the classical laws that were believed at the beginning of the century, you weren’t allowed to be overdrawn. So these classical laws would have ruled out any possibility of time travel. However, as has been described in earlier chapters, the classical laws were superseded by quantum laws based on the uncertainty principle. The quantum laws are more liberal and allow you to be overdrawn on one or two accounts provided the total balance is positive. In other words, quantum theory allows the energy density to be negative in some places, provided that this is made up for by positive energy densities in other places, so that the total energy re-mains positive. An example of how quantum theory can allow negative energy densities is provided by what is called the Casimir effect. As we saw in Chapter 7, even what we think of as “empty” space is filled with pairs of virtual particles and antiparticles that appear together, move apart, and come back together and annihilate each other. Now, suppose one has two parallel metal plates a short distance apart. The plates will act like mirrors for the virtual photons or particles of light. In fact they will form a cavity between them, a bit like an organ pipe that will resonate only at certain notes. This means that virtual photons can occur in the space between the plates only if their wavelengths (the distance between the crest of one wave and the next) fit a whole number of times into the gap between the plates. If the width of a cavity is a whole number of wavelengths plus a fraction of a wave-length, then after some reflections backward and forward between the plates, the crests of one wave will coincide with the troughs of another and the waves will cancel out.

Because the virtual photons between the plates can have only the resonant wavelengths, there will be slightly fewer of them than in the region outside the plates where virtual photons can have any wavelength. Thus there will be slightly fewer virtual photons hitting the inside surfaces of the plates than the outside surfaces. One would therefore expect a force on the plates, pushing them toward each other. This force has actually been detected and has the predicted value. Thus we have experimental evidence that virtual particles exist and have real effects.

The fact that there are fewer virtual photons between the plates means that their energy density will be less than elsewhere. But the total energy density in “empty” space far away from the plates must be zero, because otherwise the energy density would warp the space and it would not be almost flat. So, if the energy density between the plates is less than the energy density far away, it must be negative.

We thus have experimental evidence both that space-time can be warped (from the bending of light during eclipses) and that it can be curved in the way necessary to allow time travel (from the Casimir effect). One might hope therefore that as we advance in science and technology, we would eventually manage to build a time machine. But if so, why hasn’t anyone come back from the future and told us how to do it? There might be good reasons why it would be unwise to give us the secret of time travel at our present primitive state of development, but unless human nature changes radically, it is difficult to believe that some visitor from the future wouldn’t spill the beans. Of course, some people would claim that sightings of UFOs are evidence that we are being visited either by aliens or by people from the future. (If the aliens were to get here in reasonable time, they would need faster-than-light travel, so the two possibilities may be equivalent.)

However, I think that any visit by aliens or people from the future would be much more obvious and, probably, much more unpleasant. If they are going to reveal themselves at all, why do so only to those who are not regarded as reliable witnesses? If they are trying to warn us of some great danger, they are not being very effective.

A possible way to explain the absence of visitors from the future would be to say that the past is fixed because we have observed it and seen that it does not have the kind of warping needed to allow travel back from the future. On the other hand, the future is unknown and open, so it might well have the curvature required. This would mean that any time travel would be confined to the future. There would be no chance of Captain Kirk and the Starship *Enterprise* turning up at the present time.

This might explain why we have not yet been overrun by tourists from the future, but it would not avoid the problems that would arise if one were able to go back and change history. Suppose, for example, you went back and killed your great-great-grandfather while he was still a child. There are many versions of this paradox but they are essentially equivalent: one would get contradictions if one were free to change the past.

There seem to be two possible resolutions to the paradoxes posed by time travel. One I shall call the consistent histories approach. It says that even if space-time is warped so that it would be possible to travel into the past, what happens in space-time must be a consistent solution of the laws of physics. According to this viewpoint, you could not go back in time unless history showed that you had already arrived in the past and, while there, had not killed your great-great-grandfather or committed any other acts that would conflict with your current situation in the present. Moreover, when you did go back, you wouldn't be able to change recorded history. That means you wouldn't have free will to do what you wanted. Of course, one could say that free will is an illusion anyway. If there really is a complete unified theory that governs everything, it presumably also determines your actions. But it does so in a way that is impossible to calculate for an organism that is as complicated as a human being. The reason we say that humans have free will is because we can't predict what they will do. However, if the human then goes off in a rocket ship and comes back before he or she set off, we *will* be able to predict what he or she will do because it will be part of recorded history. Thus, in that situation, the time traveler would have no free will.

The other possible way to resolve the paradoxes of time travel might be called the alternative histories hypothesis. The idea here is that when time travelers go back to the past, they enter alternative histories which differ from recorded history. Thus they can act freely, without the constraint of consistency with their previous history. Steven Spiel-berg had fun with this notion in the *Back to the Future* films: Marty McFly was able to go back and change his parents' courtship to a more satisfactory history.

The alternative histories hypothesis sounds rather like Richard Feynman's way of expressing quantum theory as a sum over histories, which was described in Chapters 4 and 8. This said that the universe didn't just have a single history: rather it had every possible history, each with its own probability. However, there seems to be an important difference between Feynman's proposal and alternative histories. In Feynman's sum, each history comprises a complete space-time and everything in it. The space-time may be so warped that it is possible to travel in a rocket into the past. But the rocket would remain in the same space-time and therefore the same history, which would have to be consistent. Thus Feynman's sum over histories proposal seems to support the consistent histories hypothesis rather than the alternative histories.

The Feynman sum over histories *does* allow travel into the past on a microscopic scale. In Chapter 9 we saw that the laws of science are unchanged by combinations of the operations C, P, and T. This means that an antiparticle spinning in the anticlockwise direction and moving from A to B can also be viewed as an ordinary particle spinning clockwise and moving backward in time from B to A. Similarly, an ordinary particle moving forward in time is equivalent to an antiparticle moving backward in time. As has been discussed in this chapter and Chapter 7, "empty" space is filled with pairs of virtual particles and antiparticles that appear together, move apart, and then come back together and annihilate each other.

So, one can regard the pair of particles as a single particle moving on a closed loop in space-time. When the pair is moving forward in time (from the event at which it appears to that at which it annihilates), it is called a particle. But when the particle is traveling back in time (from the event at which the pair annihilates to that at which it appears), it is said to be an antiparticle traveling forward in time.

The explanation of how black holes can emit particles and radiation (given in Chapter 7) was that one member of a virtual particle/ antiparticle pair (say, the antiparticle) might fall into the black hole, leaving the other member without a partner with which to annihilate. The forsaken particle might fall into the hole as well, but it might also escape from the vicinity of the black hole. If so, to an observer at a distance it would appear to be a particle emitted by the black hole.

One can, however, have a different but equivalent intuitive picture of the mechanism for emission from black holes. One can regard the member of the virtual pair that fell into the black hole (say, the antiparticle) as a particle traveling backward in time out of the hole. When it gets to the point at which the virtual particle/antiparticle pair appeared together, it is scattered by the gravitational field into a particle traveling forward in time and escaping from the black hole. If, instead, it were the particle member of the virtual pair that fell into the hole, one could regard it as an antiparticle traveling back in time and coming out of the black hole. Thus the radiation by black holes shows that quantum theory allows travel back in time on a microscopic scale and that such time travel can produce observable effects.

One can therefore ask: does quantum theory allow time travel on a macroscopic scale, which people could use? At first sight, it seems it should. The Feynman sum over histories proposal is supposed to be over *all* histories. Thus it should include histories in which space-time is so warped that it is possible to travel into the past. Why then aren't we in trouble with history? Suppose, for example, someone had gone back and given the Nazis the secret of the atom bomb?

One would avoid these problems if what I call the chronology protection conjecture holds. This says that the laws of physics conspire to prevent *macroscopic* bodies from carrying information into the past. Like the cosmic censorship conjecture, it has not been proved but there are reasons to believe it is true.

The reason to believe that chronology protection operates is that when space-time is warped enough to make travel into the past possible, virtual particles moving on closed loops in space-time can become real particles traveling forward in time at or below the speed of light. As these particles can go round the loop any number of times, they pass each point on their route many times. Thus their energy is counted over and over again and the energy density will become very large. This could give space-time a positive curvature that would not allow travel into the past. It is not yet clear whether these particles would cause positive or negative curvature or whether the curvature produced by some kinds of virtual particles might cancel that produced by other kinds. Thus the possibility of time travel remains open. But I'm not going to bet on it. My opponent might have the unfair advantage of knowing the future.

PREVIOUS NEXT