Contra Time Machines

N C Thomas, C Eng, MIET

Introduction

The possibility that time machines could be constructed is taken seriously by the physics community, although the resultant paradoxes cause unease to many. This depends critically upon two assumptions:

> that time is a dimension alongside the three familiar spatial dimensions;
>
> that time dilation predicted by Special Relativity and verified experimentally implies time itself is affected by relative velocity;

In this article both these assumptions will be challenged without thereby invalidating what is physically essential in the Special and General Theories of Relativity. The result is that time machines are not possible in the sense usually envisaged.

Special Relativity

Albert Einstein developed his Special Theory of Relativity to meet two requirements or postulates:

> Physical laws should be invariant with respect to uniform rectilinear motion
>
> The velocity of light is constant *in vacuo* for all observers regardless of their state of motion

The first says that the laws of physics should not be affected by uniform relative motion, so that the behaviour of a pendulum, for example, should be governed by the same physical factors and the same mathematical equation relating them in all inertial systems i.e. systems in uniform rectilinear motion. Other examples are that we do not expect the law of conservation of energy to be correct in only one reference system, we do not expect fluids to become gases just because their containers are in relative motion, and so on. In short there is no absolute reference system for which the laws take their simplest form: they have that form in all inertial reference systems. Another way of saying this is that we do not expect Nature to be affected by the way we describe her (mathematically). Einstein himself said that he would find it "distasteful" were it otherwise (Reference 1).

The second requirement was adopted for a number of reasons, some theoretical and at least one experimental. In the 19th Century it was supposed that light waves must have a "bearer" medium analogous to the fact that waves in water, for example, must have water to bear them. This bearer or medium was called the *ether*, which was supposed to pervade all space and to have suspiciously ideal physical properties. Michaelson and Morley carried out a famous experiment in the 19th Century to detect the movement of the Earth through the ether, but obtained a null result: no such movement was detected. While there may be a number of interpretations of this remarkable result, the concensus from Einstein onwards is that there is no ether and that the velocity of light *in vacuo* is the same regardless of the state of motion of an inertial observer. Its velocity is supposed to be reduced when travelling through a medium such as air or glass, and the phenomenon of refraction is explained on that basis.

Einstein developed a set of equations governing the relative movement of inertial systems which satisfy the two postulates. They are essentially rooted in *tensors*, which are special mathemematical entities that permit laws to be expressed in a form that does not depend upon the coordinates of space and time used. For example we may select as our coordinate system the position of an object relative to London so that one measurement is along a line (an axis) running north/south through London, another axis is east/west and the third vertically up and down. Together with time we then have a coordinate system. Or we may choose to centre our system in the Sun, at the centre of gravity of the Solar System, with one axis through the vernal equinox, one at right angles to that in the Ecliptic, and the third at right angles to the Ecliptic. Again, together with time we have an equally valid coordinate system. Should Nature make her laws depend upon which of these two systems (or any other) that we select? Einstein thought not, which is the basis of the first postulate above, and tensors are a terse and elegant way of expressing that fact.

As an aside, a problem with London is that the Earth is rotating, so strictly speaking such a coordinate system is not inertial, but as it is very hard to find a familiar example we let that example illustrate broadly what is involved. The Sun based system is not exactly inertial either as the Solar System is moving round the centre of our galaxy rather than on a straight line. So the concept of an inertial system is abstract and it is hard to find one in practice. When General Relativity is taken into account this problem is actually eased because it handles acceleration as well as uniform rectilinear motion.

The tensor equations may be cast into a more transparent form, and for example that governing how velocities should be added is

$$v=\frac{v_1+v_2}{1+\frac{v_1 v_2}{c^2}}$$

where v_1 and v_2 are the velocities of two objects relative to an observer, c is the velocity of light and v is the relative velocity of the two objects as measured by the observer. Thus if $v_1 = c$ or $v_2 = c$ (or both) than $v = c$, showing how the second postulate is satisfied. Of course the two objects are travelling along the same straight line in this example, but it is readily adapted for other cases. c is an upper limit which cannot be exceeded, or even reached by massive objects.

Now suppose an observer A has a relative velocity v with respect to another observer B, and each observes an event E. Einstein showed (Reference 1 for an accessible account) that if E occurs at a distance x from A at a time t, then the distance x' of E from B in its own coordinate system is given by

$$x'=\frac{x-vt}{\sqrt{1-\frac{v^2}{c^2}}}$$

where t is the time since A and B coincided. The time t' of the event for B is given by

$$t'=\frac{t-\frac{v}{c^2}x}{\sqrt{1-\frac{v^2}{c^2}}}$$

which contrasts strongly with our intuition that t=t'. These two equations were actually first derived by Hendrik Antoon Lorentz in 1904, but Einstein gave a convincing rationale for them.

Suppose now that the event is the moment when a pendulum at rest with respect to A is at the bottom of its swing, and that it has a peroid T as seen by A, so that for A two successive such events occur at times *t* and *t+T*, the time difference trivially being calculated as (*t+T*)-*t*=*T*. For B the time difference is

$$T' = \frac{t+T-\frac{v}{c^2}x}{\sqrt{1-\frac{v^2}{c^2}}} - \frac{t-\frac{v}{c^2}x}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{T}{\sqrt{1-\frac{v^2}{c^2}}}$$

i.e. *T'* > *T* so that the pendulum appears to be swinging more slowly for B. If that pendulum is part of a clock then the clock appears to tick more slowly. The above calculation applies to all cyclic or rhythmic processes, including any type of clock, biological processes and so on. Thus a person's heart will appear to beat more slowly too, and if *v=c* it will appear to stop altogether as *T'* becomes infinite. This is the basis of the famous twins paradox, where one twin remains on Earth and the other travels away at a velocity close to *c*, and thus appears to age much more slowly. The catch is that if the travelling twin reverses his velocity <u>the same happens on the return journey</u>, for then we have

$$T' = \frac{t+T+\frac{v}{c^2}x}{\sqrt{1-\frac{v^2}{c^2}}} - \frac{t+\frac{v}{c^2}x}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{T}{\sqrt{1-\frac{v^2}{c^2}}}$$

i.e. as before clocks also tick more slowly. This contrasts with the Doppler shift, illustrating that the two phenomena are quite distinct. Thus on his return it seems that the much-travelled twin will be younger than the stay-at-home one. The paradox here is that the travelled twin should observe the other aging more slowly in an analogous way, so that in the end they should not differ in age. This has been the subject of much heated debate! See e.g. Reference 2. However sticking to Special Relativity is insufficient to describe the whole affair, as the travelled twin is not in an inertial reference frame!!! Why this simple fact is so often ignored is a mystery to the author. For accelerations are involved to set off, reverse velocity, and slow down at the end. General Relativity is required to account for the effects of acceleration (the paradox is resolved on this basis in Reference 3).

Time

We will now take issue with a conclusion Einstein drew from this which we claim need not be true. He said that because clocks tick more slowly <u>therefore time itself slows down</u>. However his equations do not show that, what they do show is that cyclic and rhythmic processes are slowed down, which has been thoroughly verified e.g. by the extended apparent lifetimes of muons in the atmosphere. It no more follows as a logical necessity that time is slowed down than that it would be if we simply lengthened the pendulum of a clock to make it tick more slowly. Clocks do not determine time! That would be the proverbial tail wagging the dog. This may seem like a merely philosophical point, but whatever label is attached to it, it is a very important point. It is intimately connected with the notion that time is a dimension which we travel through, somewhat analogously to the fact that we may travel through a spatial dimension. That the variable t enters into all equations involving motion appears to justify that notion, and physicists speak of space-time as a four-dimensional continuum. Einstein wrote that there is no essential difference between these four dimensions and that time only seems different to our kind of consciousness.

Returning to the experimental confirmation of time dilation provided by the extended life of μ mesons, these particles have a half life of 1.53×10^{-6} seconds. Experiments indicated that more muons arising from cosmic rays entering the atmosphere arrived at the surface of the Earth than would be expected based on that half life. In fact the half life was about 9 times its laboratory value due to time dilation (Reference 3). Now the half life results from processes in the muon that lead it to decay, and if those processes are slowed down then it will have a longer half life. We do not have to conclude that time itself slows down in the muon rest frame.

But is time really a dimension? Is there any evidence for that? What we know is that we require a variable t in order to calculate velocity and other variable quantities, and that it seems that t is steadily increasing. It does not really matter whether it increases steadily or not as it is the yardstick for change. If it increases in some other way, how would we know? By means of another dimension? This requires us to move on to General Relativity.

General Relativity

Obviously it would take too long to give a full account of this here (see Reference 4 for a useful account), but something is needed if we are to discuss time travel. Einstein pointed out that there is no physical experiment that could exhibit the fact that one is undergoing a rectilinear translation, and in his example a person in a closed box travelling uniformly along could not determine that fact. For example a pendulum would not reveal it for the reasons we have already seen: its laws are the same in all inertial reference systems. However if you are sitting in an aircraft and it starts doing aerobatics you certainly know who is accelerating, and even if you are a bit slow on the uptake, your stomach is not! This is why Special Relativity only considers inertial reference systems. Now the first postulate of Special Relativity was

> Physical laws should be invariant with respect to uniform rectilinear motion

Surely we should not stop there! We would like to say something like

> Physical laws should be invariant in all reference systems

But then we must somehow explain the situation in the above aircraft. This is exactly what Einstein did, as follows. Returning to his closed box, suppose you are in such a box and unknown to you it is being pulled along in empty space by a rope (we'd better not ask just how!) such that it is undergoing a uniform acceleration of 1g. If again you observe the motion of a pendulum in the box it will behave exactly as it would on the surface of the Earth i.e. you could not tell whether you were being accelerated or were in a gravitational field. Einstein then postulated that there is no difference. In other words gravity and acceleration are equivalent in all respects. The mathematics required to capture this idea is beautiful and difficult, based again on tensors for the reasons explained before. What emerges is that space-time is curved both by gravity and by acceleration. This curvature is exhibited by the fact that light does not travel on a straight line in the presence either of a gravitational field or an acceleration. In the accelerated closed box a photon travelling across the box on a path starting e.g. at right angles to the direction of motion will follow a curved path. The idea was verified by Sir Arthur Eddington and others in 1918 during an eclipse of the Sun, when stars seen close to the perimeter were displaced outwards compared with their normal positions. Also an anomalous precession of the perihelion of the planet Mercury, previously unaccounted for, could be explained by the equations of motion given by General Relativity. Furthemore the elliptic orbits of the planets round the Sun could be shown to arise from the curvature of space caused by the intense gravitational field of the Sun. Many tests of both Special and General Relativity have corroborated them. (Indeed no falsifying experiment is known to the author, although the entanglement of photons in Alain Aspect's experiment in 1982 to test Bell's inequality seems to approach that. It is said that no signal could be transmitted faster than light by that means, the point being that permanent observation of the polarisation awaiting its determination at the other end is not possible, and otherwise it is not possible to know when to test that it has been determined by an observation at the other end without receiving some other signal to say so. But it remains true that the determination of the polarisation has been transmitted faster than light, even if that is not practically usable).

So far so good. What about an object falling vertically downwards towards the Earth, does it not follow a straight line? For the point now to be made, we ignore the movement of the Earth round the Sun, and of the Solar System in our galaxy, which would suggest otherwise. The line is then straight relative to the Earth, and certainly would be were the Earth alone in the universe. So where is the curvature? It lies in the fact that the object is accelerating, following a curved *world line*, which is a special line in space-time. *Geodesics* are, in a curved space, the equivalent of straight lines in a flat space. On the surface of the Earth, for example, the geodesics are (ideally) great circles. General Relativity says that objects follow geodesics in space-time, which replaces Newton's First Law that an object remains in a state of rest or of uniform motion unless acted upon by an impressed force. There are, in curved space-time, so-called *null geodesics* which have zero length. There are no such geodesics in a flat three-dimensional space, but when time is included as if it were a dimension then there are such entities, and they are of great importance. For light travels along null geodesics. This is what distinguishes light (and other radiation) from massive objects.

Thus every object is moving on a world line which is a geodesic, the planets on their (roughly) elliptic geodesics being examples. More accurately, an object *is* a world line, for the movement is only apparent according to this view, since it only arises when one dimension is taken as the reference for change in the others, that dimension being time. We cannot speak of a space-time movement without invoking some other reference, such as yet another time-like dimension. For movement, indeed any kind of change, requires a time-like reference. The conclusion is that the universe is a static assemblage of world lines: change is only apparent as an artefact of our consciousness (according to Einstein). If the universe is to evolve, expanding as is supposed, and is not static then the world lines must be developing and changing as it evolves. But then, as we have seen, we need another reference dimension. So we end up with an infinite regress, for then we will have a five dimensional universe which is in its way static, with more complex world lines, or else undergoing change requiring a sixth reference dimension, and so on. We are left with two broad alternatives: if time is a dimension then we must accept a static universe, or else we must renounce the assumption that time is a dimension in order to evade the infinite regress.

The fact that Relativity has not so far been satisfactority combined with quantum physics, even by superstring theory, and that the mathematical concept of chaos has become respectable and unavoidable, suggests that the static universe view is incorrect. If we accept that conclusion then we must renounce the assumption that time is a dimension. This does not invalidate the experimental evidence in favour of Special and General Relativity, for it is clear that processes do slow down for moving objects and that light does follow curved paths in gravitational fields. The variable t is needed and is part of the mathematical descriptions given by physics. But we now claim that t is not a measurement of a coordinate in a dimension. Whatever time is, it is not a dimension, but it is a reference entity.

It is instructive to review the use made of the Lorentz equations to calculate T' for a pendulum. The essential conclusions of Relativity depend upon differences, where we had the difference between $(t+T)$ and t, and similarly for T'. Einstein insisted that he had swept away the notion of absolute time, so that t should never enter our equations in that guise. We used t as the time elapsed since the two observer reference frames A and B were coincident, so that it too was really also a difference in that case. This is why cyclic and rhythmic processes are readily described and understood *vis-a-vis* time dilation. But if t never arises other than in time differences, then it does not truly play the role of a coordinate. Time, it seems, measures process rates rather than coordinate positions.

Thus if we consider an object approaching the event horizon of a black hole, for example, we can well say that on-board processes will appear to slow down for outside observers, without the need to add that time slows down.

> *Physical observations can never distinguish between those two views.*

In which case there is no empirical case for saying that time itself “slows down”. We lose nothing essential from our conclusion, other than time machines.

The Light Cone

Since no physical effect is supposed to be propagated faster than the speed of light, a three dimensional hypercone in four-dimensional space-time is envisaged with its vertex at an observer such that its surface demarcates objects causally connected with that observer from those that are not. Objects outside the cone are separated from the observer by space-like intervals, those inside it by time-like intervals. Light is taken to be the demarcator between these types of interval as it travels along null-geodesics in the surface of the cone. It is then assumed by some (e.g. Reference 5) that if we could travel faster than light we would violate the demarcation of the light cone and travel backwards in time, as though overtaking light affects time itself. We would then see the past when light catches up with us as if we were actually there i.e. back in time. This forgets that the light has left the scene of the events that could thus be viewed. It is discussed because light has been slowed down in the laboratory almost to a stop, suggesting theoretically that something could then overtake it. It also relies on the assumption that velocity affects time itself, which we deny.

Wormholes and Time Machines

It has been claimed (e.g. Reference 5) that somebody travelling at near light speed “time travels into the future” due to Einstein's equations. Well, if one were willing to concede that somebody in cryogenic sleep for 100 years has time-travelled when unthawed, that loose statement could be accepted. But that interpretation is emphatically not the kind of time travel envisaged e.g. by H.G. Wells in his novel *The Time Machine*. There it is supposed that one may travel through time analogously to travelling along a space dimension. The distinction is very important if the physical possibility of time travel is to be assessed. Our interpretation of time dilation as the slowing down of physical processes rather than a slowing down of time itself leaves the conclusions drawn from Einstein's equations unaffected, as we have already said. But it denies that time travel has thereby occurred in the sense of H.G. Wells. We will now turn to claims that time travel into the past is physically possible, with all the paradoxes and problems that would then arise.

Since space-time may be curved, it follows from General Relativity that it is possible to alter the topology of space-time to include “tunnels” across space-time, like short-cuts from one world location to another. These tunnels are called wormholes, linking two locations in a non-causal manner, and it is supposed that time travel into the past could be accomplished by means of them. This is because time is assumed to be a dimension so that the radical time dilations involved would produce time travel. The catch is that enormous energy is required to create them, as may appreciated by noting that the large mass of the Sun only caused a deviation in the path of light by a fraction of a second of arc in Eddington's observations in 1918. The energy required to roll up a worm hole is thus seriously huge and should give rise to an enormous inertia (as indeed superstrings should have an enormous inertia).

If time is not in fact a dimension then Wells-style time travel is not in question, and the concept of wormholes needs re-interpreting. This demands that we re-interpret the meaning of space-time curvature. What would be observed physically is that light (and other radiation) and physical objects would follow curved paths in space accompanied by alteration in the expected frequencies of processes (clocks etc.). This is what the equations actually predict physically. But processes may alter their rates without that implying time itself is going faster or slower, as we have already noted. It is just time that is the yardstick for rates of change, not *vice-versa*. Then a wormhole would radically deviate the paths travelled by radiation and objects in its vicinity, and also the frequencies of processes. The fact that processes at one end are much slower than at the other does not constitute time travel if we adopt the above physical interpretation of the equations. I cannot murder my grandfather by making my clock go backwards very rapidly, for I remain causally disconnected from him. Likewise a wormhole, if such existed, would not have acausal implications just because it radically altered the rates of change of physical processes at one or both ends.

Many Worlds Hypothesis

The many-worlds hypothesis is not considered as a solution of the time-travel problem because it violates the conservation of energy i.e. if parallel universes arise as the result of a quantum interaction where does the vast amount of energy come from to create them? This problem is severe considering the large number of interactions continuously occurring across the whole universe.

Conclusion

In conclusion we are saying that physical processes obey Einstein's equations without the implication that time itself is affected, and that time is not a dimension. Genuine Wells-style time travel is not in question.

References

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