What is time? Answers from modern physics

Prof. Lorenzo Maccone – Univ. di Pavia

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Questions and Answers

1) I know that in maths we are able to describe a surface without having it in a coordinate system, but just using the surface itself, why can't we describe time in a similar way, using just the properties of time?

We certainly can: General relativity can be expressed in a coordinate independent way using the formalism of mathematical forms (see the "Gravitation" book of Misner, Thorne, Wheeler for an introductory account of that). We cannot use this approach to describe time in a coordinate-independent way because time is a COMPONENT of a four-vector. So a form can describe events (spacetime points), but not time by itself.

2) Because simultaneity is relative, does that mean we can perceive the future of a person before that person experiences it?

No, this is impossible if we cannot travel faster than the speed of light, or send signals faster than the speed of light. As far as we know today, this is impossible.

3) Can we try to define time as what is the difference between two events which is not related with motion and space? taking the concept of "event " as primary

Yes we can. That is the second main definition of time in physics: one of the coordinates in spacetime or the temporal distance between events. Be careful that you cannot define an event just by looking at its position in time, also the position in space must be defined.

4) If there are two people, one of them sitting, looking at her watch and the other one is running fast enough and looking at her watch, the first watch will move more than the second one?

No. For the person sitting, the watch of the running person is slower (time dilation). For the person running, the watch of the sitting person is slower (again for time dilation, because from the point of view of the running person, it is the sitting person that is moving with respect to him). This statement seems paradoxical, but if you think about it hard enough, you'll see that there is no paradox. In other words, your own clock is the fastest.

5) If space time dilates as speed increases, so time slows for the object which is moving, why does it seem to us (still) that the object shrinks?

No, spacetime does not dilate. Actually the volume of spacetime remains constant in special relativity, because time is dilating, but space is contracting, and these two effects cancel out.

6) What if we build a giant clock with a giant mechanism, so that in different parts of the mechanism time is different?

Yes, this is a very serious fundamental problem. Time may not be defined unequivocally over the dimension of the clock, so that clock is not a "good" clock. As long as you can make a clock as small as you want, this is not a fundamental problem. However, it is conceivable that quantum mechanics imposes a fundamental minimum size for a clock. Then you are in trouble: you cannot define time as "what is shown by a clock" under that scale. This is roughly the explanation of the quantum spacetime foam: below a certain scale (Planck scale) time and space lose meaning somewhat...

7) Does time in relation to something also change with distance or is it just movement/speed?

No, it is just the variation of position (i.e. speed) that influences time. The distance does not. As far as we know, the universe is homogeneous: all positions (all distances) are equivalent.

8) If you are late to class and travel at a speed fast enough to significantly travel in time, you are even later to the class? I mean a speed over the light's speed in the vacuum? meaning if you try to get to the class faster, you get there later

No. All that changes is your perceived time. In the reference frame of the class, the time it takes for you to arrive is your initial distance divided by your speed (you cannot get to class faster than a light ray, since we cannot travel faster than light). The only thing that changes is the time it takes in your reference frame. You will feel that it took LESS time than what is shown on the clock of the classroom. If you travel at a speed very close to the speed of light, from your point of view, it seems that (almost) no time has elapsed. From the point of view of the teacher, it took (almost) the same time as a light ray to arrive to class.

9) Can a quantum fluctuation of the vacuum deform the space-time enough

to create a wormhole?

This is unknown. Some people say that it does and that wormholes are continuously being created as part of the quantum foam. We don't know enough about quantum general relativity to answer this conclusively.

10) So do we have a clear definition of what time measures?

No.

11) If we travel with a light speed what will be happen to the time?

We cannot travel exactly at light speed (unless we are massless, like light). We can travel very close to light speed and what happens is explained above where I detail what happens to a student going to class at almost light speed.

12) Are astronauts on IIs younger than they should be?

Yes. From Wikipedia: "ISS time goes slower, lagging 0.007 seconds behind for every six months".

13) Does Einstein consider the universe to be 4 dimensional (3 for space and 1 for time)?

Yes. Einstein initially did not like this way of visualizing the universe. It was introduced by his former teacher Minkowski. But by the time he started working on general relativity, he realized that this geometrical way of thinking about space and time was very fruitful, and is actually necessary to really understand general relativity.

14) If you are late to class and travel at a speed fast enough to significantly travel in time, can you be even later to the class?

No: the faster you travel, the quicker you get to class (see my response above to understand what happens from your perspective and from the teacher's perspective.)

15) Does the time stop near a black hole?

Time does not flow or move, so saying that time stops is not very accurate. From the point of view of distant observers (observers that are far enough from the black hole), they see that all evolution stops for objects approaching the horizon of a black hole, including clocks. So we can say that, from the point of view of distant observers, time "stops" at the horizon. Instead, if you yourself are falling into a black hole, then nothing special happens at the horizon. If the black hole is sufficiently large that tidal effects are negligible, you would not even realize you've fallen in. This is an aspect of the "equivalence principle".

16) Professore, perché lo spazio ed il tempo non possono essere entrambe grandezze reali ma una delle due deve essere per forza complessa?

Using imaginary numbers for time is not necessary. It is actually not very useful if you want to do general relativity, but it might be useful for special relativity. You use imaginary numbers (or other similar tricks, that are technically called "signature") to distinguish space from time. They are both coordinates in general relativity, but they are NOT the same thing. Time is a temporal coordinate and space is given by three spatial coordinates. What distinguishes them is the signature.

17) Considering the equations that describe the curvature of space time, if time stops at the event horizon of a black hole, does it pass at an infinite rate in the outer space?

No. Time stops at the event horizon only for observers that sufficiently far (see my reply above). For them time in outer space passes at a finite rate.

18) If so, does this mean that the information that is destroyed in a black hole is "stored on its surface" and can't reach the singularity (and therefore not lost)?

This is one possible solution of the information loss paradox. However, it probably does not work because you can still find violations of the quantum no-cloning theorem if you take this point of view. And those violations are just as bad as information loss. However, the information loss paradox is still an open question that is still debated. For sure, the problem is the way that quantum mechanics treats time, which is not fully consistent with the way general relativity does, especially in high curvature regions as in the proximity of a black hole.

19) If time 'stops' at the speed of light, how can a photon have motion?

The photon has a motion of its SPATIAL DEGREES of freedom. There is NO INTERNAL motion of a photon. If a spaceship moves at (almost) the speed of light you see that the internal degrees of freedom (e.g. its clocks) are (almost) stationary. But that doesn't mean that the spaceship itself is stationary: it moves very quickly.

20) If space time dilates as speed increases, so time slows for the object which is moving, why does it seem to us (still) that the object shrinks?

You can prove length contraction by using time dilation: so one is a consequence of the other. I'm not sure that you can do the reverse (proving time dilation from length contraction), but I would guess so.

21) Since that discovery, has science ever considered concretely time travel?

Time travel to the past is technically called "Closed Timelike Curve". You can find many scientific articles that analyze this, including some that I mentioned in my talk (e.g. the Hawking chronology protection conjecture, the papers by Goedel, Einstein's reply, the papers by Novikov and Kip Thorne), but there are many others. All these papers are foundational papers that analyze the THEORETICAL implications of CTCs. The main reason is that they tell us something truly deep about the nature of time. Einstein himself points this out in his reply to Goedel. There are no scientific paper that take the PRACTICAL possibility of time travel seriously: as I said in my talk, it is practically impossible as far as we know. Building a time machine (i.e. creating a Closed Timelike Curve) is way way WAY beyond any current or future capabilities of humankind. The simplest way we know how to do this is to take a black hole and rotate it at relativistic speeds. Practically impossible.

For example, you can find the Novikov-Thorne paper here:
https://journals.aps.org/prd/abstract/10.1103/PhysRevD.42.1915

22) so if I get to the surface of a black hole alive, I would never age, wouldn't I?

No. You wouldn't age from the point of view of a distant observer. From your own point of view, time would pass normally. However, you have to be extremely careful: if you pass the horizon, then you will end up in the center of the black hole in a finite time (that is very short for "normal" black holes). So if you pass the horizon, you certainly will not age because you die very quickly.

23) Would a person travelling back in time affect what would happen to another person travelling forward?

Apparently yes, but only if that doesn't create a grandfather-type paradox. The general relativistic equations are too difficult to be sure of this, but Novikov and Thorne (and other people) have analyzed this situation for very simple systems like single particles and "hard billiard balls".

24) But nobody confirmed this kind of theory right?

If you mean "experimental confirmation", yes, general relativity has had many experimental confirmations. Some very spectacular, such as the gravitational wave detection. We have not been able to experimentally confirm the existence of Closed Timelike Curves (time travel) because, as I said in my talk, all mechanisms we know that can create CTCs are totally impossible to create in practice. However, if general relativity is true, then also CTCs are certainly possible IN PRINCIPLE, since they are a well established consequence of that theory. They are even rather typical consequence of general relativity in the presence of rapidly rotating objects (a consequence of "frame dragging"). As I said in my talk, people (e.g. Stephen Hawking) think that perhaps general relativity may not be true in the end, although all experiments that have tested it up now have confirmed it.

25) If time doesn't exist, where are we?

I never said that time doesn't exist. Clearly it exists.

* If in a black hole there is an absence of light, this means light is attracted at a speed higher than c, so does nit travel back in time?

In a black hole there is no absence of light. Light cannot come OUT of a black hole, but it can certainly fall IN. So the inside of a black hole (inside the horizon) is not dark in general. Light is not "attracted at a speed higher than c", the attraction has no speed.

26) How does time measurement changes the time itself on a quantum scale?

There is unfortunately NO way to describe time measurements in textbook quantum theory. Textbook quantum theory tells you that time is a parameter, not an observable. As such, it just parametrizes everything else (e.g. the quantum state), but it cannot be measured itself. This is clearly a shortcoming of the theory, since experimentalists perform time measurements (also at quantum scales) continuously. There are many proposals on how to overcome this shortcoming of textbook quantum theory, but it is still an open question at this point.

27) Could you please introduce some more references to read about this subject? it's really interesting to me

Please look at my last slide. I put many books that I found interesting there. Most of them are suitable for a general public: no prior knowledge of physics is necessary. In my slide I put the Italian titles, but you can easily find the English versions of all of them.

28) How do you know if a universe rotates?

You can find out by analyzing the light of distant stars. Goedel apparently asked some astronomers if they saw this effect in our universe. The answer is no. Our universe is not of Goedel's type.

29) Is there a "pure " time, one that isn't measured in relation to anything?

This is the absolute time of Newton. No. Apparently time is always measured relative to something else. The reason why "relativity" has this name is because time and space are relative concepts: they depend on the reference frame (i.e. they depend on who is measuring them). There is no absolute time.

30) if only paradoxes are impossibile when travelling to the past then does this mean I can't make the past gather information correlated with my presence in the past? And if so how this would be coherent

As I said in my talk, one hypothesis is that ONLY the paradoxes are impossible. If I go back to the past and drink a beer with my grandfather (instead of killing him) there is no paradox. This would be possible. And my grandpa will have this strange story about sharing a beer with a weird stranger that claimed to be his nephew.

31) Can a quantum fluctuation of the vacuum deform the space-time enough to create a wormhole? Hawking talked about a negative energy that deformed the space-time at a different way.

Please see my earlier response to a similar question.

32) Why does time dilate for a moving observer if from the frame of reference of the observer they're not moving and the surrounding are?

The time dilation is ALWAYS relative: the time of the train SLOWS FROM THE POINT OF VIEW OF THE STATION. From the point of view of the people on the train, time doesn't change at all.

33) what is thermal time?

Thermal time is one of the many different meanings of time. It is very interesting because thermodynamics is the only physical theory where there is a time direction. Processes directed towards the future look very different from processes directed towards the past. E.g. if I drop an egg, I'll see the egg splattered on the floor, but I'll never see a splattered egg that spontaneously "unsplatters" and becomes a whole egg again, jumping up. All other physical theories are time-reversal-invariant: if you flip the time direction you obtain an evolution that is just as valid as the original one.

34) What are your thoughts on time associated to the M-Theory on 11 dimensions?

I am not an expert, but I do note that many scientists working on those theories are changing subjects and are exploring topics such as applications to solid state physics. I interpret this as a signal that that theory is not too promising.

35) But if antani effect is actually reliable, as we can see from the Hawking studies than the whole time and space theory of relativity is fallen, so how do you respond to this difficult implication?

Ha ha ha.

36) How can we quantify in this way the age of our universe?

Our universe has a preferred reference frame: the one in which the cosmic microwave background is homogeneous. The age of the universe is quantified according to the time in that reference frame.

37) do you think scientists in the future will be able to travel in the past?

No.

38) So is space time independent, and if so why is time different in

different conditions?

The part which is RELATIVE is not spacetime as a whole, but the division of spacetime into space and time.

39) If there were one only centre of mass in the universe and we travel far away at the velocity of light the time will slow or accelerate?

See my previous responses.

40) But this is true (about the thermal time) only at a macroscopic level?

The laws of thermodynamics are different than the typical laws of physics because they are statistical. They are laws that refer to "emergent" phenomena that are treated only statistically. You can apply thermodynamics also to microscopic systems and it has been done, but it is not straightforward.

41) If i travel at a significant speed to make me travel to the future, can the particles that form me have increased microstates due to the increase of entropy compared to an identical twin that hasn't?

Yes. All physical processes are slowed down for the traveling twin, not only clocks. Including entropic processes. This is the reason why the traveling twin ages less and the "stationary" twin ages more.

42) Can it be that the universe is defined as how things in the universe change, and then this does not change assuming a closed universe?

One of the solutions of the "problem of time" assumes that the change is only internal and relational. So the evolution of the universe we see is only "apparent". The block universe taken as a whole is stationary with respect to an "external" time, according to the Wheeler-de Witt equation. Since the universe is all there is (there are no external degrees of freedom), this is actually reasonable: there is no external clock that could track the evolution of the whole universe.

43) And how can the "chaos" in thermodynamics evolve if time is applicable to the Universe it self, knowing the Universe doesn't change?

In the universe can be described by a quantum state, it is conceivable that that state evolves (or doesn't evolve) according to the Schrodinger equation (which becomes the Wheeler-de Witt equation in that case). In either cases, it means that no entropy builds up.

44) So as we learned , space and time aren't separate, what happens if there was no space? there would be no time? and if there was no time, there would no space???

We can write Einstein's equations and study relativity for putative universes that have a different number of space and time dimensions. Our universe has three space dimensions and one time dimensions. Spacetimes with zero time dimensions are presumably quite boring, and spacetimes with zero space dimensions are so weird I have a hard time even thinking about them.

45) As the photon goes at the speed of light, and so for example when light goes from the earth to the moon, for the photon 0 seconds had passed and for as humans 2 seconds had passed? Does it mean that the photon is in all the places he had passed at the same time?

From the putative perspective of a photon, yes. Of course a photon does not have internal degrees of freedom, so that answer is rather meaningless. However, we can think of a spaceship that is traveling at (almost) the speed of light so that, for an external observer, the spaceship time is (almost) stopped. This means that, from the point of view of the spaceship, it crosses all points of space in its trip at (almost) the same time.

46) Are we sure time is a concept which requires always just one dimension to work with?

No, we can think of universes that have more than one time dimension. There are scientific papers that explore this idea (e.g. by Max Tegmark and Steve Weinstein). Our universe has only one time dimension.

47) But with the theory of strings relativity and quantum physics can be explained together kind of a conspiracy theory?

You don't need string theory. Already normal quantum mechanics, when made relativistic, i.e. quantum field theory, looks pretty close to a conspiracy. It is VERY weird.

48) I mean, does it exists only one time coordinate?

See my reply above.

49) How man introduced time in his life? How is it possible to establish a reference system?

Sure, our perception of time is a mix of many different notions of time. For example, clock time ("time is what is shown on a clock") or thermodynamical time (we see that as we age) or other notions. Our typical reference system is given by our clocks that currently use a definition of time in terms of hyperfine transitions in Cesium atoms.

50) Is time infinite or finite?

We do not know for sure. In our universe, time probably started at the big bang and probably will go on forever. So it is infinite. But we are not sure about both of these statements at this point.

51) In those equations, in the quantum mechanic formula, it appears time. What role does it have?

In textbook quantum mechanics, time is just a parameter that indicates what is shown on an external classical clock that is used to measure the time for the quantum experiments. As I said above, this is not very satisfactory, but this is the status of the theory.

52) How often while dealing with theory problems, do physicist have to go and study further mathematics or have to ask mathematicians for help?

Rather often if your theory problems are very deep. Otherwise we typically just apply the (quite sophisticated) mathematics that is already embedded in our theories.

53) Does time have an end?

We do not know for sure. It appears that our universe is expanding and that its expansion is accelerating. If this is confirmed, then no, time does not have an end.

54) If the flows of the time is an illusion, the sentence "the entropy increases with time" should be changed, shouldn't it?

No. That sentence does not contain any word "flow". You can read that sentence as saying: "when we look at the time shown on a clock, entropy increases with increasing values of the clock time". This is a physically well formed statement.

55) What's about the end of the universe. is it possible to a reverse expansion concording with termodinamic?

Yes. The thermodynamical arrow of time is not necessarily connected to the expansion of the universe, although it is the expansion of the universe that probably created a very low entropy initial state. However, it is not clear how one could "reverse" the expansion or what that might even mean.

56) Which practical applications of a joint theory of quantum physics and relativity could be possible?

I have no idea. Einstein said a similar thing about his theory of general relativity, and after 100 years we are using it every day when we use GPS.

57) Do you think it's a problem that everything we thought we knew about our reality was postulated based on a "wrong" concept of time that we are discovering as "wrong" just now?

No. On the contrary, I think it's fascinating. Clearly the "wrong" concepts of time we used up to now where satisfactory enough for everything we did up to now. Discovering that they are wrong may open many new possibilities to us.

58) If time 'stops' at the speed of light, how can photons have motion?

I replied to a similar question above.

59) Does the wheeler de witt equation not include time as a variable?

No. That is the problem: it is an evolution equation, but time does not appear. That is why it must be interpreted as saying that the state of the universe is stationary. That probably does not mean that the universe is stationary, but we need to be careful in interpreting it.

60) If so, could the universe be deterministic?

This is a tricky question. Quantum mechanics of closed systems is deterministic. It would appear that the universe should be considered as a closed system (since by definition there is nothing else), so quantum mechanics tells us that the universe is deterministic. Of course the fact that the laws of the universe seen as a whole are deterministic does not necessarily imply that it appears that way to us. We are subsystems internal to the universe and we can then see only part of it (by necessity: it is a fundamental limitation). So we will see a non-deterministic evolution for this reason. Many scientists will say that we cannot apply quantum mechanics to the whole universe. They may be correct.

61) Why speed of light is fixed?

It is a constant of nature. There is no reason that we know. Nature is built this way. If one could find a reason for that, it would be a huge result.

62) In general relativity there are a lot of questions with no answer or no meaning. Does it mean that we need to expand the theory? Is relativity incomplete?

Not necessarily. It might mean that we are posing wrong questions based on our common sense. We know our common sense is wrong, so we should be prepared to accept that some questions that seem reasonable to our common sense are really meaningless.

However, we do know for sure that general relativity is incomplete because it doesn't work properly when quantum effects are taken into account. I guarantee that whatever theory will supersede general relativity will be even stranger than that (since it will have to reproduce all general relativity effects and it will have to also explain quantum mechanical effects).

63) Who would win between a person who can slow the time until it stops, and one who can run as fast as light?

No one can run as fast as light. And no one can slow time until it stops.

64) If I travelled to a past where I already existed, would the matter that i carry throughout my life be duplicated in that layer of the Block universe?

There will be two copies of you, but it is not a duplication. One copy is older (it comes from the future), the other is younger. When you think that you exist today and you existed yesterday, you do NOT think of that as a duplication, right? The same applies to time travel: there is no duplication even if two copies of you exist at the same time.