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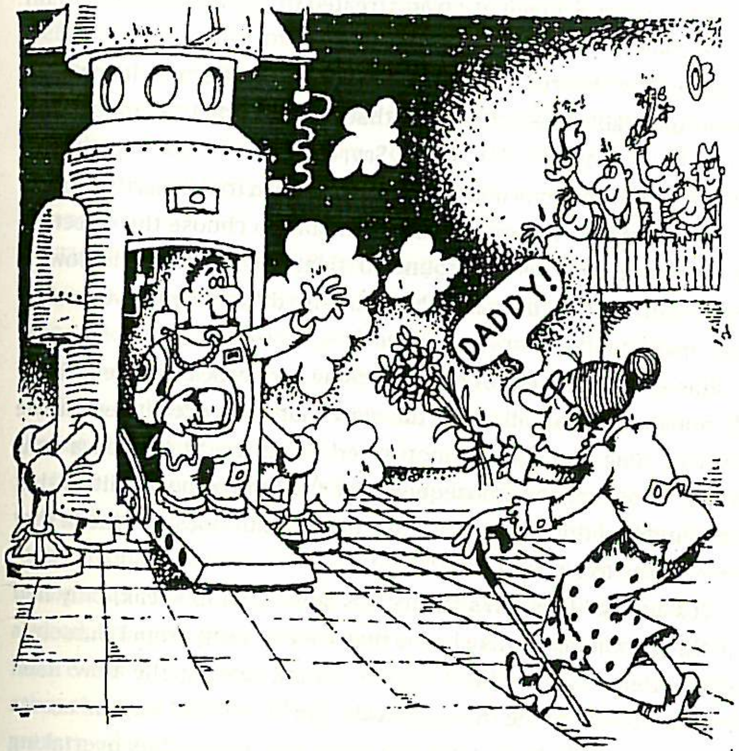
Time machine



Which of us was not immersed in our youth in Herbert Wells' famous short novel *The Time Machine*? The protagonist of this story uses a device that can travel in time to visit a very remote future of the Earth. Wells also imparted to this device the property of reverse motion into the past.

A large number of books have been written which fantasized about the possibility of freely visiting the past and the future. In all likelihood, their authors were never in doubt that their inventions belonged to pure imagination and treated this as nothing more than a literary stratagem.

The entire experience of mankind and scientific knowledge have made inevitable the conclusion that travel in time is impossible. Space is where motion is allowed. Say, travel on the Earth is possible in different directions and one can also return to the starting point. On the contrary, we are seemingly unable to choose the direction of motion in time, we are bound to 'float' passively in this flow. It was assumed that here lies the dramatic difference between time and space.

Einstein's discovery of the surprising properties of time in 1905 demonstrated the fallacy of the view that we are 'captives' of the river of time and thus cannot 'steer' on it; it was seen as a fruit of not knowing, as a consequence of the limited possibilities that mankind had during its preceding history. But does this mean that we are free to roam in time?

Yes and no! Einstein's theory has solved, so to speak, only half of this problem. It was shown that we can only propel ourselves 'downstream': move towards the future, leaving the flow itself behind. However, the theory revealed no 'upstream' way, no access to the past. Still, how could one reach the future, thus overtaking time?

To achieve this, Wells' personage jumped into the time machine, pressed a lever, the machine began to shake and then transferred

itself to different epochs, disappearing from the 'now' together with its driver.

The theory of relativity proved that this sort of traveling in time is forbidden. You would have to move through space in order to move in time. To reach the future of the planet, one has to get into the photon rocket mentioned above, accelerate it to a speed very near the velocity of light, travel through space at this tremendous speed for some time (say, a year) and then return to the Earth. From the point of view of people who were left behind on the planet, the time on the fast-moving rocket advances more slowly than their planet time. Hence, when the crew of the rocket lands at the homeport, the time lived through on the Earth is longer than that by the clocks of the astronauts; consequently, the travelers arrive in the future of their planet.

The French physicist Pierre Langevin discussed the following thought experiment in 1911. Imagine a twin brother departing on the rocket for a space voyage, leaving his twin brother on the Earth. When he comes back, he is younger than his brother who waited for him at home. For the astronaut, this is a tangible result of the voyage into the future of the Earth.

In fact, some theorists doubted that this effect was possible. They argued that Einstein's theory states the relativity of motion. Hence, the astronaut can regard himself as stationary and the Earth-bound people as speeding away in the opposite direction at the same speed. From his point of view, then, the clock on the Earth is ticking more slowly than that on the spaceship. He concludes, therefore, that the twin brother on the planet will be the younger one upon return of the rocket.

This produces an apparent paradox. Each brother considers the other as the younger one at the end of the experiment. Which argument is correct? Indeed, coming together, the brothers will identify the younger one immediately by his looks. This is the origin of the famous 'twin paradox'.

Specialists were able to sort out the situation quite quickly, so truth was out, but for the uninitiated the 'twin paradox' rumors manifested the failure of relativity theory for many years. Alas, 'reasoning' of this sort is sometimes found in literature even today. So who is older and why?

The important point is that the argument about the rate of advance of a clock is valid only from the standpoint of a 'laboratory' or, in general, bodies moving by inertia. Physicists say that Einstein's formulas (in the form he has written them) hold only in 'inertial frames of reference'. A passenger does not notice the motion only when a ship or a rocket moves without accelerating or decelerating. There is no doubt that the astronaut feels the acceleration when the rocket, say, blasts away. Hardly anybody today is ignorant of g-loads that astronauts undergo during the launch and landing stages of spaceships.

It is thus clear that the positions of a person on the Earth and an astronaut in the rocket are not equivalent. The Earth can be regarded, as a good approximation, as an almost inertial reference frame. For the space traveler to return to the home planet after a long and lengthy journey, however, it is necessary to decelerate and stop the ship, then accelerate it towards the Earth and again slow it down to land safely. Of course, the motion is not inertial during the acceleration and deceleration stages, and the astronauts undergo the corresponding loads. During these intervals of motion, the formulas written for inertial system are not applicable to the 'laboratory'-ship and the astronaut has no basis for considering the terrestrial clock to be slower.

Here I will not go into details of this process. Theorists know how to calculate time in a 'laboratory' even if it moves with acceleration. I will give the final conclusion of a physicist. There is no contradiction, and the conclusion of the observer on the Earth was correct, since his frame of reference is always inertial (with sufficient accuracy) while the rocket moved with acceleration. The 'naive' inference of the astronaut during these periods that the clock on the Earth is the slower one is wrong. Hence, the space voyager travels to the future when he returns to the Earth. The faster the motion of the rocket and the longer the flight, the more remote the future to which he is transferred.

This possibility of visiting the future is quite awesome to anyone who learns about it for the first time, while reading up on relativity theory.

When I was a third-year astronomy student at Moscow University, I accidentally noticed the 'twin paradox' among the topics offered for the term research project. Later I learnt that the adviser for this topic was a well known Soviet cosmologist A. Zelmanov.

At that time, relativity had not yet percolated into school courses of physics. Nevertheless, I had by that time already read several popular science booklets on this theory and thought that I had some notion of this paradox. True, I had no detailed knowledge of the theory itself; I remembered its 'ominous' reputation as something super-complicated and doubted that I could actually calculate anything myself. Still, the aura of mystery led me to Zelmanov.

He was a soft-spoken and sensitive man, of vast knowledge and a manner of working in a style that was rather typical for the 'old school' of the end of the 19th century. What I mean is an unhurried, thoughtful, pedantic way, when ideas are thought over for a very long time, all the calculations are extremely thorough and repeated many times, and papers are prepared for publication for years! This is so unlike the high-speed high-pressure style of today's science (in keeping with the entire life around us).

By that time Zelmanov had already suffered from the unlimited voluntaristic rule of bosses who, even though utterly incompetent in anything connected with science, ruled over it and dictated its fate. They decreed that cosmology – the science studying the structure of the entire Universe and, among other aspects, its expansion (I will talk about it later in the book) – was a pseudo-science, or non-science, contradicting or denying the 'dialectic Marxism'. At the beginning of the fifties, Zelmanov was fired from his post at the P. K. Shternberg Astronomical Institute in Moscow. When I met him, the situation had already improved and he was allowed to return to the institute.

During my first appointment with Zelmanov, he explained in detail what he expected me to calculate, what is the rate of advance for the clock on the Earth as conjectured by the astronaut, what sort of Universe will he observe from the cockpit of his spaceship etc. I could not fathom too much at that first meeting, so I started to work with the famous textbook of theoretical physics by Lev Landau and Eugenii Lifshitz: Zelmanov recommended it to me as a good preparation for tackling the problem.

A couple of weeks later I had the impression that the required chapters were pretty well understood, so I went to see Zelmanov again. He heard me out and said: 'That's just fine. You can start your calculations now.' That was a blow: 'Start calculating'. How? I did not have the slightest idea of what the first step could be. However, my adviser was a very wise tutor. He identified my obstacles immediately and hinted in a few words what to do as a start for calculating the effect involved in the motion of the reference frame 'spaceship'. I started to calculate.

Somewhat later Zelmanov advised me to tackle a fairly complicated monograph *Theory of Space, Time and Gravitation* by V. Fock. Now, quite a few things cleared up and the work went on faster; I was even able to finish the calculations in time. This was my first work in theoretical physics and it even got published several years

later. It has mostly been of methodological interest but also contained original results.

Now about the results themselves. My first question was how the space voyager is going to see the Universe through the windows of his ship – this 'laboratory' hurtling through space and time.

The astronaut will observe two effects. The first of them is the already familiar Doppler effect which makes light shift to blue when we move towards the light source, and makes it 'redden' when we move away from it.

This is not all, though. The direction in which we see remote stars changes as well if the observer's speed is very high. What makes them move? Let us recall traveling in a train or a car in the rain. While we are stationary, rain drops leave vertical traces on the windows. Once we are in motion, drops leave inclined traces which tend to tilt closer to the direction of motion of the vehicle.

The picture is similar for light. For the moving observer, light rays become tilted towards his line of flight. Hence, the astronaut should see stars as if crowding towards the point to which the rocket is directed. This phenomenon is known as aberration of light; the shifts in the visible position of stars on the sky will, of course, be very large for spaceship velocities close to that of light.

I have calculated what the sky should look like from a ship traveling at a speed of 250 000 km/s. Figure 5.1 shows what sort of pattern the crew will see. For these observers, the stars in the sky rush as if to the rocket's destination point. The density of stars here will be much higher than towards the tail, where almost no stars will be seen.

The color of stars will also change as described by the Doppler effect. In the direction of motion, the passengers will see bluish stars of enhanced brightness. In the opposite direction, there will be only infrequent dim reddish dots.

How about the schedule of the voyage? In the case study that

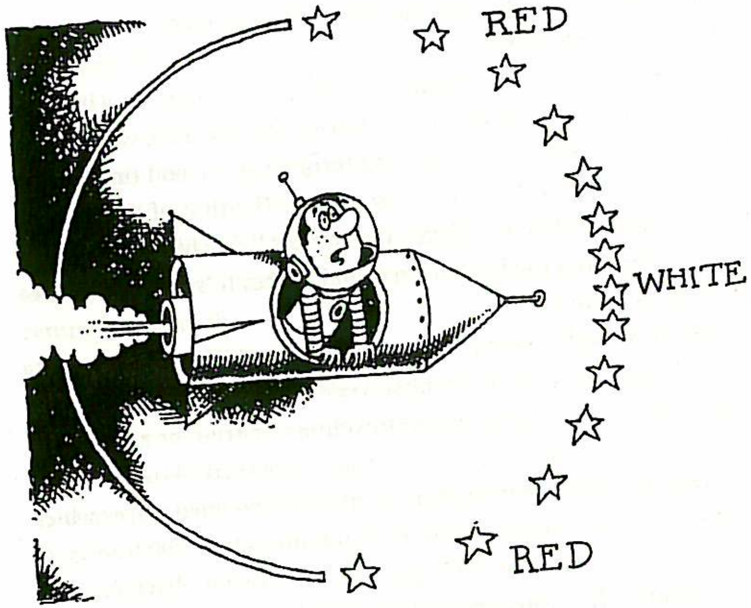


Fig. 5.1.

I chose at that time, the astronauts travel to the star which is the nearest neighbor of our Sun: Proxima Centauri lying at a distance of about 40 thousand billion kilometers (4.3 light-years) from us. By my scenario, the rocket accelerates during the first 4.5 months of the flight. The rocket engines are assumed to produce a thrust that weighs down the astronauts with a $3g$ load – three times that on the Earth. By the end of the acceleration stage, the spaceship moves at a speed of 250 000 km/s. The engines are switched off here and the ship keeps going by inertia; now the crew can contemplate the unusual view of the starry skies as described above.

On approach to Proxima Centauri, deceleration motors are switched on and the ship slows down, ultimately stopping. Then it

picks up speed again towards the Sun, decelerating on the approach to the Earth. By the clock ticking on the Earth, the flight lasts about twelve years, while the clock on board the ship reports only about seven years. Having returned to the Earth, the voyagers are thrown into the future of the Earth by five years! This is how the 'cosmic time machine' works.

It is thus clear that even at very high speeds and after relatively long journeys through the cosmos, the time jump is not very large. Nevertheless, the jump is there (rather, it will be inevitable in future interstellar travel). In principle, the time jump takes place in any motion through space, even at low speeds. However, it is normally absolutely negligible. For example, when the crew of the Soviet space station *Salyut* landed in 1988 after travelling on an orbit around the globe for a year at a speed of eight kilometers per second, they stepped into the future by a mere one hundredth of a second.

In future interstellar flights, photon-driven rockets could accelerate to speeds very close to the speed of light, much closer than in the above example with Proxima Centauri, where the speed was about 80% of the speed of light. At such truly great speeds, transfer to the future may be quite serious. Imagine, for example, that astronauts set out on a photon rocket to the center of our home stellar system, the Galaxy (this will be a journey both through space and through time). For the first half of the forward leg the rocket speeds up at a constant acceleration, so that the astronauts are under constant load, twice that on the Earth, while on the second half of the leg the rocket decelerates, again at the same constant load for the astronauts. Then everything is repeated on the return stage of the voyage towards the Earth. On the whole, the return trip should take about sixty thousand years by the terrestrial clock, with numerous generations replacing one another; on the rocket, however, the crew will register only forty years! This duration is definitely within the active span of a human life, so that the people who come back to the home port may even be the same astronauts who left it. They will, however, find themselves in a very distant future of the globe.

What will they find? Only science fiction writers know that. A host of problems that will arise would be social and psychological rather than scientific, and we cannot really say anything profound about them. The Polish science fiction author Stanislav Lem has described in the novel *Return from the Stars* very vividly the experiences of men who were ejected into time epochs that were very far from the familiar surroundings in which they grew and matured.

I also have to point out another specific feature of interstellar travel. At first glance, one tends to consider mankind as somehow captive in space. It may seem that an individual cannot get too far away from the spot where he or she was born, being as if 'tied' to this point in space by an invisible time chain. Indeed, nothing can move at a velocity exceeding that of light. Hence, one cannot escape by more than, say, a hundred light years over a lifetime of a hundred years. This distance stretches only to the stars nearest to our Sun.

In fact, this naive evaluation is based on a serious error: it ignores the slowdown of time for the space traveler. If this slowdown is taken into account, the ship can go very far indeed and visit very distant corners of the Universe.

The prospects are definitely exciting, aren't they?

However, inventive thinking strives for even more breathtaking horizons. Is it really necessary to break through space, making very long, very demanding interstellar trips? Could a bypass of some sort be devised?

I beg readers' patience, I will discuss this aspect later. I will only mention here a remark made after I presented a talk about the possibilities of such bypasses at a colloquium at the Institute of Theoretical and Experimental Physics in Moscow. The remark was

made by Professor Lev Okun, a theorist of the highest international reputation, who said to me: 'You see, I had a walk on a starry night many years ago with one of our most renowned physicists. Looking at the stars, I mused that there simply must exist some way of reaching these stars in addition to the trivial endless flight through space. My companion looked at me skeptically and dropped: "Cut out this insubstantial fantasizing, this is a matter for fairy tales only". Isn't it wonderful that these possibilities may be opening to us now? Only in theory, of course, but opening nevertheless?' He was very glad.

I want to add to these words that science has compelled us to treat very seriously even the most extravagant theoretical predictions. Among examples of realizations of the wildest dreams are the liberation of atomic energy, space flights and many others. Things that theoreticians were scribbling just yesterday on pieces of paper, become reality tomorrow. Let us be very attentive, therefore, to physicists' predictions, even if they sound too far-fetched.

Let us be content for the time being with these remarks. I will take up the search for other paths to the stars later in the book.

I will make one more remark. Relativity theory revealed a method of traveling into the future. But what about the past? Can we return to moments gone by? Can we visit distant epochs in the history of the Earth?

I have mentioned already that the theory itself did not offer any method of achieving it. How about other theories developed after Einstein's relativity: do they promise anything?

Again I beg for patience. For the moment, I will change the question: can the past be seen? A Soviet physicist A. Chernin, well-known popularizer of science, has given the following answer: 'If we can see anything at all, it is the past.' This is unexpected, and sounds like nonsense.

Actually, the situation is quite simple. We see the surrounding world via light rays. Light needs a certain time to travel to our eyes from the object we are looking at. We thus see an object as it was at the moment when light 'left' it. Of course, the speed of light being tremendously high and the familiar objects of our daily routines being not far away, light takes negligible time to cover the distance. Nevertheless, we see objects at any given moment as they were an instant before, when light started its trip. Hence, we see them in the past! Not very distant past but past all the same.

The situation is very different when we look at objects in the sky. Light takes eight minutes to reach us from the Sun. Light from stars takes years, and light from distant stellar systems takes millions and even billions of years. We observe these systems in their very distant past. This is a duration sufficient for many stars to be born, to live out their entire lives, and for entire stellar systems to arise and evolve! We observe heavenly bodies that lie at different distance at different times in the past: the farther an object, the longer its light takes to reach us, the more distant the past in which we observe it today.

This is a very worrisome property for astronomers since stellar systems at unequal distances from us are being observed at different stages of evolution of the Universe, so comparing them involves taking into account their evolution over long stretches of time. This is not easy to do, however, since our knowledge of the laws of stellar evolution is often insufficient and all sorts of surprises are possible.

Here I leave the technical difficulties to experts and return to the topic of this book.