Conyers Sixth Form Transition Work

A Level Physics

Congratulations on your enrolment to Conyers Sixth Form; please find below, tasks that will aid your transition from GCSE to Level 3 study. Your subject teacher will check completion of this work in September.

1) Watch this interesting video about quantum physics

https://www.youtube.com/watch?v=q7v5NtV8v6I&t=588s

2) Read the extract from Mr. Tompkins in Paperback provided.

3) Research Activity:

The speed of light is, to six significant figures, __________________ m/s

Find out how the speed of light has been measured at various points in history, including how:

- Our solar system has been used (17th - 18th century)
- Man made devises have been used (around the 1800-1945)
- Resent attempts (1945 – present)

Jot down some details (in outline) and comment on how close they were getting to today's accepted value of c.

The following extract is taken from:
Mr. Tompkins in Paperback (1965) by George Gamow

The book tells a series of stories (as dreams of the main character, Mr. Tompkins) if the fundamental constants of the universe were radically different - bigger or smaller - than they are.

In this story a world is imagined where the speed of light is radically smaller than is.

I
City Speed Limit

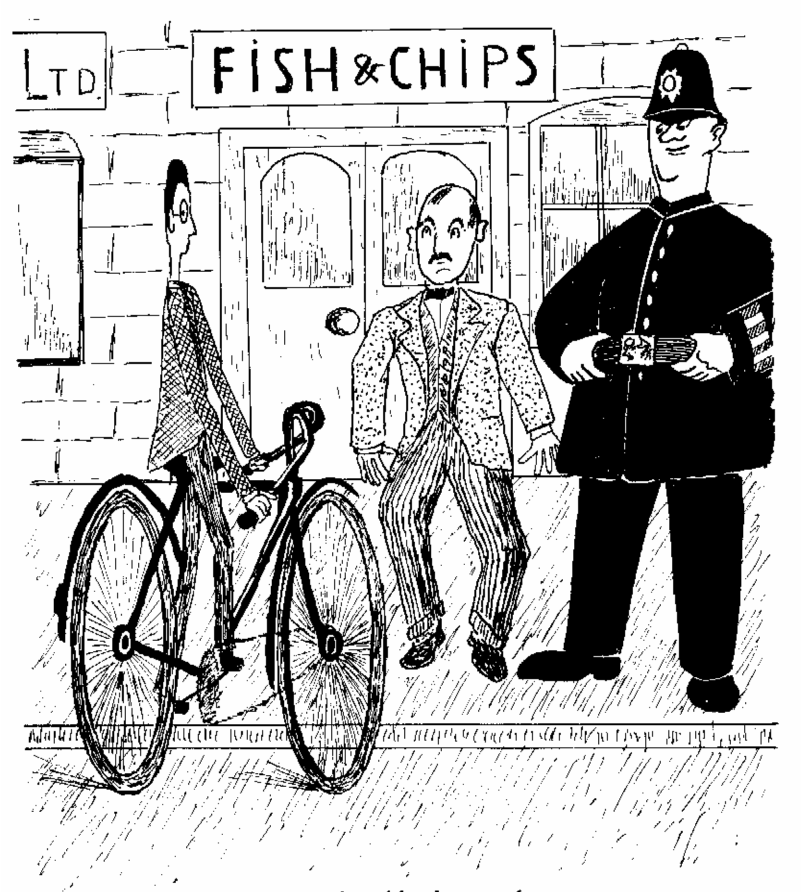
It was a bank holiday, and Mr Tompkins, the little clerk of a big city bank, slept late and had a leisurely breakfast. Trying to plan his day, he first thought about going to some afternoon movie and, opening the morning paper, turned to the entertainment page. But none of the films looked attractive to him. He detested all this Hollywood stuff, with infinite romances between popular stars.

All this Hollywood stuff!

If only there were at least one film with some real adventure, with something unusual and maybe even fantastic about it. But there was none. Unexpectedly, his eye fell on a little notice in the corner of the page. The local university was announcing a series of lectures on the problems of modern physics, and this afternoon's lecture was to be about EINSTEIN'S Theory of Relativity. Well, that might be something! He had often heard the statement that only a dozen people in the world really understood Einstein's theory. Maybe he could become the thirteenth! Surely he would go to the lecture; it might be just what he needed.

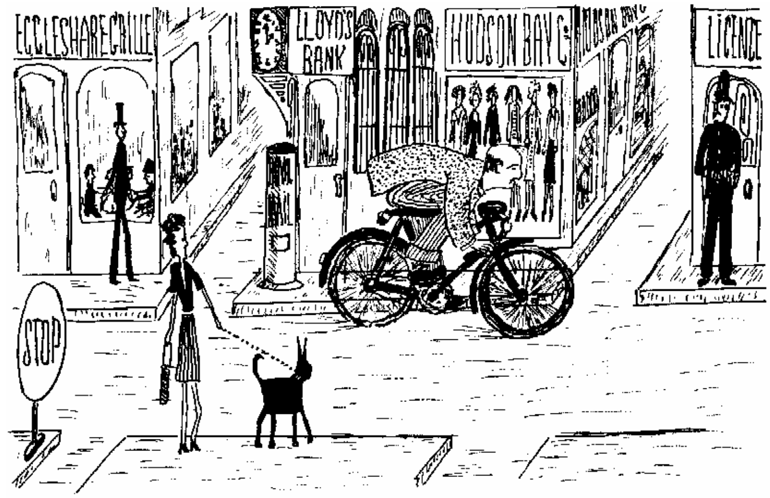
He arrived at the big university auditorium after the lecture had begun. The room was full of students, mostly young, listening with keen attention to the tall, white-bearded man near the blackboard who was trying to explain to his audience the basic ideas of the Theory of Relativity. But Mr Tompkins got only as far as understanding that the whole point of Einstein's theory is that there is a maximum velocity, the velocity of light, which cannot be surpassed by any moving material body, and that this fact leads to very strange and unusual consequences. The professor stated, however, that as the velocity of light is 186,000 miles per second, the relativity effects could hardly be observed for events of ordinary life. But the nature of these unusual effects was really much more difficult to understand, and it seemed to Mr Tompkins that all this was contradictory to common sense. He was trying to imagine the contraction of measuring rods and the odd behaviour of clocks—effects which should be expected if they move with a velocity close to that of light—when his head slowly dropped on his shoulder.

When he opened his eyes again, he found himself sitting not on a lecture room bench but on one of the benches installed by the city for the convenience of passengers waiting for a bus. It was a beautiful old city with medieval college buildings lining the street. He suspected that he must be dreaming but to his surprise there was nothing unusual happening around him; even a policeman standing on the opposite corner looked as policemen usually do. The hands of the big clock on the tower down the street were pointing to five o'clock and the streets were nearly empty. A single cyclist was coming slowly down the street and, as he approached, Mr Tompkins's eyes opened wide with astonishment. For the bicycle and the young man on it were unbelievably shortened in the direction of the motion, as if seen through a cylindrical lens. The clock on the tower struck five, and the cyclist, evidently in a hurry, stepped harder on the pedals. Mr Tompkins did not notice that he gained much in speed, but, as the result of his effort, he shortened still more and went down the street looking exactly like a picture cut out of cardboard.



Unbelievably shortened

Then Mr Tompkins felt very proud because he could understand what was happening to the cyclist—it was simply the contraction of moving bodies, about which he had just heard. ‘ Evidently nature’s speed limit is lower here,’ he concluded,’ that is why the bobby on the corner looks so lazy, he need not watch for speeders.’ In fact, a taxi moving along the street at the moment and making all the noise in the world could not do much better than the cyclist, and was just crawling along. Mr Tompkins decided to overtake the cyclist, who looked a good sort of fellow, and ask him all about it. Making sure that the policeman was looking the other way, he borrowed somebody’s bicycle standing near the kerb and sped down the street.



The city blocks became still shorter

He expected that he would be immediately shortened, and was very happy about it as his increasing figure had lately caused him some anxiety. To his great surprise, however, nothing happened to him or to his cycle. On the other hand, the picture around him completely changed. The streets grew shorter, the windows of the shops began to look like narrow slits, and the policeman on the corner became the thinnest man he had ever seen.

'By Jove!' exclaimed Mr Tompkins excitedly, 'I see the trick now. This is where the word *relativity* comes in. Everything that moves relative to me looks shorter for me, whoever works the pedals!' He was a good cyclist and was doing his best to overtake the young man. But he found that it was not at all easy to get up speed on this bicycle. Although he was working on the pedals as hard as he possibly could, the increase in speed was almost negligible. His legs already began to ache, but still he could not manage to pass a lamp-post on the corner much faster than when he had just started. It looked as if all his efforts to move faster were leading to no result. He understood now very well why the cyclist and the cab he had just met could not do any better, and he remembered the words of the professor about the impossibility of surpassing the limiting velocity of light. He noticed, however, that the city blocks became still shorter and the cyclist riding ahead of him did not now look so far away. He overtook the cyclist at the second turning, and when they had been riding side by side for a moment, was surprised to see the cyclist was actually quite a normal, sporting-looking young man. 'Oh, that must be because we do not move relative to each other,' he concluded; and he addressed the young man.

'Excuse me, sir!' he said,' Don't you find it inconvenient to live in a city with such a slow speed limit?'

'Speed limit?' returned the other in surprise,' we don't have any speed limit here. I can get anywhere as fast as I wish, or at least I could if I had a motor-cycle instead of this nothing-to-be-done-with old bike!'

'But you were moving very slowly when you passed me a moment ago,' said Mr Tompkins. 'I noticed you particularly,' 'Oh you did, did you?' said the young man, evidently offended. 'I suppose you haven't noticed that since you first addressed me we have passed five blocks. Isn't that fast enough for you?'

'But the streets became so short,' argued Mr Tompkins.

'What difference does it make anyway, whether we move faster or whether the street becomes shorter? I have to go ten blocks to get to the post office, and if I step harder on the pedals the blocks become shorter and I get there quicker. In fact, here we are,' said the young man getting off his bike.

Mr Tompkins looked at the post office clock, which showed half-past five. 'Well!' he remarked triumphantly, 'it took you half an hour to go this ten blocks, anyhow—when I saw you first it was exactly five!'

'And did you *notice* this half hour?' asked his companion. Mr Tompkins had to agree that it had really seemed to him only a few minutes. Moreover, looking at his wrist watch he saw it was showing only five minutes past five. 'Oh!' he said, ' is the post office clock fast?' 'Of course it is, or your watch is too slow, just because you have been going too fast. What's the matter with you, anyway? Did you fall down from the moon?' and the young man went into the post office.

After this conversation, Mr Tompkins realized how unfortunate it was that the old professor was not at hand to explain all these strange events to him. The young man was evidently a native, and had been accustomed to this state of things even before he had learned to walk. So Mr Tompkins was forced to explore this strange world by himself. He put his watch right by the post office clock, and to make sure that it went all right waited for ten minutes. His watch did not lose. Continuing his journey down the street he finally saw the railway station and decided to check his watch again. To his surprise it was again quite a bit slow.' Well, this must be some relativity effect, too,' concluded Mr Tompkins; and decided to ask about it from somebody more intelligent than the young cyclist.

The opportunity came very soon. A gentleman obviously in his forties got out of the train and began to move towards the exit. He was met by a very old lady, who, to Mr Tompkins's great surprise, addressed him as 'dear Grandfather'. This was too much for Mr Tompkins. Under the excuse of helping with the luggage, he started a conversation.

'Excuse me, if I am intruding into your family affairs,' said he, 'but are you really the grandfather of this nice old lady? You see, I am a stranger here, and I never. . .. ..' 'Oh, I see,' said the gentleman, smiling with his moustache. 'I suppose you are taking me for the Wandering Jew or something. But the thing is really quite simple. My business requires me to travel quite a lot, and, as I spend most of my life in the train, I naturally grow old much more slowly than my relatives living in the city. I am so glad that I came back in time to see my dear little grand-daughter still alive! But excuse me, please, I have to attend to her in the taxi,' and he hurried away leaving Mr Tompkins alone again with his problems. A couple of sandwiches from the station buffet somewhat strengthened his mental ability, and he even went so far as to claim that he had found the contradiction in the famous principle of relativity.

'Yes, of course,' thought he, sipping his coffee, "if all were relative, the traveller would appear to his relatives as a very old man, and they would appear very old to him, although both sides might in fact be fairly young. But what 1 am saying now is definitely nonsense: One could not have relative grey hair!' So lie decided to make a last attempt to find out how things really are, and turned to a solitary man in railway uniform sitting in the buffet.

'Will you be so kind, sir,' he began,' will you be good enough to tell me who is responsible for the fact that the passengers in the train grow old so much more slowly than the people staying at one place?'

'I am responsible for it,' said the man, very simply.

'Oh!' exclaimed Mr Tompkins. 'So you have solved the problem of the Philosopher's Stone of the ancient alchemists. You should be quite a famous man in the medical world. Do you occupy the chair of medicine here?'

'No,' answered the man, being quite taken aback by this,' I am just a brakeman on this railway.'

'Brakeman! You mean a brakeman. - -,' exclaimed Mr Tompkins, losing all the ground under him. 'You mean you—just put the brakes on when the train conies to the station?'

'Yes, that's what I do: and every time the train gets slowed down, the passengers gain in their age relative to other people. Of course,' he added modestly,' the engine driver who accelerates the train also does his part in the job.'

'But what has it to do with staying young?' asked Mr Tompkins in great surprise.

'Well, I don't know exactly,' said the brakeman, 'but it is so. When I asked a university professor travelling in my train once, how it comes about, he started a very long and incomprehensible speech about it, and finally said that it is something similar to 'gravitation red shift—I think he called it—on the sun. Have you heard anything about such things as red shifts?'

' No-o,' said Mr Tompkins, a little doubtfully; and the brakeman went away shaking his head.

Suddenly a heavy hand shook his shoulder, and Mr Tompkins found himself sitting not in the station cafe but in the chair of the auditorium in which he had been listening to the professor's lecture. The lights were dimmed and the room was empty. The janitor who wakened him said: 'We are closing up, Sir; if you want to sleep, better go home.' Mr Tompkins got to his feet and started toward the exit.

2
The Professor's Lecture on Relativity which caused Mr Tompkins's dream

Ladies and Gentlemen:

In a very primitive stage of development the human mind formed definite notions of space and time as the frame in which different events take place. These notions, without essential changes, have been carried forward from generation to generation, and, since the development of exact sciences, have been built into the foundations of the mathematical description of the universe. The great NEWTON perhaps gave the first clear-cut formulation of the classical notions of space and time, writing in his *Principia:*

‘Absolute space, in its own nature, without relation to anything external, remains always similar and immovable;’ and ‘Absolute, true and mathematical time, of itself, and from its own nature, flows equably without relation to anything external.’

So strong was the belief in the absolute correctness of these classical ideas about space and time that they have often been held by philosophers as given *a priori* and no scientist even thought about the possibility of doubting them.

However, just at the start of the present century it became clear that a number of results, obtained by most refined methods of experimental physics, led to clear contradictions if interpreted in the classical frame of space and time. This fact brought to one of the greatest contemporary physicists, ALBERT EINSTEIN, the revolutionary idea that there are hardly any reasons, except those of tradition, for considering the classical notions concerning space and time as absolutely true, and that they could and should be changed to fit our new and more refined experience. In fact, since the classical notions of space and time were formulated on the basis of human experience in ordinary life, we need nor be surprised that the refined methods of observation of today, based on highly developed experimental technique, indicate that these old notions are too rough and inexact, and could have been used in ordinary life and in the earlier stages of development of physics only because their deviations from the correct notions were sufficiently small. Nor need we be surprised that the broadening of the field of exploration of modern science should bring us to regions where these deviations become so very large that the classical notions could not be used at all.

The most important experimental result which led to the fundamental criticism of our classical notions was *the discovery of the fact that the velocity of light in a vacuum represents the upper limit for all possible physical velocities.* This important and unexpected conclusion resulted mainly from the experiments of the American physicist, MICHEL SON, who, at the end of last century, tried to observe the effect of the motion of the earth on the velocity of propagation of light and, to his great surprise and the surprise of all the scientific world, found that no such effect exists and that the velocity of light in a vacuum comes out always exactly the same independent of the system from which it is measured or the motion of the source from which it is emitted. There is no need to explain that such a result is extremely unusual and contradicts our most fundamental concepts concerning motion. In fact, if something is moving fast through space and you yourself move so as to meet it, the moving object will strike you with greater relative velocity, equal to the sum of velocity of the object and the observer. On the other hand, if you run away from it, it will hit you from behind with smaller velocity, equal to the difference of the two velocities.

Also, if you move, say in a car, to meet the sound propagating through the air, the velocity of the sound as measured in the car will be larger by the amount of your driving speed, or it will be correspondingly small if the sound is overtaking you. We call it the *theorem of addition of velocities* and it was always held to be self-evident.

However, the most careful experiments have shown that, in the case of light, it is no longer true, the velocity of light in a vacuum remaining always the same and

equal to 300,000 km per second (we usually denote it by the symbol c), independent of how fast the observer himself is moving.
'Yes,' you will say,' but is it not possible to construct a super-light velocity by adding several smaller velocities which can be physically attained?'
For example, we could consider a very fast-moving train, say, with three quarters the velocity of light and a tramp running along the roofs of the carriages also with three-quarters of the velocity of light.
According to the theorem of addition the total velocity should be one and a half times that of light, and the running tramp should be able to overtake the beam of light from a signal lamp. The truth, however, is that, since the constancy of the velocity of light is an experimental fact, the resulting velocity in our case must be smaller than we expect—it cannot surpass the critical value *c;* and thus we come to the conclusion that, for smaller velocities also, the classical theorem of addition must be wrong.
The mathematical treatment of the problem, into which I do not want to enter here, leads to a very simple new formula for the calculation of the resulting velocity of two superimposed motions.
If v_1 and v_2 are the two velocities to be added, the resulting velocity comes out to be

$$V = \frac{v_1 \pm v_2}{1 \pm \frac{v_1 v_2}{c^2}}.$$

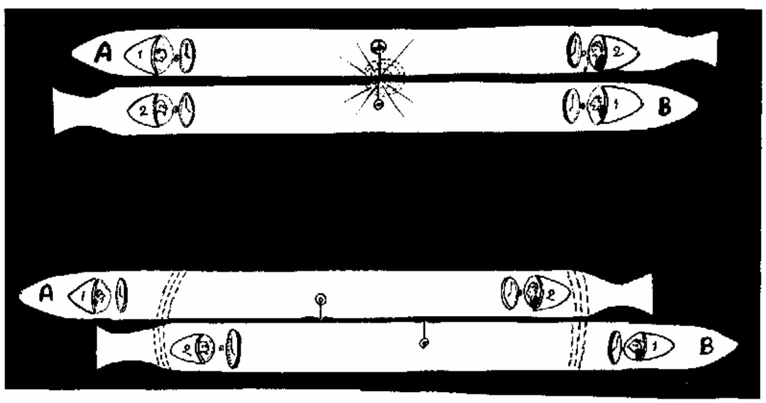
You see from this formula that if both original velocities were small, I mean small as compared with the velocity of light, the second term in the denominator of (i) can be neglected as compared with unity and you have the classical theorem of addition of velocities. If, however, v_1 and v_2 are not small the result will be always somewhat smaller than the arithmetical sum. For instance, in the example of our tramp running along a train, $v_1 = \frac{3}{4} \times c$ and $v_2 = \frac{3}{4} \times c$ formula gives for the resulting velocity $V = 24/25 \times c$ which is still smaller than the velocity of light.
In a particular case, when one of the original velocities is *c,* formula (i) gives *c* for the resulting velocity independent of what the second velocity may be. Thus, by overlapping any number of velocities, we can never surpass the velocity of light.
You might also be interested to know that this formula has been proved experimentally and it was really found that the resultant of two velocities is always somewhat smaller than their arithmetical sum.
Recognizing the existence of the upper-limit velocity we can start on the criticism of the classical ideas of space and time, directing our first blow against the notion of *simultamousness* based upon them.
When you say, 'The explosion in the mines near Cape town happened at exactly the same moment as the ham and eggs were being served in your London apartment,' you think you know what you mean. I am going to show you, however, that you do not, and that, strictly speaking, this statement has no exact meaning. In fact, what method would you use to check whether two events in two different places are simultaneous or not? You would say that the clock at both places would show the same time; but then the question arises how to set the distant clocks so

that they would show the same time simultaneously, and we are back at the original question.

Since the independence of the velocity of light in a vacuum on the motion of its source or the system in which it is measured is one of the most exactly established experimental facts, the following method of measuring the distances and setting the clock correctly on different observational stations should be recognized as the most rational and, as you will agree after thinking more about it, the only reasonable method.

A light signal is sent from the station *A* and as soon as it is received at the station *B* it is returned back to *A*. One-half of the time, as read at station *A,* between the sending and the return of the signal, multiplied by the constant velocity of light, will be denned as the distance between *A* and *B*.

The clocks on stations *A* and *B* are said to be set correctly if at the moment of arrival of the signal at *B* the local clock were showing just the average of two times recorded at *A* at the moments of sending and receiving the signal. Using this method between different observational stations established on a rigid body we arrive finally at the desired frame of reference, and can answer questions concerning the simultaneousness or time interval between two events in different places.



Two long platforms moving in opposite directions

But will these results be recognized by observers on the other systems? To answer this question, let us suppose that such frames of reference have been established on two different rigid bodies, say on two long space rockets moving with a constant speed in opposite directions, and let us now see how these two frames will check with one another. Suppose four observers are located on the front-and the rear-ends of each rocket and want first of all to set their clocks correctly. Each pair of observers can use on their rockets the modification of the above-mentioned method by sending a light signal from the middle of the rocket (as measured by measuring-stick) and setting zero point on their watches when the signal, coming from the middle of the rocket, arrives at each end of it. Thus, each pair of our observers has established, according to previous definition, the criterion of simultaneousness in their own system and have set their watches 'correctly' from their point of view, of course.

Now they decide to see whether the time readings on their rocket check with that on the other. For example, do the watches of two observers on different rockets show the same time when they are passing one another? This can be tested by the following method: In the geometrical middle of each rocket they install two electrically charged conductors, in such a way that, when the rockets pass each other, a spark jumps between the conductors, and light signals start simultaneously from the centre of each platform towards its front and rear ends. By the time the light signals, travelling with finite velocity, approach the observers, the rockets have changed their relative position and the observers *2A* and *2B* will be closer to the source of light than the observers *1A* and *1B.*

It is clear that when the light signal reaches the observer *2A,* the observer *1B* will be farther behind, so that the signal will take some additional time to reach him. Thus, if the watch of *1B* is set in such a way as to show zero time at the arrival of the signal, the observer *2A* will insist that it is behind the correct time.

In the same way another observer, *1A* will come to the conclusion that the watch of *2B,* who met the signal before him, is ahead of time. Since, according to their definition of simultaneousness, their own watches are set correctly, the observers on rocket *A* will agree that there is a difference between the watches of the observers on rocket *B.* We should not, however, forget that the observers on rocket *B,* for exactly the same reasons, will consider their own watches as set correctly but will claim that a difference of setting exists between the watches on rocket *A.*

Since both rockets are quite equivalent, this quarrel between the two groups of observers can be settled only by saying that both groups are correct from their own point of view, but that the question who is correct 'absolutely' has no physical sense.

I am afraid I have made you quite tired by these long considerations, but if you follow them carefully it will be clear to you that, as soon as our method of space—time measurement is adopted, *the notion of absolute simultaneousness vanishes, and two events in different places considered as simultaneous from one system of reference will be separated by a definite time interval from the point of view of another system.*

This proposition sounds at first extremely unusual, but does it look unusual to you if I say that, having your dinner on a train, you eat your soup and your dessert in the same point of the dining car, but in widely separated points of the railway track? However, this statement about your dinner in the train can be formulated by saying that *two events happening at different times at the same point of one system of reference will be separated by a definite space interval from the point of view of another system.*

If you compare this 'trivial' proposition with the previous 'paradoxical' one, you will see that they are absolutely symmetrical and can be transformed into one another simply by exchanging the words 'time' and 'space'.

Here is the whole point of Einstein's view: whereas in classical physics time was considered as something quite independent of space and motion 'flowing equably without relation to anything external' (Newton), in the new physics space and time are closely connected and represent just two different cross-sections of one homogeneous 'space-time continuum', in which all observable events take place.

The splitting of this four-dimensional continuum into three-dimensional space and one-dimensional time is purely arbitrary, and depends on the system from which the observations are made.

Two events, separated in space by the distance *land* in time by the interval *t* as observed in one system, will be separated by another distance *l* and another time interval *t'* as seen from another system, so that, in a certain sense one can speak about the transformation of space into time and vice versa. It is also not difficult to see why the transformation of rime into space, as in the example of the dinner in a train, is quite a common notion for us, whereas the transformation of space into time, resulting in the relativity of simultaneousness, seems very unusual. The point is that if we measure distances, say, in 'centimetres', the corresponding unit of time should be not the conventional 'second' but a 'rational unit of time', represented by the interval of time necessary for a light signal to cover a distance of one centimetre, i.e. 0.000,000,000,03 second.

Therefore, in the sphere of our ordinary experience the transformation of space intervals into time intervals leads to results practically unobservable, which seems to support the classical view that time is something absolutely independent and unchangeable.

However, when investigating motions with very high velocities, as, for example, the motion of electrons thrown out from radioactive bodies or the motion of electrons inside an atom, where the distances covered in a certain interval of time are of the same order of magnitude as the time expressed in rational units, one necessarily meets with both of the effects discussed above and the theory of relativity becomes of great importance. Even in the region of comparatively small velocities, as, for example, the motion of planets in our solar system, relativistic effects can be observed owing to the extreme precision of astronomical measurements; such observation of relativistic effects requires, however, measurements of the changes of planetary motion amounting to a fraction of an angular second per year.

As I have tried to explain to you, the criticism of the notions of space and time leads to the conclusion that space intervals can be partially converted into time intervals and the other way round; which means that the numerical value of a given distance or period of time will be different as measured from different moving systems.

A comparatively simple mathematical analysis of this problem, into which I do not, however, want to enter in these lectures, leads to a definite formula for the change of these values. It works out that any object of length *l*, moving relative to the observer with velocity *v* will be shortened by an amount depending on its velocity, and its measured length will be

$$l' = l\sqrt{1 - \frac{v^2}{c^2}}. \qquad (2)$$

$$t' = \frac{t}{\sqrt{1 - \frac{v^2}{c^2}}}. \qquad (3)$$

Analogously, any process taking time *t* will be observed from the relatively moving system as taking a longer time *t'*, given by (3)

This is the famous 'shortening of space' and 'expanding of time' in the theory of relativity.

Ordinarily, when *v* is very much less than *c* the effects are very small, but, for sufficiently large velocities, the lengths as observed from a moving system may be made arbitrarily small and time intervals arbitrarily long.

I do not want you to forget that both these effects are absolutely symmetrical systems, and, whereas the passengers on a fast-moving train will wonder why the people on the standing train are so lean and move so slowly, the passengers on the standing train will think the same about the people on the moving one.

Another important consequence of the existence of the maximum possible velocity pertains to the *mass* of moving bodies.

According to the general foundation of mechanics, the mass of a body determines the difficulty of setting it into motion or accelerating the motion already existing; the larger the mass, the more difficult it is to increase the velocity by a given amount.

The fact that no body under any circumstances can exceed the velocity of light leads us directly to the conclusion that its resistance to further acceleration or, in other words, its mass, must increase without limit when its velocity approaches the velocity of light. Mathematical analysis leads to a formula for this dependence, which is analogous to the formulae (2) and (3). If *m* is the mass for very small velocities, the mass *m* at the velocity *v* is given

$$m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}} \qquad (4)$$

and the resistance to further acceleration becomes infinite when *v* approaches *c.*

This effect of the relativistic change of mass can be easily observed experimentally on very fast-moving particles. For example, the mass of electrons emitted by radioactive bodies (with a velocity of 99% of that of light) is several times larger than in a state of rest and the masses of electrons forming so-called cosmic rays and moving often with 99-98 % of the velocity of light are loco times larger. For such velocities the classical mechanics becomes absolutely inapplicable and we enter into the domain of the pure theory of relativity.