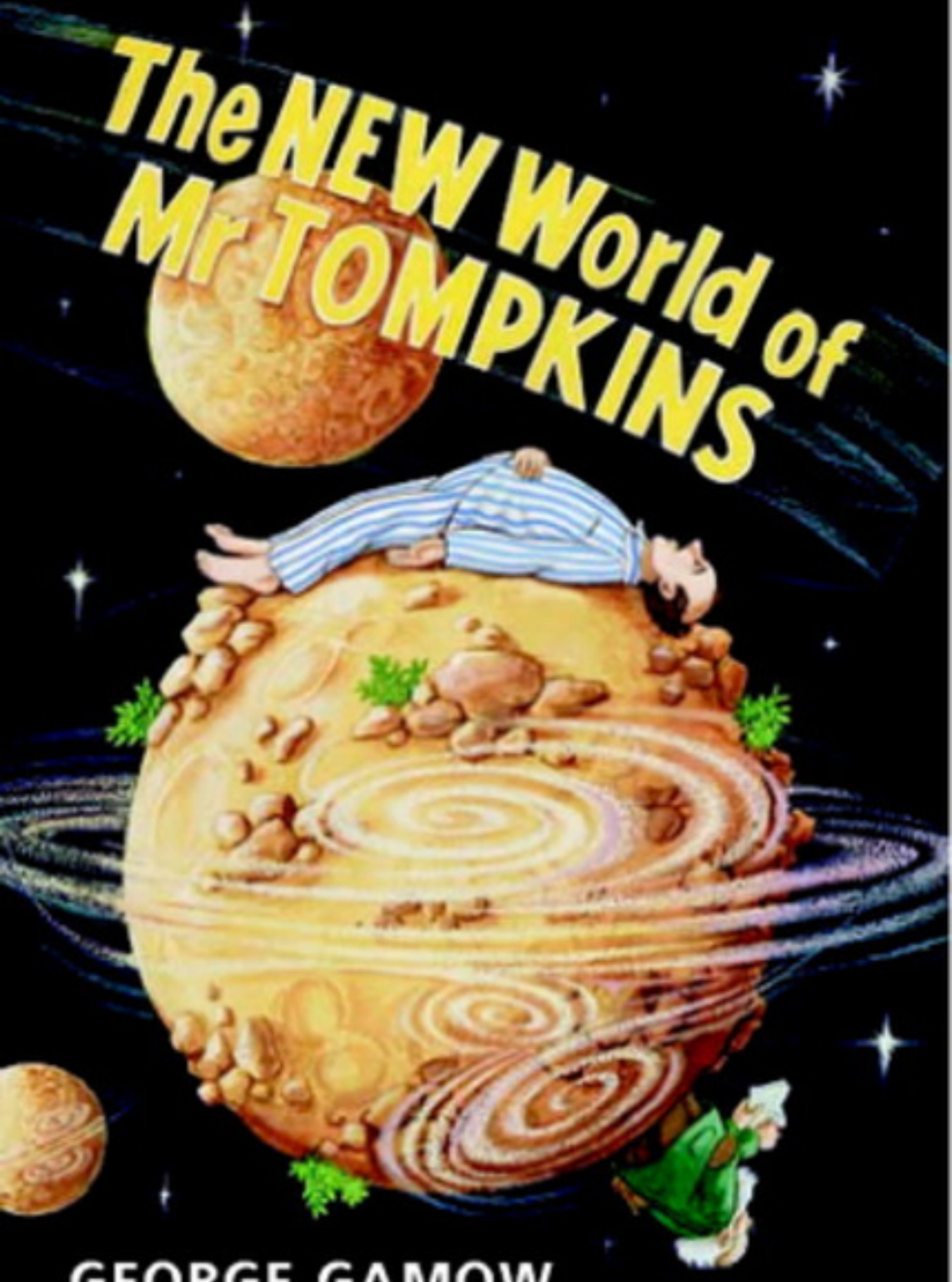
The NEW World of Mr TOMPKINS



GEORGE GAMOW
RUSSELL STANNARD

Illustrated by Mike Edwards

Mr Tompkins is back!

The mild-mannered bank clerk with the short attention span and vivid imagination has inspired, charmed and informed young and old alike since the publication of the hugely successful *Mr Tompkins in Paperback* (by George Gamow) in 1965. He is now back in a new set of adventures exploring the extreme edges of the universe – the smallest, the largest, the fastest, the farthest. Through his experiences and his dreams, you are there at Mr Tompkins's shoulder watching and taking part in the merry dance of cosmic mysteries: Einstein's relativity, bizarre effects near light-speed, the birth and death of the universe, black holes, quarks, space warps and antimatter, the fuzzy world of the quantum, the demolition derby of atom smashers, and that ultimate cosmic mystery of all … love.

Mr Tompkins, the star of these stories, was introduced in a small book, *Mr Tompkins in Wonderland*, published in 1941. This was followed in 1944 by a second volume, *Mr Tompkins Explores the Atom*. In 1965 the two books were combined with much updating and a number of new chapters as *Mr Tompkins in Paperback* (which, despite its title, was published in both paperback and hardback editions). Mr Tompkins has, for over 50 years, been a constant presence in bookshops the world over, watching his younger (perhaps more flashy) rivals come and go. He is now back to show new generations of delighted readers the way into the physics of the twenty-first century.

Russell Stannard has established a reputation as one of the most gifted popularisers of science through numerous media appearances and projects, and in particular for his *Uncle Albert Trilogy* (*The Time and Space of Uncle Albert, Black Holes and Uncle Albert,* and *Uncle Albert and the Quantum Quest*), which covers the work of Albert Einstein and quantum theory in a way that is accessible to children of 11+. These books have enjoyed much success and critical acclaim, being translated into 15 languages, shortlisted for the Rhone–Poulenc non-fiction Book Prizes, the Whitbread Children's Novel of the Year, and the American Science Writing Award.

George Gamow (1904 to 1968) was not only one of the most influential physicists of the twentieth century (one of the founders of the Big Bang theory) but was also a master at science popularisation. Of his many popular books, the best known is *Mr Tompkins in Paperback* (1965).

The NEW World of Mr Tompkins

George Gamow's classic *Mr Tompkins in Paperback*

fully revised and updated by **Russell Stannard**

Illustrated by Michael Edwards

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Reviser's Foreword

There cannot be many physicists who have not at one time or other read the Mr Tompkins adventures. Although originally intended for the layperson, Gamow's classic introduction to modern physics has had enduring, universal appeal. I myself have always regarded Mr Tompkins with the greatest affection. I was therefore delighted to be asked to update the book.

A new version was clearly long overdue, so much having happened in the 30 years since the last revision, especially in the fields of cosmology and high energy nuclear physics. But on re-reading the book, it struck me that it was not only the physics that needed attention.

For example, the current output from Hollywood could hardly be regarded as 'infinite romances between popular stars'. Again, ought one to be introducing quantum theory by reference to a tiger shoot, given our modern-day concern for endangered species? And what of 'pouting' Maud, the professor's daughter, 'engulfed in *Vogue*', wanting 'a darling mink coat', and told to 'run along, girlie' at the mere mention of physics. This hardly strikes the right note at a time when strenuous efforts are being made to persuade girls to study physics.

Then there are problems with the plot. While Gamow deserves credit for the innovative way he introduced the physics through a story, the actual storyline has always had its weaknesses. For instance, Mr Tompkins repeatedly learns new physics from his dreams before he has had any chance of being exposed to such ideas (even subliminally) through real life situations involving the professor's lectures or

conversations. Or take the case of his holiday at the seaside. He falls asleep in the train and dreams that the professor is accompanying him on his journey. It later turns out that the professor actually is on holiday with him and Mr Tompkins is fearful that he will remember what a fool he made of himself on the train – in his dream?!

At times the physics explanations are not as clear as they might have been. For instance, in dealing with the relativistic loss of simultaneity for events occurring in different locations, a situation is described where observers in two spacecraft are to compare results. But instead of adopting the viewpoint of one of these two frames of reference, the problem is addressed from a third, and unacknowledged, frame in which both craft are moving. Likewise, the account given of the shooting of the station master, while the porter was apparently reading a paper at the other end of the platform, does not in fact establish the porter's innocence – as is claimed. (The description would need to rule out the possibility of the porter firing the gun before sitting down to read the paper.)

There is the question of what to do with the 'cosmic opera'. The idea of such a work ever being staged at Covent Garden, was, of course, always farfetched. But now we are faced with the added problem that the subject of the opera – the rivalry between the Big Bang theory and the Steady State theory – can hardly be regarded as a live issue today, the experimental evidence having come down heavily in favour of the former. And yet the exclusion of this ingenious, joyful interlude would be a great loss.

Another problem concerns the illustrations. *Mr Tompkins in Paperback* was partly illustrated by John Hookham, and partly by Gamow himself. In order to describe the latest developments in physics, further illustrations would be required , so necessitating yet a third artist. Should one settle for the resulting unsatisfactory clash of styles, or adopt a completely fresh approach?

In the light of these various considerations, a decision had to be made: I could content myself with a minimal rewrite in which I simply patched up the physics and turned a blind eye to all the other

weaknesses. Alternatively, I could grasp the nettle and go for a thorough reworking.

I decided on the latter. All the chapters needed work doing on them. Chapters 7, 15, 16 and 17 are entirely new. I decided it would also be helpful to add a glossary. The detailed changes I proposed met with the approval of the Gamow family, the publishers and their panel of advisors – with the notable exception of one consultant who was of the opinion that the text should not in any way be touched. This dissenting view was a signal that I was not going to be able to please everyone! Clearly there will always be those who would rather stay with the original – which is fair enough.

But as far as this version is concerned, it is primarily aimed at those who have yet to make the acquaintance of Mr Tompkins. While trying to remain true to the spirit and approach of Gamow's original, it aims to inspire and meet the needs of the next generation of readers. As such, I would like to think that it is a version George Gamow himself might have written – had he been at work today.

Acknowledgements

Thanks are due to Michael Edwards for enlivening the text with his refreshing illustrations. I am grateful to Matt Lilley for his helpful and constructive comments on an early draft. The encouragement and support I received from the Gamow family was much appreciated.

Gamow's Preface to *Mr Tompkins in Paperback*

In the winter of 1938 I wrote a short, scientifically fantastic story (not a science fiction story) in which I tried to explain to the layman the basic ideas of the theory of curvature of space and the expanding universe. I decided to do this by exaggerating the actually existing relativistic phenomena to such an extent that they could easily be observed by the hero of the story, C. G. H.* Tompkins, a bank clerk interested in modern science.

I sent the manuscript to *Harper's Magazine* and, like all beginning authors, got it back with a rejection slip. The other half-a-dozen magazines which I tried followed suit. So I put the manuscript in a drawer of my desk and forgot about it. During the summer of the same year, I attended the International Conference of Theoretical Physics, organized by the League of Nations in Warsaw. I was chatting over a glass of excellent Polish miod with my old friend Sir Charles Darwin, the grandson of Charles (*The Origin of Species*) Darwin, and the conversation turned to the popularization of science. I told Darwin about the bad luck I had had along this line, and he said: 'Look, Gamow, when you get back to the United States dig up your manuscript and send it to Dr C. P. Snow, who is the editor of a popular scientific magazine *Discovery* published by the Cambridge University Press.'

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* The initials of Mr Tompkins originated from three fundamental physical constants: the velocity of light c, the gravitational constant G, and the quantum constant h, which have to be changed by immensely large factors in order to make their effect easily noticeable by the man on the street.

So I did just this, and a week later came a telegram from Snow saying: 'Your article will be published in the next issue. Please send more.' Thus a number of stories on Mr Tompkins, which popularised the theory of relativity and the quantum theory, appeared in subsequent issues of *Discovery*. Soon thereafter I received a letter from the Cambridge University Press, suggesting that these articles, with a few additional stories to increase the number of pages, should be published in book form. The book, called *Mr Tompkins in Wonderland*, was published by Cambridge University Press in 1940 and since that time has been reprinted sixteen times. This book was followed by the sequel, *Mr Tompkins Explores the Atom*, published in 1944 and by now reprinted nine times. In addition, both books have been translated into practically all European languages (except Russian), and also into Chinese and Hindi.

Recently the Cambridge University Press decided to unite the two original volumes into a single paperback edition, asking me to update the old material and add some more stories treating the advances in physics and related fields which took place after these books were originally published. Thus I had to add the stories on fission and fusion, the steady state universe, and exciting problems concerning elementary particles. This material forms the present book.

A few words must be said about the illustrations. The original articles in *Discovery* and the first original volume were illustrated by Mr John Hookham, who created the facial features of Mr Tompkins. When I wrote the second volume Mr Hookham had retired from work as an illustrator, and I decided to illustrate the book myself, faithfully following Hookham's style. The new illustrations in the present volume are also mine. The verses and songs appearing in this volume are written by my wife Barbara.

G. GAMOW

University of Colorado, Boulder, Colorado, USA

1 City Speed Limit

It was a public holiday, and Mr Tompkins, a 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 an afternoon movie. Opening the local newspaper, he turned to the entertainment page. But none of the films appealed to him. He detested the current obsession with sex and violence. As for the rest, it was the usual holiday fare aimed at children. If only there were at least one film with some real adventure, with something unusual and maybe challenging about it. But there was none.

Unexpectedly, his eye fell on a little notice in the corner of the page. The town's university was announcing a series of lectures on the problems of modern physics. 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! He decided to go to the lecture; it might be just what he needed.

Arriving at the big university auditorium, he found the lecture had already begun. The room was full of young students. But there was a sprinkling of older people there as well, presumably members of the public like himself. They were listening with keen attention to a tall, white-bearded man standing alongside an overhead projector. He was explaining to his audience the basic ideas of the Theory of Relativity.

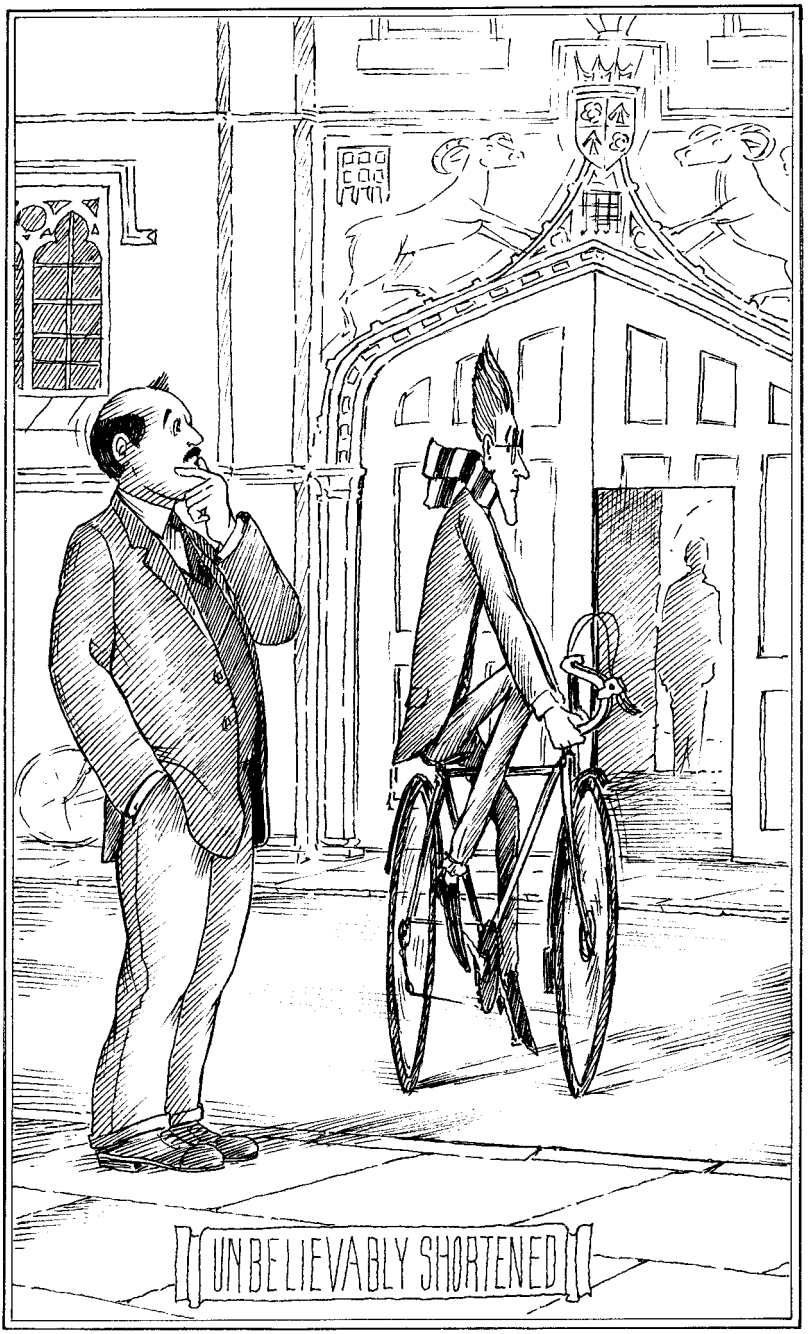
Mr Tompkins got as far as understanding that the whole point of Einstein's theory is that there is a maximum velocity, the velocity of

light, which cannot be exceeded by any moving material object. This fact leads to very strange and unusual consequences. For example, when moving close to the velocity of light, measuring rulers contract and clocks slow down. The professor stated, however, that as the velocity of light is 300,000 kilometres per second (i.e. 186,000 miles per second), these relativistic effects could hardly be observed for events of ordinary life.

It seemed to Mr Tompkins that this was all contradictory to common sense. He was trying to imagine what these effects would look like, when his head slowly dropped on his chest …

When he opened his eyes again, he found himself sitting, not on a lecture room bench, but on one of the benches provided 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 there was nothing unusual about the scene. The hands of the big clock on the college tower opposite were pointing to five o'clock.

The street was nearly empty – except for a single cyclist coming slowly towards him. As he approached, Mr Tompkins's eyes opened wide with astonishment. The bicycle and the young man on it were unbelievably shortened in the direction of their 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 a result of his effort, he shortened still further and went down the street looking rather like a flat picture cut out of cardboard. Immediately Mr Tompkins understood what was happening to the cyclist – it was the contraction of moving bodies, about which he had just heard. He felt very pleased with himself. 'Nature's speed limit must be lower here,' he concluded. 'I reckon it can't be much more than 20 m.p.h. They'll not be needing speed cameras in this town.' In fact, a speeding ambulance going past at that moment could not do much better than the cyclist; with lights flashing and siren sounding, it was really just crawling along.


UNBELIEVABLY SHORTENED

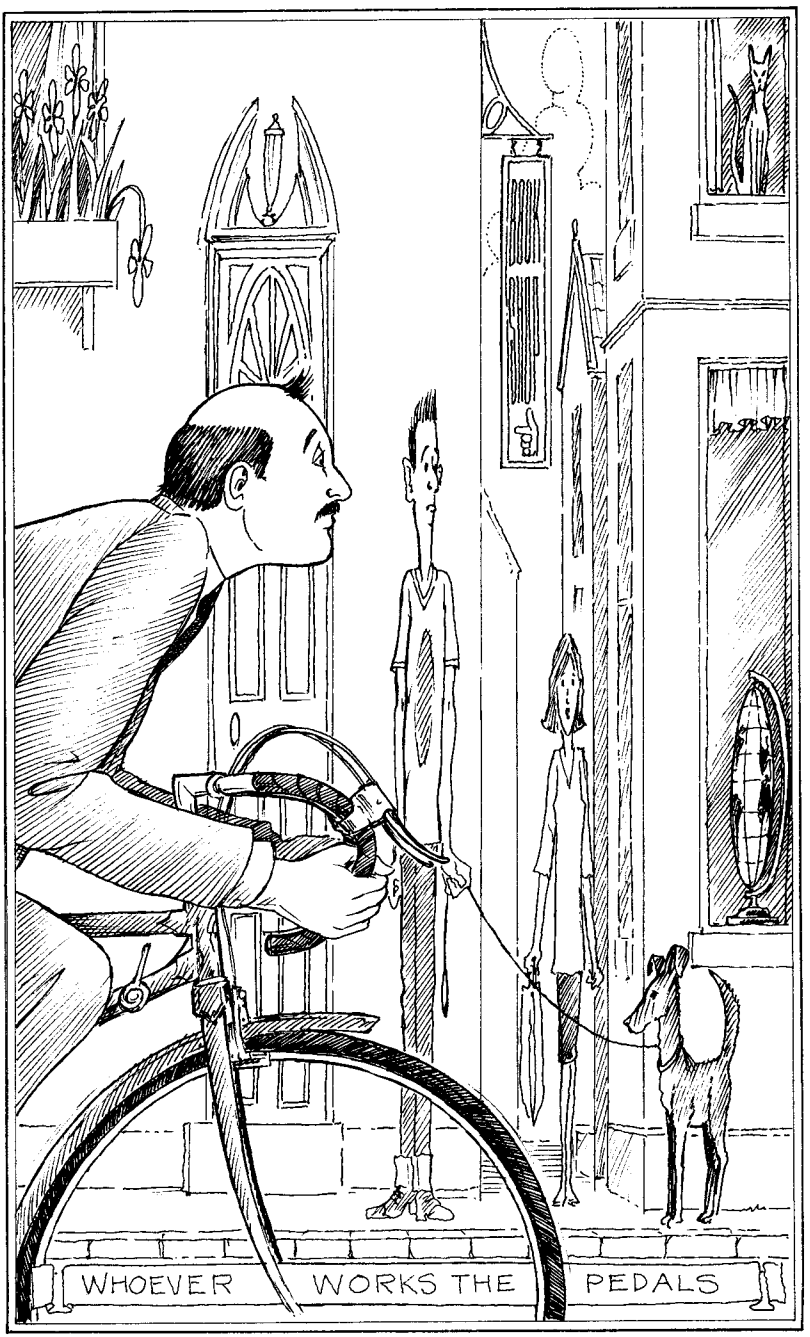
Mr Tompkins wanted to chase after the cyclist to ask him how he felt about being flattened. But how was he to catch up with him? It was then he spotted another bicycle standing against the wall of the college. Mr Tompkins thought it probably belonged to a student attending lectures who might not miss it if he were to borrow it for a short while. Making sure no-one was looking, he mounted the bike and sped down the street in pursuit of the other cyclist.

He fully expected that his newly acquired motion would immediately shorten him, and looked forward to this as his increasing girth had lately caused him some anxiety. To his surprise, however, nothing happened; both he and his cycle remained the same size and shape. On the other hand, the scene around him completely changed. The streets grew shorter, the windows of the shops became narrow slits, and the pedestrians were the thinnest people he had ever seen.

'Ah!' exclaimed Mr Tompkins excitedly. 'I get it 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 had already begun to ache, but still he could not manage to pass a lamppost on the corner much faster than when he had just started. It looked as if all his efforts to move faster were leading to nothing. He began to understand now why the ambulance could not do much better than the cyclist. It was then he remembered what the professor had said about the impossibility of exceeding the limiting velocity of light. He noticed, however, that the harder he tried, the shorter the city blocks became. The cyclist riding ahead of him did not now look so far away – and indeed he eventually managed to catch up with him. Riding side by side, he glanced across and was surprised to find that both the cyclist and his bike were now looking quite normal.

'Ah, that must be because we are no longer moving relative to each other,' he concluded.


WHOEVER WORKS THE PEDALS

'Excuse me,' he called out, 'Don't you find it inconvenient to live in a city with such a low 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 old bike!'

'But you were moving very slowly when you passed me a moment ago,' said Mr Tompkins.

'I wouldn't call it slow,' remarked the young man. 'That's the fifth block we've passed since we started talking. Isn't that fast enough for you?'

'Ah yes, but that's only because the blocks and the streets are so short now,' protested Mr Tompkins.

'What difference does it make? We move faster, or the street becomes shorter – it all comes down to the same thing in the end. I have to go ten blocks to get to the post office. 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 stopping and dismounting.

Mr Tompkins stopped too. He looked at the post office clock; it showed half-past five. 'Hah!' he exclaimed triumphantly. 'What did I tell you. You *were* going slow. It took you all of half an hour to go those ten blocks. It was exactly five o'clock by the college clock when you first passed me, and now it's half-past!'

'Did you *notice* this half hour?' asked his companion. 'Did it *seem* like half-an-hour?'

Mr Tompkins had to admit that it hadn't really seemed all that long – no more than a few minutes. Moreover, looking at his wrist watch he saw that it was showing only five minutes past five. 'Oh!' he murmured, 'Are you saying the post office clock is fast?'

'You could say that,' replied the young man. 'Or, of course, it could be your watch running slow. It's been moving relative to those clocks, right? What more do you expect?' He looked at Mr Tompkins with some exasperation. 'What's the matter with you, anyway? You sound like you're from some other planet.' With that, the young man disappeared into the post office.

Mr Tompkins thought what a pity it was the professor was not at hand to explain these strange happenings 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 reset his watch by the time shown on the post office clock, and to make sure it was still going all right, he waited for ten minutes. It now kept the same time as the post office clock, so all seemed to be well.

Resuming his journey down the street, he came to the railway station and decided to check his watch once more, this time by the station clock. To his dismay it was again quite a bit slow.

'Oh dear, relativity again,' concluded Mr Tompkins. 'It must happen everytime I move. How inconvenient. Fancy having to reset one's watch whenever you've been anywhere.'

At that moment a well-dressed gentleman emerged from the station exit. He looked to be in his forties. He glanced around and recognised an old lady waiting by the kerb side and went over to greet her. Much to Mr Tompkins's surprise, she addressed the new arrival as 'dear Grandfather'. How was that possible? How could *he* possibly be *her* grandfather?

Overcome with curiosity, Mr Tompkins went up to the pair and diffidently asked, 'Excuse me. Did I hear you rightly? Are you really her grandfather? I'm sorry, but I …'

'Ah, I see,' said the gentleman, smiling, 'perhaps I should explain. My business requires me to travel a great deal.'

Mr Tompkins still looked perplexed, so the stranger continued. 'I spend most of my life on the train. So, naturally I grow old much more slowly than my relatives living in the city. It's always such a pleasure to come back and see my dear little granddaughter. But I'm sorry, you'll have to excuse me, please …' He hailed a taxi, leaving Mr Tompkins alone again with his problems.

A couple of sandwiches from the station buffet somewhat revived him. 'Yes, of course,' he mused, sipping his coffee, 'motion slows down time, so that's why he ages less. And all motion is relative

– that's what the professor said – so that means he will appear younger to his relatives, in the same way as the relatives appear younger to him. Good. That's got that sorted out.'

But then he stopped. He put down the cup. 'Hold on. That's not right,' he thought. 'The grandaughter did *not* seem younger to him; she was older than him. Grey hair is not relative! So what does that mean? All motion is *not* relative?'

He decided to make one last attempt to find out how things really are, and turned to the only other customer in the buffet – a solitary man in railway uniform.

'Excuse me,' he began, 'would 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. 'How…'

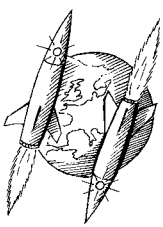
'I'm a train driver,' answered the man, as though that explained everything.

'A train driver?' repeated Mr Tompkins. 'I always wanted to be a train driver – when I was a boy, that is. But … but what's that got to do with staying young?' he added, looking more and more puzzled.

'Don't know exactly,' said the driver, 'but that's the way it is. Got it from this bloke from the university. Sitting over there we were,' he said nodding at a table by the door. 'Passing the time of day, you know. Told me all about it he did. Way over my head, mind you. Didn't understand a word of it. But he did say it was all down to acceleration and slowing down. I remember that bit. It's not just speed that affects time, he said; it's acceleration too. Every time you get pushed or pulled around on the train – as it comes into stations, or leaves stations – that upsets time for the passengers. Someone who is *not* on the train doesn't feel all those changes. As the train comes into the platform you don't find people standing on the platform having to hold onto rails or what-have-you to stop falling over in the way the passengers on the train do. So that's where the difference comes in. Somehow …' he shrugged.

Suddenly a heavy hand shook Mr Tompkins's shoulder. He found himself sitting not in the station café but on the bench of the auditorium in which he had been listening to the professor's lecture. The lights were dimmed and the room was empty. It was the janitor who had awakened him saying: 'Sorry, sir, but we're closing up. If you want to sleep, you'd be better off at home.' Mr Tompkins sheepishly got to his feet and started towards the exit.

2 The Professor's Lecture on Relativity which Caused Mr Tompkins's Dream



Ladies and gentlemen:

At a very primitive stage in the development of the human mind there 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 the exact sciences, they 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, at the start of the present century it became clear that a number of results, obtained by the most refined methods of experimental physics, led to clear contradictions if interpreted in the classical frame of space and time. This realization brought to one of the greatest twentieth century 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 not be surprised that the refined methods of observation of today, based on highly developed experimental techniques, indicate that these old notions are too rough and inexact; they have been used in ordinary life and in the earlier stages of the development of physics only because their deviations from the correct notions were too small to be noticeable. 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 that *the velocity of light in a vacuum is a constant (300,000 kilometres per second, or 186,000 miles per second), and represents the upper limit for all possible physical velocities*.

This important and unexpected conclusion was fully supported, for instance, by the experiments of the American physicists Michelson and Morley. At the end of the nineteenth century, they tried to observe the effect of the motion of the Earth on the velocity of light. They had in mind the prevailing view at the time that light was a wave moving in a medium called the aether. As such it was expected to behave in much the same way as water waves move over the surface of a pond. The Earth was expected to be moving through this aether medium in a manner similar to a boat moving over the surface of the water. The ripples caused by the boat appear to a passenger to move away more slowly from the vessel in the direction in which it is travelling than they do to the rear. In one case we have to subtract the speed of the boat from that of the water waves, and in the other we add them. We call this the *theorem of addition of velocities*. This has always been held to be self-evident. In the same way, therefore, one would expect that the speed of light would appear to differ according to its direction relative to the

motion of the Earth through the aether. Indeed, it ought to be possible to determine the speed of the Earth with respect to the aether by measuring the speed of light in different directions.

To Michelson and Morley's great surprise, and the surprise of all the scientific world, they found that no such effect exists; the velocity of light was exactly the same in all directions. This odd result prompted the suggestion that perhaps, by an unfortunate coincidence, the Earth in its orbit around the Sun just happened to be stationary relative to the aether at the time the experiment was carried out. To check that this was not so, the experiment was repeated six months later when the Earth was travelling in the reverse direction on the opposite side of its orbit. Again, no difference in the speed of light could be detected.

It having been established that the velocity of light did not behave like that of a wave, the remaining possibility was that it behaved more like that of a projectile. If we were to fire a bullet from a gun in the boat, it would seem to the passenger to leave the moving boat at the same speed in all directions – which is the behaviour Michelson and Morley found for light emitted in all directions from the moving Earth. But in that case, someone standing on the shore would find that a bullet fired in the direction in which the boat was heading would be travelling faster than one fired in the opposite direction. In the first case the speed of the boat would be added to the muzzle speed of the bullet, and in the latter it would be subtracted – again in accordance with the theorem for the addition of velocities. Accordingly, we would expect that light emitted from a source that was *moving relative to us* would have speeds dependent on the angle of emission to the direction of motion.

Experiment shows, however, that this is also not the case. Take, for example, neutral pions. These are very small sub-atomic particles which undergo decay with the emission of two pulses of light. It is found that these pulses are always emitted with the same speed whatever their direction relative to the motion of the parent pion, even when the pion itself is travelling at a speed close to that of light.

Thus, we find that whereas the first experiment showed that the velocity of light did not behave like that of a conventional wave, this second one shows that it does not behave like a conventional particle either.

In conclusion, we find that the speed of light in a vacuum has a constant value regardless of the movement of the observer (our observations from the moving Earth), or the movement of the source of light (our observations of light emitted from the moving pion).

What of the other property of light I mentioned: it being the ultimate limiting velocity?

'Ah,' you might say, 'but is it not possible to construct a super-light velocity by adding several smaller velocities?'

For example, we could imagine a very fast-moving train with a velocity of, say, three-quarters that of light, and we could have a man running along the roofs of the carriages also with a velocity three-quarters that of light. (I asked you to use your *imagination*!) According to the theorem of the addition of velocities, the total velocity should be $1\frac{1}{2}$ times that of light. That would mean the running man should be able to overtake the beam of light from a signal lamp. It seems, however, that, since the constancy of the velocity of light is an experimental observation, the resulting velocity in our case must be smaller than we expect – the classical theorem for the addition of velocities must be wrong.

The mathematical treatment of the problem – something I do not want to enter into 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, and c is the velocity of light, the resulting velocity comes out to be

$$V = \frac{(v_1 + v_2)}{\left(1 + \frac{v_1 v_2}{c^2}\right)} \qquad (1)$$

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 (the bottom bit) of (1) will be so small it can be

ignored, giving the classical theorem of addition of velocities. If, however, v_1 and v_2 are not small, the result will always be somewhat smaller than the arithmetical sum. For instance, in the example of our man running along a train, $v_1 = \frac{3}{4}c$ and $v_2 = \frac{3}{4}c$ and our formula gives the resulting velocity $V = \frac{24}{25}c$, which is still smaller than the velocity of light.

You should note that in the particular case when one of the original velocities is c, formula (1) always gives c for the resulting velocity independent of what the second velocity might be. Thus, by overlapping any number of velocities, we can never exceed the velocity of light. This formula has been confirmed experimentally; the addition 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 *simultaneity*.

When you say, 'The explosion in the mines near Capetown 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. Strictly speaking, this statement has no exact meaning.

To see this, consider what method you would use to check whether two events in two different places were simultaneous or not. You would say that the two events were simultaneous if clocks at both places showed the same time. But then the question arises as to how we are to set the distant clocks so that they 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 clocks correctly on different observational stations should be recognised as the most rational and, as you will agree after thinking more about it, the only reasonable method.