1 What to Trust to Avoid Believing in Illusions

It is darkest under the lantern according to an ancient proverb. Like its different formulations, this proverb also has different interpretations, one of which captures the essence of the way we form our views of the world. Over the centuries we have learned that Nature has given us her deepest features as apparently self-evident phenomena which explains why we understand the most familiar phenomena the least. For example, we all know what motion is, and do not bother to think even a bit about what seems to be a trivial concept to the overwhelming majority of us. But as the Eleatics argued twenty-five centuries ago and as we will see in the next chapters this concept is anything but trivial. The situation is the same with other apparently self-evident phenomena of the physical world such as gravitation, inertia, mass, space, and particularly time. While discussing the nature of time sixteen centuries ago, Saint Augustine eloquently expressed our illusory understanding of the most profound phenomena of the world: "What, then, is time? I know well enough what it is, provided that nobody asks me; but if I am asked what it is and try to explain, I am baffled" [26, p. 118]

The most familiar and apparently unquestionably obvious feature of the world – its very existence – turns out to be the greatest mystery. However, fortunately, our nature is such that that seemingly unquestionable obviousness does not last throughout our lives. In our intellectual development, we all reach a turning point when we start asking the perennial existential questions: "What is the world?"; "What am I?"; "What is the meaning of the existence of the world and myself?". The German philosopher Schopenhauer expressed this transition to enlightenment perhaps in the best way: "The lower a man stands in intellectual respects the less of a riddle does existence seem to him… but, the clearer his consciousness becomes the more the problem grasps him in its greatness" (quoted by William James in *The Problem of Being* [2]).

Plato's Allegory of the Cave

Once we reach the moment of intellectual awakening we start realizing how illusory perhaps most of our views of the world are, and try to identify and get rid of any illusions. However, the history of our civilization has shown that identifying and freeing ourselves from illusions about the world is not an easy process. Since ancient times thinkers have been suspecting that what our senses tell us about the world might not necessarily reflect the world the way it itself is. Their unanimous advice on how we can recognize and abandon illusions is to deepen constantly our knowledge about the world through education and self-education. Perhaps the most famous example is Plato's allegory of the cave in his book *The Republic* in which he describes the life of the uneducated man in order to "compare our nature in respect of education and its lack" [3]. Prisoners who spent all their lives in a cave where they were restricted to see only the shadows of artificial objects shaped as humans and animals on the wall of the cave believe that what they see are the real things [3]: "Then in every way such prisoners would deem reality to be nothing else than the shadows of the artificial objects." But when a prisoner is freed (i.e. educated) and allowed to look toward the light, he would see the actual objects and would realize "that what he had seen before was all a cheat and an illusion."

In the beginning of 21st century everyone seems to be sufficiently educated (or self-educated thanks to the enormous information that is now easily available) to form an adequate view of the world. However, as far as the physical world is concerned, it appears only a small fraction of our civilization holds a view that is firmly based on reliable knowledge provided by modern physics. The huge majority seems to hold views which contradict scientific facts about the physical world deduced from the existing experimental evidence. I think the main reason for this disturbing situation is the issue of what constitutes reliable knowledge (i.e., scientific facts) and even whether such knowledge is at all possible. Unfortunately, some scientists appear to hold an unproductive view on the nature of scientific theories according to which scientific theories are only *descriptions* of physical phenomena and for this reason we cannot deduce any reliable knowledge about the world from them since we can describe the same phenomena by other theories which present a different picture of the world.

However, most scientists hold a realistic view on the nature of scientific theories according to which *scientific theories, whose predictions have been confirmed by experiment, adequately reflect those features of the world represented by the theories.* Perhaps the best and most recent proof of that is the hunt for the Higgs boson – if physicists were unsure that their experimentally-confirmed theories adequately represented elements of reality (in this case the Higgs boson), they would not invest such huge effort and funds to test that theoretical prediction. If the Higgs boson were not discovered, then the theory of elementary particles which does not predict its existence would again make a definite claim about the world – that such a particle (with the specified properties) does not exist.

Although such examples convincingly demonstrate that accepted scientific theories do reveal the true nature of those parts and features of the world that are represented by the theories, there does not exist a unanimous consensus in exactly what sense and to what extent our theories of the physical world provide true knowledge about it. The main reason appears to be the question of whether an experimentally-confirmed theory will forever remain a correct theory about the elements of the world which it represents, and in this sense it can be regarded as the *final* theory of those elements (which means that the knowledge about those elements of the world, provided by the theory, will never be challenged and will therefore be regarded as true knowledge about that part of the world). This question is obviously of crucial importance since only such *final theories about the elements of the world they represent* can provide true knowledge about those elements – e.g., the existence of the Higgs boson is an example of a piece of true knowledge and the prediction of its *existence* constitutes an element of a theory which is final in a sense that any new theory of elementary particles will not make the Higgs boson more existent.

Sometimes it is tempting to think that if one day an experimentally-confirmed scientific theory is replaced by a new theory, the old theory might be wrong and therefore its claims about the world might be questioned and refuted. Such a temptation should instantly evaporate when an undeniable meta-theoretical fact is taken into account – that *experiments do not contradict one another*[1]. Indeed, since a theory is regarded as experimentally-confirmed when its predictions are confirmed by experiment, no new theory can disprove the first one *in the domain where its predictions were confirmed*; otherwise the experiments that confirmed the predictions of the new theory would contradict the experiments that confirmed the predictions of the first theory (e.g., the experiments at the Large Hadron Collider which confirmed the existence of the Higgs boson would be contradicted by other experiments which would confirm the prediction of a new theory, disproving the first one, that such a particle did not exist).

Because experiments do not contradict one another, a theory will never be proved wrong in the domain where its predictions have been experimentally confirmed. In this sense, such a theory is a final theory about that domain and therefore provides true knowledge about it. As I am quite aware of how philosophers and perhaps even some scientists might react to the two statements in the previous sentence (on a final theory and true knowledge), let me give two examples to clarify the meaning of these statements.

- In addition to the example of the existence of the Higgs boson, the existence of the other elementary particles (electrons. protons, etc.) also constitutes pieces of true knowledge about

[1] A skeptic may, as always, object that *so far* we have not observed such contradictions, but that might happen in the future. By the same "logic," a skeptic may also say "So far men have not given birth, but that might happen in the future." I think the philosophical doctrine of skepticism is still around only due to its continued total ignorance of how science actually works. If skeptics try to understand that scientific statements are not based on *inductive inferences*, but reflect proper understanding of the mechanism of physical phenomena revealed by experimentally tested theories, they would realize why the *universality* of scientific truths (confirmed by experiment) cannot be questioned.

the world and in this sense the Standard Model is a final theory about the domain where its predictions of the *existence* of *those* elementary particles were experimentally confirmed. For this reason, we do possess true knowledge about the existence of the known elementary particles and, due to its being *true*, that knowledge is *final* – no future theory will disprove the Standard Model in the domain where its predictions of the known elementary particles were experimentally confirmed (since no future experiments will contradict the experiments which confirmed the *existence* of those particles).

- The predictions of classical mechanics and particularly Newton's three laws have been repeatedly confirmed by experiment and for this reason classical mechanics will never be proved wrong in its domain of applicability (where its predictions have been experimentally confirmed at velocities much smaller than the velocity of light and in the case of macroscopic bodies). The situation with Newton's gravitational theory is more complicated and the analysis of the experimental verification of its predictions requires special care in order to determine the theory's proper domain of applicability. For example, Newton's theory correctly predicts how bodies fall toward the Earth's surface, but interprets that fall as being caused by a gravitational force. However, according to the modern theory of gravitation – general relativity – falling bodies move by inertia since their fall is not caused by a gravitational force, but is a manifestation of the curvature of spacetime in the Earth's vicinity (induced by the Earth's mass). Newton's theory also correctly predicts that a body at rest on the Earth's surface is subject to a gravitational force (the body's weight), and general relativity did not question the existence of that force, but clarified its nature by showing that it is inertial, not gravitational. So general relativity did not (and could not) refute the predictions of Newton's gravitational theory which were confirmed by experiment – that (and how) (i) a body falls toward the Earth (and planets orbit the Sun while falling toward it), and (ii) a body prevented from falling (e.g. while being at rest on the Earth's surface) is subject to a force. General relativity provided deeper understanding of what causes those phenomena – the curvature of spacetime – as we will see in Chapter 6.

I think the following examples most convincingly demonstrate to people who do not have a professional science background that an experimentally-confirmed theory will never be proved wrong in its domain of applicability (that domain of the world where the theory's predictions have been repeatedly confirmed by experiment), and therefore provides true knowledge about that part of the world. A thousand years from now, it will still be classical mechanics – Newton's three laws and Newton's gravitational theory (for determining the weight of objects) – that will be used in the calculations when people build buildings and bridges, for example. A thousand years from now, it will still be classical (Maxwell's) electrodynamics that will be used in the calculations of electrical motors, the electrical wiring of buildings, ordinary electrical and microwave ovens (if such things will be used then), etc.

Scientists, particularly physicists, know that the very way science works is the best proof of the "eternity" of the experimentally-confirmed theories (as physics is the strongest example in this respect, when I talk about science in this book I mean physics). Indeed, the reliable scientific knowledge provided by such theories form the foundation on which new theories are built. Such foundational knowledge has no expiration date. In 1909 Max Planck explicitly stressed that foundational knowledge (whose elements he properly called invariants) plays a central role in the advancement of physics [5]:

> The principle of relativity holds, not only for processes in physics, but also for the physicist himself, in that a fixed system of physics exists in reality only for a given physicist and for a given time. But, as in the theory of relativity, there exist invariants in the system of physics: ideas and laws which retain their meaning for all investigators and for all times, and to discover these invariants is always the real endeavor of physical research. We shall work further in this direction in order to leave behind for our successors where possible – lasting results. For if, while engaged in body and mind in patient and often modest individual endeavor, one thought strengthens and supports us, it is this, that we in physics work, not for the day only and for immediate results, but, so to speak, for eternity.

Since the dawn of science in the 17th century (mostly due to the work of Galileo and Newton) until the two major revolutions in physics in the beginning of the 20th century (relativity and quantum mechanics), foundational knowledge (i.e. reliable scientific knowledge) about the world consisted mostly of assertions about the *existence* of physical phenomena such as:

- Inertia with its two aspects – (i) a free body moves by inertia, i.e. with constant velocity (constant speed and constant direction), and (ii) a body which is subject to a force (that prevents the body from moving by inertia) resists the change in its inertial motion with constant velocity (i.e. resists its acceleration). The second aspect of the phenomenon of inertia – resistance to acceleration – is captured in Newton's second law ($\mathbf{F} = m\mathbf{a}$) whose profound meaning is that in order to prevent a body from moving by inertia (i.e. from moving with constant velocity) a force must be applied to *overcome* the resistance which the body offers to its acceleration (i.e. to the change in its velocity).

- The equivalence of action and reaction in mechanical interactions as reflected in Newton's third law – if a body exerts a force on another body, the other body instantly reacts by exerting a force equal in magnitude and opposite in direction to the force exerted by the first body.

- All bodies fall toward the Earth with the same acceleration first realized and proved by Galileo; later Newton *interpreted* that experimental fact in terms of his second law of motion – as the falling bodies accelerate they should be subject to a force (the force of gravity) which accelerates them.

- A body at rest on the Earth's surface is subject to a force (the body's weight) regarded by Newton as gravitational.

These examples of pieces of foundational knowledge, provided by Newton's mechanics, effectively asserts only the existence of the phenomena reflected in those pieces of knowledge. No real attempt has been made to *explain* those phenomena – the resistance a body offers to its acceleration was *called* (not explained) 'the body's inertia'; the cause of a body's fall and its weight were merely *labeled* 'gravitational force' with no attempt to explain the nature of that 'force' (Newton himself explicitly stated that he only *described* gravitational phenomena and made no hypothesis on their nature; as we will see in Chapter 6 even he did not believe that the 'gravitational force' he introduced to describe the gravitational phenomena could be transmitted through the empty space separating celestial bodies).

What constitutes foundational knowledge dramatically changed after the advent of special and general relativity. Not only were new phenomena added to the existing foundational knowledge about the physical world as we will see in Chapter 5 (e.g. the equivalence of mass and energy, the relativistic mass increase, and the general relativistic frame dragging effect according to which a rotating body twists the surrounding spacetime), but also *explanations* of existing and relativistic phenomena became part of foundational knowledge. In Chapter 5 we will also see why explanations, provided by the theory of relativity, do constitute foundational knowledge – *if those explanations were wrong, the experiments that confirmed the explained phenomena would be impossible*. We will have the most general proof of this strong statement shortly (in this chapter) and in detail in Chapter 5 – both the theory of relativity and the experiments which confirmed its kinematical predictions would be impossible if the world were *not* four-dimensional (with time as the fourth dimension as revealed by the theory of relativity), but three-dimensional (as our senses seem to imply). This proof is one of the best demonstrations that our theories (in this case the theory of relativity) provide true knowledge about the world.

As explanations of physical phenomena are an integral part of foundational knowledge, it is evident that only one theory of given physical phenomena provides their true explanation, which, in turn, demonstrates that scientific theories are something more than mere descriptions. Despite this, occasionally one can hear or read that different theories which describe the same physical phenomena are equivalent since they are just different descriptions of the phenomena. In some cases such a position is fine, but in other cases it is plain wrong which is best seen by the very fact of how physics works – that experiments are always performed to *choose* one of the *competing* theories describing the *same* physical phenomena.

Part of the art of doing physics is to determine whether different theories are indeed simply different descriptions of the same physical phenomena (as is the case with the three representations of classical mechanics – Newtonian, Lagrangian, and Hamiltonian), or *only one* of the theories competing to describe and explain given physical phenomena is the correct one (as is the case with general relativity, which identifies gravity with the non-Euclidean geometry of spacetime, and other alternative theories, which regard gravity as a force). The difference between these two cases can be illustrated by an example from everyday life. The first case – different theories are just different descriptions of a given phenomenon – is like the description of an event in different languages; every language correctly describes the event and therefore the different languages' accounts are equivalent. The second case – only one of the theories describing a given phenomenon is correct – is like different accounts of the same event (in any language) and, obviously, only one is correct.

The theory of relativity enriched the foundational knowledge of the physical world with explanations of physical phenomena. But, unfortunately, the other revolutionary theory of the 20th century – quantum mechanics – did not provide us with explanations of quantum phenomena that can be added to the foundational physical knowledge. Like in the case of the Newtonian mechanics, the foundational knowledge provided by quantum mechanics contained assertions only about the *existence* of new quantum phenomena. This is not surprising when it is taken into account that, like the Newtonian mechanics, which is the first experimentally-confirmed theory of the macroscopic world, quantum mechanics is the first experimentally-confirmed theory of the microscopic world (the quantum scale of the world). By contrast, the theory of relativity is the second theory of the macro scale of the world and as such is a better representation of the macro world, which enables it to reveal the true explanations of the represented phenomena.

In addition to augmenting the foundational knowledge of the physical world, the theory of relativity and quantum mechanics provided an important piece of reliable knowledge about how knowledge itself grows – new theories are more accurate representations of the world than the previous experimentally-confirmed theories and do not disprove them but incorporate them as limiting cases. After the advent of the theory of relativity and quantum mechanics this fact has been adopted by physicists as one of the necessary conditions which any new theory should meet – the predictions of any new theory should coincide with the predictions of the previous theory in the domain where those predictions have been tested by experiment.

How scientific knowledge grows by preserving the already accumulated foundational knowledge is nicely illustrated by an everyday example [4]:

> Quantum mechanics ... doesn't displace Newtonian mechanics, but incorporates it as a limit. Scientific theories grow by incorporating what is already known and adding to it, just as a tree adds layers on the outside while preserving its heartwood.

That accepted theories cannot be proved wrong in the domain where their predictions have been confirmed by experiment cannot be seriously questioned. But that some predictions of accepted theories contradict experimental results cannot be questioned either. It is precisely such contradictions that give rise to the occasional temptation to declare that if a prediction of a theory is contradicted by experiment, such a theory is wrong. Fortunately, science (physics in particular) does not work in that way at all. For example, the equations of motion of both special and general relativity spectacularly fail to describe the behaviour of quantum objects, but no one declares these theories wrong. Simply, in that case they have been employed outside of their domain of applicability where their predictions have been tested by experiment. For exactly the same reason some predictions of Newtonian mechanics contradict experimental results. Now we know that such contradictions do not prove that a theory, whose predictions have been experimentally confirmed, is wrong; they are an indication that the theory has been employed beyond its domain of applicability.

An example illustrates even better than the previous example why the already established foundational knowledge cannot be wrong. The top image on the right is a satellite picture of Montreal with low resolution. This picture can be thought of as an analog of Newtonian mechanics. There are a number of features of Montreal which are clearly seen on the satellite picture – the existence of recognizable streets and blocks of buildings especially in the downtown area. These features are the analog of foundational knowledge provided by Newtonian mechanics. No satellite pictures of increasing resolution will disprove what is clearly seen on the first picture; in exactly the same way, no theory will disprove Newtonian mechanics in the domain where its predictions have been experimentally confirmed. However, on the low-resolution image there are areas whose features are not clearly dis-

Satellite picture of Montreal with low resolution.

A higher resolution satellite picture of the region of Montreal shown in the bottom-left corner of the above picture.

tinguished – for example, the bottom-left corner of the picture does not provide unambiguous knowledge about the streets and blocks of buildings there. If we try to employ the knowledge of the downtown part of Montreal to that area, practically certainly we will fail as a new satellite picture with higher resolution (the bottom image on the right) will show (or if we simply go to the area on the image). In the same way, theories employed outside of their domain of applicability fail. Evidently, the satellite picture with higher resolution can be thought of as an analog of a new theory (e.g., special relativity) describing the same 'part' of the world (the macroscopic scale), which is described by Newtonian mechanics.

In order that one forms an adequate view of the physical world based on scientific results, the issue of why a physical theory will never be proved wrong in its domain of applicability (where its predictions have been experimentally confirmed) should be thoroughly understood and not brushed aside as purely academic. Only then one can understand why scientific theories correctly represent those features of the world, which they describe. That is why, it should be stressed that the stakes in the question of whether or not scientific theories provide true knowledge of the world are at the highest possible level. The reason is that *an affirmative answer to this question will make us trust in even counter-intuitive features of the world revealed by scientific theories, whereas a negative answer would unavoidably imply that science tells us nothing about the world and the only information about it comes from our senses.*

To see even better why the stakes are really at the highest level as far as the question of the nature of scientific theories is concerned, let us face the fact that for centuries our senses (e.g., sight and touch) have been a continued source of illusions since they do not provide sufficient and unambiguous information that would allow us to form an adequate view of the physical world. An example dealing with the central question in the book – what is the nature of reality – is *whether the information coming from our senses enables us to determine how the world exists in time.* Through our senses we are aware *only at the present moment* of our own continued existence and the continued existence of the world and uncritically interpret these sense data to mean that we (as physical bodies) and the world itself exist only at the moment 'now', which constantly changes. In other words, for centuries we have been assuming without examination that

- the fact that we realize ourselves and the world only at the present moment implies that only this moment – the moment 'now' – exists,

- the fact that we realize the existence of the world only at the moment 'now' implies that the world *itself* exists solely at that moment, and
- the continued existence (endurance) of the world through time implies that the only existent present moment constantly changes, i.e. that time flows.

For centuries these three assumptions have been regarded as a self-evident foundation of a world view, now called *presentism*, according to which only the constantly changing moment 'now' exists and for this reason everything that exists, exists solely at this moment. Stated another way, on the presentist view, only the present, which since Aristotle (as shown in the next chapter) has been regarded as a three-dimensional world, exists, whereas the past does not exist any more and the future does not exist yet. The assumption that time flows embodies the very essence of the presentist view – the existent present (the three-dimensional world at the only existent present moment) constantly stops existing by becoming past and the non-existing future constantly comes into existence by becoming present.

What prompted the writing of this book was the fact that despite the overwhelming evidence against presentism, this view continues to be held by the huge majority of our civilization even in the 21st century. In the next chapter we will see that since ancient times there have existed logical arguments against the sole existence of the present moment. In Chapter 4 and especially in Chapter 5 we will discuss in detail how the theory of relativity decisively disproved the presentist view of the world. Now I will only summarize some of the facts which (i) demonstrate the inadequacy of presentism due to its being based on information coming from our senses, which has never been properly examined by those sharing this view, and (ii) demonstrate how presentism contradicts both the theory of relativity and the experiments which confirmed its predictions.

Let us start by asking what the evidence for the presentist view is. Throughout the centuries, up to this moment, the only "evidence" has been the apparently self-evident interpretation of our sense data captured in the above three implicit assumptions behind presentism. Nothing else, no experimental evidence coming either from classical or modern science. Although it is clear, but since this is about our basic view of the world, let me specifically ask you not to believe the statement that there is no experimental evidence for presentism without reading opposite views. I think the best and fair approach is to make your own decision only after having read, in addition to this book, the most recent defence of the key feature of presentism (the reality of time flow) by several well-known physicists [6]-[9]. Here I will only comment on what George Ellis wrote in December 2008 when we discussed the reality of the flow of time while participating in the 2008 Essay Contest *The Nature of Time* organized by the Foundational Questions Institute (FQXi) [11]: "the real-world evidence that time does indeed flow is overwhelming (example: this posting was not posted till I posted it at a particular proper time along my world line)", and his response to my insistence that our everyday experience by itself (without being critically examined) does not constitute an argument for the reality of the flow of time: "I totally disagree. Our daily life experience is abundant evidence about the nature of reality. If physicist chose to ignore all that evidence, then their theories are not adequately related to the real world. They are trapped in the 'isolated laboratory' view of physics, a convenient fiction (no truly isolated laboratories exist either in space or time), instead of believing that physics should be able to describe the real world, as I do."

I think Ellis' comments eloquently show what a stubbornly persistent illusion the flow of time (which is behind the presentist view) indeed is. The apparently self-evident interpretation that our daily life experience (reflected in our sense data) proves the reality of time flow could lure even renowned scientists, like Ellis, who believe that physics does describe the real world and, more inexplicably, who are not afraid to correct their views if confronted with convincing arguments. Let us examine Ellis' comments to see that they contain no evidence whatsoever for the key element of the presentist view – that time really flows (Ellis believes that the time flow is real and holds a view according to which both the past and the present are real, but the future is not).

For Ellis "Our daily life experience is abundant evidence about the nature of reality" and is therefore evidence about the reality of time flow. Undoubtedly, he means *experimental* evidence since everything we observe in our daily life is indeed an enormous set of natural experimental facts – for example, bodies staying at rest, moving and colliding. Ellis certainly regards as such natural experimental evidence also the facts that we are aware of the existence of the world (and of our own existence) only at the present moment and for this reason we *do not observe* the future, and asserts that all these facts observed in our everyday life prove the reality of time flow and particularly his view that only the future does not exist but part of it constantly comes into existence while becoming present (this transition of the non-existing future events into the existing present events is precisely what is regarded as a real flow of time).

Ellis' comments do not provide any evidence for the reality of time flow since they contain the same implicit assumptions behind the belief that time flow is real (listed above), all of which turn out to have no experimental support. He almost explicitly takes for granted what must be proved – that the future does not exists (which could be a proof for the reality of time flow). This is seen in his own example above – "example: this posting was not posted till I posted it at a particular proper time along my world line". That is, he merely states (instead of proving) that the event of posting his comments did not exist when it was in the future and came into being when it became present. Like all who believe that this is true, i.e. that time really flows, Ellis *just asserts* that "the real-world evidence that time does indeed flow is overwhelming".

Before showing in more detail why what Ellis calls "the real-world evidence" does not constitute experimental evidence in the proper scientific sense, let me present a more general argument which, taken even alone, is sufficient to prove that. As we will see shortly and in great detail in Chapter 5, the *experiments* which confirmed the kinematical relativistic effects proved that past, present and future exist equally. As experiments do not contradict one another "the real-world evidence" cannot be regarded as experimental evidence for the non-existence of the future; otherwise "the real-world evidence" would contradict the relativistic experiments. In this situation, it is evident that the scientific approach available to all who continue to insist that the flow of time is real is to disprove the assertion that the relativistic experiments proved the equal existence of all moments of time.

Let us now see why the apparently self-evident interpretation of our sense data coming from our daily life experience (which gives rise to the illusion that time flows and to the presentist view) turns out to be a misinterpretation. This becomes immediately evident when we start asking questions to determine whether the information coming from our senses is unambiguous.

First, the fact that we realize ourselves at one single moment of time is not a proof at all that only that moment exists. To understand better the huge logical jump we make, without realizing it, when we take it as self-evident that only 'now' exists since we are aware only of this moment, consider the analogous situation with space. We are aware only of a relatively small spatial region around us, but we do not claim that only that region of space exists. It is clear why we do this – we have different kinds of indications of the existence of the rest of the space and despite that we are not directly aware of the whole of space we are certain that it exists. But we have similar indications about time – we are aware that the past moments of time existed (like distant regions of space which we visited in the past and saw that they existed), and we are certain that there will be future like there was past. Now, some may be tempted to argue that we are aware of whole regions of space *at once*, but we are always aware of a *single* moment of time – the moment 'now'. I think it will be a good idea to suppress such a temptation because it is another illusion that we are aware of whole regions of space *at once* as we will see below. Even if we forget the analogy with space, there exist three arguments against the sole existence of the present moment (and the third is decisive) – (i) the assumption that only 'now' exists leads to logical contradictions realized even by some ancient thinkers as we will see in the next chapter, (ii) there does not exist anything that even resembles a piece of physical experimental evidence for the sole reality of the present moment; if only 'now' existed, physics would have proven it by now, and (iii) we will see in Chapter 5 that the experiments which confirmed the theory of relativity provided the most convincing proof for the equal existence of all moments of time (because the theory of relativity would be impossible if only the present moment existed).

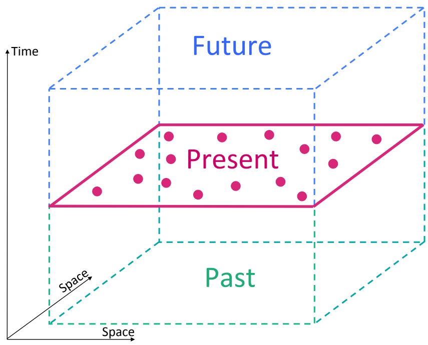
Second, the fact that we realize the world at one single moment of time is not a proof at all that the world itself exists only that moment. We do see the world around us only at the present moment, but what we see tells us nothing definite about the world. When we believe we see the world at the moment 'now', we are actually aware at this moment of mental images of different objects, which contain information coming from our senses. Even a quick analysis reveals that we need extra information in order to understand what those images represent. For example, we believe that the mental images in our mind represent three-dimensional objects, but these same images could also represent three-dimensional reflections from extra-dimensional objects. Sitting in our armchairs and contemplating about the two options will never allow us to determine which of them is the true one. Before 1908, when Einstein's mathematics professor Hermann Minkowski showed that Einstein's theory of special relativity is in fact a theory of a four-dimensional world (with all moments of time forming the fourth dimension), we had been uncritically interpreting the mental images to mean that they represent three-dimensional objects and a three-dimensional world. After 1908, the relativistic experimental evidence has been gradually convincing physicists and philosophers that the counter-intuitive interpretation of the mental images in our mind (that those images represent three-dimensional reflections from a four-dimensional world) is the correct one; indeed, as we will see shortly (and in greater detail in Chapter 5) the experiments which confirmed the kinematical predictions of special relativity proved the reality of Minkowski's four-dimensional world, which we now call spacetime (or sometimes block universe since spacetime is actually the whole history of the Universe given *en bloc*).

Rømer's discovery in 1676 that the speed of light is finite provided another example that additional information is needed to determine how to interpret the mental images through which we are aware of the external world. Before that discovery people believed that what they see at the present moment exists at that moment, but it turned out that that first naive form of presentism was an illusion – the world we see at the moment 'now' does not exist at the moment we perceive it because due to the finite speed of light we see only *past* events. When we look at a cloudless night sky we see the Moon and a myriad of stars and tend to believe that all of them and the whole world exist at once right now – at the moment 'now' when we perceive them. However, this is an obvious illusion – the mental image of the Moon of which we are aware at the present moment represents the image of the Moon which is about 1.3 seconds old (as the average distance between the Moon and the Earth is about 400,000 km and the speed of light is 300,000 km/s, it takes about 1.3 seconds for the sunlight reflected from the Moon's surface to reach our eyes), whereas the mental images of some stars may represent images of those stars that are millions of years in the past. Therefore, the mental images of which we are aware *at once at the present moment* represent images of objects that *existed at different moments in the past.* In other words, our feeling that we are aware at the moment 'now' of whole regions of space *at once* also turns out to be an illusion – space is defined in terms of *simultaneity* (as all space points corresponding to the *same* moment of time), whereas the space region we 'see' (through the distances between the objects in it) *at once* at the moment 'now' does not constitute a space region at all since it is a mosaic of small space fractions corresponding to *different* past moments of time (the greater the distance of a space fraction from us is, the more in the past it is since it takes more time for light reflected from the objects in that space fraction to reach us).

So, rigorously speaking, our senses do not tell us anything definite about what the world itself is. Only science can provide additional information which can enable us to understand what the sense data represent. That is why, in order that we hold an adequate view of the world (especially if it turns out to be frighteningly counter-intuitive), it is of paramount importance to have proof that scientific theories provide true knowledge of the world. Fortunately, as we saw above fundamental physical theories give the best proof for that. Perhaps the most spectacular proof of true knowledge of the world comes from the theory of relativity and particularly from the experiments which confirmed its kinematical predictions. That proof is spectacular on two counts. First, a specific scientific theory radically affects our view of the world by disproving the presentist view and showing that the world is four-dimensional with time as the fourth dimension. Second, how powerful this proof of true knowledge of the world is can be demonstrated by assuming for a moment that the knowledge deduced from the theory of relativity and the experiments which confirmed it is not true knowledge, i.e. that the world is three-dimensional and evolves as time really flows. Then neither the theory of relativity nor the relativistic experiments would be possible, if the world were three-dimensional. Let us sketch that proof now and we will return to it in Chapter 5.

After Rømer's discovery of the finite speed of light showed that the naive version of presentism (what we *see simultaneously* 'now' exists at this moment) was an illusion, the presentist view had been silently adjusted to accommodate that scientific fact. Its modified version is still the world view shared by the huge majority of our civilization in the 21st century which is truly inexplicable given the fact that presentism openly contradicts the relativistic experimental evidence. What makes presentism easily tested experimentally is that it is defined in terms of *simultaneity* – the present is the three-dimensional world (the space and all objects in it) which exists solely at the present moment, i.e. the present is everything that exists *simultaneously* at the moment 'now' (we saw above that space is defined in terms of simultaneity – as all space points corresponding to the *same* moment of time). As seen in the figure, the present is a class of simultaneous events (i.e., the class of all objects and space points which exist simultaneously at the present moment, since an *'event'* in the theory of relativity means 'an object or a space point at a given moment of time').

In 1905 Einstein formulated his special theory of relativity whose major result was that *observers in relative uniform motion have different times.* That was the end of a very stubbornly persistent illusion – that there existed one absolute time and the whole world was subject to its flow. The very essence of the presentist view is entirely based on the idea of absolute time – there is one absolute 'now' for the whole world and that is why, on the presentist view, everything that exists is

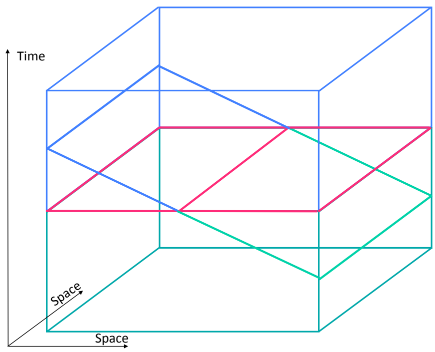


On the presentist view only the present – the three-dimensional world at the moment 'now' – exists. The past does not exist any more and the future does not exist yet.

regarded as existing simultaneously at the present moment. It seems logically unavoidable that getting rid of the illusion of absolute time should have immediately led to getting rid of the presentist illusion since according to special relativity observers in relative motion have different times, different nows, and different classes of simultaneous events, which means they have *different presents* (i.e., different three-dimensional worlds). What looked logically unavoidable, however, has not happened for over a century despite that in 1908 Minkowski announced a stunning new world view rigorously following from the fact that the many times of many observers in relative motion (introduced by Einstein) imply many spaces as well, which is *not possible in a three-dimensional world* and therefore unavoidably leads to the conclusion that what exists is an absolute (the same for all observers) four-dimensional world [12, p. 114]:

> Hereafter we would then have in the world no more *the* space, but an infinite number of spaces analogously as there is an infinite number of planes in three-dimensional space. Three-dimensional geometry becomes a chapter in four-dimensional physics.

Minkowski's argument that many spaces imply a four-dimensional world in which all moments of time form the fourth dimension is shown in the figure where the cube represents such a four-dimensional world (spacetime). Two observers in relative motion have different spaces which are represented in the figure by the horizontal and the inclined surfaces. The spacetime diagram makes Minkowski's argument completely obvious – the consequence of special relativity that two observers in relative motion have different spaces (first realized by Minkowski) implies that the world is four-dimensional because only then the two observers can have different spaces which are simply two three-dimensional cross sections of spacetime. Minkowski's explanation that observers in relative motion can have different spaces and times only in (at least) a four-dimensional world removed the mystery around Einstein's initial formulation of special relativity where Einstein merely postulated that time and simultaneity were relative. The spacetime diagram naturally explains the deep physical meaning of Einstein's relativity of simultaneity – the two surfaces (horizontal and inclined), which represent the spaces of the observers, also represent the observers' different classes of simultaneous events (since a space is a class of simultaneous events); therefore relativity of simultaneity clearly implies that the world is four-dimensional.



Two observers in relative motion can have their own relative spaces only if the two spaces are cross sections of an absolute underlying reality – spacetime.

There is some irony in the discovery of special relativity. As we will see in Chapter 4, Einstein wanted to get rid of all absolutes in physics – absolute motion, absolute space, absolute time, and absolute simultaneity, and postulated that they are all relative. This seems to have been so important to him that he named his theory published in 1905 'the theory of relativity'. Einstein's theory successfully explained the existing experimental evidence and made new radical predictions which were confirmed by experiment. Despite this success, the physical meaning of the *relativity* of physical quantities remained a complete mystery until 1908 when Minkowski showed that he could still have an important lesson to teach his already famous student. Minkowski arrived at the revolutionary view that space and time form an inseparable *absolute* four-dimensional world by realizing that relative space, relative time, and relative simultaneity can exist only in such an absolute world (as we saw in the figure above). The essence of Minkowski's lesson is that *relative quantities are manifestation of an underlying ab-*

solute reality.

Minkowski convincingly showed that merely postulating that motion, space, time, and simultaneity are relative, in order to explain the experimental evidence, is only the first step toward the true explanation (which should involve some absolute reality) of that experimental evidence since *no relative quantities would be possible if no underlying absolute reality existed.* It is this fact which made perhaps the greatest and most spectacular proof in the history of science possible – the theory of relativity and the relativistic experimental evidence *proved* that the world is four-dimensional; otherwise, if the world were three-dimensional, the theory of relativity and most importantly the experiments which confirmed its kinematical predictions would be impossible.[2]

This is clearly seen in the spacetime diagram above. If the world were three-dimensional, the cube in the diagram (representing spacetime) would be reduced to the horizontal plane (which represents a three-dimensional world, i.e. the present) and all observers in relative motion would share the *same* three-dimensional world, i.e. the *same* space and the *same* class of simultaneous events; therefore, space, time, and simultaneity would be *absolute* in contradiction with the theory of relativity.

[2] I am aware only of a single criticism of the arguments that the relativistic kinematical effects are impossible in a three-dimensional world, which are mere expansion of Minkowski's own arguments that the theory of relativity is a theory of a four-dimensional world. In a book that appeared this year (2013) F. Weinert took the *conclusion* of rigorous analyses of the relativistic effects (including an analysis of Minkowski's explanation of length contraction) to be the *argument* and tried to construct a logical fallacy. He claimed that the "argument" (if the world is four-dimensional, then we observe relativistic effects) affirms the consequent (the world is a four-dimensional block universe). What Weinert regards as the argument (or rather the premise!) is not the argument; it is the conclusion deduced from analyses of the relativistic effects and the experiments that confirmed them (as outlined here and discussed in Chapter 5). Therefore, the statement "the world should be four-dimensional in order that we observe relativistic effects" is supported by experiment (the essence of my argument, not touched by Weinert) and for this reason what Weinert constructed is not a logical fallacy, but a perfect argument. I doubt that such kind of criticism, without even touching the real arguments and analyses, can foster cooperation between scientists and philosophers. I will mention only two other wrong claims in his book – (i) that "Minkowski himself did not necessarily accept the notion of the block universe" (p. 138), and (ii) that "in his later years Einstein wavered in his support for the Parmenidean view" ("the Parmenidean block universe") (p. 141). In both cases, the reasons given by Weinert are perfectly explainable in terms of spacetime and both Minkowski and Einstein knew that. The wrong claim regarding Einstein is particularly inexplicable because Weinert undoubtedly knows well that Einstein expressed his strongest support for the block universe a month before he left this world: "the distinction between past, present and future is only a stubbornly persistent illusion" [15].

If some suspect that the contradiction is implied by the spacetime diagram itself, then simply forget the diagram. If reality were a three-dimensional world, simultaneity would be absolute in contradiction with relativity since *a three-dimensional world constitutes a single class of simultaneous events* – everything that exists *simultaneously* at the present moment (if now some suspect that the three-dimensional world is defined in such a way which leads to the contradiction with relativity, try to define it differently).

I hope you now see why I wrote that the theory of relativity's proof of the reality of Minkowski's absolute four-dimensional world is the greatest and most spectacular proof in the history of science. Never before has a scientific theory so decisively and unambiguously disproved a world view and proved another as the theory of relativity did.

The presented here sketch of the proof of the reality of spacetime (i.e. that the world is four-dimensional) involves only the major result of the theory of relativity – relativity of simultaneity (i.e., the fact that observers in relative motion have different times and different spaces). To make the proof even more convincing two remarks should be made.

First, relativity of simultaneity has never been directly tested experimentally. However, two relativistic effects – length contraction and time dilation – are specific manifestations of relativity of simultaneity and these effects have been confirmed by experiment as we will see in Chapter 5. Therefore, not only would relativity of simultaneity be impossible if the world were three-dimensional, but, what is crucial, *the experiments*, which confirmed length contraction and time dilation, would be impossible in a three-dimensional world.

Second, rigorously speaking, Minkowski's proof that the world is four-dimensional is valid only if the *existence* of physical objects and the world itself is *absolute*; only then it is possible for two observers in relative motion to have different spaces – the *relative* spaces of the two observers, represented by the horizontal and the inclined surfaces in the spacetime diagram above, are manifestations of an *absolute* four-dimensional world. In despair that the familiar presentist view of the world contradicts relativity, some might be tempted to argue that, in addition to relativizing motion, time, space, simultaneity, the theory of relativity relativized existence as well (conveniently ignoring the fact rooted in logic and mathematics after being ultimately extracted from the physical world, which Minkowski so clearly explained – that the very possibility of relative quantities implies an underlying absolute reality!). If existence were relativized, for each of two observers A and B in relative motion only his space would exist (and nothing more) and the three-dimensionality of the world would be saved at the price of relativizing the world's existence. Such an argument does reveal utter despair because relativized existence is very close to the nonsense "nonexistent existence" For example, for each of the observers A and B only his space (and therefore his three-dimensional world, i.e., his present) would exist, whereas the space of the other observer would be nonexistent existence – A knows (due to the theory of relativity) that B has a different space which therefore exists for B, but does not exist for A, and vice versa. Kurt Gödel found it necessary to comment on the possibility to relativize existence with a single sentence [16]: "The concept of existence [. . .] cannot be relativized without destroying its meaning completely." And this is not just the intuition of the famous logician (who also has contributions to general relativity) but certainly summarizes the result of a rigorous logical and philosophical analysis of what relativized existence may mean. All who tend to suspect that Gödel might have made an unfounded statement could try to disprove it by showing that existence can be relativized without destroying its meaning.

The proof of the reality of Minkowski's absolute four-dimensional world by the theory of relativity would not be the greatest and most spectacular proof in the history of science if it relied to the slightest extent on some authorities in science; the only authority on which this proof relies is the ultimate judge – the experimental evidence. Nature has been good to us since she allowed for even such an abstract logical and philosophical issue – relativization of existence – to be tested experimentally. In Chapter 5, where we will see how such a fundamental issue as the dimensionality of the world can be tested by experiment, we will also see that the experiments, which confirmed the twin 'paradox' effect, rule out the relativization of existence (those experiments would be impossible if existence were relativized). And not only this – Chapter 5 contains two additional and independent arguments, also based on the relativistic experimental evidence, which demonstrate what Gödel stressed – that relativized existence leads to nonsensical results and situations.

To summarize, even in this introductory chapter we identified a number of illusions and implicit assumptions regarding the interpretation of our sense data about the world, which have been taken for granted. When these assumptions are made explicit it becomes evident that our sense data allow for another interpretation, which is counter-intuitive. We saw (and will see in greater detail in Chapter 5) that the theory of relativity and the relativistic experimental evidence not just supported, but *proved* the counter-intuitive interpretation of the sense data.

In view of this, we can also summarize what we should trust to avoid believing in illusions:[3]

- We should trust and share a world view that is based on reliable scientific knowledge. In this way we can more easily understand and include in our world view even worryingly counter-intuitive features of the world, if the experimental evidence tells us that this is what the world is like, no matter whether we like it or not.

- We should trust that science does provide reliable (and therefore *eternal*) knowledge about the world since a scientific theory, whose predictions have been confirmed by experiment in its domain of applicability, will never be disproved in that domain by a more modern theory. The need for a thorough understanding of this issue arises from an occasional temptation that we should not worry about the implications of a scientific theory for our world view since sooner or later it would be replaced by a more modern theory which might not have such implications. As we saw above a very important lesson from the history of science is that no new theory can challenge the reliable knowledge about the world in the domain of applicability of a scientific theory where it has been proved by experiment.

The above discussion of these guiding principles is mostly intended for a wider audience without a strong scientific background. As the presentation of the arguments for the reality of Minkowski's four-dimensional world was also meant for this audience, I would like to emphasize that scientists and particularly physicists are well-aware of Minkowski's introduction of the absolute four-dimensional world (and his arguments for it) when he gave the spacetime formulation of Einstein's special relativity. There have been many physicists who have demonstrated in writing their brilliant understanding of the impact of Minkowski's idea on our view of the world.[4] Here are several examples.

A. Einstein, *Relativity: The Special and General Theory* (Routledge, London 2001) p. 152:

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[3] I think readers of this book may find Matthew Hutson's *The 7 Laws of Magical Thinking: How Irrational Beliefs Keep Us Happy, Healthy, and Sane* [17] an excellent and helpful companion.

[4] An excellent example of how philosophers adopt the implications of relativity and Minkowski's views is G. Nerlich's book *Einstein's Genie: Spacetime out of the Bottle* [18], which was just published. I think this is a major work on the metaphysics of spacetime.

> It appears therefore more natural to think of physical reality as a four-dimensional existence, instead of, as hitherto, the *evolution* of a three-dimensional existence.

A. Einstein in his letter of condolences to the widow of his longtime friend Michele Besso (Besso left this world on 15 March 1955; Einstein followed him on 18 April 1955) [15]:

> Now Besso has departed from this strange world a little ahead of me. That means nothing. People like us, who believe in physics, know that the distinction between past, present and future is only a stubbornly persistent illusion.

A. S. Eddington, *Space, Time and Gravitation: An Outline of the General Relativity Theory* (Cambridge University Press, Cambridge 1920), p. 51:

> In a perfectly determinate scheme the past and future may be regarded as lying mapped out – as much available to present exploration as the distant parts of space. Events do not happen; they are just there, and we come across them.

A. S. Eddington, *Space, Time and Gravitation: An Outline of the General Relativity Theory* (Cambridge University Press, Cambridge 1920), p. 56:

> However successful the theory of a four-dimensional world may be, it is difficult to ignore a voice inside us which whispers: "At the back of your mind, you know that a fourth dimension is all nonsense." I fancy that that voice must often have had a busy time in the past history of physics. What nonsense to say that this solid table on which I am writing is a collection of electrons moving with prodigious speeds in empty spaces, which relatively to electronic dimensions are as wide as the spaces between the planets in the solar system! What nonsense to say that the thin air is trying to crush my body with a load of 14 lbs to the square inch! What nonsense that the star cluster which I see through the telescope obviously there now, is a glimpse into a past age 50 000 years ago! Let us not be beguiled by this voice. It is discredited.

In the distant 1921 Eddington made his most explicit comment on the reality of spacetime (Minkowski's four-dimensional world) when he discussed the fact (discovered by Minkowski as mentioned above) that not only do observers in relative motion have different times but they also have different spaces, which however are fictitious since according to the theory of relativity the world is not objectively divided into such spaces and times (A.S. Eddington, The Relativity of Time, *Nature* **106** (1921) pp. 802–804, p. 803):

> It was shown by Minkowski that all these fictitious spaces and times can be united in a single continuum of four dimensions. The question is often raised whether this four-dimensional space-time is real, or merely a mathematical construction; perhaps it is sufficient to reply that it can at any rate not be less real than the fictitious space and time which it supplants.

H. Weyl, *Philosophy of Mathematics and Natural Science* (Princeton University Press, Princeton 2009) p. 116:

> The objective world simply *is*, it does not *happen*. Only to the gaze of my consciousness, crawling upward along the life line of my body, does a section of this world come to life as a fleeting image in space which continuously changes in time.

H. Weyl, *Mind and Nature: Selected Writings on Philosophy, Mathematics, and Physics* (Princeton University Press, Princeton 2009) p. 135:

> The objective world merely exists, it does not happen; as a whole it has no history. Only before the eye of the consciousness climbing up in the world line of my body, a section of this world "comes to life" and moves past it as a spatial image engaged in temporal transformation.

R. Geroch, *General Relativity: 1972 Lecture Notes* (Minkowski Institute Press, Montreal 2013), p. 7:

> There is no dynamics in spacetime: nothing ever happens there. Spacetime is an unchanging, once-and-for-all picture encompassing past, present, and future.

However, there are scientists (even physicists) who most probably regarded the claim that the world is four-dimensional as obviously wrong due to its hugely counter-intuitive implications. I am inclined to think that the reason for such ignoring of the arguments for the reality of spacetime is rather irrational. Such an attitude toward arguments for worryingly counter-intuitive new discoveries was exhibited by Cantor in a letter to Dedekind in 1877 where he explained how he viewed one of his own major results (the one-to-one correspondence of the points on a segment of a line with (i) the points on an indefinitely long line, (ii) the points on a plane, and (iii) the points on any multidimensional mathematical space) – "I see it, but I don't believe it" [19]. This book will repeatedly stress what guides scientists in their quest for understanding the world – that the nature of the world (no matter how counter-intuitive it may be) is ultimately revealed by the experimental evidence.

Anyone who disagrees with Minkowski's view of the world, should try to avoid presenting arguments against it based on other experiments or theories. First, experiments do not contradict one another. Second, as we know science does not work in this way – if we have an argument we face it, we do not ignore it and bring other arguments. The only scientific approach would be to disprove the arguments that the relativistic experiments proved that the world is four-dimensional, i.e., anyone who tries to disprove the spacetime view should disprove the arguments showing that both the theory of relativity and the experiments which confirmed its predictions are impossible in a three-dimensional world. As we saw above and as we will see in Chapter 5, those arguments can be fully understood by non-experts and therefore non-experts are also in a position to try to refute them; the only thing they have to trust is the information about the experiments that confirmed the relativistic predictions, but that information can be verified easily.

Let me assure you that I am perfectly aware of how difficult it is to accept and especially to adopt Minkowski's totally counter-intuitive view of the world. When I first realized its huge implications for virtually all areas of our life (this happened years ago in graduate school after an advanced course on electrodynamics and during a course on general relativity), my reaction was perhaps similar to the reaction of a lot of you – the world could not be that idiotic (I am sorry for this expression, but I was very emotional when I realized how utterly absurd a four-dimensional world view looked like and this was exactly my reaction). However, instead of throwing out all my books on relativity and hoping that my refusal to accept that view would make it wrong, I chose to follow the path of the scientific method. As like anyone else in the scientific field, I also recognize the experimental evidence as the ultimate judge and the only authority in science, I started to analyze the experiments which confirmed the relativistic effects with the firm intention to disprove Minkowski's view (i.e., the spacetime view of the world). But the analyses did not produce the results I was sure they would produce. Quite the opposite – it turned out that those experiments would be impossible if Minkowski's view were wrong, i.e., if the world were three-dimensional. After repeating those analyses, finally I asked myself – If the world is indeed a four-dimensional block ('frozen') universe, what should I do? Deny Minkowski's view (which is proved by the experimental evidence) simply because I do not like it? Now you know my answer – it is in front of you. And gradually I realized that the spacetime view is not as troubling as it might look at first sight.

I would not be completely surprised if there are people who might continue to believe in presentism without even trying to understand the arguments against it (which could unable them to change their world view). My hope is, if there are such people who are not amenable to outside help, that they will be able to help themselves for a very simple reason. No one can impose on us a given (even scientific) view – we are all entitled to our own views. However, we all know that in such situations there is always a small problem – Nature does not care about our personal opinions.

A century after Minkowski we all should finally face the facts which show that what appears to be self-evident to us – that the world exists only at the moment 'now' – is, as Einstein put it, "only a stubbornly persistent illusion." It is true that the view of reality which is consistent with modern science poses great challenges of its own. But taking refuge from the blinding light of truth back into the deceivingly safe and comfortable cave of ignorance should not be an option for anyone in the 21st century.