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ADVANCES IN MODERN PHYSICS:

part 2

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PREFACE

Настоящее учебное пособие включает актуальные тексты (2017-2018гг.) учебно-познавательной тематики для магистрантов физического факультета (направление 03.04.02 «Физика»).

Целью данного пособия является формирование навыков научной речи, в основе которых лежит владение характерными для научного стиля лексикограмматическими структурами. Ставится задача подготовить магистрантов к основным формам как письменного (аннотация, теоретический обзор, статья), так и устного научного общения (доклад, дискуссия).

Пособие состоит из 5 разделов, рассматривающих проблемы и достижения в сфере информационных технологий в современном мире. Каждый из них содержит аутентичные материалы (источники: *Aeon, Nautilus, Quanta Magazine*) и упражнения к ним. Раздел “Supplementary reading“ служит материалом для расширения словарного запаса и дальнейшего закрепления навыков работы с текстами по специальности.

Пособие может успешно использоваться как для аудиторных занятий, так и для внеаудиторной практики.

1. The Data That Threatened to Break Physics

Part 1

Exercise I.

Say what Russian words help to guess the meaning of the following words: rational, result, journalists, sensational, leader, computer, distance , massive, atom, bomb

Exercise II

Make sure you know the following words and word combinations:
to subvert, trench, to enshrine, muon, to rattle, caveat, tenet, bunch, to sift, timing

The Data That Threatened to Break Physics

What does a rational scientist do with an impossible result? (1)

Antonio Ereditato tells me he has no desire to engage journalists who might subvert his words into a sensational, insincere story. The reason he agreed to Skype with me is because I am a physicist and writer who spent 13 years in the trenches of experimental particle physics. Ereditato is the former leader of the 160 physicists from 13 countries that compose the OPERA collaboration, whose goal is to study neutrino physics. It was first proposed in 2000, and Ereditato led it from 2008 to 2012. Then in late winter of 2011, the impossible seemed to happen. “The guy who is looking at the data calls me,” Ereditato tells me from my computer screen. “He says, ‘I see something strange.’ ” What he saw was evidence that neutrinos traveled through 454 miles of Earth’s crust, from Switzerland to Italy—which they are supposed to do—at such a high speed that they arrived 60.7 nanoseconds faster than light could travel that distance in outer space—which should have been impossible. Over the last century, Einstein's observation that no massive object can travel faster than the speed of light in a vacuum, enshrined in his theory of special relativity, has become a keystone of how we understand the universe. If the OPERA measurement was correct, it would mark the first-ever violation of that theory: An atom bomb in the heart of our understanding of the universe. I ask Ereditato if he thought it must have been a mistake. "I don't think it's fair to say this," Ereditato tells me. "If we say that, we bias our analysis. So when we got this indication that something was so astonishing, the first reaction was, well, let's find why this is so." (2)

Wolfgang Pauli postulated the existence of neutrinos in 1930 to solve a simple problem. When nuclei undergo beta decay through the emission of an electron or a positron, the electron's antimatter equivalent, something is missing. Either something invisible is emitted along with the electron or positron, or energy must disappear. Since no repeatable experiment of anything flying, falling, moving, colliding, decaying, or staying put had ever seen energy disappear, Pauli proposed the neutrino, an invisible particle with all the properties necessary to bring beta decay into accord with the first law of thermodynamics. By invisible, I mean that when neutrinos pass through matter they rarely leave a trace. So rarely that it took almost 30 years before an experiment found physical evidence of them. Today, neutrinos are an integral part of the Standard Model's periodic table of particle physics. Here you'll find the particles that make up matter listed in pairs separated into three categories: electron neutrinos are paired with electrons, muon neutrinos with muons, and tau neutrinos with, you guessed it, taus. Neutrinos can morph from one flavor into another. For example, an electron neutrino can oscillate into a muon neutrino, and a muon neutrino can flip into a tau neutrino. "Neutrino oscillations are the first indication of physics beyond the Standard Model," Ereditato tells me. Laughing, he adds, "That's the reason why I like neutrinos." Which brings us back to the OPERA experiment. When it was conceived, evidence for neutrino oscillations was plentiful but all of it came from disappearance experiments. That is, the evidence consisted of either electron or muon neutrinos disappearing. An appearance experiment was needed, and that was OPERA's goal. The idea was for CERN, the European Organization for Nuclear Research in Geneva, to produce a beam of muon neutrinos aimed at a detector buried deep beneath Italy's Gran Sasso Mountain range. If any tau neutrinos were detected there, then neutrino oscillations were happening. Following the particle physics tradition of snazzy acronyms for experiments, "Oscillation Project with Emulsion-tRracking Apparatus" became OPERA. Measuring the speed of neutrinos as they traveled from the CNGS (CERN Neutrinos to Gran Sasso) beam to the OPERA detector was not mentioned in the proposal. But in February of 2011, OPERA turned most of its focus to exactly that. "I think as any scientist, I was very skeptical from day one," says Ereditato. "You make a check list: timing, receiver, GPS, transmitter, you check everything." Some options were checked immediately, while others required them to wait. The CERN beam, for example, could not be stopped. In the meantime, Ereditato drove his team hard. "You could not imagine how I was handling this business with my colleagues—check this, check that, do this, do that, do this, do it again!" The team tried and tested every permutation of software, hardware, and theory that they could think of, and through every step, every bug they fixed, every increment of understanding they earned, the evidence for faster than light neutrinos stood as solid as the mountain above the experiment. Then, the inevitable happened: News of the data leaked. People outside the experiment started gossiping about a violation of relativity, a result that would rattle the foundation of physics like it hadn't been rattled since 1900, when Max Planck discovered quantum physics. The rumors "spread at the speed of light," Ereditato tells me. "And then what do you do? Think about yourself taking the position of spokesperson. Do you say: No, no comment? And then everyone will blame you, all journalists: 'Oh you hide it. We want to know what is happening. We are taxpayers giving support to you, we have the right to know!' Or you make a claim." In a sinister voice, he adds: "I discovered the superluminal neutrinos." (3)

In this case, it wasn't just up to Ereditato. Large experimental collaborations like OPERA have bylaws for dealing with controversy, and voted to announce the results in public by a large majority of the collaboration. Just a few individuals voted against the announcement. "Which I respect very much. And they were right, eventually." OPERA announced its results at a special seminar at CERN. The team did not state that it had observed a violation of relativity, and instead of using phrases like "evidence for" or "discovery of," it called the data an "anomaly." But that pivotal caveat was lost in the sensation of human interaction. While the conditional made it into The New York Times headline, “Tiny Neutrinos May Have Broken Cosmic Speed Limit,” it did not make an appearance in The Guardian (“Faster Than Light Particles Found, Claim Scientists”) or Scientific American (“Particles Found to Travel Faster Than Speed of Light.”) The physics community, on the other hand, received the announcement skeptically, even cynically. No practicing professional physicist was willing to abandon special relativity any more than Wolfgang Pauli was willing to abandon conservation of energy in 1930. Still, what if? Since the confirmation of the core tenets of the Standard Model at CERN in 1983, every discovery in particle physics (except for neutrino oscillations) had just added another checkmark to that annoyingly venerable Standard Model. How could particle physicists resist the temptation to hope that something, anything, might open up the field during their lifetimes? Even Ereditato dared to hope. “Everybody was dreaming that we were right. Everybody.” (4)

In one direction lay ground-breaking physics—and in the other, potential embarrassment. Should OPERA have waited? How many more months could they have spent analyzing and reanalyzing the result? Leaning forward, Ereditato explains why a scientist can’t ignore a measurement just because it seems absurd. “Nature is talking to us, not through theories, but through experimental results. The worst data are better than the best theory. If you look for reasonable results, you would never make a discovery, or at least you will never make an unexpected discovery. You only make—this is a contradiction in terms—an expected discovery.” One thing is certain: The announcement got OPERA the help they had hoped for. A few days afterward, with the operators of the CNGS beam, they started developing a new approach to the measurement. The original analysis had to use a statistical technique to determine the neutrino's arrival time because the beam was spread out in space. The new approach was to generate neutrinos in tight bunches so that they would arrive at the detector together, making it much easier to determine their arrival time. It took two months to reconfigure the neutrino beam, perform the experiment and analyze the results—unprecedented speed for an experiment of this complexity. The faster-than-light measurement was still there. (5)

Particle physics experiments consist of complex, building-sized detectors and particle accelerators. Design and construction begin years before the first bit of data is acquired. By the time both the detector and collider are up and running, the experimentalists have developed analysis software to sift through the data and separate signals from backgrounds. Instead of testing their techniques on real data, they test them on simulated data created by replicating the response of the detector hardware to known processes. This way, when they "open the box," their measurements shouldn't be biased by any conscious or unconscious desire for discovery. Yet OPERA's faster-than-light neutrino data persisted. The next step would be to seek independent confirmation outside of OPERA itself, which is common practice. But there were no other experiments that could confirm or deny OPERA for at least several years. There was, however, another experiment at the base of Gran Sasso, called the Large Volume Detector (LVD), that could at least check OPERA's timing system. The idea was to make sure the clocks of each experiment were synchronized by comparing the arrival times of cosmic ray muons in their respective detectors. Looking back through all five years of OPERA data, the teams found a period when OPERA’s timing was off by about 73 nanoseconds. Then another mistake was found with the timing circuit that affected the bunched beam experiment: The frequency of OPERA’s clock wasn’t locked to the timing of the bunches. The combination of the two problems accounted completely for the 60 nanosecond early arrival time of the CNGS muon neutrinos. With the mistake found and fixed, OPERA’s measurement of the neutrino velocity is now the most accurate in the world. And it is perfectly consistent with Einstein’s special theory of relativity. The faint hope for new physics that wasn’t predicted by the venerable Standard Model was dead. But the performance of the OPERA team in finding a single loose cable among the thousands of electrical channels of experimental equipment was remarkable. “I am proud,” Ereditato tells me. “I should say very frankly, I was always thinking the solution would have come from very strange effects. Second order effects, somewhere that nobody thought about. I never thought such a thing (the cable), never.” Nor did the collaboration overstate the data, or make claims that were unwarranted. In fact, they made no claims at all, and worked closely with other teams in their investigation. Nevertheless, it seemed clear that someone, somewhere, had made a mistake. Maybe it was the person who attached the cable or designed the receiver, or someone else entirely. Both the OPERA leader, Ereditato, and the experimental coordinator, Dario Autiero, resigned. Ereditato’s resignation letter made it clear he was resigning for the benefit of his team: “As a result of the enormous media interest, the OPERA Collaboration found itself under anomalous and in some respects irregular pressure. External tensions do not take long to transfer to the inside of a social system comprising over 150 people, leading to the potentially dangerous outcome of potentially losing sight of scientific objectives. This is a risk too great to run. To avert it, the position of individuals must take a back seat." But did Ereditato do anything wrong? People make mistakes. Some said OPERA should have done still more tests. How many more months should they have spent? Should their allegiance to special relativity have compelled them to wait until they found the problem? No, then they would be playing into the absurd concept that scientists are bound to uphold a scientific creed. Maybe it testifies to how much scientists, especially experimentalists, want to find something new, something that hasn't been predicted, and how angry they get when it slips away. I ask Ereditato to reflect on the whole experience. "Society likes black and white," he answers. But answers in science are not always so cleanly resolved. "We have to be careful because if we give the impression that science never says yes or no, says always maybe, then people say, 'Well, then I should not trust science." Most science journalists are not scientists. Today, Ereditato is the director of the University of Bern's Laboratory for High Energy Physics, and continues to participate in a variety of neutrino experiments. The OPERA experiment, meanwhile, has different leaders and continues to hunt for neutrino oscillations and collect tau neutrinos. (6)

Adapted from Nautilus.

Exercise III.

Find paragraphs, dealing with the following: journalists, trenches, bomb, leader, screen, evidence, director, keystone, violation, bias

<u>Exercise IV</u>.

Fill in the gaps.

1. Its only sign on the surface had been a fold, or buckling, in the earth's **……….**
2. The purpose was not to **……….** the law but to openly demonstrate its injustice.
3. Stefan Friedman, a Kennedy **…………** , said she withdrew for personal reasons.
4. I'm just focused on leadership and consistency playing the quarterback **…………** .
5. These would consist of a **…….** about two feet wide and three or four feet deep.
6. Some experts **…………** that this phase of sleep helps the young brain to mature.
7. If **……….** neutrinos don't transform into electron neutrinos, this quantity is zero.
8. This step will prevent any dangerous splattering of butter as you **………** the cake.
9. One might define an anagram of a word as a **…………** of its letters.

10. About $15 million would come from tax ………. financing and other incentives.

Exercise V .

Make up sentences of your own with the following word combinations: insincere story (1), at such a high speed (1), keystone (1), by-laws (3) to uphold a scientific creed (5), to give the impression (5), for the benefit of (5), to find itself under (5), in some respects (5), do not take long to (5)

Exercise VI.

Determine whether the statements are true or false. Correct the false statements:

1. Ereditato is the former leader of the 160 physicists from 13 countries that compose the OPERA collaboration, whose goal is to study neutrino physics.
2. Over the last century, Einstein's observation that any massive object can travel faster than the speed of light in a vacuum, enshrined in his theory of special relativity, has become a keystone of how we understand the universe.
3. Wolfgang Pauli postulated the existence of neutrinos in 1930 to solve a simple problem.
4. Either something invisible is emitted along with the electron or positron, or energy must disappear.
5. Today, neutrinos are an integral part of the Standard Model's periodic table of particle physics.
6. Particle physics experiments consist of complex, building-sized detectors and particle accelerators.
7. With the mistake found and fixed, OPERA's measurement of the neutrino velocity is now the least accurate in the world.

8. OPERA’s measurement of the neutrino velocity is not perfectly consistent with Einstein’s special theory of relativity.
9. Today, Ereditato is the director of the University of Bern’s Laboratory for High Energy Physics, and continues to participate in a variety of neutrino experiments
10. The OPERA experiment, meanwhile, has different leaders and continues to hunt for neutrino oscillations and collect tau neutrinos.

Exercise VII .

Match the words to the definitions in the column on the right:

unwarrant	to prevent something bad from happening
avert	to say that something is true
to uphold	an occasion when something turns over quickly or repeatedly
to testify	to become gradually damaged, worse, or less; to cause something to do this
spokesperson	a space from which most or all of the matter has been removed, or where there is little or no matter
crust	lacking a good reason; unnecessary
to conceive	a person who makes official, public statements for a group or organization
flip	to defend or keep a principle or law, or to say that a decision that has already been made, especially a legal one, is correct:
vacuum	to invent a plan or an idea
decay	the outer layer of the earth

Exercise VIII.

Summarize the article “The Data That Threatened to Break Physics”

Part 2

Exercise I.

Identify the part of speech the words belong to.

snazzy, emulsion, permutation, increment, postulate, luminal, venerable, position, allegiance, reconfigure

Exercise II .

Form nouns from the following words:

sensational (2), experimental (2), compose (2), postulate (3), necessary (3), propose (3), integral (3), reflect (6), continue (6), participate (6)

Exercise III.

Find synonyms to the following words. Translate them into Russian:

impossible (1), desire (2), subvert (2), story (2), reason (2), goal (2), arrive (2), distance (2), massive (2), vacuum (2)

Exercise IV.

Find antonyms to the following words. Translate them into Russian:

insincere (2), agree (2), former (2), light (2), outer (2), invisible (3), existence (3), simple (3), antimatter (3), disappear (3)

Exercise V.

Match the words to make word combinations:

experimental	detectors
building-sized	neutrinos

High Energy	oscillations
second-order	accelerators
particle	results
neutrino	time
common	physics
irregular	effect
arrival	pressure
muon	practice

2. **The Universe Began With a Big Melt, Not a Big Bang**

Part 1

Exercise I.

Say what Russian words help to guess the meaning of the following words: effects, energy, galaxies, evolution, initial, fundamental , models, popular , class, inflation

Exercise II

Make sure you know the following words and word combinations: fluctuation, perturbation, bulk, amplitude, primordia, phonon, resounding, to reside, chunk, postulate,

The Universe Began With a Big Melt, Not a Big Bang

The cosmological constant and the creation of the universe. (1)

There are two tantalizing mysteries about our universe, one dealing with its final fate and the other with its beginning, that have intrigued cosmologists for decades. The community has always believed these to be independent problems—but what if they are not? The first problem has to do with the existence of something called “dark energy,” which is today accelerating the expansion of the universe and will determine its final fate. Theorists tell us that the effects of dark energy can be explained by introducing a term into Einstein’s equations of gravity called the cosmological constant. But, for this explanation to work, the cosmological constant must have a very specific—and tiny—value. In natural units, the cosmological constant is given by 1 divided by a number made of 1 followed by 123 zeros! Explaining this value is considered one of the greatest challenges faced by theoretical physics today. The second problem relates to another crucial number that shapes our universe, and is related to the formation of structures like galaxies and groups of galaxies. We know that the early universe, while being very smooth, also contained tiny fluctuations in density that acted as seeds for all the cosmic structures we see today. These fluctuations must have a specific magnitude and shape to be consistent with present-day observations. Understanding how these tiny fluctuations were created during the earliest stages in the evolution of the universe, and explaining their magnitude and shape, is an equally fascinating mystery in cosmology. (2)

In the conventional approaches to cosmology, these two numbers—the numerical value of the cosmological constant and the magnitude of initial perturbations—are considered unrelated. After all, one deals with the earliest phase of the universe, and the other with a very late phase, separated in cosmic time by about 14 billion years. What’s more, standard cosmology does not offer any explanation for these two numbers from fundamental principles. The conventional models of the universe are totally silent about the numerical value of the cosmological constant, or predict a totally inappropriate value. As regards the magnitude of the initial perturbations, the most popular approach is to obtain it from a class of models that describe inflation, which is a period of rapid growth in the early phase of the universe. The trouble with inflationary models is that they can be designed to produce virtually any desired result, and hence totally lack predictive power. (3)

My recent work connects both these numbers to cosmogenesis—the creation of the universe—and explains their precise numerical values. My paper demonstrates that the very existence of the cosmological constant, as well as its tiny value, can be understood as a direct consequence of the information content of cosmic spacetime.The analysis also leads to the correct value for the size and shape of the small fluctuations in the early universe. The remarkable confluence of these fundamental constants has important implications for our understanding of the universe. In particular, it rewrites our understanding of the Big Bang, and removes the need for any period of inflation in the early phase of the universe. The Big Bang is probably the most famous feature of standard cosmology. But it is also an undesirable one. That's because the classical model of the universe, described by Einstein's equations, breaks down in the conditions of the Big Bang, which include an infinite density and temperature, or what physicists call a singularity. But what if there were no singularity? Since the 1960s, physicists have been working on describing the universe without a Big Bang by attempting to unify gravitational theory and quantum theory into something called quantum gravity. Physicists John Wheeler and Bryce deWitt were the first to apply these ideas to a hypothetical pre-geometric phase of the universe, in which notions of space and time have not yet-emerged from some as-yet unknown structure. This heralded the study of quantum cosmology, in which physicists attempted to describe the dynamics of simple models of the universe in a quantum language. Needless to say, several different, but related, ideas for the description of the pre-geometric phase mushroomed over the decades. The unifying theme of these models is that the classical universe arises, without any singularity, through a transition from a pre-geometric phase to one in which spacetime is described by Einstein’s equations. The main difficulty in constructing such a description is that we do not have a complete theory of quantum gravity, which would allow us to model the pre-geometric phase in detail. The key new ingredient we have introduced, which helps to bypass this technical difficulty, is the concept of cosmic information. The idea that information should play a key role in the description of physics has gained considerable support in recent times. This notion arises in several contexts when one attempts to combine the principles of quantum theory and gravity like, for example, in the study of quantum black holes. There is also the intriguing notion of holography in some of these models, which suggests that the information content in a bulk region can be related to the information content on its boundary. But, unfortunately, the mathematical description of the information turns out to be different in different contexts, and we still have not found a unifying principle applicable in all cases. Therefore, in order to apply the notion of information to the whole universe, we have to first come up with a definition for it that is physically appropriate. The definition of cosmic information that we used can be best illustrated with an analogy. When a piece of ice melts to form water, a transition from solid to liquid phase takes place. The actual dynamics of the phase transition can be very complex but the total number of atoms in the ice will be the same as the total number of atoms in water. This number represents the number of degrees of freedom in the system, which does not change during the phase transition. Similarly, the phase transition that led to the birth of the universe can be described by a number that links the degrees of freedom in the pre-geometric phase with those of the classical spacetime. Using this number, which we call “CosmIn,” we can connect the two phases of the universe, bypassing the complications of a complete quantum gravity model. CosmIn, being a physical observable number, must be finite. In addition, we have been able to demonstrate that CosmIn will be finite only if the universe undergoes an accelerated phase of expansion at late times, exactly as we observe today. This connection not only suggests a fundamental reason for the existence of the cosmological constant, but also a means of calculating its numerical value—if we know the value of CosmIn. The value of CosmIn in the pre-geometric or quantum gravitational phase of the universe can be determined using results repeatedly suggested by several models of quantum gravity. It turns out that the total information transferred from the quantum gravitational phase to the classical phase must be equal to a simple number: 4π, just the area of a sphere of unit radius. This is equivalent to one unit of information per unit surface area of a sphere of unit radius. Using this fact, we can relate the numerical value of the cosmological constant to the energy scale at which the universe made a transition from the quantum gravitational phase to the classical phase. This transition energy scale, in turn, can be related to the second enigmatic feature of our universe: the magnitude of the tiny quantum fluctuations in the early universe that grew to form the galaxies and galaxy clusters that we see today. The popular procedure for calculating the size of these fluctuations is to use inflationary models of the universe, which describe the early universe as going through an enormous and rapid increase in size. But inflationary models come in all shapes and sizes and can be designed to produce any value whatsoever for this amplitude. It's also worth nothing that the shape of the primordial fluctuations was originally obtained by Edward Robert Harrison in 1970 (and independently by Yakov B. Zeldovich) and is called the Harrison-Zeldovich spectrum. What many people fail to appreciate or emphasize is that Harrison derived his result more than a decade before inflationary models were invented! (4)

Our model allows us to relate both the numbers—the numerical value of the cosmological constant and the size of the primordial fluctuations—to the energy scale at which the pre-geometric universe went through a phase transition and became the classical universe we all live in. When we choose the appropriate energy scale, we obtain the correct observed value for both these quantities. This, in turn, leads to an algebraic relation between the cosmological constant, the amplitude of the primordial fluctuations and the value of the CosmIn. We can turn this relation around, using the observed values of the cosmological parameters, and test whether the CosmIn is indeed 4π. The theory passes the test with flying colors; we find that CosmIn, determined from observations, is equal to 4π to an accuracy of one part in 1,000. It is incredible that a complex combination of cosmological parameters—considered unrelated to each other—should have such a simple value. The conventional approach must consider this result as a random numerical coincidence. We, on the other hand, believe it is telling us something deep and beautiful about our universe. We believe ours is the first effort to link the numerical value of the cosmological constant to the size of the fluctuations in the early universe, and the first to obtain both these numbers from a model which has no adjustable parameters and relates them to the energy scale at which the classical universe came into being. All of these ideas rest within the broader framework of quantum gravity, a theory that physicists still do not have even after nearly five decades of work. One of the strengths of our model is that it does not require the details of quantum gravity to be worked out. But it does provide two significant hints regarding the nature of quantum gravity and the structure of spacetime. First, it strongly suggests that spacetime should be thought of as made of microscopic degrees of freedom, just as matter is made of atoms. Second, it suggests that the correct theory of the origin of the universe is very likely to involve a phase transition from a pre-geometric phase to the classical phase. These hints could also answer a key question: Why, after decades of work, have theorists still not merged gravity and quantum theory? We believe this can be best illustrated with another analogy. We know that fluid mechanics can be described as a self-consistent physical theory, expressed with a set of equations. If we take these equations as fundamental and apply the principles of quantum theory to them, we can discover interesting new phenomena, like, for example, the notion of phonons and their interactions. However, we can never get to the quantum structure of matter with such an approach. There is evidence to suggest that the equations describing gravity are similar to the equations of fluid mechanics in this way. (5)

In other words, reinterpreting equations describing gravity by using the principles of quantum theory is analogous to applying quantum principles to the equations of fluid mechanics. We will not discover the quantum nature of spacetime this way—which, we believe, is the reason decades of effort to quantize Einstein's theory have led to resounding failures. What is required instead is to re-examine the nature of gravity and learn what it tells us about the microscopic structure of spacetime. Such an approach is precisely what the physicist Ludwig Boltzmann used to understand that thermal phenomena require that matter be made of discrete degrees of freedom (in other words, atoms). Boltzmann essentially said that, if something can be hot, it must contain microscopic degrees of freedom. Spacetime, too, can possess temperature and thus can appear to be hot to certain observers. This idea came up first through the work of Jacob Bekenstein and Stephen Hawking in the specific context of black holes. Very soon afterward, in the mid-70s, work by Bill Unruh and Paul Davies showed that this is a very general feature of spacetime. If you combine Boltzmann's paradigm with the fact that spacetime—like normal matter—can be hot, you are led to the conclusion that spacetime must possess internal degrees of freedom, like the atoms in matter. Theoretical evidence supporting this conclusion has emerged in recent years. This observation holds the key to understanding the micro-structure of spacetime and quickly leads to three remarkable results. First, the evolution of a region of spacetime can be described in terms of the degrees of freedom (or, equivalently, the information content) that resides in the bulk and boundary of that region. Second, gravity becomes immune to changes in the zero level of energy. In Einstein's theory, gravity responds to the absolute amount of energy, making the cosmological constant virtually impossible to calculate. This is not the case in a paradigm based on information content. Third, the information approach suggests that we should not think of cosmic evolution as described by a specific solution to Einstein’s equations. Instead, those equations arise in a suitable limit from a more exact set of equations describing the quantum degrees of freedom of the spacetime.The information approach, validated by our CosmIn model, gives us a vivid new picture of the universe as being analogous to a large chunk of ice containing a point source of heat. The heat source melts the ice around it, creating a region of water, which in turn expands, reaching local thermodynamic equilibrium. At large scales, close to the boundary of the phases, the molecules have not yet reached equilibrium, since the chunk of ice is being heated up from the inside. (6)

This is similar to how our universe behaves. The region with water is analogous to the observed universe (described by Einstein’s theory). It is surrounded by a pre-geometric phase (analogous to ice) that is described by—as yet unknown—laws of quantum gravity. The notion of a Big Bang is completely eliminated, and replaced by a transition from one phase to another at the boundary. And the need for an inflationary period in the universe’s early history is also eliminated. The entire framework is simple and elegant because it is described by a single parameter: the energy scale of the early-universe phase transition from pre-geometry to Einsteinian geometry. This is unlike standard inflationary models, which lack any predictive power. Our model does not use any untested physics. The *only* postulate we make is that the information content of the universe should be equal to 4π, the area of a unit sphere. The work opens up three new avenues of research: First, it invites us to explore the physics of the pre-geometric phase in different quantum gravitational models. Second, it opens the opportunity to explore the specific notion of cosmic information used in this work and attempt to relate it to other, similar ideas of information used in other contexts. Third, it reinforces the notion that spacetime is made of more elementary degrees of freedom—just as matter is made of atoms—and challenges us to study different phases of spacetime just as we explore different phases of matter in condensed matter physics. (7)

Adapted from Nautilus.

Exercise III.

Find paragraphs, dealing with the following: fate, term, shape, conventional, standard, hence, cosmogenesis, singularity, hypothetical, heralded

Exercise IV.

Fill in the gaps.

1. Experiments at the pond illustrate groundwater **……..** and soil erosion.

2. On average New Zealand only experiences a few **………** 6 earthquakes each year.

3. **…………..** theory is the only known approach to manage the quantum field theory.

4. Workers have suffered massive layoffs during the **………..** to a market economy.

5. The **………** of the tides is relatively low and strongly varies across the sea.

6. For some of the genes, an even higher expression is observed in the organ …………….

7. In this condition, ………….. accumulates in the lungs and makes breathing difficult.

8. Such ……… sounds are much too high-pitched for humans to hear, Gauthier said.

9. Related fields are ………… physics, mineralogy, and materials science.

10. The seat and the footrest on the chair are …… for both height and depth.

Exercise V .

Make up sentences of your own with the following word combinations:

fail to (4), to come into being (5), within the framework of (5), to come up (6), in terms of (6), immune to (6), to hold the key to (6), at large scales (6), to reach equilibrium (6), to heat up from the inside (6)

Exercise VI.

Determine whether the statements are true or false. Correct the false statements:

1. There are two tantalizing mysteries about our universe, one dealing with its final fate and the other with its beginning, that have intrigued cosmologists for decades.
2. The first problem has to do with the existence of something called "dark energy," which is today accelerating the expansion of the universe and will determine its final fate.

3. Theorists tell us that the effects of dark energy can be explained by introducing a term into Einstein's equations of gravity called the cosmological constant.

4. The second problem relates to another crucial number that shapes our universe, and is related to the formation of structures like galaxies and groups of galaxies.

5. In the conventional approaches to cosmology the numerical value of the cosmological constant and the magnitude of initial perturbations—are considered related.

6. As regards the magnitude of the initial perturbations, the most popular approach is to obtain it from a class of models that describe inflation, which is a period of rapid growth in the late phase of the universe.

7. The classical model of the universe, described by Einstein's equations, breaks down in the conditions of the Big Bang, which include an infinite density and velocity, or what physicists call a singularity.

8. Since the 1960s, physicists have been working on describing the universe without a Big Bang by attempting to unify gravitational theory and quantum theory into something called quantum gravity.

9. In order to apply the notion of information to the whole universe, we have to first come up with a definition for it that is physically appropriate.

10. CosmIn, being a physical observable number, must be infinite.

Exercise VII .

Match the words to the definitions in the column on the right:

liquid	the distance between the top and the bottom of a wave
galaxy	a method or way of doing something

spectrum	large size or great importance
to reinforce	a change from one form or type to another, or the process by which this happens
equilibrium	modifiable
magnitude	range
transition	one of the independent groups of stars in the universe
adjustable	a substance, such as water, that is not solid or a gas and that can be poured easily
avenue	to make something stronger
amplitude	a state of balance

ExerciseVIII.

Summarize the article “The Universe Began With a Big Melt, Not a Big Bang”.

Part 2

Exercise I.

Identify the part of speech the words belong to. explanation, specific, theoretical, crucial, density, cosmic, structure, consistent, observation, evolution

Exercise II .

Form adjectives from the following words:

universe (1), creation (1), mystery (2), relate (2), silent (3), totally (3), value (3), period (3), universe (3),. virtually (3)

Exercise III.

Find synonyms to the following words. Translate them into Russian:

bang (1), melt (1), intrigue (2), accelerate (2), determine (2), effect (2), introduce (2), tiny (2), divide (2), structure (2)

Exercise IV .

Find antonyms to the following words. Translate them into Russian:

final (2), expansion (2), follow (2), early (2), equally (3), initial (3), unrelated (3), separate (3), offer (3), fundamental (3)

Exercise V.

Match the words to make word combinations:

gravitational	gravity
condensed	mechanics
black	period
unit	phase
quantum	models
microscopic	holes
inflationary	radius
fluid	Melt
pre-geometric	matter
Big	structure

3. How Do You Say “Life” in Physics?

Part 1

Exercise I.

Say what Russian words help to guess the meaning of the following words: information, institute, technology, architect, adaptation, function, biology, unique, nanometer, group

Exercise II.

Make sure you know the following words and word combinations.
lifelike, unwelcome, to impart, to accrue, to resolve, stumbling, bootstrap, recast, to shuffle, puddle

How Do You Say “Life” in Physics?

A new theory sheds light on the emergence of life’s complexity. (1)

Jeremy England is concerned about words—about what they mean, about the universes they contain. He avoids ones like “consciousness” and “information”; too loaded, he says. His caution is understandable. The 34-year-old assistant professor of physics at the Massachusetts Institute of Technology is the architect of a new theory called “dissipative adaptation,” which has helped to explain how complex, life-like function can self-organize and emerge from simpler things, including inanimate matter. This proposition has earned England a somewhat unwelcome nickname: the next Charles Darwin. But England’s story is just as much about language as it is about biology. There are some 6,800 unique languages in use today. Not every word translates perfectly, and meaning sometimes falls through the cracks. For instance, there is no English translation for the Japanese *wabi-sabi*—the idea of finding beauty in imperfection—or for the German *waldeinsamkeit*, the feeling of being alone in the woods. Different fields of science, too, are languages unto themselves, and scientific explanations are sometimes just translations. "Red," for instance, is a translation of the phrase "620-750 nanometer wavelength." "Temperature" is a translation of "the average speed of a group of particles." The more complex a translation, the more meaning it imparts. "Gravity" means "the geometry of spacetime." What about life? We think we know life when we see it. Darwin's theory even explains how one form of life evolves into another. But what is the difference between a robin and a rock, when both obey the same physical laws? In other words, how do you say "life" in physics? Some have argued that the word is untranslatable. But maybe it simply needed the right translator. (2)

Unraveled, each protein is made up of the same 20 amino acids. Yet somehow, once they are folded into shape, each carries out a specific and vital process required for life. When you string a few hundred of amino acids together, suddenly you get this machine that looks like it is made for a particular purpose. The pieces, individually obeying nothing more than the basic laws of physics, collectively accrue function. Function seems absent from the world of physics: Time and space don't exist for any reason, but just are. In biology, systems are fine-tuned to act. To move, catalyze, and construct. The word "function" trapezes between life and not-life. As England would tell an audience at Sweden's Karolinska Institutet, physics doesn't make a distinction between life and not-life. But biology does. His friend engaged him in long conversations about the Austrian-British philosopher Ludwig Wittgenstein. Some philosophers had maintained that a word's meaning inheres in the physical object out there in the world. Wittgenstein, however, argued that a word's meaning depends on its context, a context determined by the people who are using it. Playing a language game is sort of like speaking in code—if two people are participating in an activity that's well understood by both parties, they can use fewer and simpler words to make themselves heard. Different groups of people—musicians, politicians, scientists, and so on—employ language games that suit their separate needs. New language games are constantly bursting into being. Meaning changes shape. Words adapt. "In making that kind of a point, he's channeling the same kind of idea that I also locate in, among other places, the opening passages of the Hebrew Bible," says England. "In the beginning, God created the heavens and the earth ..." Here, the Hebrew word for "create" is *bara*, the word for "heavens" is *shamayim*, and the word for "earth" is *aretz*; but their true meanings, England says, only come into view through their context in the following verses. For instance, it becomes clear that *bara*, creation, entails a process of giving names to things; the creation of the world is the creation of a language game. "God said, 'Let there be light,' and there was light." God created light by speaking its name. "We have heard this phrase so many times that by the time we are old enough to ponder it, we easily miss its simplest point," England says. "The light by which we see the world comes from the way we talk about it." That might be important, thought England, if you're trying to use the language of physics to describe biology. Which he was compelled to do. As a young faculty member at MIT, he neither wanted to stop doing biology, nor thinking about theoretical physics. “When you refuse to let go of two things that are divergent in the way they cause you to talk,” he says, “it forces you in the direction of translation.” In the Jewish tradition, “miracles” don’t necessarily defy the laws of nature. Instead, a miracle is a phenomenon that was previously considered unimaginable. Witnesses to that miracle are called upon to reframe their assumptions and resolve contradictions. In short, they must start to think about their world in a new light. To the physicist steeped in statistical mechanics, life can, in this sense, appear miraculous. The second law of thermodynamics demands that for a closed system—like a gas in a box, or the universe as a whole—disorder must increase over time. Snow melts into a puddle, but a puddle does not (on its own) spontaneously take the shape of a snowflake. Were you to see a puddle do this, you’d assume you were watching a movie in reverse, as if time were moving backward. The second law imposes an irreversibility on the behavior of large groups of particles, allowing us to play with words like “past,” “present,” and “future.” The arrow of time points in the direction of disorder. The arrow of life, however, points the opposite way. From a simple seed grows an intricately structured flower, and from the lifeless Earth, forests and jungles. How is it that the rules governing those atoms we call “life” could be so drastically different from those that govern the rest of the atoms in the universe? In 1944, physicist Erwin Schrödinger tackled this question in a little book called *What is Life?*. He recognized that living organisms, unlike a gas in a box, are open systems. That is, they admit the transfer of energy between themselves and a larger environment. Even as life maintains its internal order, its loss of heat to the environment allows the universe to experience an overall increase in entropy (or disorder) in accordance with the second law. At the same time, Schrödinger pointed to a second mystery. The mechanism that gives rise to the arrow of time, he said, cannot be the same mechanism that gives rise to the arrow of life. Time's arrow arises from the statistics of large numbers—when you have enough atoms milling about, there are simply so many more disordered configurations than ordered ones that the chance of their stumbling into a more ordered state is nil. But when it comes to life, order and irreversibility must reign even at the microscopic scale, with far fewer atoms in play. At this scale, atoms don't come in large enough numbers for their statistics to yield regularities like the second law. A nucleotide—the building block of RNA and DNA, the basic components of life—is, for example, made of just 30 atoms. And yet, Schrödinger noted, genetic codes hold up impossibly well, sometimes over millions of generations, "with a durability or permanence that borders upon the miraculous." So how does a gene resist decay? Something deeper than statistics had to be at play, something that could allow small groups of atoms to irreversibly pull themselves up by their bootstraps and become something "alive." (3)

A clue came half a century later, when an English chemist named Gavin Crooks mathematically described microscopic irreversibility for the first time. In a single equation Crooks showed that a small open system driven by an external source of energy could change in an irreversible way, as long as it dissipates its energy as it changes. Imagine you’re standing in front of a fence. You want to get to the other side, but the fence is too tall to jump. Then a friend hands you a stick, which you can use to hop to the other side. But once you’re there, you can use the same stick to hop the fence again and end up back where you started. The external source of energy (the stick) allows you to make a change, but a reversible one. Now imagine that instead of a stick, your friend hands you a jet pack. You fire up the jet pack and it launches you over the fence. The jet pack dissipates its fuel out into the surrounding air, so that by the time you land, there’s not enough energy left in your pack to get you back over the fence again. You’re stuck on the far side. Your change is irreversible. Crooks showed that a group of atoms could similarly take a burst of external energy and use it to transform itself into a new configuration—jumping the fence, so to speak. If the atoms dissipate the energy while they transform, the change could be irreversible. They could always use the next burst of energy that comes along to transition back, and often they will. But sometimes they won’t. Sometimes they’ll use that next burst to transition into yet another new state, dissipating their energy once again, transforming themselves step by step. In this way, dissipation doesn’t ensure irreversibility, but irreversibility requires dissipation. Crooks’ result was very general, applying to any transformation of a system out of equilibrium—including, potentially, life. But, says England, “there was caution about the question of what could be said about a big messy many-body system with huge amounts of dissipation in it. It seemed like these results were true but maybe difficult to operationalize for calculation.” It was clear from the Crooks equation that in order to achieve the kind of irreversibility that is a hallmark of life, a system would need to be particularly good at absorbing and dissipating heat. But he knew that wasn’t the whole picture. Finally, something clicked. Given a particular energy source, some arrangements of atoms will be better at absorbing and spending it than others. These arrangements are more likely to undergo an irreversible transformation. What if some systems get better at doing this than others over time? Then the series of irreversible transformations become an effect that compounds, pulling itself up by its bootstraps. England put pencil to paper and wrote a generalization of the second law of thermodynamics that takes into account a system’s dissipative history, and which, he says, sheds light on the emergence of the structures and functions of life. In a paper, he put it this way: While any given change in shape for the system is mostly random, the most durable and irreversible of these shifts in configuration occur when the system happens to be momentarily better at absorbing and dissipating work. With the passage of time, the “memory” of these less erasable changes accumulates preferentially, and the system increasingly adopts shapes that resemble those in its history where dissipation occurred. Looking backward at the likely history of a product of this process, the structure will appear to us like it has self-organized into a state that is “well adapted” to the environmental conditions. This is the phenomenon of dissipative adaptation. Of course, a system of atoms isn’t trying to do anything—it’s just blindly, randomly, shuffling itself around. And yet, through its journey from one shape to another, a constellation of chemical stories, it self-organizes into something that looks to us like it has adapted. (4)

How do you say "life" in physics? England called it "dissipative adaptation." Natural selection could be recast as a special case of the more generalized phenomenon of dissipative adaptation, a dialect of a more fundamental language. The theory challenges us to rethink the remarkable functions that make life special: "We have more flexibility in the places we look for function," says England. The emergence of complex function from a collection of weakly interacting particles, without any strong coordination, is now a process that can be broken down into many small irreversible transformations driven by an external drive. It could be easier for things like proteins to emerge than we'd thought. The theory doesn't just help us peer into the past— it also suggests new design and engineering approaches. "If I want to mimic something that living things do, maybe it doesn't have to mimic living things as much as I thought it did." One example may be something called "emergent computation," which England and members of his lab are currently studying. The goal is to get systems of particles to evolve an ability to predict changes in their environment, without receiving any design instructions on how to do so. Getting good at absorbing and dissipating energy in a fluctuating environment requires some degree of anticipation, after all. "If we succeed in doing this, the argument will be that somehow the particles in the system are interacting in such a way as to effectively implement a calculation about the future based on the statistics of the past," England says. That could impact technologies that are based on predictive power, from neural networks to bots that tell us when to buy a plane ticket. Jeremy Gunawardena, associate professor of systems biology at Harvard University, isn't entirely sold on the approach. “England is hoping that he can avoid thinking about the chemistry and see the abstract essentials of life emerging as a physical necessity,” he says. “I am not convinced. However, I think it is great that he is working on the problem and I am sure we will learn something interesting from it.” Which is fair enough. After all, in the words of the late Umberto Eco, “translation is the art of failure.” The failures and trade-offs in this brand-new translation remain to be discovered. There may not, at the end of the day, be just one language to express the complexities of life. But England wants us to try a new one. (5)

Adapted from Nautilus.

Exercise III.

Find paragraphs, dealing with the following: lament, array, multifaceted, caution, architect, nickname, cracks, imperfection, obey, unraveled

Exercise IV.

Fill in the gaps.

1. In a cell, the DNA **…………..** enzyme plays an important role in duplicating DNA.
2. It was also the first **…………** sequence of a ribonucleic acid ever determined.
3. We look to **…………..** of information, not information as best known at the moment.
4. Coaches still diagram plays in the huddle on a white board with an **……….** marker.

5. In fact, the investigators learned that the search itself may …… some risks.

6. Besides, it uses such ………… mannequins to sell clothes to both men and women.

7. Also, there's a way to get rid of ………… dinner guests and trick a bartender.

8. I have a ………… for all those people who think Bill Stewart is a bad coach.

9. The other two basic functions are to provide liquidity and to ……… confidence.

10. As you ………. dollars, you can dispense them to whatever organizations you want.

Exercise V .

Make up sentences of your own with the following word combinations: to shed light on (1), to be concerned about(1), to put pencil to paper (1), trade-off (1), to be folded into shape (2), to burst into being (3), come into view (3), through context (3), in short (3), in a new light (3).

Exercise VI.

Determine whether the statements are true or false. Correct the false statements:

1. The 34-year-old assistant professor of physics at the Massachusetts Institute of Technology is the architect of a new theory called "dissipative adaptation," which has helped to explain how complex, life-

like function can self-organize and emerge from simpler things, including animate matter.

2. There are some 6,000 unique languages in use today. Every word translates perfectly.
3. Different fields of science, too, are languages unto themselves, and scientific explanations are sometimes just translations.
4. “Red,” for instance, is a translation of the phrase “620-750 nanometer wavelength.”
5. “Temperature” is a translation of “the average speed of a group of particles.”
6. The more complex a translation, the less meaning it imparts.
7. “Gravity” means “the geometry of spacetime.”
8. Unraveled, each protein is made up of different 20 amino acids.
9. As England would tell an audience at Sweden’s Karolinska Institutet, physics makes a distinction between life and not-life.
10. Different groups of people—musicians, politicians, scientists, and so on—employ language games that suit their separate needs.

Exercise VII .

Match the words to the definitions in the column on the right:

nil	to make operational
to entail	completely new, especially not yet used
assistant professor	one of a group of chemical compounds found in living cells in nucleic acids such as DNA and RNA

to ponder	to involve or make something necessary
to defy	a member of a college or university faculty who ranks above an instructor and below an associate professor
to tackle	nothing
nucleotide	to refuse to obey or to do something in the usual or expected way
brand-new	a small, brown European bird with a red front, or a similar but slightly larger brown bird of North America
to operationalize	to try to deal with something or someone
robin	to consider something carefully for a long time

<u>Exercise VIII</u>.

Summarize the article “How Do You Say “Life” in Physics?”

Part 2

<u>Exercise I.</u>

Identify the part of speech the words belong to:

dissipative, proposition, intricately, drastically, momentarily, anticipation, erasable, permanence, miraculous, polymerase

Exercise II .

Form verbs from the following words: understandable (2), dissipative (2), explanation (2), translation (2), collectively (3), activity (3), creation (3), contradiction (3), transformation (4), calculation (4)

Exercise III.

Find synonyms to the following words. Translate them into Russian: contain (2), avoid (2), consciousness (2), adaptation (2), complex (2), translate (2), average (2), evolve (2), argue (2), require (3)

Exercise IV.

Find antonyms to the following words. Translate them into Russian: complexity (1), loaded (2), unwelcome (2), alone (2), untranslatable (2), vital (3), specific (3), particular (3), absent (3), refuse(3)

Exercise V.

Match the words to make word combinations:

nanometer	matter
dissipative	mechanics
associate	wavelength
inanimate	adaptation
average	acids
physical	professor
separate	purpose
particular	needs
amino	speed
statistical	laws

4. Must science be testable?

Part 1

Exercise I.

Say what Russian words help to guess the meaning of the following words: philosophy, total, paradigmatic, optimistic, details, formulation, test, fact, conceptual, moment

Exercise II

Make sure you know the following words and word combination

to reconcile, diatribe, confirmatory, to concede, quip, ancillary, verge, stalling, concomitant, amenable

Must science be testable?

String wars among physicists have highlighted just how much science needs philosophy – and not just the amateur version (1)

The general theory of relativity is sound science. This was the conclusion reached a number of decades ago by Karl Popper, one of the most influential philosophers of science. Popper was interested in what he called the 'demarcation problem', or how to make sense of the difference between science and non-science, and in particular science and pseudoscience. He thought long and hard about it and proposed a simple criterion: falsifiability. For a notion to be considered scientific it would have to be shown that, at the least in principle, it could be demonstrated to be false, if it were, in fact false. Popper was impressed by Einstein's theory because it had recently been spectacularly confirmed during the 1919 total eclipse of the Sun, so he proposed it as a paradigmatic example of good science. As it turns out, Popper's high regard for the crucial experiment of 1919 may have been a bit optimistic: when we look at the historical details we discover that the earlier formulation of Einstein's theory actually contained a mathematical error that predicted twice as much bending of light by large gravitational masses like the Sun – the very thing that was tested during the eclipse. And if the theory had been tested in 1914 (as was originally planned), it would have been (apparently) falsified. Moreover, there were some significant errors in the 1919 observations, and one of the leading astronomers who conducted the test, Arthur Eddington, may actually have cherry picked his data to make them look like the cleanest possible confirmation of Einstein. Life, and science, are complicated. This is all good and well, but why should something written near the beginning of last century by a philosopher – however prominent – be of interest today? Well, you might have heard of string theory. It's something that the fundamental physics community has been playing around with for a few decades now, in their pursuit of what Nobel physicist Steven Weinberg grandly called 'a theory of everything'. It isn't really a theory of everything, and in fact, technically, string theory isn't even a theory, not if by that name one means mature conceptual constructions, such as the theory of evolution. In fact, string theory is better described as a general framework – the most mathematically sophisticated one available at the moment – to resolve a fundamental problem in modern physics: general relativity and quantum mechanics are highly successful scientific theories, and yet, when they are applied to certain problems, like the physics of black holes, or that of the singularity that gave origin to the universe, they give us sharply contrasting predictions. (2)

Physicists agree that this means that either theory, or both, are therefore wrong or incomplete. String theory is one attempt at reconciling the two by subsuming both into a broader theoretical framework. There is only one problem: while some in the fundamental physics community confidently argue that string theory is not only a very promising scientific theory, but pretty much ‘the only game in town,’ others scornfully respond that it isn’t even science, since it doesn’t make contact with the empirical evidence: features of the theory are impossible to test experimentally, and they are the mathematical equivalent of metaphysical speculation. And metaphysics isn’t a complimentary word in the lingo of scientists. Surprisingly, the ongoing, increasingly public and acerbic diatribe often centres on the ideas of one Karl Popper. What, exactly, is going on? I had a front row seat at one round of such, shall we say, frank discussions last year, when I was invited to Munich to participate in a workshop on the status of fundamental physics, and particularly on what some refer to as ‘the string wars’. The organiser, Richard Dawid, of the University of Stockholm, is a philosopher of science with a strong background in theoretical physics. He is also a proponent of string theory and aims at shielding it from the accusation of engaging in flights of mathematical fancy decoupled from any real science. My role there was to make sure that participants – an eclectic mix of scientists and philosophers, with a Nobel winner thrown in the mix – were clear on something I teach in my introductory course in philosophy of science: what exactly Popper said and why, since some of those physicists had hurled accusations at their critical colleagues, loudly advocating the ejection of the very idea of falsification from scientific practice. In the months preceding the workshop, a number of high profile players in the field had been using all sorts of means – from articles in the prestigious Nature magazine to Twitter – to pursue a no-holds-barred public relations campaign to wrestle, or retain, control of the soul of contemporary fundamental physics. Let me give you a taste of the exchange, to set the mood: ‘The fear is that it would become difficult to separate such ‘science’ from science fiction,’ said George Ellis, chastising the pro-string party. Peter Galison made crystal clear what the stakes are when he wrote: ‘This is a debate about the nature of physical knowledge.’ On the other side, however, cosmologist Sean Carroll tweeted:‘Falsifiability is just a simple motto that non-philosophically-trained scientists have latched onto.’ Finally (but there is more, much more, out there), Leonard Susskind mockingly introduced the neologism ‘Popperazzi’ to label an extremely naive (in his view) way of thinking about how science works. This surprisingly blunt – and very public – talk from prestigious academics is what happens when scientists help themselves to, or conversely categorically reject, philosophical notions that they plainly have not given sufficient thought to. In this case, it was Popper’s philosophy of science and its application to the demarcation problem. What makes this particularly ironic for someone like me, who started his academic career as a scientist (evolutionary biology) and eventually moved to philosophy after a constructive midlife crisis, is that a good number of scientists nowadays – and especially physicists – don’t seem to hold philosophy in particularly high regard. Just in the last few years Stephen Hawking has declared philosophy dead, Lawrence Krauss has quipped that philosophy reminds him of that old Woody Allen joke, ‘those that can’t do, teach, and those that can’t teach, teach gym,’ and science popularisers Neil deGrasse Tyson and Bill Nye have both wondered loudly why any young man would decide to ‘waste’ his time studying philosophy in college. This is a rather novel, and by no means universal, attitude among physicists. Compare the above contemptuousness with what Einstein himself wrote to his friend Robert Thorton in 1944 on the same subject: ‘I fully agree with you about the significance and educational value of methodology as well as history and philosophy of science. So many people today – and even professional scientists – seem to me like somebody who has seen thousands of trees but has never seen a forest. A knowledge of the historic and philosophical background gives that kind of independence from prejudices of his generation from which most scientists are suffering. This independence created by philosophical insight is – in my opinion – the mark of distinction between a mere artisan or specialist and a real seeker after truth.’ By Einstein’s standard then, there are a lot of artisans but comparatively few seekers of truth among contemporary physicists! To put things in perspective, of course, Einstein’s opinion of philosophy may not have been representative even then, and certainly modern string theorists are a small group within the physics community, and string theorists on Twitter are an ever smaller, possibly more voluble subset within that group. The philosophical noise they make is likely not representative of what physicists in general think and say, but it matters all the same precisely because they are so prominent; those loud debates on social media and in the popular science magazines define how much of the public perceives physics, and even how many physicists perceive the big issues of their field. (3)

That said, the publicly visible portion of the physics community nowadays seems split between people who are openly dismissive of philosophy and those who think they got the pertinent philosophy right but their ideological opponents haven't. At stake isn't just the usually tiny academic pie, but public appreciation of and respect for both the humanities and the sciences, not to mention millions of dollars in research grants (for the physicists, not the philosophers). Time, therefore, to take a more serious look at the meaning of Popper's philosophy and why it is still very much relevant to science, when properly understood. As we have seen, Popper's message is deceptively simple, and – when repackaged in a tweet – has in fact deceived many in underestimating the sophistication of the underlying philosophy. If one were to turn that philosophy into a bumper sticker slogan it would read something like: 'If it ain't falsifiable, it ain't science, stop wasting your time and money.'But good philosophy doesn't lend itself to bumper sticker summaries, so one cannot stop there and pretend that there is nothing more to say. Popper himself changed his mind throughout his career about a number of issues related to falsification, as any thoughtful thinker would do when exposed to criticisms and counterexamples from his colleagues. For instance, he initially rejected any role for verification in establishing scientific theories, thinking that it was far too easy to 'verify' a notion if one were actively looking for confirmatory evidence.

Sure enough, modern psychologists have a name for this tendency, common to laypeople as well as scientists: confirmation bias. Nonetheless, later on Popper conceded that verification – especially of very daring and novel predictions – is part of a sound scientific approach. After all, the reason Einstein became a scientific celebrity overnight after the 1919 total eclipse is precisely because astronomers had verified the predictions of his theory all over the planet and found them in satisfactory agreement with the empirical data. For Popper this did not mean that the theory of general relativity was ‘true,’ but only that it survived to fight another day. Indeed, nowadays we don’t think the theory is true, because of the above mentioned conflicts, in certain domains, with quantum mechanics. But it has withstood a very good number of high stakes challenges over the past century, and its most recent confirmation came with the first detection of gravitational waves. When one tests Einstein’s theory using telescopes and photographic plates directed at the Sun, one is really simultaneously putting to the test the focal theory, plus the theory of optics that goes into designing the telescopes, plus the assumptions behind the mathematical calculations needed to analyse the data, plus a lot of other things that scientists simply take for granted and assume to be true in the background, while their attention is trained on the main theory. But if something goes wrong and there is a mismatch between the theory of interest and the observations, this isn’t enough to immediately rule out the theory, since a failure in one of the ancillary assumptions might be to blame instead. That is why scientific hypotheses need to be tested repeatedly and under a variety of conditions before we can be reasonably confident of the results. (4)

Ludwig Wittgenstein was another highly influential 20th century philosopher. Wittgenstein never wrote about philosophy of science, let alone fundamental physics. But he was very much interested in language, its logic, and its uses. He pointed out that there are many concepts that we seem to be able to use effectively, and that yet are not amenable to the sort of clear definition. In the case of the distinction between science and pseudoscience, we think there are important differences, so we try to draw tentative borders in order to highlight them. Surely one would give up too much, as either a scientist or a philosopher, if one were to reject the strongly intuitive idea that there is something fundamentally different between, say, astrology and astronomy. The question is where, approximately, the difference lies. Similarly, many of the participants in the Munich workshop, and the 'string wars' more generally, did feel that there is an important distinction between fundamental physics as it is commonly conceived and what string theorists are proposing. Richard Dawid objects to the term 'post-empirical science,' preferring instead 'non-empirical theory assessment', but whatever one calls it, he is aware that he and his fellow travellers are proposing a major departure from the way we have done science since the time of Galileo. True, the Italian physicist himself largely engaged in theoretical arguments and thought experiments (he likely never did drop balls from the leaning tower of Pisa), but his ideas were certainly falsifiable and have been, over and over, subjected to experimental tests (most spectacularly on the Apollo 15 Moon landing). The broader question then is: are we on the verge of developing a whole new science, or is this going to be regarded by future historians as a temporary stalling of scientific progress? Alternatively, is it possible that fundamental physics is reaching an end not because we've figured out everything we wanted to figure out, but because we have come to the limits of what our brains and technologies can possibly do? These are serious questions that ought to be of interest not just to scientists and philosophers, but to the public at large. What is weird about the string wars and the concomitant use and misuse of philosophy of science is that both scientists and philosophers have bigger targets to jointly address for the sake of society, if only they could stop squabbling and focus on what their joint intellectual forces may accomplish. Rather than laying into each other in the crude terms sketched above, they should work together not just to forge a better science, but to counter true pseudoscience: homeopaths and psychics, just to mention a couple of obvious examples, keep making tons of money by fooling people, and damaging their physical and mental health. Those are worthy targets of critical analysis, and it is the moral responsibility of a public intellectual or academic – be they a scientist or a philosopher – to do their best to improve as much as possible the society that affords them the luxury of discussing fundamental physics. (5)

Adapted from Aeon.

<u>Exercise III</u>.

Find paragraphs, dealing with the following: no-holds-barred, to chastise, to latch, artisan, squabbling, to subsume, laypeople, criterion, notion, spectacularly

<u>Exercise IV</u>.

Fill in the gaps.

1. The fabulous lighting and welcoming ambience of Orlando's **……………** new arena?
2. Then the **…………** monsoons failed to arrive, which sent food prices skyrocketing.
3. Most managers have numbers they use, but some speak the **…..** better than others.
4. He described the meeting at Santa Marta, Colombia, as **………..**, direct and sincere
5. During the **……….**, they discussed ways for the city to bring in more business.
6. Chondroitin sulfate is a complex carbohydrate that helps cartilage **………..** water.
7. Zawahiri, a physician, was the son of two of the cities most **………..** families.
8. I saw a **………….** once, when I was England captain and I was quite stressed.
9. We **………** a car touring holiday in Europe but are worried about the cost of fuel.
10. Lucy paid Craig a surprise visit, wanting to **………..**, but he had her arrested.

Exercise V .

Make up sentences of your own with the following word combinations: the only game in town, to put things in perspective(3), to hurl accusations at (3), high profile players (3), all sorts of means (3), in one's view (3), by no means (3), loud debates (3), at stake (4), to take a more serious look at (4)

<u>Exercise VI</u>.

Determine whether the statements are true or false. Correct the false statements:

1. Popper was interested in what he called the 'demarcation problem', or how to make sense of the difference between science and non-science, and in particular science and pseudoscience.
2. For a notion to be considered scientific it would have to be shown that, at the least in principle, it could be demonstrated to be false, if it were, in fact false.
3. As it turns out, Popper's high regard for the crucial experiment of 1919 may have been a bit optimistic: when we look at the historical details we discover that the earlier formulation of Einstein's theory actually contained a mathematical error that predicted twice as much bending of light by large gravitational masses like the Sun – the very thing that was tested during the eclipse.
4. And if the theory had been tested in 1914 (as was originally planned), it would have been (apparently) falsified.
5. Moreover, there were no significant errors in the 1919 observations, and one of the leading astronomers who conducted the test, Arthur Eddington, may actually have cherry picked his

data to make them look like the cleanest possible confirmation of Einstein.

6. In fact, string theory is better described as a general framework – the least mathematically sophisticated one available at the moment – to resolve a fundamental problem in modern physics.
7. General relativity and quantum mechanics are highly successful scientific theories, and yet, when they are applied to certain problems, like the physics of black holes, or that of the singularity that gave origin to the universe, they give us sharply contrasting predictions.
8. There is only one problem: while some in the fundamental physics community confidently argue that string theory is not only a very promising scientific theory, but pretty much 'the only game in town,' others scornfully respond that it isn't even science, since it doesn't make contact with the empirical evidence: features of the theory are possible to test experimentally, and they are the mathematical equivalent of metaphysical speculation.
9. By Einstein's standard then, there are a lot of seekers of truth but comparatively few artisans among contemporary physicists!
10. Einstein's opinion of philosophy may have been representative.

<u>Exercise VII</u> .

Match the words to the definitions in the column on the right:

lingo	a system of thought or a theory that is not formed in a scientific way
homeopath	to keep or continue to have something:
workshop	to want to have or do something
to retain	honest, sincere, and truthful

spectacular	a type of language that contains a lot of unusual or technical expressions
tentative	a room or building where things are made or repaired using machines and/or tools
pseudoscience	a person who treats ill people byhomeopathy
frank	very exciting to look at
fancy	not certain or confident
to decouple	to separate from someone or somethingelse; to separate something from something else that it was joined to or part of

Exercise VIII.

Summarize the article “Must science be testable?”

Part 2

Exercise I.

Identify the part of speech the words belong to.

crucial, demarcation, acerbic, ejection, contemptuous, scornful, voluble, prominent, dismissive, pertinent

Exercise II .

Form adverbs from the following words:

general (2), total (2), good (2), historical (2), prominent (2), fundamental (2), successful (8), scientific (9), certain (9), origin (9)

Exercise III.

Find synonyms to the following words. Translate them into Russian:

version (2), conclusion (2), eclipse (2), error (2), predict (2), mass (2), leading (2), conduct (2), beginning (2), community (2)

Exercise IV .

Find antonyms to the following words. Translate them into Russian:

amateur (2), influential (2), hard (2), false (2), impress (2), optimistic (2), discover (2), significant (2), clean (2), complicated (2)

Exercise V.

Match the words to make word combinations:

focal	relativity
high	science
sound	regard
amateur	theory
demarcation	masses
total	evidence
high	version
gravitational	regard
general	problem
empirical	eclipse

SUPPLEMENTARY READING

1. ‘Quantum Atmospheres’ May Reveal Secrets of Matter

A new theory proposes that the quantum properties of an object extend into an “atmosphere” that surrounds the material.

Over the past several years, some materials have proved to be a playground for physicists. These materials aren’t made of anything special — just normal particles such as protons, neutrons and electrons. But they are more than the sum of their parts. These materials boast a range of remarkable properties and phenomena and have even led physicists to new phases of matter — beyond the solid, gas and liquid phases we’re most familiar with. One class of material that especially excites physicists is the topological insulator — and, more broadly, topological phases, whose theoretical foundations earned their discoverers a Nobel Prize in 2016. On the surface of a topological insulator, electrons flow smoothly, while on the inside, electrons are immobile. Its surface is thus a metal-like conductor, yet its interior is a ceramic-like insulator. Topological insulators have drawn attention for their unusual physics as well as for their potential use in quantum computers and so-called spintronic devices, which utilize electrons’ spins as well as their charge. But such exotic behaviors aren’t always obvious. “You can’t just tell easily by looking at the material in conventional ways whether it has these kinds of properties,” said Frank Wilczek, a physicist at the Massachusetts Institute of Technology and winner of the 2004 Nobel Prize in Physics.

This means a host of seemingly ordinary materials might harbor hidden — yet unusual and possibly useful — properties. In a paper recently posted online, Wilczek and Qing-Dong Jiang, a physicist at Stockholm University, propose a new way to discover such properties: by probing a thin aura that surrounds the material, something they’ve dubbed a quantum atmosphere.

Some of a material’s fundamental quantum properties could manifest in this atmosphere, which physicists could then measure. If confirmed in experiments, not only would this phenomenon be one of only a few macroscopic consequences of quantum mechanics, Wilczek said, but it could also be a powerful tool for exploring an array of new materials.

"Had you asked me if something like this could occur, I would've said that seems like a reasonable idea," said Taylor Hughes, a condensed matter theorist at the University of Illinois, Urbana-Champaign. But, he added, "I would imagine the effect to be very small." In the new analysis, however, Jiang and Wilczek calculated that, in principle, a quantum atmospheric effect would be well within the range of detectability.

Not only that, Wilczek said, but detecting such effects may be achievable sooner rather than later. A quantum atmosphere, Wilczek explained, is a thin zone of influence around a material. According to quantum mechanics, a vacuum isn't completely empty; rather, it's filled with quantum fluctuations. For example, if you take two uncharged plates and bring them together in a vacuum, only quantum fluctuations with wavelengths shorter than the distance between the plates can squeeze between them. Outside the plates, however, fluctuations of all wavelengths can fit. The energy outside will be greater than inside, resulting in a net force that pushes the plates together. Called the Casimir effect, this phenomenon is similar to the influence from a quantum atmosphere, Wilczek said.

Just as a plate feels a stronger force as it nears another one, a needlelike probe would feel an effect from the quantum atmosphere as it approaches a material. "It's just like any atmosphere," Wilczek said. "You get close to it, and you start to see its influence." And the nature of that influence depends on the quantum properties of the material itself.

Those properties can be extraordinary. Certain materials act like their own universes with their own physical laws, as if comprising what's recently been called a materials multiverse. "A very important idea in modern condensed matter physics is that we're in possession of these materials — say, a topological insulator — which have different sets of rules inside," said Peter Armitage, a condensed matter physicist at Johns Hopkins University.

Some materials, for example, harbor objects that act as magnetic monopoles — point-like magnets with a north pole but no south pole. Physicists have also detected so-called quasiparticles withfractional electric charge and quasiparticles that act as their own antimatter, with the ability to annihilate themselves.

If similarly exotic properties exist in other materials, they could reveal themselves in quantum atmospheres. You could, in principle, discover all sorts of new properties simply by probing the atmospheres of materials, Wilczek said.

To demonstrate their idea, Jiang and Wilczek focused on an unorthodox set of rules called axion electrodynamics, which could give rise to unique properties. Wilczek came up with the theory in 1987 to describe how a hypothetical particle called an axion would interact with electricity and magnetism. (Physicists had previouslyproposed the axion as a solution to one of physics' biggest unsolved questions: why interactions involving the strong force are the same even when particles are swapped with their antiparticles and reflected in a mirror, preserving so-called charge and parity symmetry.) To this day, no one has found any evidence that axions exist, even though they've recently garnered renewed interest as a candidate for dark matter.

While these rules don't seem to be valid in most of the universe, it turns out they can come into play inside a material such as a topological insulator. "The way electromagnetic fields interact with these new kinds of matter called topological insulators is basically the same way they would interact with a collection of axions," Wilczek said.

If a material such as a topological insulator obeys axion electrodynamics, its quantum atmosphere could induce a telltale effect on anything that crosses into the atmosphere. Jiang and Wilczek calculated that such an effect would be similar to that of a magnetic field. In particular, they found that if you were to place some system of atoms or molecules in the atmosphere, their quantum energy levels would be altered. A researcher could then measure these altered levels using standard laboratory techniques. "It's kind of an unconventional but a quite interesting idea," said Armitage.

One such potential system is a diamond probe imbued with features called nitrogen-vacancy (NV) centers. An NV center is a type of defect in a diamond's crystal structure where some of the diamond's carbon atoms are swapped out for nitrogen atoms, and where the spot adjacent to the nitrogen is empty. The quantum state of this system is highly sensitive, allowing NV centers to sniff out even very weak magnetic fields. This property makes them powerful sensors that can be used for a variety of applications in geology and biology.

"This is a nice proof of principle," Hughes said. One application, he added, could be to map out a material's properties. By passing an NV center across a material like a topological insulator, you can determine how its properties may vary along the surface.

Jiang and Wilczek's paper, which they have submitted to Physical Review Letters, details only the quantum atmospheric influence derived from axion electrodynamics. To determine how other kinds of properties affect an atmosphere, Wilczek said, you would have to do different calculations.

Fundamentally, the properties that quantum atmospheres unmask are symmetries. Different phases of matter, and the properties unique to a phase, can be thought of in terms of symmetry. In a solid crystal, for example, atoms are arranged in a symmetric lattice that shifts or rotates to form an identical crystal pattern. When you apply heat, however, the bonds break, the lattice structure collapses, and the material — now a liquid with markedly different properties — loses its symmetry.

Materials can break other fundamental symmetries such as the time-reversal symmetry that most laws of physics obey. Or phenomena may be different when looked at in the mirror, a violation of parity symmetry.

Whether these symmetries are broken in a material could signify previously unknown phase transitions and potentially exotic properties. A material with certain broken symmetries would induce the same violations in a probe that's inside its quantum atmosphere, Wilczek said. For example, in a material that adheres to axion electrodynamics, time and parity symmetry are each broken, but the combination of the two is not. By probing a material's atmosphere, you could learn whether it follows this symmetry-breaking pattern and to what extent — and thus what bizarre behaviors it may have, he said.

"Some materials will be secretly breaking symmetries that we didn't know about and that we didn't suspect," he said. "They seem very innocent, but somehow they've been hiding in secret."

Wilczek said he's already talked with experimentalists who are interested in testing the idea. What's more, he said, experiments should be readily feasible, hopefully coming to fruition not in years, but in only weeks and months.

If everything works out, then the term "quantum atmosphere" may find a permanent spot in the physics lexicon. Wilczek has previously coined terms like axions, anyons (quasiparticles that may be useful for quantum computing) and time crystals (structures that move in regular and repeating patterns without using energy). He has a good track record of coming up with names that stick, Armitage said. "'Quantum atmospheres' is another good one." *Adapted from Quanta Magazine*

2. To get a grip on altruism, see humans as molecules

What is life?' In 1943, Erwin Schrödinger posed this question in a series of lectures at Trinity College, Dublin. Already famous as a hero of the quantum revolution, he charged scientists with a new mission: to begin to account for the activity of living creatures using tools and intuitions from physics.

Seventy-five years later, the biophysics revolution is ongoing. Schrödinger's call to action inspired his colleagues to look at the building blocks of life at all scales, from the diminutive DNA molecule to schooling fish and the construction of anthills. My research group at Harvard University focuses on altruism, or why creatures sacrifice themselves for the common good. But rather than relying on psychology or moral philosophy, we approach this problem using thermodynamics – how the laws governing heat and the interaction of microscopic particles might translate into macroscopic behaviour. Can we explain altruism by casting humans as atoms and molecules, and societies or populations as solids, liquids or gases?

We model altruism as a simple interaction between two individuals – say, Ayla and Babak. Both must pick one of two options: cooperate or defect. If Ayla cooperates with Babak, she pays a small cost, say $1, to a central bank that immediately gives $5 to Babak. Defecting equates to doing absolutely nothing. Therefore, if both players defect, their personal balance is unchanged; if both players cooperate, they each gain $4; if one cooperates and the other defects, the former loses $1 and the latter gains $5.

The rules at work are fairly simple, and we can easily imagine some large-scale consequences. Economic prosperity will be highest, for example, when everyone cooperates. What's good for the community as a whole also seems good for the individual. However, global cooperation is not so easy to attain, which is where things get interesting.

Imagine a large number of individuals, interacting according to this cooperate/defect model, but unable to see or speak to one another. Without any actual physical interaction, there's no way to recognise an individual on the 'other side', so everyone picks either cooperate or defect, and sticks with it for many interactions. Next, imagine that individuals are allowed to compare their respective profits every now and again. If a cooperator and a defector compare pots, the cooperator will always be disappointed – a defector gets $5 per cooperator in the room, but a cooperator gets $4 per cooperator and loses $1 per defector. The disgruntled cooperator will switch to defect, increasing the financial load on cooperators, who are driven further and further into debt until everyone has switched to defect.

But this can't be right. Despite the apparently law-like tendency towards selfishness, we still see examples of cooperation and self-sacrifice all around us, even when individuals are 'invisible' to each other. Citizens can make sacrifices during blackouts and droughts for the sake of maintaining the flow of electricity and water, and people will occasionally risk their lives in order to help total strangers.

It turns out that our thought experiment has two fatal flaws. The first is that we don't behave the same way around everybody: we're more likely to cooperate with friends and family than with strangers. Our ideas about the microscopic rules of interaction might be wrong. Secondly, we might be naive about which individuals interact. Even if we keep with our very simplified rules, it's unrealistic to assume that everyone is equally likely to come into contact with one another, especially in bigger groups.

In fact, the fine details of the social network – who is connected to whom, and how many people are involved – have an incredibly strong impact on the behaviours that flourish or perish within it. Martin Nowak is the head of our lab; he says in his book SuperCooperators (2011), co-authored with Roger Highfield, that you can look at population structure as you would the phases of a physical substance. Think about H2O molecules bumping into one another. The population structure of ice (where molecules are unmoving and can 'see' only a few others nearby) will produce a different set of interactions to water (where molecules often 'see' the same close neighbours often, but also move around and explore other neighbourhoods) or steam (where there are no familiar neighbours, and molecules careen about wildly).

Raising the temperature of a solid will eventually turn it into a liquid, and then a gas. Similarly, we can think of a kind of 'social temperature' that dictates the rate at which people interact, and how unfamiliar they are to us. In the thought experiment, we often encounter people we hardly know, much like a hot gas of molecules crashing into one another, or forcing our way through a crowd to board the subway. In this scenario (much like in real subways), it is hard to foster cooperation. What happens at the other end of the spectrum – in 'solids'? A solid population would be unchanging, just like the molecules in a brick or rock. You'd always see the same people, and know their reputation and behaviour. For most of us, this solid, crystalline phase represents the backbone of our social life. We have long-lasting connections to friends and family, and interact with them often, but don't see as many friends-of-friends or family members several-times removed.

The fact that these connections are rare can help to insulate you from defectors. If there is one defector on the subway platform, you might be susceptible to getting swindled – but if your cousin's partner's plumber, Donny, happens to be a defector, you are unlikely to be affected in any way. So if we start with connections between everyone, as in a gas, cooperation will fail – because everyone is susceptible to the few jerks. But if we begin to snip these social wires, we might produce connected cooperators who are well insulated, feeling the effects of defectors only through friends-of-friends-of-friends.

Solid semiconductors – bits of metal that are the backbone of every gadget in the modern world – open up another perspective on the physics of altruism. In semiconductors, changes in the microscopic structure of a metal can affect how much electricity must be applied to 'activate' it, such that the amount of current passing through jumps from zero to a particular number. Similarly, a recent paper in Nature written by my colleagues predicted how large a financial reward (the electricity) is required for altruism to 'turn on' and spread through a group (the semiconductor). Some networks require a reward of $1.05, for example, and are pretty great conductors of altruism; some demand $100 or more, and are very difficult to activate.

What about 'liquid' populations? In an earlier paper, we examined how cooperation conducts in supple social materials such as clubs, workplaces, coffee shops and artistic movements. Here individuals belong to one or more groups and can change their memberships as they like. If it's easy to switch, then a liquid almost effortlessly sustains cooperation – at the sign of the first defector, all the cooperators simply leave and restart the organisation elsewhere. But when there are barriers to migration, rules-of-thumb start to appear. If moving is costly, cope with defectors for as long as you can before leaving; otherwise, bail and take as many cooperators with you as possible.

Of course, the real social fabric is a complex mix of populations in many phases. We have strong ties that we occasionally form and break; we join and leave organisations quite freely; we have hundreds of micro-interactions with a gaseous mix of strangers in trains and airports.

However, by studying each of these phases as physicists, we come away approaching a recipe for altruism – rules for certain structures that might foster cooperation. What we've observed so far is that strong local connections enhance altruism everywhere. Mobility and flexibility put a brake on defection, but we can't have so much as to create a gaseous regime where cooperation is stifled. Scientists still have a long way to travel to understand the physics of biological systems – but I like to think Schrödinger might be pleased by how far we have come.

Adapted from Aeon