А.И. Матяшевская, Е.В. Тиден

ADVANCES IN MODERN PHYSICS:

part 3

Учебное пособие

Саратов

2018

Составители - А.И. Матяшевская, Е.В. Тиден

Advances in Modern Physics: part 3: Учебное пособие по иностранному языку для студентов неязыкового вуза /Сост. А.И. Матяшевская, Е.В. Тиден. — Саратов, 2018. — 69 с.

Рецензент:

Кандидат философских наук Шилова С.А.

Table of Contents

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. Roger Penrose On Why Consciousness Does Not Compute

Part 1

Exercise I.

Say what Russian words help to guess the meaning of the following words: mental, anesthesiologist, brilliant, geometric, forms, design, crystallography, interests, fantasy, tome

Exercise II

Make sure you know the following words and word combinations:
to compute, crackpot, to coalesce, lattice, Orchestrated Objective Reduction, brew, uneasy, roundabout, speck, emulated

Roger Penrose On Why Consciousness Does Not Compute

The emperor of physics defends his controversial theory of mind(1)

Once you start poking around in consciousness studies, you will soon encounter the specter of Sir Roger Penrose, the renowned Oxford physicist with an audacious—and quite possibly crackpot—theory about the quantum origins of consciousness. He believes we must go beyond neuroscience and into the mysterious world of quantum mechanics to explain our rich mental life. No one quite knows what to make of this theory, developed with the American anesthesiologist Stuart Hameroff, but conventional wisdom goes something like this: Their theory is almost certainly wrong, but since Penrose is so brilliant ("One of the very few people I've met in my life who, without reservation, I call a genius," physicist Lee Smolin has said), we'd be foolish to dismiss their theory out of hand. Penrose, 85, is a mathematical physicist who made his name decades ago with groundbreaking work in general relativity and then, working with Stephen Hawking, helped conceptualize black holes and gravitational singularities, a point of infinite density out of which the universe may have formed. He also invented "twistor theory," a new way to connect quantum mechanics with the structure of spacetime. His discovery of certain geometric forms known as "Penrose tiles"—an ingenious design of non-repeating patterns—led to new directions of study in mathematics and crystallography. The breadth of Penrose's interests is extraordinary, which is evident in his recent book *Fashion, Faith and Fantasy in the New Physics of the Universe*—a dense 500-page tome that challenges some of the trendiest but still unproven theories in physics, from the multiple dimensions of string theory to cosmic inflation in the first moment of the Big Bang. He considers these theories to be fanciful and implausible. Penrose doesn't seem to mind being branded a maverick, though he disputes the label in regard to his work in physics. But his theory of consciousness pushes the edges of what's considered plausible science and has left critics wondering why he embraces a theory based on so little evidence. (2)

Most scientists regard quantum mechanics as irrelevant to our understanding of how the brain works. Still, it's not hard to see why Penrose's theory has gained attention. Artificial intelligence experts have been predicting some sort of computer brain for decades, with little to show so far. And for all the recent advances in neurobiology, we seem no closer to solving the mind-brain problem than we were a century ago. Even if the human brain's neurons could be completely mapped—which would be one of the great triumphs in the history of science—it's not clear that we'd be any closer to explaining how this 3-pound mass of wet tissue generates the immaterial world of our thoughts and feelings. Something seems to be missing in current theories of consciousness. The philosopher David Chalmers has speculated that consciousness may be a fundamental property of nature existing outside the known laws of physics. Others—often branded "mysterians"—claim that subjective experience is simply beyond the capacity of science to explain. Penrose's theory promises a deeper level of explanation. He starts with the premise that consciousness is not computational, and it's beyond anything that neuroscience, biology, or physics can now explain. "We need a major revolution in our understanding of the physical world in order to accommodate consciousness," Penrose told me in a recent interview. "The most likely place, if we're not going to go outside physics altogether, is in this big unknown—namely, making sense of quantum mechanics." He draws on the basic properties of quantum computing, in which bits (qubits) of information can be in multiple states—for instance, in the "on" or "off" position—at the same time. These quantum states exist simultaneously—the "superposition"—before coalescing into a single, almost instantaneous, calculation. Quantum coherence occurs when a huge number of things—say, a whole system of electrons—act together in one quantum state. (3)

It was Hameroff's idea that quantum coherence happens in microtubules, protein structures inside the brain's neurons. And what are microtubules, you ask? They are tubular structures that play a role in determining the cell's shape, as well as its movements, which includes cell division. Hameroff suggests that microtubules are the quantum device that Penrose had been looking for in his theory. In neurons, microtubules help control the strength of synaptic connections, and their tube-like shape might protect them from the surrounding noise of the larger neuron. The microtubules' symmetry and lattice structure are of particular interest to Penrose. He believes "this reeks of something quantum mechanical." Still, you'd need more than just a continuous flood of random moments of quantum coherence to have any impact on consciousness. The process would need to be structured, or orchestrated, in some way so we can make conscious choices. In the Penrose-Hameroff theory of Orchestrated Objective Reduction, known as Orch-OR, these moments of conscious awareness are orchestrated by the microtubules in our brains, which—they believe—have the capacity to store and process information and memory. "Objective Reduction" refers to Penrose's ideas about quantum gravity—how superposition applies to different spacetime geometries—which he regards as a still-undiscovered theory in physics. All of this is an impossibly ambitious theory that draws on Penrose's thinking about the deep structure of the universe, from quantum mechanics to relativity. As Smolin has said, "All Roger's thoughts are connected ... his philosophical thinking, his ideas about quantum mechanics, his ideas about the brain and the mind." (4)

This is a heady brew, but unconvincing to critics. Most scientists believe the brain is too warm and wet for quantum states to have any influence on neuronal activity because quantum coherence only seems possible in highly protected and frigid environments. The most damning critique has come from Max Tegmark, a professor of physics at the Massachusetts Institute of Technology, who calculated that any quantum effects within microtubules would break down after 100 quadrillionths of a second. “For my thoughts to correspond to a quantum computation, they’d need to finish before decoherence kicked in, so I’d need to be able to think fast enough to have 10,000,000,000,000 thoughts each second,” Tegmark writes in his book *Our Mathematical Universe: My Quest for the Ultimate Nature of Reality*. “Perhaps Roger Penrose can think that fast, but I sure can’t.” Even Penrose’s old collaborator Stephen Hawking is dubious. “I get uneasy when people, especially theoretical physicists, talk about consciousness,” he’s written. “His argument seemed to be that consciousness is a mystery and quantum gravity is another mystery so they must be related.” Penrose dismisses Hawking’s criticism, saying their disagreement is really about the nature of quantum mechanics. (5)

Penrose explained that his interest in consciousness goes back to his discovery of Gödel’s incompleteness theorem while he was a graduate student at Cambridge. Gödel’s theorem, you may recall, shows that certain claims in mathematics are true but cannot be proven. “This, to me, was an absolutely stunning revelation,” he said. “It told me that whatever is going on in our understanding is not computational.” Like many others, Penrose struggled with the weirdness of quantum theory. “As Schrödinger clearly pointed out with his poor cat, which was dead and alive at the same time, he made this point deliberately to show why his own equation can’t be the whole truth. He was more or less saying, ‘That’s nonsense.’ ” But what, I asked, does any of this have to do with consciousness? “You see, my argument is very roundabout. I think this is why people don’t tend to follow me. They’ll pick up on it later, or they reject it later, but they don’t follow argument.” Penrose then launched into his critique of why computers, for all their brute calculating power, lack any understanding of what they're doing. "What I'm saying—and this is my leap of imagination which people boggle at —I'm saying what's going on in the brain must be taking advantage not just of quantum mechanics, but where it goes wrong," he said. "It's where quantum mechanics needs to be superseded." So we need a new science that doesn't yet exist? "That's right. Exactly." I pointed out that he hadn't mentioned biology or the widely held belief that consciousness is an emergent property of the brain. Then he told me why he felt compelled to write his first book on consciousness. It was after he heard a BBC interview with Marvin Minsky, a founding father of artificial intelligence, who had famously pronounced that the human brain is "just a computer made of meat." His claims compelled Penrose to write *The Emperor's New Mind*, arguing that human thinking will never be emulated by a machine. The book had the feel of an extended thought experiment on the non-algorithmic nature of consciousness and why it can only be understood in relation to Gödel's theorem and quantum physics. As we probed the deeper implications of Penrose's theory about consciousness, it wasn't always clear where to draw the line between the scientific and philosophical dimensions of his thinking. Consider, for example, superposition in quantum theory. How could Schrödinger's cat be both dead and alive before we open the box? "An element of proto-consciousness takes place whenever a decision is made in the universe," he said. "I'm not talking about the brain. I'm talking about an object which is put into a superposition of two places. Say it's a speck of dust that you put into two locations at once. Now, in a small fraction of a second, it will become one or the other. Which does it become? Well, that's a choice. Is it a choice made by the universe? Does the speck of dust make this choice? Maybe it's a free choice. I have no idea." (6)

Like much of his thinking, there's a "yes, but" here. And so it is with his ideas about free will. "I've certainly grown up thinking the universe is deterministic. Then I evolved into saying, 'Well, maybe it's deterministic but it's not computable.' But is it something more subtle than that? Is it several layers deeper? If it's something we use for our conscious understanding, it's going to be a lot deeper than even straightforward, non-computable deterministic physics. It's a kind of delicate borderline between completely deterministic behavior and something which is completely free." Even if you're skeptical of Penrose's argument about consciousness, it's tempting to root for him. The science of consciousness feels stuck, and here's a theory—however speculative—that suggests a possible way forward. The fact that Penrose is asking so much of us—not just to accept quantum coherence in microtubules but also his contention that consciousness can only be explained by still-undiscovered laws of physics—may simply be too far-reaching to ground a new scientific theory. And there's another problem as well. Suppose 20 or 200 years from now the broad outlines of Orch-OR are confirmed. Have we explained consciousness—or just pushed the mind-brain problem into a deeper mystery, the quantum mind-body problem? Can we ever bridge the gap between the physical and immaterial worlds? As I wondered why Penrose keeps hammering away at his theory on consciousness after all these years, I asked him if he thinks there's any inherent meaning in the universe. His answer surprised me. "Somehow, our consciousness is the reason the universe is here.” So does he think there’s intelligent life—or consciousness—somewhere else in the cosmos? “Yes, but it may be extremely rare.” But if consciousness is the point of this whole shebang, wouldn’t you expect to find some evidence of it beyond Earth? “Well, I’m not so sure our own universe is that favorably disposed toward consciousness,” he said. “You could imagine a universe with a lot more consciousness that’s peppered all over the place. Why aren’t we in one of those rather than this one where it seems to be a rather uncommon activity? “So, yes, we want to see the purpose of it. I don’t know. Maybe it’s attributing the wrong word. Purpose—what does that mean?” He chuckled. (7)

Adapted from Nautilus.

Exercise III.

Find paragraphs, dealing with the following: encounter, mental, anesthesiologist, genius, groundbreaking, ingenious, breadth, faith, implausible, maverick

Exercise IV.

Fill in the gaps.

1. Salazar lost **…………** in the dugout and was airlifted to a nearby hospital.

2. An **……….** opening choice was Mozart's Divertimento in D major, an early work.

3. There is still **…………** over the quantity of bad loans carried by Japanese banks.

4. Time will tell what really happened at Bondi, but for now we can only **……….**

5. The slower the Earth's rotation, the higher the **……….** of the whole universe.

6. Atoms in solids are bound in a regular **…………**, which normally keeps them rigid.

7. That's one of many reasons the awful story of Phoebe Prince leaves me so **…………..**

8. There is no doubt that these animals are weird and fantastic for that **…………...**

9. I lived in Stokenchurch for 18 years and I now live near Handy Cross **……………**

10. They are doing ongoing research to predict, prevent or curtail **……..** events.

Exercise IV.

Make up sentences of your own with the following word combinations:
to poke around (1), to go beyond (1), without reservation (1), out of hand (1), in regard to (1), on little evidence (1), beyond the capacity of (2), to draw on (2), to boggle at (5) , to take advantage (5) , the whole shebang (7)

Exercise VI.

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

1. Sir Roger Penrose believes we must go beyond neuroscience and into the mysterious world of quantum mechanics to explain our rich mental life.
2. Penrose, 85, is a mathematical physicist who made his name decades ago with groundbreaking work in general relativity and then, working with Stephen Hawking, helped conceptualize black holes and gravitational singularities, a point of infinite density out of which the universe may have formed.
3. He also invented "string theory," a new way to connect quantum mechanics with the structure of spacetime.
4. The breadth of Penrose's interests is extraordinary, which is evident in his recent book Fashion, Faith and Fantasy in the New Physics of the Universe—a dense 500-page tome that challenges some of the trendiest and proven theories in physics, from the multiple dimensions of string theory to cosmic inflation in the first moment of the Big Bang.
5. Penrose considers string theory to be plausible.
6. Most scientists regard quantum mechanics as relevant to our understanding of how the brain works.
7. Artificial intelligence experts have been predicting some sort of computer brain for decades, with little to show so far.
8. And for all the recent advances in neurobiology, we seem closer to solving the mind-brain problem than we were a century ago.
9. The physicist David Chalmers has speculated that consciousness may be a fundamental property of nature existing outside the known laws of physics.
10. Gödel's theorem, you may recall, shows that certain claims in mathematics are proven but cannot be true.

Exercise VII .

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

theorem	very many of the same type, or of different types
crystallography	thinking and acting in an independent way, often behaving differently from the expected or usual way
dispute	a science that deals with the forms and structures of crystals
speculate	to decide that something or someone is not important and not worth considering
maverick	(especially in mathematics) a formal statement that can be shown to be true by logic
premise	any of the minute tubules in eukaryotic cytoplasm
to orchestrate	an argument or disagreement, especially an official one between, for example, workers and employers or two countries with a common border
multiple	to guess possible answers to a question when you do not have enough information to be certain
microtubule	an idea or theory on which a statement or action is based
dismiss	to arrange something carefully, and sometimes unfairly, so as to achieve a wanted result

<u>Exercise VIII</u>.

Summarize the article “Roger Penrose On Why Consciousness Does Not Compute”

Part 2

Exercise I.

Identify the part of speech the words belong to.

consciousness, audacious, ingenious, breadth, fanciful, computational, coherence, dubious, weirdness, contention

Exercise II .

Form nouns from the following words:

mental (1), conceptualize (2), gravitational (2), form (2), invent (2), connect (2), geometric (2), evident (2), dense (2), predict (3)

Exercise III.

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

defend (1), foolish (2), dismiss (2), singularity (2), way (2), pattern (2), direction (2), interest (2), recent (2), multiple (2)

Exercise IV.

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

controversial (1), believe (2), rich (2), wisdom (2), wrong (2), new (7), extraordinary (2), edge (8), irrelevant (2), artificial (3)

Exercise V.

Match the words to make word combinations:

tube-like	structures
Penrose	intelligence
infinite	theorem

emergent	brew
conventional	density
Gödel’s	property
artificial	tiles
tubular	wisdom
heady	coherence
quantum	shape

2. To Understand Your Past, Look to Your Future

Part 1

Exercise I.

Say what Russian words help to guess the meaning of the following words: schema, situations, phenomena, combine, programs, opposite, alternative, regularly, seriously, paradox

Exercise II.

Make sure you know the following words and word combinations: morass, footing, bookend, least-action, constrained, caveat, mesh, to nest, to diverge, to reside

To Understand Your Past, Look to Your Future

An alternative to the Newtonian worldview promises to help explain quantum weirdness (1)

You're thinking about time all wrong, according to our best physical theories. In Einstein's general theory of relativity, there's no conceptual distinction between the past and the future, let alone an objective line of "now." There's also no sense in which time "flows"; instead, all of space and time is just *there* in some four-dimensional structure. What's more, all the fundamental laws of physics work essentially the same both forward and backward. None of these facts are easy to accept, because they're in direct conflict with our subjective experience of time. But don't feel too bad: They're hard even for *physicists* to accept, an ongoing tension that places physics in conflict not just with common sense but also with itself. As much as physicists talk about time symmetry, they do not allow themselves to invoke the future, only the past, when seeking to explain occurrences in the world.When formulating explanations, most of us tend to think in terms laid down by Isaac Newton over 300 years ago. This “Newtonian Schema” takes the past as primary and uses it to solve for the future, explaining our universe one time-step at a time. Some researchers even go so far as to think of the universe as the output of a forward-running computer program, a picture that is a natural extension of this schema. Even though our view of time has changed dramatically in the last century, the Newtonian Schema has somehow endured as our most popular physics framework. But imposing old Newtonian Schema thinking on new quantum-scale phenomena has landed us in situations with no good explanations whatsoever. If these phenomena seem inexplicable, we may just be thinking about them in the wrong way. Much better explanations become available if we are willing to take the future into account as well as the past. But Newtonian-style thinking is inherently incapable of such time-neutral explanations. Computer programs run in only one direction, and trying to combine two programs running in opposite directions leads to the paradoxical morass of poorly plotted time-travel movies. In order to treat the future as seriously as we treat the past, we clearly need an alternative to the Newtonian Schema. And we have one. Most physicists are well aware of a different framework, an alternative where space and time are analyzed in an even-handed manner. This so-called Lagrangian Schema also has old roots and has become an essential tool in every field of fundamental physics. But even physicists who regularly use this approach have resisted the last obvious step: thinking of the Lagrangian Schema not just as a mathematical trick, but as a way to explain the world. Perhaps we haven't been taking our own theories seriously enough. The Lagrangian Schema doesn't just allow future-based explanations. It *demands* them. By treating the future and the past on the same footing, this framework avoids paradoxes and makes new explanatory opportunities available. And it just might be the viewpoint that physics needs for the next major breakthrough. (2)

The first step toward understanding the Lagrangian Schema is to fully set aside the temporal "flow" of Newtonian thinking. This can best be done by treating spacetime regions holistically: considering the full duration all at once, rather than as sequential frames of a movie. We can picture regions of spacetime as bounded four-dimensional structures, with not just spatial boundaries, but also temporal boundaries—the initial and final bookends of the region. All of classical physics, from electricity to black holes, can be expressed via the simple Lagrangian-based principle of "least-action." To use it on a spacetime region, you first describe how physical parameters are constrained over the entire boundary. Then, for each set of possible events inside that boundary, you calculate a quantity called the "action." The set of events with the lowest value of the action is the one that will actually occur, given the original boundary constraints and a few other technical caveats. For instance, when a ray of light travels from point A to point B, the action corresponds to the amount of travel time. The actual path is the fastest route, given the intermediate obstacles. By this way of thinking, a light ray bends at a glass interface simply because it minimizes the overall travel time. The Lagrangian Schema works a bit differently in quantum physics and yields probabilities rather than decisive predictions, but the basics are the same: Spacetime boundary constraints are still imposed all at once. By Newtonian logic, this sounds quite strange. The light ray at A seems to possess foreknowledge (about point B and future obstacles), vast computational ability (to survey the different paths), and agency (to choose the fastest one). But this strangeness is merely evidence that Newtonian and Lagrangian thinking don't mesh—and that we probably shouldn't anthropomorphize light rays. Instead of explaining events via only the past, the Lagrangian Schema starts with the entire boundary constraint—including, crucially, the final boundary. If you don't impose a final constraint—for light rays, the location of point B—this approach fails to give the proper answer. But if used properly, the success of the mathematics indicates a clear logical priority of the boundary constraint: The boundary of any spacetime region explains the interior. The Lagrangian approach provides the most elegant and flexible account of known physics, and physicists often prefer it. Still, despite the wide applicability of Lagrangian-based principles, even the physicists who use them don't take them literally. It is hard to accept that events might be explained by what goes on in the future. After all, there are obvious distinctions between past and future. Given that we see such an evident arrow of time, how could future boundaries possibly matter just as much as past ones? But there's a way to reconcile the Lagrangian Schema with our causal experience. We just have to think sufficiently big, without losing sight of the details. (3)

Suppose you take a flash photograph of a statue. Each ray of light obeys the least-action principle, giving a perfectly time-symmetric account of its path. But taken together, there's an obvious asymmetry:

The initial boundaries A are all clustered together at the flash, while the final boundaries B are spread out over the statue. Furthermore, it's perfectly clear that the spreading of light from A is a much better explanation of the illumination at B than vice-versa. Even if the ray paths were viewed in reverse, no one would plausibly claim that the light was concentrated at the flashbulb because of complex patterns of light on the statue. One lesson here is that satisfying explanations account for complicated events in terms of simple givens. They take a single fact, with just a few relevant parameters, to explain a plurality of events. This should be evident no matter which schema one is using. But this asymmetry of A and B is not a rebuttal to the Lagrangian perspective, which merely says that A and B together can best explain the details of what happens in between. Even in the Lagrangian Schema, A and B are not independent of each other. To see how they're related, we need to think bigger. According to the boundary framework of the Lagrangian Schema, explanations don't chain. They nest. In other words, we don't picture event A leading to event B leading to event C. Instead, we treat a small spacetime region in its entirety; then we treat this region as part of a larger region (in both space and time). Applying the same Lagrangian logic, the larger boundaries should now explain everything in their interior, including the original boundaries. Running this procedure for the statue example, we find the same asymmetry of bulb and illumination writ larger. That is, we find a satisfying explanation for the camera flash in its past, but we don't explain the illumination of the statue by looking to its future. Then we can enclose that larger system in an even bigger one, and so on, until we have gone all the way out to the cosmological boundary—the external constraints on our entire universe. To the best of our knowledge, we see the same asymmetry at that scale: an unusual, smooth distribution of matter near the big bang, and greater disorder in the future. (4)

Looking at ordinary spacetime regions from a Lagrangian perspective, the fact that initial boundaries (light rays diverging from flashbulbs) are simpler than final boundaries (lit statues) is strong evidence that our closest cosmological boundary lies to our past. The consistency of this ordering implies there is no corresponding cosmological boundary in the comparable future. So given the Big Bang as our best explanation of the obvious features of our universe, the evident direction of time is essentially no different from the spatial temperature gradient you feel when standing next to a cold window. In neither case is space or time asymmetric; it's just a matter of where you are located relative to the nearest boundary constraint. On the classical scales that we typically observe, we don't get any new information from the future boundary that we didn't already have in the past. If this held true at all scales, the Lagrangian Schema would be in trouble, because the future boundary wouldn't really matter at all. But in fact it isn't true when we get down to the level of quantum uncertainty: Microscopic future details cannot be deduced from only the past. And the quantum scale is where the real power of the Lagrangian Schema becomes evident. Quantum entanglement is a concept that defies Newtonian Schema explanations. Other quantum phenomena may also turn out to have an underlying simpler account, an explanation that could reside in ordinary space and time without any action at a distance. Maybe the probabilities in quantum theory will turn out to be like probabilities in every other scientific discipline: simply due to parameters that we don't know (because some of them lie in the future). (5)

Any such line of research will certainly raise significant questions. If the future can constrain the past, why are the consequences confined to the quantum level? Why can't we use quantum phenomena to send messages into the past? At what scales does the cosmological boundary dominate, and how exactly should we generalize Lagrangian-based approaches to make this all work? Addressing such questions might not just help physics; it might also inform how we see ourselves as part of our four-dimensional universe. For example, according to the Lagrangian Schema, microscopic details in any region are not entirely constrained by the past boundary. On the level of the atoms in your brain, there are relevant but unknown constraints in the future. Perhaps this line of thinking could even help to explain our sense of free will, by providing a new sense in which the future is not purely determined by what has come before. Certainly it would require us to rethink the idea that there is a neat and objective difference between a fixed past and an open future. Almost every time science has found a deeper, simpler, more satisfying explanation, it has led to a cascade of further scientific advances. So if there is a deeper account of quantum phenomena that we haven't yet grasped, mastering that deeper level could lead to crucial advances in the vast array of technologies that utilize quantum effects. Mistaken instincts have certainly slowed past physics advances, and our instincts about time are as strong as they come. But there is a clear path forward to explaining some of nature's deepest mysteries, if we can simply make ourselves look to the future. (6) *Adated from Nautilus.*

Exercise III.

Find paragraphs, dealing with the following:

four-dimensional, essentially, subjective, tension, invoke, framework, instinct, cascade, parameter, inexplicable

Exercise IV.

Fill in the gaps.

1. It's a **…………..** sound, almost like the noise a smoke detector makes before it dies.
2. That's because, **………** speaking, I have a pretty healthy diet and lifestyle.
3. Any costs that rise above the cap would be met by the state under such a **………...**
4. No government has the right to use the law to **……….** falsehoods on its citizens.
5. Don't worry, this sort of disturbing phenomena is a comfortably rare **…………..**
6. The last such **……….** upheaval was in the 1980s, before I went to law school.
7. As a rule, it is a pity to let armed groups **………..** authority and get away with it.
8. Infected people carry thousands of organisms, many of which **……..** in the brain.
9. We can only be grateful Telstra chose to **………** its thoughts to just 25 pages.

10. Where they do, private costs and benefits ……… from public costs and benefits.

Exercise V.

Make up sentences of your own with the following word combinations: to run in one direction (1), to run in opposite directions (1),to take something seriously (1), all at once (1), to the best of our knowledge, as strong/good/tough as they come, taken together (4), vice-versa (4), in reverse (4), to raise significant questions (6)

(2), (2), (2), (2), (2)

Exercise VI.

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

1. In Einstein's general theory of relativity, there's conceptual distinction between the past and the future, let alone an objective line of "now."
2. As much as physicists talk about time symmetry, they do not allow themselves to invoke the past.
3. Some researchers even go so far as to think of the universe as the output of a forward-running computer program, a picture that is a natural extension of this schema.
4. Even though our view of time has changed dramatically in the last century, the Newtonian Schema has somehow endured as our most popular physics framework.
5. But imposing old Newtonian Schema thinking on new quantum-scale phenomena has landed us in situations with no good explanations whatsoever.
6. Much better explanations become available if we are willing to take the future into account as well as the past.

7. Newtonian-style thinking is inherently capable of such time-neutral explanations.
8. Computer programs run in only one direction, and trying to combine two programs running in one direction leads to the paradoxical morass of poorly plotted time-travel movies.
9. In order to treat the future as seriously as we treat the past, we don't clearly need an alternative to the Newtonian Schema.
10. The first step toward understanding the Lagrangian Schema is to fully set aside the temporal "flow" of Newtonian thinking.

Exercise VII .

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

weird	to refuse to obey or to do something in the usual or expected way
scheme	to keep someone or something within limits
to impose	to find a way in which two situations or beliefs that are opposed to each other can agree and exist together
to yield	very strange and unusual, unexpected, or not natural
even-handed	a plan for doing or organizing something
to invoke	with two halves, sides, or parts that are not exactly the same in shape and size
defy	to officially force a rule, tax, punishment, etc.
to reconcile	to supply or produce something
to confine	treating everyone fairly and equally
asymmetry	to cause something to be used; bring into effect

ExerciseVIII.

Summarize the article “To Understand Your Past, Look to Your Future”.

Part 2

Exercise I.

Identify the part of speech the words belong to.

occurrence, crucially, rebuttal, entirety, comparable, gradient, holistically, inherently, foreknowledge, plausibility

Exercise II .

Form verbs from the following words:

explanation (2), action (3), decisive (3), applicability (3), illumination (3), distribution (3)

Exercise III.

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

alternative (1), fundamental (2), law (2), conflict (2), allow (2), primary (2), solve (2), extension (2), view (2), change (2), purely (2)

Exercise IV .

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

distinction (2), forward (2), accept (2), direct (2), symmetry (2), future (2), available (2), incapable (2), seriously (2), aware (2)

Exercise V.

Match the words to make word combinations:

relevant	movies
least-action	frames
light	trick

flash	programs
four-dimensional	rays
time-travel	bulb
computer	parameters
flash	principle
mathematical	universe
sequential	photograph

3. Physics's pangolin

Part 1

Exercise I.

Say what Russian words help to guess the meaning of the following words: categories, individual, schizophrenic, synthesis, absurd, discipline, march, status, myth, religion.

Exercise II

Make sure you know the following words and word combinations.
to beset, riven, to rive, to swirl, slit, to proliferate, daring, parse, filing, hitherto, to burgeon, to corral, premise, mire, to extricate

Physics's pangolin

Trying to resolve the stubborn paradoxes of their field, physicists craft ever more mind-boggling visions of reality (1)

Theoretical physics is beset by a paradox that remains as mysterious today as it was a century ago: at the subatomic level things are simultaneously particles and waves. Subatomic reality appears to us as two different categories of being. But there is another paradox in play. Physics itself is riven by the competing frameworks of quantum theory and general relativity. When it comes to the very big and the extremely small, physical reality appears to be not one thing, but two. Where quantum theory describes the subatomic realm as a domain of individual quanta, all jitterbug and jumps, general relativity depicts happenings on the cosmological scale as a stately waltz of smooth flowing space-time.

Physicists are deeply aware of the schizophrenic nature of their science and long to find a synthesis, or unification. Such is the goal of a so-called 'theory of everything'. However, to non-physicists, these competing lines of thought, and the paradoxes they entrain, can seem not just bewildering but absurd. No other scientific discipline elicits such contradictory responses. On the one hand, then, physics is taken to be a march toward an ultimate understanding of reality; on the other, it is seen as no different in status to the understandings handed down to us by myth or religion. Quite apart from the physical tensions that exist between them, relativity and quantum theory each pose philosophical problems. Are space and time fundamental qualities of the universe, as general relativity suggests, or are they byproducts of something even more basic, something that might arise from a quantum process? Looking at quantum mechanics, huge debates swirl around the simplest situations. Does the universe split into multiple copies of itself every time an electron changes orbit in an atom, or every time a photon of light passes through a slit? Some say yes, others say absolutely not. Theoretical physicists can't even agree on what the celebrated waves of quantum theory mean Are the waves physically real, or are they just mathematical representations of probability distributions? Are the 'particles' guided by the 'waves'? And, if so, how? The dilemma posed by wave-particle duality is the tip of an iceberg on which many ships have been broken and wrecked. Undeterred, some theoretical physicists are resorting to increasingly bold measures in their attempts to resolve these dilemmas. Take the 'many-worlds' interpretation of quantum theory, which proposes that every time a subatomic action takes place the universe splits into multiple, slightly different, copies of itself, with each new 'world' representing one of the possible outcomes. (2)

When this idea was first proposed in 1957 by the American physicist Hugh Everett, it was considered an almost lunatic-fringe position. Even 20 years later, when I was a physics student, many of my professors thought it was a kind of madness to go down this path. Yet in recent years the many-worlds position has become mainstream. The idea of ever-proliferating array of universes has been given further credence as a result of being taken up by string theorists, who argue that every mathematically possible version of the string theory equations corresponds to an actually existing universe, and estimate that there are 10 to the power of 500 different possibilities. To put this in perspective: physicists believe that in our universe there are approximately 10 to the power of 80 subatomic particles. In string cosmology, the totality of existing universes exceeds the number of particles in our universe by more than 400 orders of magnitude. Nothing in our experience compares to this unimaginably vast number. Every universe that can be mathematically imagined within the string parameters — including ones in which you exist with a tail, to use an example given by the American string theorist Brian Greene — is said to be manifest somewhere in a vast supra-spatial array 'beyond' the space-time bubble of our own universe. What is so daring here is that the equations are taken to be the fundamental reality. The fact that the mathematics allows for gazillions of variations is seen to be evidence for gazillions of actual worlds. At the very least, it raises serious questions about the relationship between our mathematical models of reality, and reality itself. While it is true that in the history of physics many important discoveries have emerged from revelations within equations — Paul Dirac's formulation for antimatter being perhaps the most famous example — one does not need to be a relativist to feel sceptical about the idea that the only way forward now is to accept an infinite cosmic 'landscape' of universes that embrace every conceivable version of world history, including those in which the Middle Ages never ended or Hitler won. (3)

It is hard to see ways out of this tunnel, but in the work of the British anthropologist Mary Douglas I believe we can find a tool for thinking about some of these questions. Her book ends with a far-reaching thesis about human language and the limits of all language systems. Given that physics is couched in the language-system of mathematics, her argument is worth considering here. In a nutshell, Douglas notes that all languages parse the world into categories; in English, for instance, we call some things 'mammals' and other things 'lizards' and have no trouble recognising the two separate groups. Yet there are some things that do not fit neatly into either category: the pangolin, for example. We all tend to think that our categories of understanding are necessarily real. Yet when we have them, she says, 'we have to either face the fact that some realities elude them, or else blind ourselves to the inadequacy of the concepts'. If we take this analysis seriously, then, in Douglas' terms, might it be that particle-waves are our pangolins? Perhaps what we are encountering here is not so much the edge of reality, but the limits of the physicists' category system. Physics is grounded in the language of mathematics. It is a so-called 'hard' science, a term meant to imply that physics is unfuzzy —

unlike, say, biology whose classification systems have always been disputed. Based in mathematics, the classifications of physicists are supposed to have a rigour that other sciences lack. According to Galileo Galilei, nature was ‘a book’ that had been written by God, who had used the language of mathematics because it was seen to be timeless. While modern physics is no longer formally tied to Christian faith, its long association with religion lingers in the many references that physicists continue to make about ‘the mind of God’. In order to articulate a more nuanced conception of what physics is, we need to explain how the mathematics ‘arises’ in the world, in ways other than assuming that it was put there there by some kind of transcendent being or process. To approach this question dispassionately, it is necessary to focus on the creation of physics as a science. When we say that ‘mathematics is the language of physics’, we mean that physicists consciously comb the world for patterns that are mathematically describable; these patterns are our ‘laws of nature’. Since mathematical patterns proceed from numbers, much of the physicist’s task involves finding ways to extract numbers from physical phenomena, thus giving us the raw material for our quest for patterns or ‘laws’. Stop for a moment and take a look around you. What do you think can be quantified? What colours and forms present themselves to your eye? Is the room bright or dark? Does the air feel hot or cold? What odours do you smell? Which, if any, of these qualities of experience might be measured? To a large degree, progress in physics has been made by slowly extending the range of answers. Take colour. In the late 19th century physicists discovered that each colour in the rainbow, when diffracted through a prism, corresponds to a different wavelength of light. Colour can be correlated with numbers — both the wavelength and frequency of an electromagnetic wave. Here we have one half of our duality: the wave. The discovery of electromagnetic waves was in fact one of the great triumphs of the quantification project. In the 1820s, Michael Faraday noticed that, if he sprinkled iron filings around a magnet, the fragments would spontaneously assemble into a pattern of lines that, he conjectured, were caused by a 'magnetic field'. Invisible fields smacked of magic. Yet, later in the 19th century, James Clerk Maxwell showed that magnetic and electric fields were linked by a precise set of equations — today known as Maxwell's Laws — that enabled him to predict the existence of radio waves. The quantification of these hitherto unsuspected aspects of our world — these hidden invisible 'fields' — has led to the whole gamut of modern telecommunications on which so much of modern life is now staged. (4)

Turning to the other side of our duality – the particle – with a burgeoning array of electrical and magnetic equipment, physicists in the late 19th and early 20th centuries began to probe matter. They discovered that atoms were composed from parts holding positive and negative charge. The negative electrons, were found to revolve around a positive nucleus in pairs, with each member of the pair in a slightly different state, or 'spin'. Spin turns out to be a fundamental quality of the subatomic realm. Matter particles, such as electrons, have a spin value of one half. Particles of light, or photons, have a spin value of one. In short, one of the qualities that distinguishes 'matter' from 'energy' is the spin value of its particles. We have seen how light acts like a wave, yet experiments over the past century have shown that under many conditions it behaves instead like a stream of particles. In the photoelectric effect (the explanation of which won Albert Einstein his Nobel Prize in 1921), individual photons knock electrons out of their atomic orbits. In Thomas Young's double-slit experiment of 1805, light behaves simultaneously like waves and particles. Here, a stream of detectably separate photons are mysteriously guided by a wave whose effect becomes manifest over a long period of time. What is the source of this wave and how does it influence billions of isolated photons separated by great stretches of time and space? The late Nobel laureate Richard Feynman — a pioneer of quantum field theory — stated in 1965 that the double-slit experiment lay at 'the heart of quantum mechanics'. Indeed, physicists have been debating how to interpret its proof of light's duality for the past 200 years. Just as waves of light sometimes behave like particles of matter, particles of matter can sometimes behave like waves. In many situations, electrons are clearly particles: we fire them from electron guns inside the cathode-ray tubes of old-fashioned TV sets and each electron that hits the screen causes a tiny phosphor to glow. Yet, in orbiting around atoms, electrons behave like three-dimensional waves. Electron microscopes put the wave-quality of these particles to work; here, in effect, they act like short-wavelengths of light. (5)

Wave-particle duality is a core feature of our world. Or rather, we should say, it is a core feature of our mathematical descriptions of our world. But what is critical to note here is that however ambiguous our images, the universe itself remains whole. Instrumentally speaking, the project of quantification has led physicists to powerful insights and practical gain: the computer on which you are reading this article would not exist if physicists hadn’t discovered the equations that describe the band-gaps in semiconducting materials. Microchips, plasma screens and cellphones are all byproducts of quantification and, every decade, physicists identify new qualities of our world that are amendable to measurement, leading to new technological possibilities. No language other than maths is capable of expressing interactions between particle spin and electromagnetic field strength. The physicists, with their equations, have shown us new dimensions of our world. That said, we should be wary of claims about ultimate truth. The qualities that are amenable to quantification are those that are shared. All electrons are essentially the same: given a set of physical circumstances, every electron will behave like any other. But humans are not like this, it is our individuality that makes us human. Douglas’s point about attempting to corral experience into logical categories of non-contradiction has obvious application to physics, particularly to recent work on the interface between quantum theory and relativity. One of the most mysterious findings of quantum science is that two or more subatomic particles can be ‘entangled’. Once particles are entangled, what we do to one immediately affects the other, even if the particles are hundreds of kilometres apart. Yet this contradicts a basic premise of special relativity, which states that no signal can travel faster than the speed of light. Entanglement suggests that either quantum theory or special relativity, or both, will have to be rethought. More challenging still, consider what might happen if we tried to send two entangled photons to two separate satellites orbiting in space, as a team of Chinese physicists, working with the entanglement theorist Anton Zeilinger, is currently hoping to do. Here the situation is compounded by the fact that what happens in near-Earth orbit is affected by both special and general relativity. The details are complex, but suffice it to say that special relativity suggests that the motion of the satellites will cause time to appear to slow down, while the effect of the weaker gravitational field in space should cause time to speed up. Given this, it is impossible to say which of the photons would be received first at which satellite. To an observer on the ground, both photons should appear to arrive at the same time. Yet to an observer on satellite one, the photon at satellite two should appear to arrive first, while to an observer on satellite two the photon at satellite one should appear to arrive first. We are in a mire of contradiction and no one knows what would in fact happen here. If the Chinese experiment goes ahead, we might find that some radical new physics is required. You will notice that the ambiguity in these examples focuses on the issue of time — as do many paradoxes relating to relativity and quantum theory. Time indeed is a huge conundrum throughout physics, and paradoxes surround it at many levels of being. The American physicist Lee Smolin argues that for 400 years physicists have been thinking about time in ways that are fundamentally at odds with human experience and therefore wrong. In order to extricate ourselves from some of the deepest paradoxes in physics, he says, its very foundations must be reconceived: the idea that nature consists fundamentally of atoms with immutable properties moving through unchanging space, guided by timeless laws, underlies a view in which time is absent or diminished. This view has been the basis for centuries of progress in science, but its usefulness for fundamental physics and cosmology has come to an end. In order to resolve contradictions between how physicists describe time and how we experience time, Smolin says physicists must abandon the notion of time as an unchanging ideal and embrace an evolutionary concept of natural laws. This is radical stuff, but at the heart of his book is a worthy idea: Smolin is against the reflexive reification of equations. As our mathematical descriptions of time are so starkly in conflict with our experience of time, it is our descriptions that will have to change, he says. In the early days of quantum mechanics, Niels Bohr liked to say that we might never know what 'reality' is, calling the universe 'a great smoky dragon', and claiming that all we could do with our science was to create ever more predictive models. Will we accept, at some point, that there are limits to the quantification project? Or will we be drawn into ever more complex and expensive quests — CERN mark two, Hubble, the sequel — as we try to root out every lingering paradox? In Douglas's view, ambiguity is an inherent feature of language that we must face up to, at some point, or drive ourselves into distraction. (6)

Adapted from Aeon.

Exercise III.

Find paragraphs, dealing with the following: lament, array, multifaceted, simultaneously, domain, schizophrenic, entrain, contradictory, ultimate, byproduct

Exercise IV.

Fill in the gaps.

1. Wannstedt isn't being ………….., he is just doing what has always worked for him.

2. Even after eight months, Riley says the flood continues to ………… people's lives.

3. She said it wasn't possible to ………… yet how much emissions would be reduced.

4. As with other psychological exams, findings are based on the ………. of answers.

5. Our only definite reptile sighting was of a living one, a scuttling sand …………….

6. Run knife around inner ………… of ramekin, and turn out the pate onto serving pate.

7. This is yet another sitcom based on the ……….. of the Emasculated American Man.

8. The only ………… is in how far they take it, which is left to our imagination.

9. Donovan used his speed to ………… linebacker Starr Fuimaono and get to the corner.

10. The third ………… indicated that the animal could choose to go to either location.

Exercise V .

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

to be aware of (1), to hand down to (1), the tip of an iceberg (1), to resolve these dilemmas (1), to go down this path (2), to put this in perspective (2), to root out (6), to face up to (6), at some point (6)

Exercise VI.

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

1. Trying to resolve the stubborn paradoxes of their field, physicists craft ever less mind-boggling visions of reality.
2. Practical physics is beset by a paradox that remains as mysterious today as it was a century ago: at the subatomic level things are simultaneously particles and waves.
3. Atomic reality appears to us as two different categories of being.
4. Physics itself is riven by the competing frameworks of quantum theory and general relativity.
5. When it comes to the very big and the extremely small, physical reality appears to be one thing.
6. Physicists are not deeply aware of the schizophrenic nature of their science and long to find a synthesis, or unification.
7. However, to physicists, these competing lines of thought, and the paradoxes they entrain, can seem not just bewildering but absurd.
8. No other scientific discipline elicits such contradictory responses. On the one hand, then, physics is taken to be a march toward an ultimate understanding of reality; on the other, it is seen as no different in status to the understandings handed down to us by myth or religion.
9. Quite apart from the physical tensions that exist between them, relativity and quantum theory each pose philosophical problems.

10. Theoretical physicists can agree on what the celebrated waves of quantum theory mean.

Exercise VII .

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

stubborn	the distance between two waves of energy
to estimate	not succeed in achieving it
lizard	the fact that people are made to follow rules in a very severe way
to elude	to destroy or badly damage somethi ng
edge	a small reptile that has a long body, four short legs, a long tail, and thick skin
odour	to confuse someone
wreck	a smell
wavelength	opposed to change or suggestion
rigour	to guess the size, cost, etc.,
to bewilder	the outer or furthest point of something

Exercise VIII.

Summarize the article “Physics’s pangolin”

Part 2

Exercise I.

Identify the part of speech the words belong to.

totality, spatial, gazzilion, revelation, conceivable, transcendent, amenable, ambiguity, immutable, stately

Exercise II .

Form adjectives from the following words: compete (1), extremely (2), deeply (2), absolutely (2), duality (2), power (3), approximately (3), totality (3) unimaginably (3), mathematically (3)

Exercise III.

Find synonyms to the following words. Translate them into Russian: stubborn (1), paradoxes (1), vision (1), remain (2), describe (2), depict (2), synthesis (2), unification (2), goal (2), discipline (2)

Exercise IV.

Find antonyms to the following words. Translate them into Russian: reality (1), individual (2), aware (2), find (2), absurd (2), contradictory (2), agree (2), physically (2), real (2), vast (3)

Exercise V.

Match the words to make word combinations:

contradictory	microscopes
three-dimensional	fringe
electron	responses
electron	duality
lunatic	tubes

cathode-ray	waves
subatomic	guns
cathode-ray	tube
physical	reality
wave-particle	tensions

4. Too Many Worlds

Part 1

Exercise I.

Say what Russian words help to guess the meaning of the following words: parallel, conference, theme, personal, colleagues, interpretation, publicity, criticisms, logically, experts

Exercise II

Make sure you know the following words and word combination placid, hunch, smear, to shrug, fudge, sleight, myriad, deem, corollary, to demur

Too many worlds

Nobody knows what happens inside quantum experiments. So why are some so keen to believe in parallel universes? (1)

Participants at a conference on the placid shore of Lake Traunsee in Austria were polled on what they thought the meeting was about. You might imagine that this question would have been settled in advance, but since the broad theme was quantum theory, perhaps a degree of uncertainty was to be expected. The title of the conference was 'Quantum Physics and the Nature of Reality'. The poll, completed by 33 of the participating physicists, mathematicians and philosophers, posed a range of unresolved questions about the relationship between those two things, one of which was: 'What is your favourite interpretation of quantum mechanics?' The word 'favourite' speaks volumes. Isn't science supposed to be decided by experiment and observation, free from personal preferences? But experiments in quantum physics have been obstinately silent on what itmeans. All we can do is develop hunches, intuitions and, yes, cherished ideas. Of these, the survey offered no fewer than 11 to choose from (as well as ‘other’ and ‘none’). The most popular (supported by 42 per cent of the very small sample) was basically the

view put forward by Niels Bohr, Werner Heisenberg and their colleagues in the early days of quantum theory. Today it is known as the Copenhagen Interpretation. More on that below. You might not recognise most of the other alternatives, such as QBism, Relational Quantum Mechanics. Maybe you haven’t heard of the Copenhagen Interpretation either. But in third place (18 per cent) was the Many Worlds Interpretation (MWI), and I suspect you do know something about that, since the MWI is the one with all the publicity. It tells us that we have multiple selves, living other lives in other universes, quite possibly doing all the things that we dream of but will never achieve (or never dare). Who could resist such an idea? Yet resist we should. We should resist not just because MWI is unlikely to be true, or even because, since no one knows how to test it, the idea is perhaps not truly scientific at all. Those are valid criticisms, but the main reason we should hold out is that it is incoherent, both philosophically and logically. And yet, it attracts both publicity and extraordinarily confident endorsement. Why? To understand that, we need to see why, more than 100 years after quantum theory was first conceived, experts are still gathering to debate what it means. (2)

Despite its shaky foundations, quantum mechanics is extraordinarily successful. In fact you'd be hard pushed to find a more successful scientific theory. It can predict all kinds of phenomena with amazing precision, from the colours of grass and sky to the transparency of glass, the way enzymes work and how the Sun shines.This is because it is largely a technique: a set of procedures for calculating what properties substances ought to have based on the positions and energies of their constituent subatomic particles. The calculations are hard. For anything more complicated than a hydrogen atom, it is necessary to make simplifications and approximations. But we can do that very reliably – and so the vast majority of physicists, chemists and engineers who use quantum theory today don't need to go to conferences on the nature of reality. They can do their job perfectly well if, in the words of the physicist David Mermin, they just 'shut up and calculate'. It is true, though, that the equations seem to insist on some strange things. They imply that very small entities such as atoms and subatomic particles can be in several places at the same time. A single electron can seem to pass through two holes at once, interfering with its own motion as if it was a wave. What's more, we can't know everything about a particle at the same time: Heisenberg's uncertainty principle forbids such perfect knowledge. And two particles can seem to affect one another instantly across immense tracts of space, in apparent violation of Albert Einstein's theory of special relativity. Quantum scientists, for the most part, just accept such things. They are no longer especially controversial. What really divides opinion is the fact that the theory seems to do away with the idea of an objective reality that we can study 'from the outside'.

Such a notion has been central to science from its beginnings – and yet quantum mechanics insists that we can't make a measurement without influencing what we measure. (3)

The most widely used form of quantum maths, devised by Erwin Schrödinger in the 1920s, involves an abstract object called a wavefunction. This wavefunction expresses all that can be known about a quantum object, such as a particle. But it doesn't tell you what properties the object has. Instead, it enumerates all the possible properties it could have, along with their relative probabilities. Which of these possibilities is real? Is an electron here or there? We can find out by looking. But here's the thing: quantum mechanics seems to be telling us that the very act of looking – of making a measurement – forces the universe to make that decision, at random. Before we look, there are only probabilities. When we open the box, those probabilities give way to a single, determinate actuality: something conventionally called collapse of the wavefunction. But wavefunction collapse isn't actually part of the theory: it has to be put in by hand, as it were. That's rightly considered to be most unsatisfactory. We are left with what's called the Measurement Problem, which really comes down to this: between the rainbow-smear of probabilities in our equations and the matter-of-fact determinacy of everything we can actually measure, what on Earth is going on? Hence the menu of options at the Traunsee conference. The dominant view, the Copenhagen Interpretation, just shrugs and accepts wavefunction collapse as an additional ingredient of the theory, a clumsy fudge that we don't understand but which we seem forced to make do with, at least for now. Another view is that the transition from probability to actuality isn't just a mathematical sleight-of-hand but is in fact a physical process, a little like the radioactive decay of an atom. That's the Objective Collapse interpretation, and among its advocates is Roger Penrose, who suspects that it might involve gravity. And then there's the Many Worlds option – though its proponents, who include heavyweights such as Stephen Hawking and the Nobel laureate Frank Wilczek, are oddly reluctant to concede that their preferred view admits of any rivals. As far as they are concerned, the MWI is the only way of taking quantum theory seriously. It 'should be (but is not) uncontroversial', according to Wilczek. The idea first appeared in the 1957 doctoral thesis of the US physicist Hugh Everett. He asked why, instead of fretting about the cumbersome nature of wavefunction collapse, we don't just do away with it. What if this collapse is just an illusion, and all the possibilities announced in the wavefunction have a physical reality? Perhaps when we make a measurement we see only one of those realities, yet the others have a separate existence, too. An existence where? This is where the many worlds come in. Everett himself never used that term, but in the 1970s the physicist Bryce DeWitt started championing his proposals, and it was DeWitt who argued that the alternative outcomes of the experiment must exist in a parallel reality: another world. You measure the path of an electron, and in this world it seems to go this way, but in another world it went that way. That requires a parallel, identical apparatus for the electron to traverse. More – it requires a parallel you to measure it. Once begun, this process of fabrication has no end: you have to build an entire parallel universe around that one electron, identical in all respects except where the electron went. You avoid the complication of wavefunction collapse, but at the expense of making another universe. This picture really gets extravagant when you appreciate what a measurement is. In one view, any interaction between one quantum entity and another – a photon of light bouncing off an atom – can produce alternative outcomes, and so demands parallel universes. As DeWitt put it: 'every quantum transition taking place on every star, in every galaxy, in every remote corner of the universe is splitting our local world on earth into myriads of copies'. Recall that this profusion is deemed necessary only because we don't yet understand wavefunction collapse. 'If you prefer a simple and purely mathematical theory, then you – like me – are stuck with the many-worlds interpretation,' claims one of the view's most prominent popularisers, the MIT physicist Max Tegmark. That would be easier to swallow if the 'mathematical simplicity' were not so cheaply bought. The corollary of Everett's proposal is that there is in fact just a single wavefunction for the entire universe. The 'simple maths' comes from representing this universal wavefunction as the symbol Ψ: allegedly a complete description of everything that is or ever was, including the stuff we don't yet understand. And Many Worlders are oddly evasive about specifying exactly what constitutes a 'measurement' or 'experiment' that induces the splitting of Ψ into multiple worlds. You might sense some issues being swept under the carpet here. (4)

But let's stick with it. In the 'multiverse' of the Many Worlds view, says Tegmark, 'all possible states exist at every instant. The act of making a decision – a 'decision' here being interchangeable with an experiment or measurement – causes a person to split into multiple copies.' Brian Greene, another prominent MWI advocate, tells us gleefully that ‘each copy is you’.Each of these individuals has its own consciousness, and so each believes he or she is ‘you’ – but the real ‘you’ is their sum total. This means that Greene and Tegmark don’t support the MWI at all – it’s only these particular copies (and presumably some others) who do. ‘Listen to me, not them!’ Tegmark might reply. But don’t they all say that? Compared with these problems, the difficulty of testing the MWI experimentally (which would seem necessary if it is to be considered truly scientific) is a small matter. But this is (speaking as an ex-physicist) very much a physicist’s blind spot: a failure to recognise – or perhaps to care – that problems arising at a level beyond that of the fundamental, abstract theory can be anything more than a minor inconvenience. Until Many Worlders can take seriously the philosophical implications of their vision, it’s not clear why their colleagues, or the rest of us, should demur from the judgment of the philosopher of science Robert Crease that the MWI is ‘one of the most implausible and unrealistic ideas in the history of science’. Here, after all, is a theory that seems to allow everything conceivable to happen. (5)

Adapted from Aeon.

Exercise III.

Find paragraphs, dealing with the following: placid, volume, logically, valid, hunches, endorsement, shaky, experts, precision, interfering

Exercise IV.

Fill in the gaps.

1. Keep commercial products on hand that use **……….** action to break down the smell.

2. While these values may appear exact, they're actually an **……….**, at best.

3. Efforts to test the **…………** of the findings have produced troubling results.

4. For your children, divorce is an **…………** issue they have had no preparation for.

5. When the show started, only friends, family and a few **…….** strangers listened.

6. In **…………** the ground work for the deal had been laid almost a month earlier.

7. For beginners, ……….. varieties of cherry tomatoes may be easiest.

8. Florida, like many of America's biggest states, can be frustrating to **……...**

9. That's why I always create that **………** between me as a person and the character.

10. The dog's head was **…………**, but Farrell and another officer were able to free him.

Exercise V .

Make up sentences of your own with the following word combinations: be keen to (1), to poll on (1), settled in advance (1), put forward by(1), with all the publicity (1), to do away (3), at random (3), collapse of the wave function (3), as it were (3), to speak volumes

<u>Exercise VI</u>.

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

1. Nobody knows what happens inside quantum experiments.
2. Despite its shaky foundations, quantum mechanics is extraordinarily successful.
3. What's more, we can't know everything about a particle at the same time: Heisenberg's certainty principle forbids such perfect knowledge.
4. And two particles can not seem to affect one another instantly across immense tracts of space, in apparent violation of Albert Einstein's theory of special relativity.
5. The most widely used form of quantum maths, devised by Erwin Schrödinger in the 1920s, involves an abstract object called a wavefunction.
6. This wavefunction expresses all that can be known about a quantum object, such as a particle.
7. Quantum mechanics seems to be telling us that the very act of looking – of making a measurement – forces the universe to make that decision, at random.
8. Wavefunction collapse is actually part of the theory: it has to be put in by hand, as it were.
9. In the 1970s the physicist Bryce DeWitt started championing his proposals, and it was DeWitt who argued that the alternative outcomes of the experiment must exist in a parallel reality: another world.
10. The corollary of Everett's proposal is that there is in fact not just a single wavefunction for the entire universe.

<u>Exercise VII</u> .

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

enzyme	not expressed in a way that can be understood, or not able to talk clearly
obstinate	to cause something to happen
immense	an obstinate thing or problem is difficult to deal with, remove, or defeat
to devise	difficult to do or manage and taking a lot of time and effort
to induce	any of a group of chemical substances that are produced by living cells and which cause particular chemical reactions to happen
stuck	a study in which people are asked for their opinions about a subject or person
cumbersome	extremely large in size or degree
to traverse	to invent something, esp. with intelligence or imagination
poll	unable to move from a particular positionor place,

	or unable to change a situation:
incoherent	to move or travel through an area

Exercise VIII.

Summarize the article "Too many worlds".

Part 2

Exercise I.

Identify the part of speech the words belong to.

endorsement, approximation, reliability, actuality, determinate, fusion, evasive, presumably, gleefully, allegedly

Exercise II .

Form adverbs from the following words:

experiment (1), uncertainty (2), complete (2), alternative (2), personal (2), silent (2), confident (2), successful (3), approximation (3), perfect (3)

Exercise III.

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

parallel (1), poll (2), imagine (2), expect (2), title (2), participate (2), range (2), favourite (2), interpretation (2), sample (2)

Exercise IV.

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

inside (1), broad (2), unresolved (2), free (2), popular (2), recognise (2), resist (2), unlikely (2), forbid (3), transparency (3)

Exercise V.

Match the words to make word combinations:

matter-of-fact	atom
unresolved	collapse
Nobel	preferences
hydrogen	laureate
personal	questions
wavefunction	collapse
blind	experiments
parallel	determinacy
quantum	spot
objective	universes

SUPPLEMENTARY READING

1. Famous Experiment Dooms Alternative to Quantum Weirdness

Oil droplets guided by "pilot waves" have failed to reproduce the results of the quantum double-slit experiment, crushing a century-old dream that there exists a single, concrete reality.

In 2005, a student working in the fluid physicist Yves Couder's laboratory in Paris discovered by chance that tiny oil droplets bounced when plopped onto the surface of a vibrating oil bath. Moreover, as the droplets bounced, they started to bunny-hop around the liquid's surface. Couder soon figured out that the droplets were "surfing on their own wave," as he put it — kicking up the wave as they bounced and then getting propelled around by the slanted contours of the wave.

As he watched the surfing droplets, Couder realized that they exactly embodied an early, largely forgotten vision of the quantum world devised by the French physicist Louis de Broglie.

A century ago, de Broglie refused to give up on a classical understanding of reality even as the unsettling outcomes of the first particle experiments suggested to most physicists that reality, at the quantum scale, is not as it seems. The standard "Copenhagen interpretation" of quantum mechanics, originated at that time by the Danish physicist Niels Bohr, broke with the past by declaring that nothing at the quantum scale is "real" until it is observed. Facts on the ground, like particles' locations, are mere matters of chance, defined by a spread-out probability wave, until the moment of measurement, when the wave mysteriously collapses to a point, the particle hops to, and a single reality sets in. In the 1920s, Bohr persuaded most of his contemporaries to embrace the weirdness of a probabilistic universe, the inherent fuzziness of nature, and the puzzling wave-particle duality of all things.

But some physicists objected, Albert Einstein and de Broglie among them. Einstein doubted that God "plays dice." De Broglie insisted that everything at the quantum scale was perfectly normal and above-board. He devised a version of quantum theory that treated both the wave and the particle aspects of light, electrons and everything else as entirely tangible. His "pilot-wave" theory envisioned concrete particles, always with definite locations, that are guided through space by real pilot waves — much like the waves propelling Couder's bouncing droplets.

De Broglie couldn't nail down the physical nature of the pilot wave, however, and he struggled to extend his description to more than one particle. At the celebrated 1927 Solvay Conference, a gathering of luminaries to debate the meaning of quantum mechanics, Bohr's more radical views carried the day.

De Broglie's pilot-wave vision of the quantum world was little remembered 78 years later, when the Paris droplets started bouncing. Suddenly, Couder and his colleagues had an "analogue system" for experimentally exploring de Broglie's idea.

Straightaway, they saw the droplets exhibit surprisingly quantum-like behaviors — only traversing certain "quantized" orbits around the center of their liquid baths, for instance, and sometimes randomly jumping between orbits, as electrons do in atoms. There and in bouncing-droplet labs that soon sprang up at the Massachusetts Institute of Technology and elsewhere, droplets were seen to tunnel through barriers and perform other acts previously thought to be uniquely quantum. In reproducing quantum phenomena without any of the mystery, the bouncing-droplet experiments rekindled in some physicists de Broglie's old dream of a reality at the quantum scale that consists of pilot waves and particles instead of probability waves and conundrums. But a series of bouncing-droplet findings since 2015 has crushed this dream. The results indicate that Couder's most striking demonstration of quantum-like phenomena, back in 2006 — "the experiment that got me hooked on this problem," the fluid dynamicist Paul Milewski said — was in error. Repeat runs of the experiment, called the "double-slit experiment," have contradicted Couder's initial results and revealed the double-slit experiment to be the breaking point of both the bouncing-droplet analogy and de Broglie's pilot-wave vision of quantum mechanics.

Improbably, the person who put the irreparable crack in de Broglie's idea is Niels Bohr's grandson, the fluid physicist Tomas Bohr. A professor at the Technical University of Denmark who, as a child, enjoyed puzzling over riddles posed by his grandfather, Tomas Bohr heard about Couder's bouncing-droplet experiments seven years ago and was immediately intrigued. "I felt a genuine interest in trying to see whether you could really get a deterministic quantum mechanics," he said about his decision to enter the fray. Given his family history, he added, “maybe I also felt some obligation. I felt I should really try to see if it was true or not.”

The physicist Richard Feynman called the double-slit experiment “impossible, absolutely impossible, to explain in any classical way,” and said it “has in it the heart of quantum mechanics. In reality, it contains the only mystery.”

In the experiment, particles are shot toward two slits in a barrier, and the ones that pass through the slits hit a sensor some distance away on the other side. Where any one particle ends up is always a surprise, but if you shoot many particles toward the slits, you start to see stripes develop in their detected locations, indicating places where they can and cannot go. The stripy pattern suggests that each particle is actually a wave that encounters the slitted barrier and passes through both slits at once, producing two wavefronts that converge and interfere, cresting in some places and canceling out in between. Each particle materializes in the sensor at the location of one of the crests of this strange probability wave.

Stranger still, when you add a second sensor and detect which slit each particle passes through, the interference stripes disappear, as if the probability wave, known as the wave function, has collapsed. This time, particles pass straight through their chosen slits to either of two spots on the far sensor.

To explain the double-slit experiment, a Copenhagenist will point to quantum uncertainty, arguing that the trajectory of each particle cannot be exactly known and is thus defined only probabilistically, by a wave function. After passing through both slits, as any wave would, and interfering on the other side, the wave function representing the particle’s possible locations is then “collapsed” by the sensor, which somehow selects a single reality from among the possibilities. Questions abound, both scientific and philosophical; Niels Bohr, who tended to answer questions with more questions, welcomed them.

To de Broglie, the double-slit experiment didn’t require an abstract, mysteriously collapsing wave function. Instead, he conceived of a real particle riding on a real pilot wave. The particle passes like driftwood through one slit or the other in the double-slit screen, even as the pilot wave passes through both. On the other side, the particle goes where the two wavefronts of the pilot wave constructively interfere and doesn’t go where they cancel out. De Broglie never actually derived dynamical equations to describe this complicated wave-particle-slit interplay. But with bouncing droplets in hand, Couder and a collaborator, Emmanuel Fort, moved quickly to perform the double-slit experiment, reporting their astonishing results in Physical Review Letters in 2006.

After recording the trajectories of 75 bouncing droplets through a double-slit barrier, Couder and Fort thought they detected rough stripes in the droplets' final locations — an interference-like pattern that seemed as if it could only come from the pilot wave. Double-slit interference, considered "impossible to explain in any classical way," was happening without mystery before everyone's eyes. Drawn by the potential quantum implications, the fluid dynamicist John Bushstarted up a bouncing-droplet lab of his own at MIT and led others to the cause. Tomas Bohr heard Couder talk about his results in 2011 and later discussed the experiments at length with Bush. He teamed up with an experimentalist colleague, Anders Andersen, to study bouncing droplets further. "We really became fascinated with, in particular, the double-slit experiment," Andersen said.

Bohr and Andersen's group in Denmark, Bush's team at MIT, and a team led by the quantum physicist Herman Batelaan at the University of Nebraska all set out to repeat the bouncing-droplet double-slit experiment. After perfecting their experimental setups, getting rid of air currents, and setting oil droplets bouncing on pilot waves toward two slits, none of the teams saw the interference-like pattern reported by Couder and Fort. Droplets went through the slits in almost straight lines, and no stripes appeared. The French pair's earlier mistake is now attributed to noise, faulty methodology and insufficient statistics. "The double-slit experiment, for me — it's a bit of a disappointment," said Milewski, who is the head of the department of mathematical sciences at the University of Bath.

Bush's detailed double-slit studies, published earlier this year, showed no hint of interference, but he still thinks it might be possible to generate an interference pattern with pilot waves when the right combination of parameters is found — the right frequency for the vibrating fluid bath, perhaps, or a necessary addition of noise. Milewski shares this hope. However, in the Denmark group's paper reporting their null double-slit results, Tomas Bohr presented a thought experiment that appears to demolish de Broglie's pilot-wave picture completely.

In this hypothetical "gedanken" version of the double-slit experiment, the particles, before arriving at the slitted barrier, have to pass to one side or the other of a central dividing wall. In standard quantum mechanics, this wall can be very long, and it won't matter, because the wave function representing the possible paths of a particle will simply go both ways around the wall, pass through both slits, and interfere. But in de Broglie's picture, and likewise in the bouncing-droplet experiments, the driving force of the whole operation — the particle — can go only one way or the other, losing contact with the part of the pilot wave that passes to the other side of the wall. Unsustained by the particle or droplet, the wavefront disperses long before reaching its slit, and there's no interference pattern. The Danish researchers verified these arguments with computer simulations.

In explaining his decision to keep studying bouncing droplets, Bush said, "I never liked gedanken experiments. The beauty of this situation is you can actually do the experiment." But the dividing-wall thought experiment highlights, in starkly simple form, the inherent problem with de Broglie's idea. In a quantum reality driven by local interactions between a particle and a pilot wave, you lose the necessary symmetry to produce double-slit interference and other nonlocal quantum phenomena. An ethereal, nonlocal wave function is needed that can travel unimpeded on both sides of any wall. "To get the real quantum mechanical result, it's really important that the possible paths of the particle enter in a democratic way," Tomas Bohr said. But with pilot waves, "since one of these sides in the experiment carries a particle and one doesn't, you'll never get that right. You're breaking this very important symmetry in quantum mechanics."

Experts note that the simplest version of de Broglie's theory was bound to fail. In describing individual particles guided by corresponding pilot waves, de Broglie didn't account for the way multiple interacting particles become "entangled," or defined by a single, joint, nonlocal wave function that keeps their properties correlated even after the particles have traveled light-years apart. Experiments with entangled photons starting in the 1970s proved that quantum mechanics must be nonlocal. A theory of local interactions between a particle and its pilot wave like de Broglie's would need to get a whole lot weirder in the jump from one particle to two to account for nonlocal entanglement.

Until his death in 1987, de Broglie questioned the arguments about nonlocality and entanglement and continued to believe that real pilot waves might somehow stir up the necessary long-distance connections. That improbable dream, shared by some bouncing-droplet experimenters, might have been allowed to stubbornly persist until now, but with pilot waves unable to even generate double-slit interference in the case of single particles, the dream collapses like a scrutinized wave function.

Early on, de Broglie did offer a kind of compromise, a version of his theory that was promulgated again in 1952 by the physicist David Bohm, and which is now known as Bohmian mechanics or de Broglie-Bohm theory. In this picture, there's an abstract wave function that extends through space — an entity that's just as mysterious in this theoretical framework as it is in the Copenhagen interpretation — as well as real particles somewhere in it. Proofs in the 1970s showed that de Broglie-Bohm theory makes exactly the same predictions as standard quantum mechanics. However, with one element of classical reality restored — concrete particles — new mysteries arise, like how or why a mathematical wave function that's spread everywhere in space is bolted in certain places to physical particles. "Quantum mechanics is not less weird from that perspective," Tomas Bohr said. Most physicists agree, but it's really just a matter of taste, since the experimental predictions are identical.

Tomas Bohr attributes his grandfather's certainty that nature is incurably weird at the quantum scale to Niels Bohr's most important physics research: his 1913 calculations of the electronic energy levels of the hydrogen atom. Bohr realized that when electrons jump between orbits, releasing quantized packets of light, there was no mechanical picture of the situation that made sense. He couldn't relate the electrons' energy levels to their rotational motion. Even causality failed, because electrons seemingly know before they jump where they are going to land, in order to emit a photon of the correct energy. "He was probably more aware than most of how weird that whole thing was," Tomas Bohr said. "He was just somehow philosophically inclined in such a way that he was ready to accept that nature was that strange — and most people were not."

In the last few years, Tomas has often wondered what his grandfather would have said about the bouncing-droplet experiments. "I think he would have been very interested," he said, adding with a laugh, "He would probably have been much quicker than me to figure out what he thought about it. But he would have thought it was an ingenious thing, that you could generate such a system, because it's surprisingly close to what de Broglie was talking about." *Adapted from Quanta Magazine.*

2. The retraction war

Scientists seek demigod status, journals want blockbuster results, and retractions are on the rise: is science broken?

On 5 August 2014, a celebrated Japanese scientist was found dead, hanging by his neck at his workplace, his shoes politely removed and placed on the landing of the stairs. Yoshiki Sasai, 52, was a legendary stem-cell expert, widely regarded as an exceptional scientist, who worked at the RIKEN Center for Developmental Biology in Kobe. Seven months before he killed himself, Sasai and colleagues in Japan and Boston announced a stupefying research breakthrough in two papers in Nature. They claimed that ordinary mouse blood cells could be transformed into powerful stem cells – the holy grail of regenerative medicine – by simply bathing them in a mildly acidic solution (called STAP, for stimulus-triggered acquisition of pluripotency).

Almost instantly, the work was called into question. Accusations surfaced in the science blogosphere that images in the papers had been duplicated or altered, and at least eight scientists announced that they were unable to reproduce the experiment. In February 2014, RIKEN launched an internal investigation, and found the 30-year-old lead author, Haruko Obokata, guilty of scientific misconduct (which includes falsification, fabrication, or plagiarism). She had been Sasai's protégé.

In June, Science reported that earlier versions of the STAP work had been rejected by three top journals: Cell, Science and even Nature itself. Sciencequoted RIKEN's report, where peer reviewers raised many troubling questions. 'This is such an extraordinary claim that a very high level of proof is required,' wrote one. Another said the paper was 'simply not credible'. Scientists once again took to the blogosphere asking why Nature had published flawed work and whether journals today value hype over substantive science.

In July, Nature retracted both papers – essentially stamping them with a scarlet letter. Retraction lofted the scandal to worldwide infamy. One evening, when Obokata left work in a taxi, a reporter on a motorcycle started following her. She stopped at a hotel, but was pursued up the escalator and into the bathroom by five journalists, including a cameraman, and sprained her right elbow trying to get away.

Then, in August, Sasai killed himself. This was in spite of the fact that he'd been cleared of fraud, and his share of responsibility was linked to lack of proper oversight. In a suicide note to his family, he wrote that he was 'worn out by the unjust bashing in the mass media'. His brokenhearted family simply said: 'We feel crushed by a deep sorrow… we see nothing but despair.'

That same month, RIKEN also announced it was conducting a second investigation into possible laboratory contamination during the experiments. The institution's reputation was still so damaged that in late October six top administrators volunteered to atone by returning between one and three months of their salary.

Based on this narrative, one might conclude that retraction is a near-perfect guillotine, heartless perhaps, but an alarmingly potent tool for self-correction in science.

That is not the case. The STAP story is a tale of all that's troubled in the scientific enterprise today: scientists seeking demigod status and flying too close to the sun with their claims; journals smitten with a potential blockbuster finding, and overlooking vexing questions ahead of publication; retractions on the rise, entering mainstream awareness, and leaving an entire scientific community frightened of the resulting stigma.

Retraction was meant to be a corrective for any mistakes or occasional misconduct in science but it has, at times, taken on a superhero persona instead. Like Superman, retraction can be too powerful, wiping out whole careers with a single blow. Yet it is also like Clark Kent, so mild it can be ignored while fraudsters continue publishing and receiving grants. The process is so wrought that just 5 per cent of scientific misconduct ever results in retraction, leaving an abundance of error in play to obfuscate the facts.

Scientists are increasingly aware of the amount of bad science out there – the word 'reproducibility' has become a kind of rallying cry for those who would reform science today. How can we ensure that studies are sound and can be reproduced by other scientists in separate labs?

The edifice upon which science is built is self-correction. And self-correction generally works. Scientists make mistakes, and science corrects those mistakes. This happens when results cannot be reproduced, and the original work is found in error. An erratum is issued when errors are relatively minor, and do not invalidate the basic assumptions and conclusions of the study as a whole. A retraction is issued when the study is no longer valid. A retraction withdraws, refutes or reverses the entire scientific finding.

It is the infamous retractions that mesmerise us, of course. The stem-cell scandals – not just STAP, but also the South Korean researcher Hwang Woo-suk, found guilty in 2009 of embezzlement and bioethical violations after making false claims that he had cloned human embryos and generated cloned stem cells. Or the tumble from grace in 2011 of the prominent Dutch social psychologist Diederik Stapel, who faked data on at least 55 papers on topics such as the human tendency to stereotype or discriminate. Or the infamous 1998 paper in The Lancet by the British researcher Andrew Wakefield and others that linked autism and vaccines, and influenced many thousands of parents on both sides of the Atlantic to stop vaccinating their children.

Woo-suk, who bowed to the judgment, was fired, sentenced to a two-year, suspended prison sentence, and barred from further stem-cell research (though he currently works at another institute). Admitting his error, Stapel lost his job and his PhD. Wakefield lost his UK medical licence, though he defends his research to this day. Most retractions are not as notorious, but studies do show that highly cited papers – those eye-catching findings that the scientific community notices – are more likely to be retracted.

Nobody knows exactly when the first retraction appeared, though Galileo is unforgettable for being ordered to recant his theory that the Sun, not the Earth, was at the centre of the Universe. He was placed under house arrest for life. In modern times, retractions began to trickle out in the 1970s, but it wasn't until the late 1990s that the numbers actually started rising.

By the early 2000s, about 30 papers a year were retracted. In 2014, more than 400 retracted papers will be indexed by the Web of Science, an online database of science publications. The many scarlet Rs have triggered soul-searching essays in big-name journals, such as an essay in this October'sNature, suggesting that this surge highlights weaknesses in the scientific endeavour itself.

Retraction matters so much to so many because the scientific enterprise is key to our survival, and so that enterprise must be sound. Retraction is today's 'window into the scientific process', to quote the tagline of one of the most-read blogs in science, Retraction Watch (15 million page views in a mere four years, and 125,000 unique visitors a month). The site's weekly round-up of news and commentary on scientific fraud and error can be as gripping as the latest episode of the TV crime drama CSI.

Yet the system is flawed, in part because retraction carries a terrible sting. In 2008, Joshua Klopper, an endocrinologist at the University of Colorado, briefly considered leaving academia when he was threatened with retraction for reporting an honest error using a misidentified cell culture (a melanoma that was mislabelled as thyroid cancer at labs around the world). He informed the journal, Clinical Cancer Research, and offered an erratum. The editors threatened him with retraction and, according to Klopper, told him that he could file a formal complaint about any other scientists who had published on the same misidentified line. Klopper said: ‘Throw my colleagues under the bus or be the only one slapped with a retraction? This kind of response sets a precedent where nobody who has made a mistake will want to come forward to correct an error.’ Ultimately, the journal relented and, a year later, published an erratum. Klopper told me: ‘It is now one of my prouder moments. I did the right thing.’

If scientists shun retraction, then journal editors willingly follow in their footsteps. ‘Honesty should be a badge of honour for scientists and journals alike,’ says the UK medical editor Elizabeth Wager, who helped draft the Committee on Publication Ethics (COPE) Code of Conduct. But in a review of the trouble with retractions, Wager and a colleague found journal editors reluctant to retract. And even when they do, they might be vague, as a courtesy to the scientists. When in 2011 Wager and her colleague Peter Williams reviewed 312 retractions from 1998 to 2008, they found that some journals actually omit the reason for the retraction, while others use ambiguous wording or euphemisms. ‘It’s incredibly important that the journals make it clear why an article was retracted,’ said Wager.

Journals are no longer stodgy stuffings in the stacks of libraries: they are slick and beautiful, with arresting headlines that garner major media attention. Top journals compete for submissions by top scientists. A metric called the ‘impact factor’ (which reports the average number of citations of articles a journal receives in a given year) is as potent a calling card as the bestseller list or the top 10 hit songs. The largest academic publishing conglomerates boast fat profit margins of 35 per cent. Losing star contributors could rock the empire.

Wager also thinks journals fear retractions because of potential litigation, and for good reason. Lawyering-up is an increasingly common response to the potential damage inflicted by retraction. In July 2014, Guangwen Tang, a rice researcher at Tufts University in Boston, sued both Tufts and the American Journal of Clinical Nutrition, which had announced its intention to retract a paper of hers. She claimed the retraction constituted defamation; the paper still stands.

In October 2014, the Wayne State University pathologist Fazlul Sarkar, recipient of $13 million in grants from the US National Institutes of Health, initiated a lawsuit against a site called PubPeer, which allows anonymous 'post-publication' peer review in the form of comments on a paper. Sometimes such comments have led to retractions. Sarkar's lawsuit claimed he lost a substantial job offer from the University of Mississippi because of questions raised on the site about his work.

The medical scientist Paul Brookes, a whistleblower from the University of Rochester in New York, ran a blog called Science Fraud for six months. The blog cited 274 papers with apparent problems, leading to 16 retractions and 47 corrections. But in 2013, Brookes had to shut it down under threat of lawsuits.

When all is said and done, even retracting a paper might not be enough to kill it. In the world of science, such papers can rise from the grave like zombies, and even receive positive citations. Just take a glance at these depressing numbers: a 1999 study found that 235 papers retracted between 1966 and 1996 received more than 2,000 post-retraction citations but fewer than 8 per cent of those citations acknowledged the retraction. The rest cited the papers as valid.

The study of 1,779 retracted articles published between 1973 and 2010 found that they continue to be cited as sound many years after retraction notices had been issued. A remarkable 2010 study of Stephen Breuning – formerly a psychologist at the University of Pittsburgh, who had 24 of 25 published articles discredited by the National Institutes of Mental Health, and who in 1988 was convicted of scientific misconduct by a federal judge – found that his papers still received positive citations all the way through to 2006. In fact, an upsurge of positive citations for Breuning started in the year 2000 – as if time had washed away the negatives, replenishing a lost reputation. So although citations of a retracted paper, and of scientist's work overall, do fall after a retraction, the scientific literature does not purge itself the way it should.

Even more astonishing are the second lives of some retracted papers. Just as one man's poison is another man's medicine, one journal's retraction can be another's prestigious publication. A 2012 study demonstrating that rats exposed to genetically engineered maize were more likely to develop tumours and die earlier was quickly retracted by Food and Chemical Toxicology after an uproar from other scientists. In 2014, the paper was essentially republished by Environmental Sciences Europe. It was based on the same data, and contained only minor rephrasing.

Despite this kind of snafu, a relentless storm is reshaping the way science is conveyed and received today. Fraud and error are harder to hide, because of the democratising influence of technology and the world wide web. Plagiarism-detecting software, which can scan a paper and give a report within minutes, is widely available. Replication or manipulation of images is easier to sleuth out, because most papers are now widely available in digital versions viewable from any computer. The rise of online post-publication peer review is also reshaping the scientific endeavour before our very eyes.

If all the reforms already available were widely adopted, routine corrections might become commonplace. But these reforms aren't being widely adopted, yet. The geneticist Roderick MacLeod, of the German biobank DSMZ, says: 'There is a malignant inertia out there. The status quo exerts great power over us, and we tend to do what we always did.'

It is still not mandatory for every scientist to upload raw data to a hosting site (a common one is Figshare), even though online storage is now essentially infinite and cheap or free. Many journals have policies that data should be deposited and freely available, but most do not enforce those policies. And it's nearly impossible to investigate suspected fraud without access to the raw data. Wager tells of journal editors complaining that authors had conveniently lost data in 'lab fires, floods, catastrophic computer crashes, or more bizarrely, attacks by termites'.

The pathobiologist Kenneth Witwer of Johns Hopkins University in Baltimore found that fewer than 40 per cent of the 127 studies in his specialty field (microRNA) actually submitted raw data. Is reluctance to share data linked with low study quality? Nobody knows. If other scientists – some of whom are superb data sleuths – have access to your raw data, it's a deterrent to fraud. And it makes sense to store data safely, freely and publicly, even if there's no misconduct.

Post-publication peer review, taking place entirely online, is another tsunami reshaping the scientific landscape. The largest database of archived peer-reviewed abstracts, PubMed, now allows comments on its PubMed Commons by the scientific community. Any scientist who has had an article published and archived on PubMed can register and comment. Numerous blogs and sites serve as informal reviews, especially of image duplication or fabrication. The whistleblower Brookes recently published a study on internet publicity and corrective action. Although his study was small, it found that papers which received public discussion had a sevenfold greater correction or retraction rate.

Another potential game-changer is a service called CrossMark. For journals that subscribe to CrossMark, every paper is stamped with a digital logo, and any researcher can, at any time, even years hence, click on the logo to see if a paper has been cited, corrected, updated or retracted. This could be a tremendous help to researchers who download their own treasure trove of significant papers, numbering in the thousands – all the while unaware of subsequent changes in a given paper's status. Unfortunately, CrossMark, which is a relatively new service, has not been widely adopted. In a similar vein, the MacArthur Foundation has funded the first freely available database of online retractions under the auspices of a new group called the Center for Scientific Integrity, created by Retraction Watch to house its efforts.

There's no doubt that widespread change is underway. But ultimately, for retraction to lose its stigma, and for reforms to be widely adopted, the culture of science itself needs to shift. Ivan Oransky, the co-founder of Retraction Watch, says: 'We need to change the unparalleled power of the published paper.'

A single paper published in Nature, Cell, Science or other elite journals can set a scientist's entire career on secure high ground. And a researcher with a grand string of such publication pearls, as well as prestigious grants, ascends to the scientific equivalent of a rock star. This leads to extreme competition for the precious few slots, and harms collaborative science. As Ferric Fang, the editor-in-chief of the journal Infection and Immunity, said: 'In the end, what matters are the joys of discovery and the innumerable contributions both large and small that we all make through contact with other scientists.'

Science needs to be nudged back to its humble but glorious beginnings, when discovery itself was the means and the end. Retraction can then take its place in a pantheon of data-sharing, open commentary, proper citation of papers, willingness to correct mistakes, and the greater good of all.

Adapted from Aeon.