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ADVANCES IN MODERN PHYSICS:

part 4

Учебное пособие

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PREFACE

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

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

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

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

1. The Fifth Force of Physics Is Hanging by a Thread

Part 1

Exercise I.

Say what Russian words help to guess the meaning of the following words: modern, balance, astronaut, journal chemical, composition, motivation, inertia, product, accelerate.

Exercise II.

Make sure you know the following words and word combinations: premeter, abate, torque, tug, dangling, tripod, fray, to cemend, baryon, terrain

The Fifth Force of Physics Is Hanging by a Thread

As scientists chase tantalizing hints of a new force, modern physics hangs in the balance. (1)

How about that! Mr. Galileo was correct in his findings. That conclusion wasn't based on the most careful experiment you'll ever see, but it was one of the most spectacular in its way—because it was performed on the moon. In 1971, Apollo 15 astronaut David Scott dropped a feather and a hammer from the same height and found that they hit the lunar surface at the same time. The acceleration due to gravity doesn't depend on a body's mass or composition, just as Galileo asserted from his experiment on the Leaning Tower of Pisa. Or does it? Jump forward to the front-page headline of The New York Times in January 1986: "Hints of 5th Force in the Universe Challenge Galileo's Findings." The newspaper was reporting on a paper in the premier physics journal Physical Review Letters by physicist Ephraim Fischbach and his colleagues, describing evidence that the acceleration due to gravity does vary depending on the chemical composition of the object in question. Gravity, it seemed, was not quite what we thought it was: its effects are modified by what the The New York Times' reporter christened a "fifth force," adding to the four fundamental forces we already know. More than 30 years later, many experiments have sought to verify this putative fifth force. Yet despite their extraordinary accuracy, none has ever found convincing evidence for it. That search shows no sign of abating, however. Recently a new tantalizing hint that such a force exists has emerged from experiments in nuclear physics, provoking fresh speculation and excitement. What hangs in the balance are some of the foundational principles of modern physics. Some physicists believe that a fifth force is permitted, even demanded, by efforts to extend and unify the current fundamental theories. Others hope such a force might shed light on the mysterious dark matter that seems to outweigh all the ordinary matter in the universe. (2)

Why speculate about another fundamental force of nature, when there's no good evidence for it? The original motivation was appreciated even in Galileo's time: There are two ways of thinking about mass. One comes from inertia: An object's mass is its "resistance" to being moved, this being greater the more massive it is. The other comes from gravity: According to Isaac Newton's law of universal gravitation, the force of gravity experienced between two masses, such as an apple and the Earth, is proportional to the product of their masses divided by the square of the distance between them. This force causes a falling apple to accelerate. If, and only if, the two definitions of mass are the same, the gravitational acceleration doesn't depend on the amount of mass being accelerated. Are they the same, though? If they aren't, then different masses would fall under gravity at different rates. The intuitive notion that a greater mass should "fall faster" had motivated tests before Galileo. The Dutch natural philosopher Simon Stevin is thought to have dropped lead balls from the clock tower in Delft around 1586, finding no detectable difference in how long they took to reach the ground. Newton himself tested the idea around 1680 by measuring whether pendulums of different mass but identical length have the same period of swing—as they should if gravitational acceleration is mass-independent. His studies were repeated with more accuracy by the German scientist Friedrich Wilhelm Bessel in 1832. Neither of them found any detectable difference. The idea that inertial and gravitational mass are the same is known as the weak equivalence principle. It became a crucial issue when Einstein formulated his theory of general relativity around 1912-16, which rested on the central idea that the acceleration caused by gravity is the same as the acceleration of an object subject to the same force in free space. If that's not true, general relativity won't work. "The equivalence principle is one of the basic assumptions of general relativity," says Stephan Schlamminger, who works at the Mecca of high-precision measurement, the National Institute of Standards and Technology. "As such, it should be thoroughly tested. Tests of the equivalence principle are relatively cheap and simple, but could have a huge impact if a violation was found. It would be careless not to perform these experiments." If the weak equivalence principle fails, then there are two possibilities. Either Newton's expression for the force of gravity between two masses (which is also what general relativity predicts if gravity is not extreme) is slightly inaccurate and needs tweaking. Or gravity might be fine as it stands—but there might be a new, fifth force that makes it look different. That fifth force would add to the four we already know to exist: gravity, electromagnetism, and the strong and weak nuclear forces that govern the interactions of subatomic particles inside atomic nuclei. Whether we think about "modified gravity" or a fifth force is, says Fischbach, in the end just a semantic distinction. Either way, says Feng, there is "no reason at all that there can't be a fifth force that we have not noticed until now." (3)

By the time Einstein pinned his new gravitational theory to it, the weak equivalence principle had already undergone some very exacting tests. At the end of the 19th century a Hungarian nobleman named Baron Loránd Eőtvős, working at the University of Budapest, realized it could be tested by placing two masses in delicate balance. Eőtvős used an instrument known as a torsion balance. He attached two objects to the ends of a horizontal rod suspended by a thread. If the objects have the same weight—the same gravitational mass—then the rod is balanced horizontally. But the masses also experience a centrifugal force due to the rotation of the Earth, which depends on the objects' inertial masses. If inertial mass is the same as the gravitational mass, all the forces are in balance and the rod stays still. But if they differ, then the masses will tend to swing away from the horizontal because of the Earth's rotation. And if the two masses experience a different "swing"—one possibility would be because the deviation from the weak equivalence principle is dependent on composition—then the rod will experience a net twisting force (torque), and it will rotate. Even if this rotation is very slight, it might be detected by, say, measuring the deflection of a light beam from a mirror attached to the rod. Now, the fact is that the force of gravity does vary slightly from place to place on the Earth anyway. That's because the planet is not a smooth uniform sphere. Rocks have different density, and so exert a very slightly different gravitational tug. And at the precision of Eőtvős's experiments, even the presence of the nearby university buildings could disturb the results. One way of eliminating these local variations is to carry out the measurements for two different orientations of the dangling rod—say, east-west and north-south. Both should experience the same local effects of gravity, but the centrifugal forces will differ—and thus any deviation from weak equivalence would show up as a difference in torque between the two measurements. This approach fits with the general strategy of setting up the balance experiment to be sensitive to differences in gravitational acceleration between two test masses or configurations: That way, you don't need to worry about local effects or about how accurately you can measure absolute forces. Local perturbations might, however, also vary in time: Even a passing truck could induce a tiny gravitational disturbance. So the researchers had to take care to rule out such things. In fact, even the presence of the observing experimenter might matter. Eőtvős built a revised torsion balance that was a masterpiece of precision engineering. On one end of the hanging rod was a standard platinum mass, while the samples of other materials were suspended from the other end. The rod was mounted on a tripod that could pivot to alter its orientation. A telescope and mirror attached to the moving parts could show if any rotation of the rod had occurred. Tiny imbalances in temperature of the environment could induce warping of the apparatus, leading to spurious rotation, and so the whole assembly was encased in a sealed, insulated chamber. To make the experiments even more exquisitely accurate, the researchers later took to conducting them in a darkened, closed room, so that no light could produce temperature variations. (4)

So by the end of the 19th century, there seemed to be no reason to doubt the weak equivalence principle. But at that very time, new reasons began appearing. For one thing, the discovery of radioactivity suggested the presence of an unknown source of energy locked inside atoms. What's more, Einstein's theory of special relativity offered a new perspective on matter and mass. Mass, it seemed, could be converted to energy—and it was sensitive to velocity, increasing as the speed of an object approached the speed of light. Mindful of all this, in 1906 the Royal Scientific Society of Göttingen in Germany offered a 4,500-mark prize for more sensitive tests of the equivalence of "inertia and gravitation," citing Eőtvős' experiments as inspiration. Eőtvős himself couldn't resist returning to the fray. "He was the world expert in this kind of experiment," says Fischbach. He and his students dusted off their torsion-balance experiments, devoting thousands of hours to testing different materials: copper, water, dense wood, and more. They submitted their findings in 1909, claiming an improved accuracy of one part in 200 million. But the full report of the work wasn't published until 1922, three years after Eőtvős' death. One of his students, János Renner, continued the work and published it in Hungarian in 1935, claiming to verify the weak equivalence principle to one part in 2-5 billion. Was such sensitivity really possible back then? Physicist Robert Dicke, a specialist in general relativity, expressed doubts when he came to tackle the same question in the 1960s. Regardless of whether Dicke's criticisms are valid, he and his coworkers used a more sophisticated torsion balance that achieved an accuracy of one in 100 billion. They did it by measuring the acceleration of their test masses caused not by the Earth's gravity but by that of the sun. This meant there was no need to disturb the balance by rotating it: The direction of the gravitational attraction was itself being rotated as the Earth moved around the sun. Any deviation from weak equivalence should have showed up as a signal varying every 24 hours in step with the Earth's rotation, giving a precise way to discriminate between this and false signals due to local gravitational variations or other disturbances. Dicke and his colleagues saw no sign of such deviations: No indication that Newton's law of gravity needed amending with a fifth force. Were physicists satisfied now? Are they ever? (5)

Fischbach became interested in the fifth force after hearing about an experiment performed by his colleague Roberto Colella and coworkers in 1975, which looked at the effects of Newtonian gravity on subatomic particles. Fischbach wondered whether it would be possible to conduct similar experiments with subatomic particles in a situation where the gravity is strong enough to make general relativity, rather than Newton's theory, the proper description of gravity—that might then offer a completely new way of testing Einstein's theory. He began to think about doing so using exotic particles called kaons and their antimatter siblings anti-kaons, which are produced in particle accelerators. Analyzing studies of kaons at the Fermilab accelerator facility led Fischbach to suspect that some kind of new force might be affecting the particles' behavior, which was sensitive to a quantity called the baryon number, denoted *B*. This is a property of fundamental particles that, unlike mass or energy, doesn't have any everyday meaning. It is equal to a simple arithmetic sum of the number of even more fundamental constituents called quarks and antiquarks that make up the protons and neutrons of atomic nuclei. Here's the thing, though: If this new force depended on baryon number, it should depend on the chemical composition of materials, since different chemical elements have different numbers of protons and neutrons. More precisely, it would depend on the ratio of *B* to the masses of the component atoms. Naively it might seem that this ratio should be constant for everything, since atomic mass comes from the sum of protons and neutrons. But actually a small part of the total mass of all those constituents is converted into the energy that binds them together, which varies from atom to atom. So each element has a unique *B*/mass ratio. A force that depends on composition. Wasn't that what Eőtvős had been looking for? Fischbach decided to go back and look closely at the Hungarian baron's results. In the fall of 1985, he and his student calculated the *B*/mass ratio for the substances in the samples of Eőtvős and his students. What they found astonished them. The Hungarian team had found very small deviations for the measured gravitational acceleration of different substances, but apparently lacking any pattern, suggesting that these were just random errors. But when Fischbach plotted these deviations against the *B*/mass ratio, he saw a straight-line relationship, suggesting a force that induced a very small repulsion between masses, weakening their gravitational attraction. Considering that our paper was suggesting the presence of a new force in nature," wrote Fischbach, "it may seem surprising that the referring process went as smoothly as it did." But maybe the path was smoothed by the fact that there were already both theoretical and experimental reasons to suspect a fifth force might exist. By 1988 Fischbach counted no fewer than 45 experiments searching for a fifth force. Yet five years later only one had produced any sign of it. (6)

After a few decades of almost universal non-detection of a fifth force, you might think the game is over. But if anything, reasons to believe in a fifth force have become ever more attractive and diverse as physicists seek to extend the foundations of their science. "There are now thousands of papers suggesting new fundamental interactions that could be a source of a fifth force," says Fischbach. "The theoretical motivation is quite overwhelming." For example, the latest theories that attempt to extend physics beyond the "standard model," which accounts for all the known particles and their interactions, throw up several possibilities for new interactions as they attempt to uncover the next layer of reality. Some of those theories predict new particles that could act as the "carriers" of previously unknown forces, just as the electromagnetic, strong, and weak forces are known to be associated with "force particles" such as the photon. A group of models predicting deviations from Newtonian gravity called Modified Newtonian Dynamics (MOND) have also been put forward to account for some aspects of the movements of stars in galaxies that are otherwise conventionally explained by invoking a hypothetical “dark matter” that interacts with ordinary matter only (or perhaps almost only) via gravitational attraction. No clear evidence has been discovered to support MOND theories, but some physicists have found them increasingly promising as extensive searches for dark-matter particles have yielded no sign. Alternatively a fifth force might help us find out about dark matter itself. As far as we know, dark matter only interacts with other matter through gravity. But if it turned out to feel a fifth force too, then, Feng says, “it could provide a ‘portal’ through which we can finally interact with dark matter in a way that is not purely gravitational, so we can understand what dark matter is.” What’s more, some theories that invoke extra dimensions of space beyond our familiar three—such as the currently most favored versions of string theory—predict that there could be forces similar to but considerably stronger than gravity acting over short distances of millimeters or less. That’s the scale at which some researchers are now looking. It means measuring the forces, with extraordinary precision, between small masses separated by very small gaps. The difficulty with such measurements is that there is already a force of attraction between objects this close, called the Casimir force. This has the same origin as the so-called van der Waals forces that operate at even closer approach, and which stick molecules together weakly. These forces come from the synchronized sloshing of clouds of electrons in the objects, which give rise to electrostatic attraction because of the electrons’ charge. Casimir forces are basically what van der Waals forces become when the objects are far enough apart —more than a few nanometers—for the time delay between the electron fluctuations across the gap to matter. Fischbach and his coworkers found a way to suppress the Casimir force, making it about a million times weaker by coating their test masses with a layer of gold. Torsion-balance measurements can be used in this region, too. Researchers at the Institute for Cosmic Ray Research at the University of Tokyo have used the device to look for deviations from the standard Casimir force caused by a fifth force. All they found were yet stricter lower limits on how strong such a force can be. (7)

As well as detecting a fifth force directly, it might still be possible to spot it the way Fischbach originally thought to look: through the high-energy collisions of fundamental particles. In 2015 a team at the Institute for Nuclear Research in Hungary reported something unexpected when an unstable form of beryllium atoms, formed by firing protons at a lithium foil, decays by emitting pairs of electrons and their antimatter counterparts positrons. There was a rise in the number of electron-positron pairs ejected from the sample at an angle of about 140 degrees, which standard theories of nuclear physics couldn't explain. Although they haven't yet been replicated by other researchers, the Hungarian findings look pretty solid. The chance that they are just a random statistical fluctuation is tiny, says Feng: about 1 in 100 billion. "More than that, the data fit beautifully the hypothesis that they're caused by a new particle," he says. "If such a new particle exists, this is exactly how it would come to light." "We have yet to confirm it is a new particle," admits Feng, "but it would be revolutionary if true—the biggest discovery in particle physics in at least 40 years." His theoretical work predicts that the putative new particle is just 33 times heavier than the electron. If so, it shouldn't be hard to make in particle collisions—but it would be hard to see. "It is very weakly interacting, and we've shown that it would have eluded all previous experiments," says Feng. Perhaps, he adds, it could be sought at colliders such as the Large Hadron Collider at the particle-physics center CERN in Geneva. The hypothesis of a fifth force is, then, anything but exhausted. In fact it's fair to say that any observations in fundamental physics or cosmology that can't be explained by our current theories—by the Standard Model of particle physics or by general relativity—are apt to get physicists talking about new forces or new types of matter, such as dark matter and dark energy. That's simply the way physics has always worked: When all else fails, you place a new piece on the board and see how it moves. Sure, we haven't yet seen any convincing evidence for a fifth force, but neither have we seen a direct sign of dark matter or extra dimensions, and not for want of looking. We have ruled out a great deal of the territory that a fifth force might inhabit, but there is still plenty of terrain left in shadow. (8)

Adapted from Nautilus.

Exercise III.

Find paragraphs, dealing with the following: tantalizing, spectacular, astronaut, composition, headline, premier, modify, putative, provoking, outweigh

Exercise IV.

Fill in the gaps.

1. He points out that Albert Einstein demonstrated the**……….** of mass-energy.

2. This is the basic ………. of science, and how essentially all science happens.

3. You will find a set screw holding the steel ………………….., or what's left of it, in place.

4. Vodafone said it was ordered to ………. mobile-phone services in selected areas.

5. This method can be derived from the field picture through ………… theory.

6. Such an ………… , however, would be costly and who knows if it'd actually work.

7. However, an …………. majority of Muslims living in Germany reject terrorism.

8. When the bread is done, line the pan with aluminum ……. and coat with olive oil.

9. He sent a blessing via the Vatican news ………… for its launch in June last year.

10. This conception of ………….. is very different from the fictitious force.

Exercise V.

Make up sentences of your own with the following word combinations: the front-page headline (1), convincing evidence (1), to show no sign of (1), shed light on (1), to fall under gravity (2), at different rates (2), a crucial issue (2), to be rested on (2), high-precision measurement (2) , to rule out (8)

Exercise VI.

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

1. The newspaper was reporting on a paper in the premier physics journal Physical Review Letters by physicist Ephraim Fischbach and his

colleagues, describing evidence that the acceleration due to gravity does vary depending on the physical composition of the object in question.

2. According to Isaac Newton's law of universal gravitation, the force of gravity experienced between two masses, such as an apple and the Earth, is proportional to the product of their masses divided by the square of the distance between them.

3. The Dutch natural philosopher Simon Stevin is thought to have dropped iron balls from the clock tower in Delft around 1586, finding no detectable difference in how long they took to reach the ground.

4. Newton himself tested the idea around 1680 by measuring whether pendulums of identical mass but different length have the same period of swing—as they should if gravitational acceleration is mass-independent.

5. The idea that inertial and gravitational mass are the different is known as the weak equivalence principle.

6. It became a crucial issue when Newton formulated his theory of general relativity around 1912-16, which rested on the central idea that the acceleration caused by gravity is the same as the acceleration of an object subject to the same force in free space.

7. "The equivalence principle is one of the basic assumptions of general relativity," says Stephan Schlamminger, who works at the Mecca of high-precision measurement, the National Institute of Standards and Technology.

8. Tests of the equivalence principle are expensive and simple.

9. The fifth force would add to the four we already know to exist: gravity, electromagnetism, and the strong and weak nuclear forces that govern the interactions of subatomic particles inside atomic nuclei.

10. Eőtvős used an instrument known as a torsion balance.

Exercise VII .

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

to tweak	to cause something to be used; bring into effect
rod	to protect someone or something from outside influences
to suspend	to turn or twist
overwhelming	a very thin sheet of metal, especially used to wrap food in to keep it fresh
to invoke	to bend or twist so that the surface is no longer flat or straight:
foil	to change something slightly, especially in order to make it more correct, effective, or suitable
to exert	to hang
insulated	very great or very large
to pivot	a long, thin pole made of wood or metal
warp	to make a mental or physical effort

Exercise VIII.

Summarize the article "The Fifth Force of Physics Is Hanging by a Thread".

Part 2

Exercise I.

Identify the part of speech the words belong to.

spectacular, putative, deflection, perturbation, apparatus, exquisitely, spurious, putative, portal, pendulum

Exercise II .

Form nouns from the following words:

chemical (2), verify (2), exist (2), emerge (2), fresh (2), unify (2), speculate (3), appreciate (3), move (3), divide (3)

Exercise III.

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

conclusion (2), experiment (2), perform (2), height (2), acceleration (2), depend (2), evidence (2), vary (2), convince (2), search (2)

Exercise IV.

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

modern (1), force (1), correct (2), careful (2), surface (2), add (2), extraordinary (2), accuracy (2), balance (2), current (2)

Exercise V.

Match the words to make word combinations:

equivalence	nuclei
torsion	principle
centrifugal	foil
mertial	balance
gravitational	balance
dark	rod
lithium	force
horizontal	mass
torsion	matter
atomic	acceleration

2. Quantum gravity

Part 1

Exercise I.

Say what Russian words help to guess the meaning of the following words: telecoms, rocket, cylinder, missions, automatic, communications, satellites, laser, photons, commercial

Exercise II.

Make sure you know the following words and word combinations:
to heave, to streak, to mesh, to clamp, canvas, to swerve, Loop quantum gravity, clear-cut, to traverse, to glean

Quantum gravity

The most exciting discovery in physics could come about thanks to telecoms satellites. Is a single theory of reality in sight? (1)

Watching a rocket as it slowly starts to heave itself out of Earth's deep gravity well and then streaks up into the blue, you suddenly grasp on a visceral level the energies involved in space exploration. One minute that huge cylinder is sitting quietly on its launching pad; the next, its engines fire up with a brilliant burst of light. Clouds of exhaust fill the sky, and the waves of body-shaking thunder never seem to end. To get anywhere in space, you have to travel astounding distances. Even the Moon is about 400,000 km away. And yet the hardest part – energy-wise, anyway – is just getting off the ground. Clear that hurdle, slip the bonds of Earth, and you're off. Gravity's influence falls away and suddenly, travel becomes a lot cheaper. So it might be surprising to hear that the most exciting new frontier in space exploration starts a mere 2,000 km above the terrestrial surface. We aren't talking about manned missions, automatic rovers or even probes. We're talking about satellites. Even more prosaically, we're talking about communications satellites, in low Earth orbit. Yes, they'll be fitted with precision laser equipment that sends and receives particles of light – photons – in their fundamental quantum states. But the missions will be an essentially commercial proposition, paid for, in all probability, by banks eager to protect themselves against fraud. Perhaps that doesn't sound very romantic. So consider this: those satellites could change the way we see our Universe as much as any space mission to date. For the first time, we will be able to test quantum physics in space. We'll get our best chance yet to see how it meshes with that other great physical theory, relativity. And at this point, we have very little idea what happens next. Since its discovery in 1900 and its formalisation in the 1920s, quantum mechanics has remained unchallenged as our basic theory of the submicroscopic world. Everything we know about energy and matter can (in principle) be derived from its equations. In an extended form, known as quantum field theory, it underlies the 'Standard Model' – which is to say, all that we know about the elementary particles. It's difficult to overstate the explanatory power of the Standard Model. Physics has identified four fundamental forces at work in the Universe. The Standard Model accounts for three of them. It explains the electromagnetic force that holds atoms and molecules together; the strong force that binds quarks into protons and neutrons and clamps them together in atomic nuclei; and the weak force that releases electrons orclamps from a nucleus in the form of beta decay. The only thing the model leaves out is gravity, the weakest of the four. Gravity has a theory of its own – general relativity, which Albert Einstein published in 1916. Many physicists believe we should be able to capture all our fundamental forces with a single theory. It's fair to say that this has yet to be achieved. The problem is, quantum theory and relativity are based on utterly different premises. In the Standard Model, forces arise from the interchange of elementary particles. Electromagnetism is caused by the emission and absorption of photons. Other particles cause the strong and weak forces. In a way, the micro-scale world functions like a crowd of kids pelting each other with snowballs. Gravity is different. In fact, according to general relativity, it's not really a force at all. Picture an empty canvas hammock stretched out flat between two trees. In places where there are no big masses (stars, for example), spacetime is a bit like that. An apple placed on the hammock would stay put. Given a shove, it would roll across the canvas in a straight line (in the real Universe, that's how bodies behave when they are far away from any large masses). But when you settle your mass into the hammock, you distort its flatness into a dip. Given a shove, the apple would swerve around the dip – or maybe just roll straight into your side. In much the same way, when a planet orbits a sun, there's no force pulling it – it is simply following a curved path in distorted spacetime. Gravity is what we call that curvature. As the American physicist John Wheeler put it: 'Mass tells spacetime how to curve, and spacetime tells mass how to move.' This geometrical character sets general relativity apart from quantum mechanics. They might have been lumped together as 'modern physics’ in the 20th century, but really, these theories merely coexist. As the British physicist J J Thomson wrote in 1925 in a different context, they are like a ‘tiger and shark, each is supreme in his own element but helpless in that of the other’. And yet the prospect of bringing them together remains irresistible. It might be true that we have working theories for all the fundamental forces, but until we can unite them within a single theory, important parts of the cosmic environment and its history remain obscure. (2)

Such as? Well, using our existing theories we can trace the history of the Universe back almost to the Big Bang itself, 13.8 billion years ago. Almost but not quite: we know next to nothing about the first 10-43 seconds. What we can say is that the cosmos must have been extremely small and hot at that point. That earliest ‘Planck epoch’ is defined using tiny fundamental units invented by Max Planck – a length of about 10-35 metres, a mass of about 10-8 kg, and a duration of about 10-43 seconds. The Planck length, far smaller than any elementary particle or distance that we could measure, is the ultimate quantum uncertainty in location. It is the scale at which gravitational and quantum effects are equally strong. What that means is that, when the Universe was still that small, it could be understood only through a theory that includes both gravity and quantum mechanics. Such a theory is also necessary for black holes, those cosmic zones where mass is so concentrated that not even light can escape its gravitational effects. Black holes are common– they exist at the centre of our galaxy and many others – and though general relativity predicts them, it does not fully describe them. In particular, it is silent about what happens at their centres, where spacetime becomes infinitely curved. So, a decent theory of quantum gravity would shine a light into some mysterious places. Sadly, our best efforts to develop this theory remain unconvincing. One idea is that gravity is carried by hypothetical particles, just like the other three forces. These 'gravitons' are predicted by string theory, in which elementary particles are quantum states of tiny vibrating strings. But string theory itself is controversial, mainly because, despite the beauty of its mathematics, it fails to generate anything resembling a testable prediction (as Einstein said: 'If you are out to describe the truth, leave elegance to the tailor'). A competing theory called loop quantum gravity, in which spacetime itself has a quantum nature, also lacks testable implications. What to do, then? In physics, mathematical beauty and ingenuity are never enough by themselves. What is needed is data – especially new data. And it happens that the prospects for that are suddenly very good. Recall that quantum mechanics describes the micro-world of fundamental particles. General relativity, meanwhile, describes how celestial bodies operate over great distances – it governs the vast expanses of the cosmos. What we don't yet know is what happens to quantum phenomena over long distances. In short, we haven't tried to do quantum experiments where relativity gets in the way. Yet. Today, the opportunity to do just that looks likely to emerge from a plan to improve our current telecommunications infrastructure. At the moment, a lot of data – internet, TV and suchlike – is transmitted as pulses of light through a global fibre-optic network. Those pulses are made of photons, of course, but the network does not make use of the photon's exotic quantum properties. The new idea is to see what happens when it does. Let's look at photons for a moment. Each one has an electric field that can be polarised – that is, it can be made to point in either of two directions at right angles to one another, which at the Earth's surface are 'horizontal' and 'vertical'. We could indicate the former with a '0' and the latter with a '1'. And once we're thinking about our photon that way, it's only a short leap to seeing it as a binary bit, like a switch in a computer processor. But there's a twist. A regular computer bit is always 0 or 1, with no other options. The quantum nature of a photon, by contrast, allows it to represent 0 and 1 simultaneously. It's a sort of super-bit. We call it a 'quantum bit', or qubit for short. Qubit-based computers, now being designed, are expected to far outperform ordinary computers for certain problems. And there's one area where the use of qubits is anticipated with particular eagerness: data security. In any communications system, sensitive information such as financial data can be encoded and sent to a recipient who has the key to the code. The trouble is, it's always possible for a third party to sneak into the network and secretly learn the key. Qubits should prevent that. Using a procedure called 'quantum key distribution' (QKD for short), the innate quantum uncertainty about the polarisation of each photon allows us to generate a long random string of 0s and 1s, which can then be sent as a totally secure key. It's secure because any interception would be detected – reading the bits changes them, thanks to the Heisenberg Uncertainty Principle. (3)

Well, that's the theory. In practice, it turns out that photon qubits cannot reliably be sent through long stretches of optical fibre. So researchers are developing an audacious new plan for a secure global data network: they intend to transmit qubits between ground stations and space satellites in low Earth orbit (LEO) at altitudes up to 2,000 km. The most advanced effort, supported by the Chinese Academy of Sciences, is based at the University of Science and Technology of China (USTC). Its stated goal is to launch a Quantum Science satellite, equipped to test both secure quantum communications and fundamental quantum effects. Once qubits can be exchanged with this or any other satellite, we can begin examining quantum mechanics in space. Surely the first thing to look into would be the exotic effect of entanglement – what Einstein called ‘spooky action at a distance’. Entanglement means that, once two quantum particles have interacted, they remain linked no matter how far apart, so that measuring one instantly affects the other. We can, for instance, prepare a photon pair so that they are oppositely polarised (horizontal and vertical, 0 and 1), without knowing which is which. As soon as the polarisation of photon 1 is measured, no matter what the result, measurement of photon 2 will reveal the other value with no physical connection between the two. The strangeness of quantum entanglement was first laid out in the 1935 ‘EPR’ paper by Einstein, Boris Podolsky and Nathan Rosen. EPR argued that entanglement contradicts ‘local realism’, which is the idea that objects have innate properties independent of measurement and that they cannot affect each other any sooner than light can travel between them. In 1964, the Northern Irish theorist John Bell showed that, if data from two entangled particles obey a mathematical relationship called Bell’s Inequality (as it appears they do), they must violate local realism. And they must violate it ‘instantaneously’, through a quantum feature such that ‘the setting of one measuring device can influence the reading of another instrument however remote’. However remote? Entanglement has been tested up to a distance of 143 km, by Anton Zeilinger at the University of Vienna. In 2012, Zeilinger’s former student Jian-Wei Pan, who heads the USTC quantum satellite effort, achieved entanglement over distances nearly as large. And then, in an important ‘proof of principle’ demonstration in 2013, he managed to transmit photon qubits 800 km from a ground station to an orbiting German satellite and back. Results like these start to make quantum research in space look very doable. (4)

So what can we hope to investigate? The first experiments to push into new regimes would use LEO satellites to test entanglement up to a distance of 2,000 km. If entanglement and Bell’s Inequality still hold, that would give the strongest evidence yet against local realism. An important result. But if either failed within that distance, then the meaning of entanglement would have to be utterly rethought. That would be even more interesting. LEO measurements could also support a test not possible on Earth. When an observer measures one of an entangled pair of photons, in principle that simultaneously determines the state of its partner as measured by a second observer. But in special relativity, the meaning of the word ‘simultaneous’ is complicated. Observers moving relative to one another who measure two physically separated events will disagree over who made the measurement first. The time difference is too small to measure at earthly speeds, but LEO satellites move fast enough that the apparent paradox could be examined to explore the supposedly instantaneous nature of entanglement. However, current quantum technology might be sufficient to transfer qubits and test entanglement still further out – to geostationary satellites 36,000 km above the Earth’s equator, and even 10 times further, to the

Moon. At these distances, the curvature of spacetime starts to become important. For that reason, Thomas Jennewein thinks experiments in this broader regime are most likely to discover something big. Such as? One example concerns what is called gravitational redshift. We know that a photon's wavelength moves towards the red end of the spectrum as the photon climbs upwards against gravity. The reason is because time dilates – that is, clocks literally run slower – the more intense the gravitational field becomes. Even in the short climb to a LEO satellite, photon qubits ought to be redshifted, which would mean we can determine whether time dilation applies at the quantum level – another important result. But if we try this and similar experiments at greater distances, we should see more intricate examples of quantum-gravitational interaction. For one thing, the curvature of spacetime would affect the polarisation of photons and hence any measurements of quantum entanglement. Near the Earth's surface, photons follow straight lines, which means that their horizontal and vertical polarisation directions are fixed. This allows us to do clear-cut entanglement experiments in which measuring photon 1 as 'horizontal' makes photon 2 yield 'vertical', and vice-versa. But if two entangled photons follow different relativistic curved paths in space, the directions of their electric fields and polarisations would seem to depend on the details of the curvatures. In this way relativity becomes mixed into an innately quantum mechanical effect. Polarised photons might also allow us to explore the hypothesis that spacetime itself is quantised – that is, not smooth as in general relativity, but a granular structure made of discrete Planck-sized cells. Evidence for this would be a huge step towards a theory of quantum gravity. The trouble is, we don't currently have any hope of probing these tiny units directly. This difficulty has inspired physicists to come up with an alternative – the Holometer at the Fermi National Accelerator Laboratory near Chicago. This sensitive device is designed to detect the 'jitter' in laser beams as they are affected by the randomness inherent in a quantised spacetime. An approach based on polarised photons in space came from researchers at Imperial College, London. Each time a photon traverses a Planck cell, quantum randomness would slightly shift the direction of the photon's electric field. The accumulation of many quantum 'kicks' as a photon travels a long distance through numerous cells would measurably change the polarisation, indicating a granular spacetime. The distance would need to be billions of kilometres at least – the size of the Solar System – which is far beyond present quantum technology, but it's nice to dream big. Further experiments could use entanglement to examine the history of the Universe. In theory, as the cosmos grew from its tiny beginnings, the corresponding changes in spacetime curvature should have altered entanglement in ways that can be traced back to presently unknown details of cosmic development. Entanglement studies could even bear on an old cosmological question: are the physical laws that we have derived on Earth valid for the whole Universe? Since the time of Copernicus, scientists and philosophers have considered this question from different perspectives, but have had little direct evidence to draw on. If entanglement proves to be truly infinite in scope, it could be the ultimate tool to glean answers from distant cosmic locations. Governments and financial institutions such as major banks will welcome the day when quantum satellites can securely transmit sensitive data. But the biggest winners of the quantum network will surely be researchers eager for new fundamental discoveries. (5)

Adapted from Aeon.

Exercise III.

Find paragraphs, dealing with the following: rocket, mere, automatic, precision, commercial, to date, mesh, unchallenged, elementary, overstate

Exercise IV.

Fill in the gaps.

1. The child was able to struggle and break free from the man's ……… and run away.
2. They had the first man in space, the first woman in space, the first ……….. in space, the first space station, even the first landing of an unmanned craft on the moon.
3. Large nets could be cast to ………. the geese, but that would cost about $6,000.
4. No, it's just a frame made of paper tubes with white ………. curtains in between.
5. Foods that are high in ……… and low in fat tend to have a lower energy density.
6. The moment you see a Rubik's Cube, you know you're supposed to ……….. the pieces.
7. The more government does, the more it withholds from those it ………… serves.
8. Knowledge of her ………. peril will spread to other counties around Washington.

9. Even the plot twist that provides an ………….. hopeful ending is no surprise.

10. It discovered the top ……… and tau neutrino, winning the Standard Model cup 2-1.

Exercise V.

Make up sentences of your own with the following word combinations: to come about (1), be in sight (1), fire up with (1), to get off (1), in all probability (1), to hold together (1), in a way (1), to pelt each other with snowballs (1), to lump together(1)

Exercise VI.

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

1. Everything we know about energy and matter can (in principle) be derived from its equations.
2. The weak force that binds quarks into protons and neutrons and clamps them together in atomic nuclei; and the strong force that releases electrons orclamps from a nucleus in the form of beta decay.
3. The only thing the model leaves out is gravity, the strongest of the four.
4. Gravity has a theory of its own – general relativity, which Albert Einstein discovered in 1916.
5. The problem is, quantum theory and relativity are based on similar premises.
6. In the Standard Model, forces arise from the interchange of elementary particles.
7. Electromagnetism is caused by the emission and absorption of photons.
8. The Planck length, far bigger than any elementary particle or distance that we could measure, is the ultimate quantum uncertainty in location.

9. What that means is that, when the Universe was still that small, it could be understood only through a theory that includes both gravity and quantum mechanics.

10. Black holes are common– they exist at the edge of our galaxy and many others – and though general relativity predicts them, it does not fully describe them.

Exercise VII.

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

probe	to take someone as a prisoner, or to take something into your possession:
fraud	to examine something with a tool, especially in order to find something that is hidden
hammock	one of the most basic forms of matter that make up atoms
to grasp	a net or strong piece of cloth, wide enough for a person to lie on, hanging between twopoles or trees to which it is attached
to capture	a solid or hollow tube with long straight sides and two circular ends the same size, or an object shaped like this, often used as a container
fibre	a natural object moving around a larger object in space
twist	the crime of getting money by deceiving people
quark	any of the thread-like parts that form

	plant or artificial material and can be made into cloth
cylinder	to quickly take something in your hand(s) and hold it firmly
sattelite	to turn something, especially repeatedly, or to turn or wrap one thing around another

Exercise VIII.

Summarize the article “Quantum gravity”.

Part 2

Exercise I.

Identify the part of speech the words belong to.

ceral, exhaustexplanatory, merely, tailor, celestrial, interception, supposedly, inherent, sattelite, unconvincing

Exercise II .

Form verbs from the following words:

exploration (2), communication (2), proposition (2), emission (2), absorption (2), curvature (2), testable(3), prediction (3), implication (3), information (3)

Exercise III.

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

travel (2), exciting (2), terrestrial (2), satellite (2), equipment (2), receive (2), protect (2), fraud (2), chance (2), underline (2)

Exercise IV .

Find antonyms to the following words. Translate them into Russian: slowly (2), start (2), deep (2), well (2), suddenly (2), cheaper (2), surprising (2), prosaically (2), eager (2), strong (2)

Exercise V.

Match the words to make word combinations:

terrestrial	world
automatic	pad
Bell's	rovers
Planck-sized	paradox
visceral	surface
body-shaking	cells
launching	level
Einstein-Podolsky-Rosen	satellites
submicroscopic	inequality
telecoms	thunder

3. Our quantum problem

Part 1

Exercise I.

Say what Russian words help to guess the meaning of the following words: collapse, electrons, positive, electrical, model, fraction, structure, collisions, central, spiral

Exercise II.

Make sure you know the following words and word combinations.
to undermine, to whirl, feeble, disparate, insofar, gibe, profoundly, inconceivable, beam, akin

Our quantum problem

When the deepest theory we have seems to undermine science itself, some kind of collapse looks inevitable (1)

In 1909, Ernest Rutherford, Hans Geiger and Ernest Marsden took a piece of radium and used it to fire charged particles at a sheet of gold foil. They wanted to test the then-dominant theory that atoms were simply clusters of electrons floating in little seas of positive electrical charge (the so-called 'plum pudding' model). What came next, said Rutherford, was 'the most incredible event that has ever happened to me in my life'. Despite the airy thinness of the foil, a small fraction of the particles bounced straight back at the source. Instead of whooshing straight through the thin soup of electrons that should have been all that hovered in their path, the particles had encountered something solid enough to push back. Something was wrong with matter. Somewhere, reality had departed from the best available model. But where? The first big insight came from Rutherford himself. He realised that, if the structure of the atom were to permit collisions of the magnitude that his team had observed, its mass must be concentrated in a central nucleus, with electrons whirling around it. Could such a structure be stable? Why didn't the electrons just spiral into the centre, leaking electromagnetic radiation as they fell? Such concerns prompted the Danish physicist Niels Bohr to formulate a rather oddly rigid model of the atom, using artificial-seeming rules about electron orbits and energy levels to keep everything in order. It was ugly but it seemed to work. Then, in 1924, a French physicist named Louis de Broglie argued that Bohr's model would make more sense if we assumed that the electrons orbiting the atomic nucleus (and indeed everything else that had hitherto been considered a particle) either came with, or in some sense could behave like, waves. If Bohr's atom had seemed a little arbitrary, de Broglie's improved version was almost incomprehensible. Physical theory might have recovered some grip on reality but it seemed to have decisively parted company from common sense. And yet, as Albert Einstein said on reading de Broglie's thesis, here was 'the first feeble ray of light on this worst of our physics enigmas'. By 1926, these disparate intuitions and partial models were already unified into a new mathematical theory called quantum mechanics. Within a few years, the implications for nuclear physics were being confirmed. It was clear from the start that quantum theory challenged all our previous preconceptions about the nature of matter and how it behaves, and indeed about what science can possibly – even in principle – say about these questions. Over the years, this very slipperiness has made it irresistible to hucksters of various descriptions. I regularly receive ads offering to teach me how to make quantum jumps into alternate universes, tap into my infinite quantum self-energy, and make other exciting-sounding excursions from the plane of reason and meaning. It's worth stressing, then, that the theory itself is both mathematically precise and extremely well confirmed by experiment. Quantum mechanics has correctly predicted the outcomes of a vast range of investigations, from the scattering of X-rays by crystals to the discovery of the Higgs boson at the Large Hadron Collider. It successfully explains a vast range of natural phenomena, including the structure of atoms and molecules, nuclear fission and fusion, the way light interacts with matter, how stars evolve and shine, and how the elements forming the world around us were originally created. Yet it puzzled many of its founders, including Einstein and Erwin Schrödinger, and it continues to puzzle physicists today. Einstein in particular never quite accepted it. In a 1935 paper co-written with Boris Podolsky and Nathan Rosen, Einstein asked: 'Can the Quantum-Mechanical Description of Physical Reality Be Considered Complete?' He concluded that it could not. Given apparently sensible demands on what a description of physical reality must entail, it seemed that something must be missing. We needed a deeper theory to understand physical reality fully.Later theoretical work by the Irish physicist John Bell and subsequent experiments suggested that the apparently reasonable demands of that 1935 paper could never be satisfied. Had Einstein lived to see this work, he would surely have agreed that his own search for a deeper theory of reality needed to follow a different path from the one he sketched in 1935. Even so, I believe that Einstein would have remained convinced that a deeper theory was needed. None of the ways we have so far found of looking at quantum theory are entirely believable. In fact, it's worse than that. To be ruthlessly honest, none of them even quite makes sense. But that might be about to change. (2)

Here's the basic problem. While the mathematics of quantum theory works very well in telling us what to expect at the end of an experiment, it seems peculiarly conceptually confusing when we try to understand what was happening during the experiment. To calculate what outcomes we might expect when we fire protons at one another in the Large Hadron Collider, we need to analyse what – at first sight – look like many different stories. The same final set of particles detected after a collision might have been generated by lots of different possible sequences of energy exchanges involving lots of different possible collections of particles. We can't tell which particles were involved from the final set of detected particles. We don't get a list of possible explanations for what happened, of which one (although we don't know which) must be the correct one. We get a mathematical recipe that tells us to combine, in an elegant but conceptually mysterious way, numbers attached to each possible explanation. Then we use the result of this calculation to work out the likelihood of any given final result. But here's the twist. Unlike the mathematical theory of probability, this quantum recipe requires us to make different possible stories cancel each other out, or fully or partially reinforce each other. This means that the net chance of an outcome arising from several possible stories can be more or less than the sum of the chances associated with each. One attempt to make sense of this situation is the so-called ‘Copenhagen interpretation’ of quantum theory, versions of which were advocated by Bohr, Werner Heisenberg and other leading quantum theorists in the first half of the last century. According to this approach, a scientific question makes sense only if we have a direct way of verifying the answer. So, asking what we’ll see in our particle detectors is a scientific question; asking what happened in the experiment before anything registered in our detectors isn’t, because we weren’t looking. To be looking, we’d have had to put detectors in the middle of the experiment, and then it would have been a different experiment. In trying to highlight the absurd-seeming consequences of this view, Schrödinger minted what has become its best-known popular icon – an imaginary experiment with a sealed box containing a cat that is simultaneously alive and dead, only resolving into one or other definite state when an experimenter opens the box. The Copenhagen interpretation rests on the principle of verification, according to which a scientific statement is meaningful only if we have some means of verifying its truth. To some of the founders of quantum theory, as well as to later adherents of the Copenhagen interpretation, this came to seem an almost self-evident description of the scientific process. But if you take this position seriously, then you have to accept that the Higgs boson wasn’t actually discovered at the Large Hadron Collider, since no one has ever directly detected a Higgs boson, and we have no direct evidence to support the claim that the Higgs boson is a real particle. Insofar as we learnt anything about nature from the Large Hadron Collider, it was merely what sort of records you get in your detectors when you build something like the Large Hadron Collider. It's hard to imagine the scientists who work on it, or the citizens who funded them, being very enthusiastic about this justification, but on a strict Copenhagen view it's the best we can do. It gets worse. Quantum theory is supposed to describe the behaviour of elementary particles, atoms, molecules and every other form of matter in the universe. This includes us, our planet and, of course, the Large Hadron Collider. In that sense, everything since the Big Bang has been one giant quantum experiment, in which all the particles in the universe, including those we think of as making up the Earth and our own bodies, are involved. But if theory tells us we're among the sets of particles involved a giant quantum experiment, the position I've just outlined tells us we can't justify any statement about what has happened or is happening until the experiment is over. Only at the end, when we might perhaps imagine some technologically advanced alien experimenters in the future looking at the final state of the universe, can any meaningful statement be made. Of course, this final observation will never happen. By definition, no one is sitting outside the universe waiting to observe the final outcome at the end of time. And even if the idea of observers waiting outside the universe made sense – which it doesn't – on this view their final observations still wouldn't allow them to say anything about what happened between the Big Bang and the end of time. We end up concluding that quantum theory doesn't allow us to justify making any scientific statement at all about the past, present or future. Our most fundamental scientific theory turns out to be a threat to the whole enterprise of science. For these and related reasons, the Copenhagen interpretation gradually fell out of general favour. (3)

Its great rival was first set out in a 1957 paper written by one of the stranger figures in the history of 20th-century physics, Hugh Everett III. One way of thinking about his ideas on quantum theory is that our difficulties in getting a description of quantum reality arise from a tension between the mathematics – which, as we have seen, tells us to make calculations involving many different possible stories about what might have really happened – and the apparently incontrovertible fact that, at the end of an experiment, we see that only one thing actually did happen. This led Everett to ask a question that seems at first sight stupid, but which turns out to be very deep: how do we know that we only get one outcome to a quantum experiment? What if we take the hint from the mathematics and consider a picture of reality in which many different things actually do happen – everything, in fact, that quantum theory allows? And what if we take this to its logical conclusion and accept the same view of cosmology, so that all the different possible histories of the evolution of the universe are realised? We end up, Everett argued, with what became known as a 'many worlds' picture of reality, one in which it is constantly forming new branches describing alternative – but equally real – future continuations of the same present state. On this view, every time any of us does a quantum experiment with several possible outcomes, all those outcomes are enacted in different branches of reality, each of which contains a copy of our self whose memories are identical up to the start of experiment, but each of whom sees different results. The same picture holds true more generally in cosmology: alongside the reality we currently habit, there are many others in which the history of the universe and our planet was ever so slightly different, many more in which humanity exists on Earth but the course of human history was significantly different from ours, and many more still in which nothing resembling Earth or its inhabitants can be found. This might sound like unbelievable science fiction. To such a gibe, Everett and his followers would reply that science has taught us many things that seemed incredible at first. Other critics object that the 'many worlds' scenario seems like an absurdly extravagant and inelegant hypothesis. But to this, too, Everettians have an answer: given the mathematics of quantum theory, on which everyone agrees, their proposal is actually the simplest option. The many worlds are there in the equations. To eliminate them you have to add something new, or else change them – and we don't have any experimental evidence telling us that something should be added or that the equations need changing. Everettians might have a point, then, when they argue that their ideas deserve a hearing. The problem is that, from Everett and his early followers onwards, they have never managed to agree on a clear story about how exactly this picture of branching worlds is supposed to emerge from the fundamental equations of quantum theory, and how this single world that we see, with experimental outcomes that are apparently random but which follow definite statistical laws, might then be explained. Indeed, the big unresolved, and seemingly unsolvable, problem here is how statistical laws can possibly emerge at all when the Everettian picture of branching worlds has no randomness in it. If we do an experiment with an uncertain outcome, Everett's proposal says that everything that could possibly happen (including the very unlikely outcomes) will in fact take place. It's possible that Everettians can sketch some explanation of why it seems to ‘us’ (really, to any one of our many future successors) that ‘we’ see only one outcome. But that only replaces ‘everything will actually happen’ with ‘anything could seem to happen to us’. To do science, we need to able to test statements such as ‘there’s a one-in-three chance X will happen to us’ and ‘it’s incredibly unlikely that Y will happen to us’ – but it isn’t at all obvious that Everett’s ideas support any such statements. (4)

If we cannot get a coherent story about physical reality from the Copenhagen interpretation of quantum theory and we cannot get a scientifically adequate one from many-worlds theory, where do we turn? We could, as some physicists suggest, simply give up on the hope of finding any description of an objective external reality. But it is very hard to see how to do this without also giving up on science. The hypothesis that our universe began from something like a Big Bang, our account of the evolution of galaxies and stars, the formation of the elements and of planets and all of chemistry, biology, physics, archaeology and human history – all rely on propositions about real observer-independent facts and events. Once we assume the existence of an external world that changes over time, these interrelated propositions form a logically coherent set; chemistry depends on cosmology, evolution on chemistry, history on evolution and so on. Without that assumption, it is very hard to see how one might make sense of any of these disciplines, let alone see a unifying picture that underlies them all and explains their deep interrelations and mutual dependence. Physics poses many puzzles, and the focus of the physics community shifts over time. Most theoretical physicists today do not work on this question about what really happens in quantum experiments. Among those who think about it at all, many hope that we can find a way of thinking about quantum theory in which reality somehow evaporates or never arises. That seems like wishful thinking to me. The alternative is to accept that quantum theory cannot be a complete fundamental theory of nature. Some of the most interesting work in fundamental physics in the past few decades has been in the search for new theories that agree with quantum theory in its predictions to date, but which include a beable description of reality, and so give us a profoundly different fundamental picture of the world. What sort of quantities might do the trick? One early idea comes from Louis de Broglie, whom we met earlier, and David Bohm. The essence of their proposal is that, in addition to the mathematical quantities given to us by quantum theory, we also have equations defining a definite path through space and time for each elementary particle in nature. These paths are determined by the initial state of the universe and, in this sense, de Broglie-Bohm theory can be thought of as a deterministic theory, rather like the pre-quantum theories given by Newton's and Maxwell's equations. Unfortunately, de Broglie and Bohm's equations also share another property of Newton's equations: an action at any point in space has instantaneous effects on particles at arbitrarily distant points. Because these effects would not be directly detectable, this would not actually allow us to send signals faster than light, and so it does not lead to observations that contradict Einstein's special theory of relativity. It does, however, very much violate the beautiful symmetry principles incorporated in the underlying mathematics. For this reason, and also because de Broglie and Bohm's ideas work well for particles but are hard to generalise to electromagnetic and other fields, it seems impossible to find a version of the scheme that is consistent with much of modern theoretical physics. Still, de Broglie and Bohm's great achievement was to show that we can find a mathematically consistent description of reality alongside quantum theory. In the 1980s, a much more promising avenue opened up, thanks to the efforts of Giancarlo Ghirardi, Alberto Rimini, Tullio Weber and Philip Pearle. Their approach became known as the 'spontaneous collapse' model and their brilliant insight was that we can find mathematical laws that describe how the innumerable possible outcomes encoded in a quantum description of an experiment get reduced to the one actual result that we see. As we have already noted, the tension between these two descriptions is at the heart of the quantum reality problem. When using standard quantum theory, physicists often say that the wave function – a mathematical object that encodes all the potential possibilities – 'collapses' to the measured outcome at the end of an experiment. This 'collapse', though, is no more than a figure of speech, which only highlights the awkward fact that we do not understand what is really happening. By contrast, in Ghirardi-Rimini-Weber-Pearle models, collapse becomes a well-defined mathematical and physical process, taking place at definite points in space, following precise equations and going on all the time in the world around us, whether or not we are making measurements. According to these new equations, the more particles there are in a physical system, the faster the collapse rate. Left isolated, a single electron will collapse so rarely that we essentially never see any effect. On the other hand, anything large enough to be visible – even a dust grain – has enough particles in it that it collapses very quickly compared to human perception times. (In Schrödinger's famous thought experiment, the cat's quantum state would resolve in next to no time, leaving us with either a live cat or a dead one, not some strange quantum combination of both.) One way of thinking about reality in these models, first suggested by Bell, is to take the beables to be the points in space and time at which the collapses take place. On this view, a dust grain is actually a little galaxy of collapse points, winking instantaneously in and out of existence within or near to (what we normally think of as) the small region of space that it occupies. Collapse models do not make exactly the same predictions as quantum theory, which could turn out to be either a strength or a weakness. Since quantum theory is very well confirmed, this disagreement might seem to rule these new models out. However, the exact rate of collapses per particle is a free parameter that is not fixed by the mathematics of the basic proposal. It is perfectly possible to tailor this value such that the differences between collapse model predictions and those of quantum theory are so tiny that no experiment to date would have detected it, and at the same time large enough that the models give a satisfactory solution to the reality problem (ie, everything that seems definite and real to us actually is real and definite). That said, we presently have no theoretically good reason why the parameter should be in the range that allows this explanation to work. On the other hand, history tells us that deep physical insights, not least quantum theory itself, have often come to light only when technology advances sufficiently. The first evidence for what turns out to be a revolutionary change in our understanding of nature can often be a tiny difference between what current theory predicts and what is observed in some crucial experiment. There are other theoretical problems with collapse models. Although they do not seem to conflict with special relativity or with field theories in the way that de Broglie-Bohm theory does, incorporating the collapse idea into these fundamental theories nevertheless poses formidable technical problems. Even on an optimistic view, the results in this direction to date represent work in progress rather than a fully satisfactory solution. Compared with the extraordinary depth and beauty of Einstein's general theory of relativity, or of quantum theory itself, collapse models disappoint. This could simply mean that we have not properly understood them, or not yet seen the majestic deeper theory of which they form a part. It seems likelier, though, that collapse models are at best only a step in roughly the right direction. I suspect that, like de Broglie-Bohm theory, they will eventually be seen as pointers on the way to a deeper understanding of physical reality – extraordinarily important achievements, but not fundamentally correct descriptions.The best answer we can give at present, if collapse models and other recent ideas for beable theories are any guide, is that we should expect to see something new when some relevant quantity in the experiment gets large. In particular, the peculiar and intriguing phenomenon called quantum interference – which seems to give direct evidence that different possible paths which could have been followed during an experiment all contribute to the outcome – should start to break down as we try to demonstrate it for larger and larger objects, or over larger and larger scales. This makes some intuitive sense. Quantum theory was developed to explain the behaviour of atoms and other small systems, and has been well tested only on small scales. It would always have been a brave and perhaps foolhardy extrapolation to assume that it works on all scales, up to and including the entire universe. Given the self-contradictions involved in the extrapolation and the profound obstacles that seem to prevent any solution of the reality problem within standard quantum theory, the most natural assumption is that, like every previous theory of physics, quantum mechanics will turn out only approximately true, applying within a limited domain only. (5)

A number of experimental groups around the world are now trying to find the boundaries of that domain, testing quantum interference for larger and larger molecules (the current record is for molecules comprising around 1,000 atoms), and ultimately for small crystals and even viruses and other living organisms. This would also allow us to investigate the outlandish but not utterly inconceivable hunch that the boundaries of quantum theory have to do with the complexity of a system, or even with life itself, rather than just size. Researchers have proposed space-based experiments to test the interference between very widely separated beams and will no doubt spring into action once quantum technology becomes available on satellites, as it probably will in the next few years. With luck, if the ideas I have outlined are on the right lines, we might have a good chance of detecting the limits of quantum theory in the next decade or two. At the same time we can hope for some insight into the nature and structure of physical reality. Anyone who expects it to look like Newtonian billiard-balls bouncing around in space and time, or anything remotely akin to pre-quantum physical ideas, will surely be disappointed. Quantum theory might not be fundamentally correct, but it would not have worked so well for so long if its strange and beautiful mathematics did not form an important part of the deep structure of nature. Whatever underlies it might well seem weirder still, more remote from everyday human intuitions, and perhaps even more challenging mathematically. Nature is far richer than our imaginations, and we will almost certainly need new experimental data to take our understanding of quantum reality further. If the past is any guide, it should be an extraordinarily interesting scientific journey. (6)

Adapted from Aeon.

Exercise III.

Find paragraphs, dealing with the following: lament, array, multifaceted, cluster, whooshing, concentrate, prompt, rigid, hitherto, arbitrary

Exercise IV.

Fill in the gaps.

1. Some worry that rising food and energy prices will **……………** the global economy.
2. The **………..** of the Iron Curtain brought about a political revolution in Europe.
3. Handling of **………..** has also been blamed for Curie's death due to aplastic anemia.
4. Atoms in solids are bound in a regular lattice, which normally keeps them **…………...**
5. Health-care reform does not need to be accomplished on some **………….** timetable.

6. It was terribly ……………, and I finally used the one Martha Stewart had online.

7. However, critics of arms control say ……… of nuclear tests remains poor.

8. Does anyone really believe California needs politicians who can ………. more laws?

9. You've said that we're a ……….. musical species and every culture has music.

10. That helps with the overall packaging and gives you more grip on ……….. roads.

Exercise V .

Make up sentences of your own with the following word combinations: to keep everything in order (1), in some sense (1), from the start (1), to be honest (1), to make sense (1), at first sight (2), to work out (2), to be looking (2), to rest on (2), to take seriously (2)

Exercise VI.

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

1. In 1909, Ernest Rutherford, Hans Geiger and Ernest Marsden took a piece of radium and used it to fire charged particles at a sheet of silver foil.

2. Despite the airy thinness of the foil, a small fraction of the particles bounced straight back at the source.

3. Theory of general relativity successfully explains a vast range of natural phenomena, including the structure of atoms and molecules,

nuclear fission and fusion, the way light interacts with matter, how stars evolve and shine, and how the elements forming the world around us were originally created.

4. While the mathematics of quantum theory works very well during the experiment, it seems peculiarly conceptually confusing when we try to understand what was happening at the end of an experiment.

5. Like the mathematical theory of probability, this quantum recipe requires us to make different possible stories cancel each other out, or fully or partially reinforce each other.

6. In trying to highlight the absurd-seeming consequences of this view, Schrödinger minted what has become its best-known popular icon – an imaginary experiment with a sealed box containing a rabbit that is simultaneously alive and dead, only resolving into one or other definite state when an experimenter opens the box.

7. We have direct evidence to support the claim that the Higgs boson is a real particle.

8. Quantum theory is supposed to describe the behaviour of elementary particles, atoms, molecules and every other form of matter in the universe.

9. Everything since the Big Bang has been one giant quantum experiment, in which all the particles in the universe, including those we think of as making up the Earth and our own bodies, are involved.

10. Only at the end, when we might perhaps imagine some technologically advanced alien experimenters in the future looking at the final state of the universe, can any meaningful statement be made.

Exercise VII .

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

collapse	a very thin sheet of metal, especially used to wrap food in to keep it fresh
radium	to stay in one place in the air, usually by moving the wings quickly
foil	to put something into action, especially to make something law
to hover	To suddenly be unable to continue or work correctly
rigid	a radioactive chemical element that is used in the treatment of some diseases, especially cancer
to reinforce	to involve or make something necessary
justification	strange and unusual and difficult to accept or like
to entail	stiff or fixed; not able to be bent or moved:
outlandish	a good reason or explanation for something

to enact	to make something stronger

Exercise VIII.

Summarize the article “Our quantum problem”

Part 2

Exercise I.

Identify the part of speech the words belong to.

fraction, arbitrary, implication, preconception, slippery, ruthlessly, confusing, verification, adherent, formidable,

Exercise II .

Form adjectives from the following words: thinness (2), mass (2), centre (2), energy (2), reality (2), sense (2), possibly (2), extremely(2), well(2), experiment(2)

Exercise III.

Find synonyms to the following words. Translate them into Russian: sheet (2), incredible (2), event (2), source (2), model (2), realize (2), formulate (2), improve (2), version (2), incomprehensible (2)

Exercise IV.

Find antonyms to the following words. Translate them into Russian: undermine (1), collapse (1), inevitable (1), positive (2), thin (2), depart (2), available (2), central (2), stable (2), ugly (2)

Exercise V.

Match the words to make word combinations:

elementary	evidence
final	favour

sealed	laws
nuclear	orbits
statistical	particles
quantum	box
general	thinking
direct	fission
wishful	set
electron	interference

4. The Superfluid Universe

Part 1

Exercise I.

Say what Russian words help to guess the meaning of the following words: conceptual, typical, mathematics, familiar, territory, address, galactic-scale, modifying, exclusive, aspects

Exercise II

Make sure you know the following words and word combination

to breeze, clump, cusp, to invoke, to posit, well-trodden, WIMP, to infer, to condensate, spurious

The Superfluid Universe

Quantum effects are not just subatomic: they can be expressed across galaxies, and solve the puzzle of dark matter (1)

Most of the matter in the Universe is invisible, composed of some substance that leaves no mark as it breezes through us – and through all of the detectors the scientists have created to catch it. But this dark matter might not consist of unseen particle clouds, as most theorists have assumed. Instead, it might be something even stranger: a superfluid that condensed to puddles billions of years ago, seeding the galaxies we observe today. This new proposal has vast implications for cosmology and physics. Superfluid dark matter overcomes many of the theoretical problems with the particle clouds. It explains the long-running, increasingly frustrating failure to identify the individual constituents within these clouds. And it offers a scientific path forward, yielding specific predictions that could soon be testable. Superfluid dark matter has important conceptual implications as well. It suggests that the common picture of the Universe as a mass of individual particles bound together by forces misses much of the richness of nature. Most of the matter in the Universe might be utterly unlike the matter in your body: not composed of atoms, and not even built of particles as we normally understand them, but instead a coherent whole of vast extension. ‘For many years, people had a very simple model for dark matter: collisionless particles that don’t emit light,’ says Justin Khoury, a professor of theoretical physics at the University of Pennsylvania. ‘But in the last 20 years or so, as observations and computer simulations have improved, there are some tensions on galactic scales with this simple model.’ Collisionless dark-matter particles do not substantially interact with each other, and therefore do not settle down into compact structures equivalent to stars and planets. Since dark matter does not (by definition) emit light, the evidence for it comes from its gravitational effects: unseen material seems to have influenced the formation, rotation and motions of galaxies. On very large scales, collisionless dark matter generally matches up well with astronomical observations. On smaller scales, however, this popular and widely used dark-matter model predicts that more material would clump in galactic centres than astronomers actually find, an issue known as the ‘cusp problem’. The model also results in too many satellite galaxies for the Milky Way, and it fails to explain why the ones we have lie almost on a plane. Finally, collisionless dark matter gives no hint as to why the brightness of spiral galaxies is correlated with their rotation velocity. The simple model, it seems, was too simple. One possible explanation for these shortcomings is that physicists have missed an important astrophysical process in galaxy formation. But Khoury doesn't think so. For him, the problems hint at something deeper. It isn't only that the model of collisionless, cold dark matter has its difficulties fitting some data, it's that an entirely different model does better with exactly those observations with which the standard model has difficulties. Instead of invoking new, undiscovered particles, this different model posits that the evidence for dark matter is instead due to a modification of gravity. There is no direct way to measure how gravity behaves over distances of thousands or millions of light years. Subtle effects that cannot be detected on Earth could be powerful enough to have a significant influence on entire galaxies. The modification of gravity is stunningly successful in some cases, but has problems elsewhere. On the one hand, it fits the rotations of galaxies with remarkably little effort and explains why their brightness-velocity relations all seem alike: modified gravity allows less variation from galaxy to galaxy than does the formation of particle clouds, which could all be different. On the other hand, modified gravity struggles with the observational data for distances much larger or smaller than the size of a typical galaxy. On those scales, it's the cold dark matter model that works better. It is notoriously difficult to change anything about Albert Einstein's theory of gravity without ruining it altogether, so most physicists have opted for the safer alternative of particle dark matter. For them, conjecturing new particles is a well-trodden way to solve problems, and the mathematics is familiar territory. But Khoury doesn't want to pick a side. He wants the best of both, to make the best possible fit with the real Universe. 'Traditionally, people have tried to address the galactic-scale problems by modifying gravity; that's been the alternative to dark matter,' Khoury says. 'For some reasons, these two approaches have been considered exclusive: either you're in the modified gravity camp, or you're in the particle dark matter camp. But why couldn't it be both? So the approach we've taken is that both phenomena, modified gravity and particle dark matter, could just be aspects of the same theory.' (2)

Evidence for dark matter has been building since its discovery by the Swiss astronomer Fritz Zwicky more than 80 years ago. In 1933, Zwicky had his eyes on the Hooker telescope at Mount Wilson Observatory in California, and aimed at the Coma Cluster. The Coma Cluster is a swarm of about 1,000 galaxies bound together by the pull of their own gravitational field. In such a bound system, the velocities of the constituents – in this case, galaxies – depend on the total mass that is bound. Zwicky noted that the galaxies were moving much more quickly than the visible mass combined could account for, and he speculated that the cluster must contain unseen matter. Physicists might have dismissed this case as a peculiarity. But it became apparent that Zwicky's observation was the rule rather than the exception when the American astronomer Vera Rubin, starting in the 1960s, studied the rotation of spiral galaxies. The velocity of stars on orbits far away from a galaxy's centre depends on the total mass (and hence gravitational pull) of the bound system, in this case the mass of the galaxy. Rubin's measurements showed that dozens of galaxies were rotating more rapidly than only the visible matter had led her to expect. Ever since Rubin's observations brought dark matter to the limelight, it has ranked top on the list of physicists' unsolved problems. With steadily improving telescope technology, the observational support for dark matter has accumulated and become more precise. Physicists are now able to perceive the subtle distortions caused by the gravitational warping of space-time near galaxy clusters. This distortion, known as weak gravitational lensing, slightly deforms the images of more distant stellar objects; their light bends around the cluster, whose gravity acts as a lens. From the strength of this effect, the cluster's total mass can be calculated, demonstrating the presence of dark matter. By this method, physicists have even generated maps of the distribution of dark matter. Combining this with other lines of evidence, they have deduced that 85 per cent of the matter in the Universe must be dark. With more data, physicists could also exclude the idea that dark matter consists of unseen clumps of ordinary atoms, like the ones Earth is made of (technically known as baryonic matter). This normal matter interacts too strongly with itself; it would not produce the observed distribution of dark matter. Dark matter also cannot be made of stars that collapsed to black holes or other very dim stellar objects. If that were so, these objects would have to vastly outnumber the stars in our galaxy and cause intense gravitational distortions that could be readily observed. Nor can dark matter be made of other known particles, such as the weakly interacting neutrinos that are emitted abundantly by stars. Neutrinos would not clump enough to create the observed galactic structures. Therefore, to explain what makes up dark matter, physicists instead had to theorise about new, so far undetected, particles. The most widely used ones fall into two broad classes: weakly interacting massive particles (WIMPs) and much lighter axions, though there is no shortage of more complex hypotheses that combine various types of particles. But all attempts to detect any of these particles directly, rather than inferring their presence from their gravitational pull, have so far been unsuccessful. Instead of solving the mystery, the direct-detection experiments have only deepened it. It is impossible to be interested in cosmology today without being interested in dark matter,' says Stefano Liberati, a physics professor at the International School for Advanced Studies (SISSA) in Italy. Liberati and his collaborators have independently worked out an explanation for dark matter very similar to Khoury's. When Liberati first learned how successful modifications of gravity are on galactic scales where cold dark matter models fall short, he immediately tried to think of ways to combine the two. 'It made me think: maybe dark matter at small scales makes a type of phase transition,' he says. 'Maybe it transforms into a type of fluid, in particular a superfluid. If it forms a condensate at the scale of galaxies, this really solves a lot of problems.' (3)

Superfluids do not exist in daily human experience, but they are well-known to physicists. They are analogous to superconductors, a class of materials that moves electricity without resistance. When cooled to temperatures near absolute zero, helium likewise starts flowing without resistance. It will creep through the tiniest pores, and even slide out of trays by moving up walls. Such 'superfluid' behaviour isn't specific to helium; it is a phase of matter that, at low enough temperatures, can be reached by other particles too. First predicted in 1924 by Einstein and the Indian physicist Satyendra Bose, this whole class of ultra-cold superfluids is now known as Bose-Einstein condensates. Liberati realised that dark matter might have a superfluid state as well. Bose-Einstein condensates are best understood as a mixture of two components: one that is superfluid and one that isn't. The two components behave very differently. The superfluid one exhibits long-range quantum effects, no viscosity, and unexpected correlations over large distance scales; it is as if it was made of much larger particles than its actual tiny constituents. The other normal component behaves like the fluids we are used to; it sticks to containers and to itself – it has a viscosity. The ratio between the two components depends on the condensate's temperature: the higher the temperature, the more dominant the normal component. We are used to thinking that quantum physics dominates only the microscopic realm. But the more physicists have learned about quantum theory, the more it has become clear that this isn't so. Bose-Einstein condensates are one of the best-studied substances that allow quantum effects to spread widely through a medium. In theory, quantum behaviour can span arbitrarily large distances, provided it isn't disturbed too much. In a warm and noisy environment such as Earth, fragile quantum effects are quickly destroyed. That is why we don't normally observe the stranger aspects of quantum physics, such as the ability of particles to behave like waves. But initiate quantum behaviour in a cool, quiet place and it will last. A cool, quiet place like, for example, outer space. There, quantum effects might stretch across vast distances. If dark matter were a Bose-Einstein condensate – one with quantum effects spreading throughout whole galaxies – this state would naturally account for two different behavioural modes of dark matter. Within galaxies themselves, most of the dark matter would be in the superfluid phase. But across galaxy clusters that include much intergalactic space, most of the dark matter would be in the normal phase, giving rise to a different behaviour. According to Khoury and collaborators, it is possible to explain the observed effects of dark matter with a simple model of a Bose-Einstein condensate, one that has only a few open parameters (that is, just a few properties that must have the right attributes to make the model work). The idea that dark matter might be a Bose-Einstein condensate had circled through the astrophysics community before, but this version is different. What makes Khoury's new idea so compelling is that he claims the superfluid dark matter could also mimic modified gravity: it achieves his goal of combining the best of both models. Gravity, it turns out, must not actually be modified to get the results seen in the modified gravity theories. A coherent superfluid can give rise to the same equations, and the same behaviours. In this way, Khoury's model combines the advantages of both cold dark matter and modified gravity, without the disadvantages of either. Superfluid dark matter might also overcome the biggest challenge for modified gravity: most astrophysicists dislike it. Many of these researchers have a background in particle physics, and the equations of modified gravity are nothing like what they are used to. To the particle physicist, they look unappealing, unnatural even. They seem made up merely to fit the bill. But superfluid dark matter offers a different, perhaps more natural way of coming at the equations. According to Khoury, the equations for superfluid dark matter don't belong to the realm of elementary particle physics. They emerge from theory in condensed matter physics, where they describe not the fundamental particles, but their emergent long-range behaviour. In Khoury's model, the equations that appear in modified gravity are not those of the individual particles. Instead, they are a description of the particles' collective interplay. Such equations are unfamiliar to many particle physicists, which is why the relation between superfluidity and modified gravity remained unnoticed for so long. Unlike the equations of modified gravity, however, the equations describing superfluids already have a strong theoretical foundation – just in condensed-matter physics. That Khoury noticed the connection was serendipity. He came across literature in condensed matter physics that used equations very similar to the ones he knew from modified gravity: 'And then the rest just fit in,' he says. 'I thought all of this just formed a nice picture to unify the two phenomena.' Returning to the observational evidence for dark matter, Khoury's superfluid approach could solve many problems with the existing models. To begin with, the superfluid prevents dark matter from clumping too much in galactic centres, eliminating the spurious 'cusp', because the superfluid phase evens out any strong density fluctuations. 'A superfluid will have a coherence length a distance over which all of the matter is in the same state,' Liberati says. 'You already know that you can't have a cusp.' (4)

The superfluid generates patterns of attraction identical to those of the equations of modified gravity, so it can reproduce the observed regularity of galactic rotation curves. However, unlike modified gravity, it behaves this way only in the temperature range in which the superfluid component is dominant. On the larger scale of galactic clusters, the dark matter gets too agitated (that is, too hot) and loses its superfluid properties. In this way, superfluid dark matter could have seeded the formation of visible galaxies while, in its non-superfluid phase, it would match up with the observed structure of clusters. Khoury's approach explains why astronomers do not see any evidence of modified gravity within the solar system. 'The Sun itself creates such a huge gravitational field that it would locally destroy the superfluid's coherence,' he says. 'In the vicinity of the solar system, you shouldn't think in terms of a coherent superfluid. The Sun acts like an impurity. It's like there's dirt in the fluid.' Finally, the superfluid model explains why physicists have not been able to find dark matter particles. Starting in the 1980s, dozens of different experiments have looked for direct evidence of such particles. The experiments generally use large, well-shielded tanks of different materials that might, on rare occasions, interact with a dark matter particle and produce an observable signal. Despite a wide variety of techniques and materials, using detectors that are carefully shielded and hidden away in underground mines to filter out false signals, no conclusive evidence of dark matter has been found. With that lack of detection, the once-derided idea that dark matter might be something other than just another type of particle is becoming more compelling. If dark matter is a superfluid, the particles it is made of must be lightweight, much lighter than the hypothetical dark particles that have been the targets of most of the searches. The superfluid's constituents are probably too slight to show up in the experiments currently running. A better and unique prediction of Khoury's model is that a superfluid's quantum behaviour should leave a telltale pattern in galactic collisions. When the dark matter condensate from one galaxy runs into that of another, the collision would create interference patterns – ripples in the distribution of matter and gravity, which would affect how the galaxies settle. Superfluid dark matter also makes predictions for the friction between the dark matter components within galaxy clusters; such friction would again produce distinctive patterns of gravitational attraction. Observations of gravitational lensing could detect these fingerprints of superfluid dark matter, provided we know exactly what we're looking for. To quantify the predictions, computer simulations are necessary. Khoury is currently working on just such a project with researchers at the University of Oxford. Simulations should also show whether the expected number of satellite galaxies from superfluid dark matter agrees better with observations than do the predictions of the current models. Amanda Weltman, a cosmologist at the University of Cape Town, who works on dark matter but was not involved in this research, finds the new model 'very interesting and creative'. But she says she will reserve judgment until she sees some experimental confirmation, some signature that would distinctively support superfluids: 'Such an observation would then lend real weight to their ideas.' If the supercomputer simulations are a success, Khoury might be able to produce that kind of evidence. Then we will have to get used to an even stranger view of the Universe – one filled not just with dark matter, but with frictionless fluids swirling around all of the bright galaxies. Arkani-Hamed is more skeptical, not quite ready to give up on cold dark matter. 'But if they don't discover WIMPs in the next set of experiments, they're not going to see them for 20 years,' he says. The time is ripe, he thinks, to take a fresh look at models built around unconventional particles or modified theories of gravity. Or a model that combines the best of both dark worlds. (5)

Adapted from Aeon.

Exercise III.

Find paragraphs, dealing with the following: cloud, to puddle, vast, fresh, skeptical, frictionless, judgment, simulations, fingerprints, project

Exercise IV.

Fill in the gaps.

1. Colin Markland relishes the feel of an ocean ………… as it musses his white hair.

2. Adding to their **……….** , shores they have cleaned of oil may be oiled again.

3. The project tested his talents in computer design, carpentry and **…………** art.

4. One thing many people overlook when landing in India is that the big cities with international ariports are just an **………….** of our western cities.

5. This dark matter accounts for the uniform **…….** data without modifying Newton's law of gravity.

6. The camera in the capsule now enabled them to observe how the **…………** spread.

7. It seems reasonable to assume a **………….** between wealth and entrepreneurship.

8. Of course, customers don't have to wait until April to eat **…………** California kiwi.

9. His former research group at Cornell currently studies **……..** -helium solids.

10. He behaved that way also before getting ill, he never was **………** on any issue.

Exercise V.

Make up sentences of your own with the following word combinations: to solve the puzzle (1), to leave no mark (2), on very large scales (2), to match up well with (2), on smaller scales (2), on a plane (2), to give no hint (2), to pick a side (2), to fall short (3), to fit the bill (4).

Exercise VI.

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

1. Most of the matter in the Universe is visible.
2. 'For many years , people had a very simple model for dark matter: collisionless particles that emit light,' says Justin Khoury, a professor of theoretical physics at the University of Pennsylvania.
3. Collisionless dark-matter particles substantially interact with each other, and therefore do not settle down into compact structures equivalent to stars and planets.
4. On very large scales, collisionless dark matter does not generally match up well with astronomical observations.

5. On smaller scales, however, this popular and widely used dark-matter model predicts that more material would clump in galactic centres than astronomers actually find, an issue known as the ‘cusp problem’.

6. There is no direct way to measure how gravity behaves over distances of thousands or millions of light years.

7. Evidence for dark matter has been building since its discovery by the Swiss astronomer Fritz Zwicky more than 80 years ago.

8. In 1933, Zwicky had his eyes on the Hooker telescope at Mount Wilson Observatory in California, and aimed at the Coma Cluster.

9. The Coma Cluster is a swarm of about 1,000 galaxies bound together by the pull of their own gravitational field.

10. Zwicky noted that the galaxies were moving much more slowly than the visible mass combined could account for, and he speculated that the cluster must contain unseen matter.

Exercise VII .

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

to constitute	wholly developed
attribute	to form or make something
coherent	a quality or characteristic that someone or something has
telltale	an unusual state of matter noted only in liquid helium cooled to near absolute zero and characterized by apparently frictionless flow (as through fine holes)
ripe	a substance, especially a metal, that allows

	an electrical current to move freely t hrough it at a very low temperature
superfluids	something strange or not known that has not yet been explained or understood
spiral	having its parts related in an organized and reasonable way
hypotheses	important because of showing information
mystery	a shape made up of curves, each one above or wider than the one before
superconductor	an idea or explanation for something that is based on known facts but has notyet been proved

Exercise VIII.

Summarize the article "The Superfluid Universe".

Part 2

Exercise I.

Identify the part of speech the words belong to.

frustration, implication, conceptual, extention, correlation, serendipity, impurity, vicinity, conjecture, compelling

Exercise II .

Form adverbs from the following words: individual (2), specific (2), unlike (2), nature (2), equivalent (2), popular (2), different (2), evidence (2), direct (2), powerful (2)

Exercise III.

Find synonyms to the following words. Translate them into Russian: puzzle (1), mark (2), consist (2), overcome (2), identify (2), constituent (2), picture (2), individual (2), emit (2), tension (2)

Exercise IV .

Find antonyms to the following words. Translate them into Russian: invisible (2), create (2), catch (2), unseen (2), failure (2), compact (2), fail (2), cold (2), dark (2), undiscovered (2)

Exercise V.

Match the words to make word combinations:

particle	evidence
theoretical	velocity
Coma	physics
coherence	picture
rotation	Cluster
condensed-matter	foundation
conclusive	matter
astronomical	length
condendensed	observations
common	clouds

SUPPLEMENTARY READING

Who knows what

For decades the sciences and the humanities have fought for knowledge supremacy. Both sides are wrong-headed

Whenever we try to make an inventory of humankind's store of knowledge, we stumble into an ongoing battle between what CP Snow called 'the two cultures'. On one side are the humanities, on the other are the sciences (natural and physical), with social science and philosophy caught somewhere in the middle. This is more than a turf dispute among academics. It strikes at the core of what we mean by human knowledge.

Snow brought this debate into the open with his essay The Two Cultures and the Scientific Revolution, published in 1959. He started his career as a scientist and then moved to the humanities, where he was dismayed at the attitudes of his new colleagues. 'A good many times,' he wrote, 'I have been present at gatherings of people who, by the standards of the traditional culture, are thought highly educated and who have with considerable gusto been expressing their incredulity at the illiteracy of scientists. Once or twice I have been provoked and have asked the company how many of them could describe the Second Law of Thermodynamics. The response was cold: it was also negative. Yet I was asking something which is the scientific equivalent of: Have you read a work of Shakespeare's?'

That was more than half a century ago. If anything, the situation has got worse. Throughout the 1990s, postmodernist, deconstructionist and radical feminist authors (the likes of Michel Foucault, Jacques Derrida, Bruno Latour and Sandra Harding) wrote all sorts of nonsense about science, clearly without understanding what scientists actually do. The feminist philosopher Harding once boasted: 'I doubt that in our wildest dreams we ever imagined we would have to reinvent both science and theorising itself'. That's a striking claim given the dearth of novel results arising from feminist science. The last time I checked, there were no uniquely feminist energy sources on the horizon.

In order to satirise this kind of pretentiousness, in 1996 the physicist Alan Sokal submitted a paper to the postmodernist journal *Social Text*. He called it 'Transgressing the Boundaries: Toward a Transformative Hermeneutics of Quantum Gravity'. There is no such thing as a hermeneutics of quantum gravity, transformative or not, and the paper consisted entirely of calculated nonsense. Nevertheless, the journal published it. The moral, Sokal concluded, was that postmodern writing on science depended on ‘radical-sounding assertions’ that can be given ‘two alternative readings: one as interesting, radical, and grossly false; the other as boring and trivially true’. Blame for the culture wars doesn’t lay squarely on the shoulders of humanists, however. Scientists have employed their own overblown rhetoric to aggrandise their doings and dismiss what they haven’t read or understood. Their target, interestingly, is often philosophy. Stephen Hawking began his 2010 book The Grand Design by declaring philosophy dead — though he neglected to provide evidence or argument for such a startling conclusion. Earlier this year, the theoretical physicist Lawrence Krauss told The Atlantic magazine that philosophy ‘reminds me of that old Woody Allen joke: those that can’t do, teach, and those that can’t teach, teach gym. And the worst part of philosophy is the philosophy of science; the only people, as far as I can tell, that read work by philosophers of science are other philosophers of science. It has no impact on physics whatsoever’.

To begin with, it is fair to point out that the only people who read works in theoretical physics are theoretical physicists, so by Krauss’s own reasoning both fields are irrelevant to everybody else (they aren’t, of course). Secondly, Krauss, and Hawking for that matter, seem to miss the fact that the business of philosophy is not to solve scientific problems — we’ve got science for that. Objecting to philosophy on these grounds is like complaining that historians of science haven’t solved a single puzzle in theoretical physics. That’s because historians do history, not science. When was the last time a theoretical physicist solved a problem in history? And as the philosopher Daniel Dennett wrote in Darwin’s Dangerous Idea (1995), a book that has been very popular among scientists: ‘There is no such thing as philosophy-free science; there is only science whose philosophical baggage is taken on board without examination’. Whether or not they realise it, Hawking and Krauss need philosophy as a background condition for what they do. Perhaps the most ambitious contemporary attempt at reconfiguring the relationship between the sciences and the humanities comes from the biologist EO Wilson. In his 1998 book, Consilience: The Unity of Knowledge, he proposed nothing less than to explain the whole of human experience in terms of the natural sciences. Beginning with the premise that we are biological beings, he attempted to make sense of society, the arts, ethics and religion in terms of our evolutionary heritage. 'I remember very well the time I was captured by the dream of unified learning,' he wrote. 'I discovered evolution. Suddenly — that is not too strong a word — I saw the world in a wholly new way'.

Wilson claims that we can engage in a process of 'consilience' that leads to an intellectually and aesthetically satisfactory unity of knowledge. Here is how he defines two versions of consilience: 'To dissect a phenomenon into its elements … is consilience by reduction. To reconstitute it, and especially to predict with knowledge gained by reduction how nature assembled it in the first place, is consilience by synthesis'. Despite the unfamiliar name, this is actually a standard approach in the natural sciences, and it goes back to Descartes. In order to understand a complex problem, we break it down into smaller chunks, get a grasp on those, and then put the whole thing back together. The strategy is called reductionism and it has been highly successful in fundamental physics, though its success has been more limited in biology and other natural sciences. The overall image that Wilson seems to have in mind is of a downward spiral wherein complex aspects of human culture — literature, for example — are understood first in terms of the social sciences (sociology, psychology), and then more mechanistically by the biological sciences (neurobiology, evolutionary biology), before finally being reduced to physics. After all, everything is made of quarks (or strings), isn't it?

Before we can see where Wilson and his followers go wrong, we need to make a distinction between two meanings of reductionism. There is ontological reduction, which has to do with what exists, and epistemic reduction, which has to do with what we know. The first one is the idea that the bottom level of reality (say, quarks, or strings) is causally sufficient to account for everything else (atoms, cells, you and me, planets, galaxies and so forth). Epistemic reductionism, on the other hand, claims that knowledge of the bottom level is sufficient to reconstruct knowledge of everything else. It holds that we will eventually be able to derive a quantum mechanical theory of planetary motions and of the genius of Shakespeare. The notion of ontological reductionism is widely accepted in physics and in certain philosophical quarters, though there really isn't any compelling evidence one way or the other. Truth be told, we don't know whether the laws that control the behaviour of quarks scale up to the level of societies and galaxies, or whether large complex systems exhibit novel behaviour that can't be reduced to lower ontological levels. I am, therefore, agnostic about ontological reductionism. Fortunately for the purposes of this discussion, it doesn't matter one way or the other. The real game lies in the other direction.

Epistemic reductionism is obviously false. We do not have — nor are we ever likely to have — a quantum mechanical theory of planets or of human behaviour. Even if possible in principle, such a theory would be too complicated to compute or to understand. Chemistry might have become a branch of physics via a successful reduction, and neurobiology certainly informs psychology. But not even the most ardent physicist would attempt to produce an explanation of, say, ecosystems in terms of subatomic particles. The impossibility of this sort of epistemic reductionism therefore puts one significant constraint on Wilson-type consilience. The big question, then, is how far we can push the programme. Let's begin in the obvious place. If culture has to be understood in terms of biology, then genes must have quite a bit to do with it. Wilson, however, is too sophisticated to fall into straightforward genetic determinism. Instead he tells us: 'Genes prescribe epigenetic rules, which are the regularities of sensory perception and mental development that animate and channel the acquisition of culture'. As it happens, I have worked on epigenetics. The word actually refers to all the molecular processes that mediate the effects of genes during plant and animal development. The problem from Wilson's point of view is this: biologists don't know what 'epigenetic rules' are. They don't know how to quantify them or how to study them. For explanatory purposes, they are vacuous.

Wilson's next move is to invoke Richard Dawkins's idea of 'memes', or units of cultural evolution. If culture is made of discrete units that can replicate in the environment of human society, perhaps there is a way to bring evolutionary theory to bear directly on culture. Instead of genes (or epigenes), we apply Darwinian principles to memes. Unfortunately for consilience, the research programme of memetics is in big trouble. Scientists and philosophers have cast doubt on the usefulness, even the coherence, of the very concept. As my evolutionary biology colleague Jerry Coyne has said, it is 'completely tautological, unable to explain why a meme spreads except by asserting, post facto, that it had qualities enabling it to spread'. We don't know how to define memes in a way that is operationally useful to the practicing scientist, we don't know why some memes are successful and others not, and we have no clue as to the physical substrate, if any, of which memes are made. Tellingly, the Journal of Memetics closed a few years ago for lack of submissions.

None of the above, of course, is to say that biology is irrelevant to human culture. We are indeed biological entities, so lots of what we do is connected with food, sex and social status. But we are also physical entities, and humanity has found cultural ways to exploit or get around physics. We built aeroplanes to fly despite the limitations imposed by gravity, and we invented endless variations on the basic biological themes, from Shakespeare's sonnets to Picasso's paintings. In each case, the supposedly fundamental sciences give us only a very partial picture of the whole. If we take the idea of unity of knowledge seriously, there are some broad categories of inquiry that we should try to integrate into our picture. This turns out to be harder than we might think. Take mathematics and logic. Wilson is keen on these disciplines. 'The dream of objective truth peaked,' he writes, 'with logical positivism' — that is, with a philosophical movement of the 1920s and '30s that attempted to capture the essence of scientific statements using logic. Mathematics, too, is central to his scheme. Because of its effectiveness in the natural sciences, it 'seems to point arrowlike toward the ultimate goal of objective truth'.

Let's leave aside the pretty well-established fact that human beings aren't in the business of 'ultimate objective truth'. When we come down to it, is scientific knowledge the same kind of thing as mathematical-logical knowledge? They are, I think, quite different. Look at what counts as a 'fact' in science: for instance the statement that there are four natural satellites of Jupiter that can be seen through small telescopes from Earth. These satellites were discovered by Galileo Galilei in the 17th century, and represented the first example of a solar-like system within our own Sun-centred one. Indeed, Galilei used this as a major reason to take seriously the then-highly controversial Copernican theory. By contrast, take a mathematical 'fact', such as the demonstration of the Pythagorean theorem. Or a logical fact, such as a truth table that tells you the conditions under which particular combinations of premises yield true or false conclusions according to the rules of deduction. These two latter sorts of knowledge do resemble one another in certain ways; some philosophers regard mathematics as a type of logical system. Yet neither looks anything like a fact as it is understood in the natural sciences. Therefore, 'unifying knowledge' in this area looks like an empty aim: all we can say is that we have natural sciences over here and maths over there, and that the latter is often useful (for reasons that are not at all clear, by the way) to the former.

Let's consider yet another type of fact, more germane to the project of reducing the humanities to the sciences. I happen to have a strong conviction that the music of Ludwig van Beethoven is better than that of Britney Spears. To me, that's an aesthetic fact. I hope it's also clear that this is a 'fact' (based on my 'knowledge' of music) that has a different structure and content from both logical-mathematical and natural-scientific facts. Indeed, it isn't a fact at all: it's an aesthetic judgment, one to which I have a strong emotional attachment. Now, I do not doubt that my ability to make aesthetic judgments in general is influenced by the kind of biological being that I am. I need to have a particular type of auditory system even to hear Beethoven and Spears, and that system presumably accounts for why musicians rarely produce pieces outside a certain range of sound frequencies. Still, it seems hard to deny that my particular judgment about Beethoven versus Spears is primarily the result of my culture and psychology and upbringing. People in different times and cultures, or with different temperaments, have disagreed and will disagree with me — and they might feel just as strongly about their tastes as I do about mine (of course, they would be 'wrong'). Clearly, there are aspects of human culture in which the very notion of 'objective and ultimate truth' is a category mistake.

Let's set aside the goal of unifying all knowledge. How are we doing in the millennia-long quest for absolute and objective truth? Not so well, it seems, and that is largely because of the devastating contributions of a few philosophers and logicians, particularly David Hume, Bertrand Russell and Kurt Gödel. In the 18th century, Hume formulated what is now known as the problem of induction. He noted that both in science and everyday experience we use a type of reasoning that philosophers call induction, which consists in generalising from examples. Hume also pointed out that we do not seem to have a logical justification for the inductive process itself. Why then do we believe that inductive reasoning is reliable? The answer is that it has worked so far. Ah, but to say so is to deploy inductive reasoning to justify inductive reasoning, which seems circular. Plenty of philosophers have tried to solve the problem of induction without success: we do not have an independent, rational justification for the most common type of reasoning employed by laypeople and professional scientists. Hume didn't say that we should therefore all quit and go home in desperation. Indeed, we don't have an alternative but to keep using induction. But it ought to be a sobering thought that our empirical knowledge is based on no solid foundation other than that 'it works'.

What about maths and logic? At the beginning of the 20th century, a number of logicians, mathematicians and philosophers of mathematics were trying to establish firm logical foundations for mathematics and similar formal systems. The most famous such attempt was made by Bertrand Russell and Alfred North Whitehead, and it resulted in their Principia Mathematica (1910-13), one of the most impenetrable reads of all time. It failed. A few years later the logician Kurt Gödel explained why. His two 'incompleteness theorems' proved — logically — that any sufficiently complex mathematical or logical system will contain truths that cannot be proven from within that system. Russell conceded this fatal blow to his enterprise, as well as the larger moral that we have to be content with unprovable truths even in mathematics. If we add to Gödel's results the well-known fact that logical proofs and mathematical theorems have to start from assumptions (or axioms) that are themselves unprovable (or, in the case of some deductive reasoning like syllogisms, are derived from empirical observations and generalisation — ie, from induction), it seems that the quest for true and objective knowledge is revealed as a mirage.

At this point one might wonder what exactly is at stake here. Why are Wilson and his followers in search of a unified theory of everything, a single way to understand human knowledge? Wilson gives the answer explicitly in his book, and I think it also applies implicitly to some of his fellow travellers, for instance the physicist Steven Weinberg in his book Dreams of a Final Theory (1992). The motive is philosophical. More specifically, it is aesthetic. Some scientists really value simplicity and elegance of explanations, and use these criteria in evaluating of the relative worth of different theories. Wilson calls this 'the Ionian enchantment', and names the first chapter of Consilience accordingly. But the irony here is obvious. Neither simplicity nor elegance are empirical concepts: they are philosophical judgments. There is no reason to believe a priori that the universe can be explained by simple and elegant theories, and indeed the historical record of physics includes several instances when the simplest of competing theories turned out to be wrong.Enough with the demolition project. Is it possible to reconstruct something like Wilson's consilience, but in a more reasonable manner? Think about visual art. Its history includes prehistoric cave paintings, Michelangelo, Picasso, and contemporary abstraction. It is reasonable to think that science — perhaps a combination of evolutionary biology and cognitive science — can tell us something about why our ancestors started painting to begin with, as well as why we like certain types of patterns: symmetrical figures, for instance, and repetitions of a certain degree of complexity. Yet these sorts of explanations massively underdetermine the variety of ways of doing visual art, both across centuries and across cultures. Picasso's cubism is not about symmetry, for instance; indeed, it's about breaking symmetry. And it is hard to imagine an explanation of the rise of, say, the Impressionist movement that doesn't invoke the specific cultural circumstances of late 19th century France, and the biographies and psychologies of individual artists.

We find a similar situation with maths. It is plausible that our ability to count and do simple arithmetic gave us an evolutionary advantage and was therefore the result of natural selection. (Notice, however, that this is a speculative argument: we don't have access to the kind of evidence needed to test the hypothesis.) But what on earth is the possible adaptive value of highly abstract mathematics? Why would evolution produce brains such as Andrew Wiles's, capable of solving Fermat's last theorem? Biology sets the background conditions for such feats of human ingenuity, since a brain of a particular type is necessary to accomplish them. But biology by itself has little else to say about how some human cultures took a historical path that ended up producing a small group of often socially awkward people who devote their lives to solving abstruse mathematical problems. Or, finally, take morality, perhaps the most important aspect of what it means to be human. Much has been written on the evolutionary origins of morality, and many good and plausible ideas have been proposed. Our moral sense might well have originated in the context of social life as intelligent primates: other social primates do show behaviours consistent with the basic building blocks of morality such as fairness toward other members of the group, even when they aren't kin. But it is a very long way from that to Aristotle's Nicomachean Ethics, or Jeremy Bentham and John Stuart Mill's utilitarianism. These works and concepts were possible because we are biological beings of a certain kind. Nevertheless, we need to take cultural history, psychology and philosophy seriously in order to account for them.

Here's a final thought. Wilson's project depends on the assumption that there is such a thing as human knowledge as a unifiable category. For him, disciplinary boundaries are accidents of history that need to be eliminated. But what if they helped to explain some further fact? An intriguing view has been proposed in different contexts by the linguist Noam Chomsky, in his Reflections on Language (1975), and the philosopher Colin McGinn, in The Problem of Consciousness (1991). The basic idea is to take seriously the fact that human brains evolved to solve the problems of life on the savannah during the Pleistocene, not to discover the ultimate nature of reality. From this perspective, it is delightfully surprising that we learn as much as science lets us and ponder as much as philosophy allows. All the same, we know that there are limits to the power of the human mind: just try to memorise a sequence of a million digits. Perhaps some of the disciplinary boundaries that have evolved over the centuries reflect our epistemic limitations.Seen this way, the differences between philosophy, biology, physics, the social sciences and so on might not be the result of the arbitrary caprice of academic administrators and faculty; they might instead reflect a natural way in which human beings understand the world and their role in it. There might be better ways to organise our knowledge in some absolute sense, but perhaps what we have come up with is something that works well for us, as biological-cultural beings with a certain history. This isn't a suggestion to give up, much less a mystical injunction to go 'beyond science'. There is nothing beyond science. But there is important stuff before it: there are human emotions, expressed by literature, music and the visual arts; there is culture; there is history. The best understanding of the whole shebang that humanity can hope for will involve a continuous dialogue between all our various disciplines. This is a more humble take on human knowledge than the quest for consilience, but it is one that, ironically, is more in synch with what the natural sciences tell us about being human. Is one discipiline better than the other when it comes to understanding humanity?

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