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Английский язык для механиков и математиков

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Целью пособия является совершенствование навыков чтения, говорения и письма для формирования необходимой языковой, речевой и социокультурной компетенции, позволяющей эффективно использовать английский язык в профессиональной среде.

Для студентов и аспирантов механико-математического факультета МГУ.

Рецензент:
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Цель пособия — обеспечить условия для формирования необходимой языковой, речевой и социокультурной компетенции, позволяющей в дальнейшем использовать английский язык как средство для удовлетворения прежде всего профессиональных потребностей в области чтения, говорения и письма. Оно может быть использовано на занятиях со студентами и аспирантами, владеющими английским языком на уровне не ниже intermediate.

Структура пособия. Пособие состоит из двух частей (Part One и Part Two), каждая из которых подразделяется на уроки (Units) и сопровождается приложением (Appendix). В качестве текстовой основы использованы в основном отрывки статей из научно-популярного журнала Scientific American (1999–2009 гг.). Первая часть (Part One, Units I–VIII, Appendix) посвящена некоторым вопросам механики, тогда как во второй части (Part Two, Units IX–XV, Appendix) рассматриваются некоторые вопросы математики. Хочется надеяться, что этот материал будет интересен, поскольку статьи посвящены актуальным научным исследованиям и написаны известными специалистами в своей области. Это обстоятельство, с нашей точки зрения, свидетельствует о познавательной ценности текстов. Однако чтение в данном пособии рассматривается не просто как способ получения необходимой информации, что само по себе важно, но и как средство формирования смежных языковых и речевых навыков и умений. Многолетний опыт обучения студентов и аспирантов свидетельствует о том, что «чтение позволяет учащимся оптимизировать процесс усвоения языкового и речевого материала»[1].

Каждый урок (Unit) включает лексику этого урока (Word Combinations, Vocabulary Notes, Key Terms), тренировочные упражнения, тексты на английском и русском языках, краткую информацию об авторах этих текстов. Предполагается, если иное не оговорено, беспереводное чтение. Проверка понимания прочитанного осуществляется с помощью ответов на вопро-

[1] Е. Н. Соловова. Методика обучения иностранным языкам. Базовый курс лекций. — М.: Просвещение 2002, с. 141.

сы (Comprehension Exercises) и дискуссии по содержанию. К переводу же рекомендуется прибегать лишь в отдельных случаях (см. выделенные предложения). Это следует делать тогда, когда мы сталкиваемся с такими языковыми явлениями, которые вызывают трудности у русскоязычных студентов. Для того, чтобы снять эти трудности и прояснить ситуацию, разработана система упражнений, некоторые из которых содержат необходимый комментарий. При этом учитывается также и частотность того или иного явления, преследуя практическую целесообразность соответствующего упражнения.

Раздел Vocabulary Notes составлен с использованием Macmillan English Dictionary for Advanced Learners и Oxford Advanced Learner's Dictionary с целью помочь студентам научиться работать с толковыми англо-английскими словарями, которые снабжены не только дефинициями слов, но и дают представление о сочетаемости слов в английском языке и рассматривают особенности их употребления. Это позволит предупредить ошибки и минимизировать явление интерференции, т.е. отрицательного влияния родного языка на формирование соответствующих языковых и речевых навыков.

Большое внимание в пособии уделяется развитию навыков говорения, в частности в разделе Conversational Practice, когда на занятии моделируется реальная ситуация общения, провоцирующая мыслительную деятельность в рамках проблематики, затронутой в прочитанных текстах. Коммуникативными по содержанию являются также и упражнения на письмо, предполагающие написание рефератов, мини-докладов и т.д. Закреплению лексики урока способствует упражнение на передачу содержания по-английски русского текста, тематически созвучного с основным текстом урока.

В приложении (Appendix) представлены тексты из периодических журналов, которые предназначены для самостоятельной работы студентов.

Выражаем искреннюю благодарность рецензенту пособия — доктору филологических наук, профессору Е. Б. Яковлевой, а также Ю. Б. Григорьевой, Р. Ю. Рогову и А. А. Савченко за помощь, оказанную при подготовке пособия к печати.

Contents

Part One

Unit I

Text I

WAS EINSTEIN RIGHT?[2]

Unlike nearly all his contemporaries, Albert Einstein thought quantum mechanics would give way to a classical theory. Some researchers nowadays are inclined to agree

by George Musser

THE AUTHOR

George Musser exists in a quantum superposition of staff writer and staff editor.

Word Combinations

to doubt smb's greatness
to make an effort/redouble one's effort
to eclipse one's scientific rationality
to walk down the same road
to yield to a fundamental theory
to supersede a theory
to overcome limitations
in the pursuit of a theory
to offer a reason for smth
compelling conceptual foundations

[2]Scientific American, September 2004, pp. 88–89

a theoretical framework
to be a matter of time
to be the first to do smth
to fail to do smth
to provide a way to do smth
to trigger a collapse
the idea derives from
the randomness of smth
a coin toss
to exceed the limit
an obvious response to smth
hidden variables
to obey the law
to look random
to propose doing smth
not to mention
rather than the other way round
to handle a problem

I Read the questions and find answers in the text that follows.

1. What does Einstein's idea of a unified theory suggest?
2. What are the pros and cons of the quantum theory as a framework of the unified theory?

Einstein has become such an icon that it sounds sacrilegious to suggest he was wrong. *Even his notorious "biggest blunder" merely reinforces his aura of infallibility: the supposed mistake turns out to explain astronomical observations quite nicely* [see "A Cosmic Conundrum," by Lawrence M. Krauss and Michael S. Turner, p.71]. *But if most laypeople are scandalized by claims that Einstein may have been wrong, most theoretical physicists would be much more startled if he had been right.*

Although no one doubts the man's greatness, physicists wonder what happened to him during the quantum revolution of the 1920s and 1930s. Textbooks and biographies depict him as the quantum's deadbeat dad. In 1905 he helped to bring the basic concepts into the world, but as quantum mechanics matured, *all he seemed to do was wag his finger.* He made little effort to build up the theory and much to tear it down. *A reactionary mysticism — embodied in his famous pronouncement, "I shall never believe that God plays dice with the world" — appeared to eclipse his scientific rationality.*

Estranged from the quantum mainstream, Einstein spent his final decades in quixotic pursuit of a unified theory of physics. String theorists and others who later took up that pursuit vowed not to walk down the same road. Their assumption has been that when the general theory of relativity (which describes gravity) meets quantum mechanics (which handles everything else), *it is relativity that must give way*. Einstein's masterpiece, though not strictly "wrong", will ultimately be exposed as mere approximation.

COLLAPSING THEORIES

In recent years, though, as physicists have redoubled their efforts to grok quantum theory, a growing number have come to admire Einstein's position. "This guy saw more deeply and more quickly into the central issues of quantum mechanics than many give him credit for", says Christopher Fuchs of Bell Labs. Some even agree with Einstein that the quantum must eventually yield to a more fundamental theory. "We shouldn't just assume quantum mechanics is going to make it through unaltered," says Raphael Bousso of the University of California at Berkley.

Those are strong words, because quantum mechanics is the most successful theoretical framework in the history of science. It has superseded all the classical theories that preceded it, except for general relativity, and most physicists think its total victory is just a matter of time. After all, relativity is riddled with holes — black holes. It predicts that stars can collapse to infinitesimal points but fails to explain what happens then. Clearly, the theory is incomplete. A natural way to overcome its limitations would be to subsume it in a quantum theory of gravity, such as string theory.

Still, something is rotten in the state of quantumland, too. As Einstein was among the first to realize, quantum mechanics, too, is incomplete. It offers no reason for why individual physical events happen, provides no way to get at objects' intrinsic properties and has no compelling conceptual foundations. Moreover, quantum theory turns the clock back to a pre-Einsteinian conception of space and time. It says, for example, that *an eight-liter bucket can hold eight times as much as a one-liter bucket*. That is true in everyday life, but relativity cautions that the eight-liter bucket can ultimately hold only four times as much — that is, the true capacity of buckets goes up in proportion to their surface area rather than their volume. This restriction is known as the holographic limit. *When the contents of the buckets are dense* *enough, exceeding the limit triggers a collapse to a black hole.* Black holes may thus signal the breakdown not only of relativity but also of quantum theory (not to mention buckets).

The obvious response to an incomplete theory is to try to complete it. Since the 1920s, several researchers have proposed rounding out quantum mechanics with "hidden variables." The idea is that quantum mechanics actually derives from classical mechanics *rather than the other way round*. Particles have definite positions and velocities and obey Newton's laws (or their relativistic extension). *They appear to behave in funky quantum ways simply because we don't, or can't, see this underlying order.* "In these models, the randomness of quantum mechanics is like a coin toss," says Carsten van de Bruck of the University of Sheffield in England. "It looks random, but it's not really random. You could write down a deterministic equation."

II Translate the italicized sentences into Russian. Explain the use of the grammar constructions.

III Vocabulary Notes

(Macmillan English Dictionary for Advanced Learners)

to alter — (verb) 1. to make smth or smb different; 2. to become different

to caution — (verb) to warn; *caution* (noun) — careful thought to avoid risks or danger

to compel — (verb) to force smb to do smth; *compelling* — (adj.) 1. interesting or exciting enough to keep your attention completely; 2. able to persuade smb to do smth or persuade them that smth is true — compelling evidence, compelling conceptual foundations

to depict — (verb) to describe smb or smth using words or pictures, to portray; *depiction* — (noun) portrayal

to embody — (verb) 1. to be the best possible example of a particular idea, quality or principle; 2. to include smth; *embodiment* (noun)

estranged (adj.) — alienated — feeling that you don't belong to a particular society; *estrangement* (noun)

to grok — (verb) to look into the problem closely

funky — (adj.) fashionable in a way that is unusual and shows a lot of imagination
inclined to do smth — (verb) to feel like doing smth (e.g.: I am inclined to agree with you)
infallible (adj) — impeccable — not capable of making mistakes; *infallibility* (noun) — impeccability
an issue — (noun) 1. an argument, an important topic for discussion; 2. publication of a special edition
notorious (adj.) famous for smth bad; — *notoriety* (noun) bad glory
a pronouncement — (noun) an official public statement
pursuit — (noun) of smth — the action of looking for or trying to find smth, *a quixotic pursuit* — (noun) the ideas that are quixotic are not practical and usually do not succeed (Don Quixote); *to pursue* — (verb) to follow a course of actions
to reinforce — (verb) to make an idea, belief or feeling stronger (e.g.: the latest figures reinforce the view that economic growth is slowing); *reinforcement* — (noun) the process of reinforcing smth
to riddle — to make many holes in smth: to be riddled with bullets; to be riddled with mistakes
sacrilegious — (adj.) not showing respect for a holy place, idea etc; *sacrilege* (noun)
to scandalize — (verb) to shock smb by doing smth they consider is not proper or immoral
to startle — (verb) to make a person feel suddenly frightened or surprised by smth; *startled* — (adj.) frightened or surprised by smth
to subsume in/into smth — (verb) to include smth in a particular group
to supersede — (verb) to replace
to underlie — (verb) to be a real or basic cause of or reason for smth
to vow — (verb) to pledge, to swear, to promise, to declare smth solemnly; *a vow* — (noun)
to wonder — (verb) to think about smth, because you want to know more facts about it
to yield — (verb) to produce smth useful such as information or

evidence (e.g.: the search for truth is beginning to yield fruitful results/benefits); *to yield to smth* — to finally agree to do what someone else wants you to do (e.g.: to yield to smb's demands — to stop opposing smb or smth); to bend or break under pressure; *yield* — (noun)

Mind the difference between the two words: to be *successful* (e.g.: Quantum mechanics is the most successful theoretical framework in the history of science) — to achieve smth you attempted to do; *successive* (e.g.: He remains champion for the six successive years) — coming or happening one after another in a series; a *concept* (e.g.: He can't grasp the main concepts of mathematics) — an idea of smth that exists; a *conception* (e.g.: His conception of the world is very unusual and strange) — a belief about what smth is like.

IV Comprehension Exercises

Answer the following questions.

1. What are most laypeople scandalized by?
2. How do textbooks and biographies depict Einstein during the quantum revolution of the 1920s and 1930s?
3. How will you interpret Einstein's famous pronouncement: "I shall never believe that God plays dice with the world"?
4. Why does the author of the article call Einstein's efforts to create a unified theory of physics quixotic?
5. What has been the assumption of string theorists as to which theory must give way?
6. How has the situation recently changed?
7. Why have a growing number of physicists come to admire Einstein's position?
8. Why is general relativity considered to be incomplete?
9. We know that quantum mechanics is the most successful theoretical framework in the history of science. It has superseded all the classical theories that preceded it except for general relativity and most physicists think that its total

victory is just a matter of time. Still, quantum mechanics, too, is incomplete. Will you explain why?

10. What is the idea of "hidden variables"?

V Grammar

1. You are given a sentence from the text. Find the subject and the predicate in the principal clause. Translate the sentence. What part of speech is the subject?

   When the contents of the buckets are dense enough, exceeding the limit triggers a collapse to a black hole.

2. Analyze the grammar construction of the following sentences.

   It is relativity *that* must give way.
   It was Einstein *who* suggested a unified theory of physics.

   Give your own examples.

3. Change the following word combinations getting rid of the Genitive Case.

   e.g.: eight liters' bucket — an eight-liter bucket

   five pounds' note, three miles' walk, half an hour's lesson, six months' term, three minutes' talk, five minutes' walk, two kilometers' distance;

4. Pay attention to the expression "a number of" always taking a plural verb unlike its counterpart "the number of".

   e.g.: A large number of people have applied.
   e.g.: The number of people applying has increased this year.

   a. A considerable number of animals (to die; Pres. Perfect).
   b. A number of problems (to arise; Pres. Perfect).
   c. The number of books (to be) sufficient.
   d. A number of students (to have) part-time jobs.
   e. Quite a number of paintings (to be sold; Pres. Perfect Passive).
   f. The number of unemployed people (to go up; Pres. Contin.).

5. Translate into Russian.

a. The third way to measure the constant is to study entire clusters of galaxies *rather than* single galaxies.
b. It is important to invest in new machinery *rather than* to increase wages.
c. We want the matter settled sooner *rather than* later.
d. To explain the known elements, Kelvin asked two colleagues to list all the hundreds of ways a string could be knotted. Although elements *turned out to be made* of atoms *rather than* knots, by then mathematicians were hooked on knot theory.

6. The verbs to seem, to look, to appear, to sound, to feel are followed by an adjective (not by an adverb): to sound sacrilegious, to seem probable, to appear evident, to feel confident, to look nice. Make up sentences of your own.
7. Give the three forms of the verbs: to underlie, to take, to tear, to bring, to break, to give, to make, to feel, to overcome.
8. Comment on the use of tenses:
   Unlike nearly all his contemporaries, Albert Einstein thought quantum mechanics would give way to a classical theory. Some researchers nowadays are inclined to agree.
9. Translate the following sentences into Russian. Explain the use of the corresponding grammar constructions. Make up sentences of your own.

   a. Einstein *may have been* wrong.
   b. Most theoretical physicists *would be* much more startled if he *had been* right.

   c. We { suggest / demand / insist / propose } + Gerund or Subjunctive Mood

   e.g. Einstein suggested that the unified theory (should) be derived.
10. Complex Subject — the Nominative with the Infinitive — with the predicate expressed by the verbs to appear, to chance, to happen, to seem, to turn out, to prove is used in the Active

Voice only. Use the subordinate clause instead of Complex Subject.

a. The Earth seems to be flat.
b. Fermat appears to have known a proof before 1683.
c. The famous ancient construction problems proved to be unsolvable.
d. Gauss happened to visit the University of Helmstedt in 1798 where he found that his fame had preceded him.
e. Light from a receding body appears to be of longer wavelength (i.e. redder) than it does from a stationary object.

11. Fill in the necessary prepositions. If necessary consult the text.

a. But if most laypeople are scandalized ... claims that Einstein may have been wrong, most theoretical physicists would be much more startled if he had been right.
b. Some even agree with Einstein that the quantum must eventually yield ... a more fundamental theory.
c. Quantum theory turns the clock back ... a pre-Einsteinian conception of space and time.
d. Although no one doubts the man's greatness, physicists wonder what happened ... him during the quantum revolution of the 1920s and 1930s.
e. After all, relativity is riddled ... holes — black holes.
f. The obvious response ... an incomplete theory is to try to complete it.

12. Which words can be used together in phrases?

much more	wrong
little (much)	dense
strictly	effort
quite	startled
enough	nicely

13. Try to recollect how these phrases are used in the text.
To build up the theory..., his scientific rationality..., Einstein's masterpiece..., a growing number have come..., the most successful theoretical framework..., just a matter of time...,

fails to explain..., particles have definite positions..., the randomness of quantum mechanics....

VI Phrasal Verbs and Idioms

to tear smth down — to bring down, destroy, demolish
to take up a pursuit — to catch up, to pick up, to intercept an idea
to make it through — not to die of a serious illness or an accident, to survive
to round out — to make smth more thorough or complete, to bring to perfection
to trigger off smth - to make smth happen suddenly, usually smth bad
to build up a theory — gradually understand and create a theory
to bring into the world — to cause smb or smth to be involved in smth
to turn the clock back — to reverse time
to go up in proportion — to increase
to give way to — to yield to
to give smb credit for smth — to honour smb, to say or believe that smb is responsible for smth that has happened, especially smth important or successful

VII Exercises

a. Give English equivalents to the following words and word combinations.

интересоваться	чтить кого-то за что-то
уступать дорогу	любители, непрофессионалы, дилетанты
структура, рамка	донкихотские цели
преследовать цель	спорный вопрос/предмет обсуждения
выпуск газеты	не считая, не говоря уж о...
включать	дурная слава

кощунство	представление
убедительное свидетельство	официальное публичное заявление
понятие	шедевр
заменить	изрешетить что-то
включить в определенную группу	быть отчужденным
клясться	воплощать; воплощение
аура непогрешимости	подчиниться закону
быть склонным что-то сделать	

b. Give synonyms to the following words.

to pledge	to include
to caution	to unite
to declare	to replace
to honour	to yield to
to expose	to introduce
to be aware	to prove to be
to predict	intrinsic
to supply	finally
to embody	an argument
to follow a course of activity	impeccable
to describe	surprised
to handle	a breakdown
to destroy	a mistake
to overcome	convincing results

c. Give antonyms to the following words.

complete	static
to appear	to resist
to be aware	to expose
to build up	to unite
to increase	inclined
mature	simple

d. Match a phrasal verb in the left column with its equivalent in the right one.

1. to tear it down	a. to survive
2. to round out	b. to destroy, to demolish
3. to make it through	c. to make smth more thorough or complete
4. to turn out	d. to reverse time
5. to bring smth into the world	e. to create
6. to build up	f. to increase
7. to take up (a pursuit)	g. to prove to be
8. to go up in proportion	h. to cause smth to be involved in smth
9. to turn the clock back	i. to catch up, to pick up a course of action

VIII Key Terms

STRING THEORY — according to String Theory, the laws of physics that we see operating in the world depend on how extra dimensions of space are curled up into a tiny bundle. A map of all possible configurations of the extra dimensions produces a landscape wherein each valley corresponds to a stable set of laws. The entire visible universe exists within a region of space that is associated with a valley of the landscape that happens to produce laws of physics suitable for the evolution of life

THEORETICAL LANDSCAPE populated with an array of innumerable possible universes is predicted by string theory. The landscape has perhaps 10500 valleys, each one of which corresponds to a set of laws of physics that may operate in vast bubbles of space. Our visible universe would be one relatively small region within one such bubble. (Overview of the String Theory Landscape by R. Bousso and J. Polchinski)

THE GENERAL THEORY OF RELATIVITY — Einstein's theory of the universe which states that all motion is relative and treats time as a fourth dimension related to space

QUANTUM MECHANICS (Quantum Theory) — a theory or system based on the idea that energy exists in units that cannot be divided. Quantum (pl. quanta): 1. a very small quantity of electromagnetic energy; 2. a quantity of smth, especially a very small one

A TRIGGER — a small device that releases a spring when pressure is applied. To trigger off smth — to be a cause of a sudden often violent reaction
A COIN TOSS — an action of throwing a coin into the air in order to decide smth by chance according to which side is facing upwards when it lands (playing dice; a die - dice)
A FRAMEWORK — a structure giving strength and support to smth; a set of principles or ideas used as a basis for one's judgements, decisions, etc. (Oxford Advanced Learner's Dictionary)
A HOLOGRAPH — a kind of a picture that is three-dimensional (doesn't look flat)
A BLACK HOLE — an area in outer space where the force of gravity is so strong that light and everything else around it is pulled into it.

IX Conversational Practice

Agree or disagree with the statements. Justify your choice. Add some sentences to develop your idea. Use the introductory phrases.

Right it is. Quite so.	I am afraid, it is wrong.
Absolutely correct.	On the contrary. Far from it.
I quite agree. I come along with you.	Excuse me, but... Not at all.
What I mean to say is...	Not quite so. My point is that...
I think, it is right.	It is not the case.
In a sense, it is true.	Just the other way round. It is unlikely. There is one more point.
I share this viewpoint.	

1. Albert Einstein thought that a classical theory would give way to quantum mechanics.
2. Einstein has become such an icon that it sounds sacrilegious to suggest he was wrong.
3. Even his notorious "biggest blunder" merely reinforced his aura of infallibility (see Text II — A Cosmic Conundrum).

4. Most laypeople are not scandalized by claims that Einstein may have been wrong.
5. In 1905 he helped to bring the basic concepts into the world.
6. He made much effort to build up the theory.
7. Estranged from the quantum mainstream, Einstein spent his final decades in quixotic pursuit of a unified theory of physics.
8. String theorists and others who later took up that pursuit vowed to walk down the same road.
9. In recent years a growing number of physicists have come to admire Einstein's position.
10. Quantum mechanics is the most successful theoretical framework in the history of science. Most physicists think that its total victory is a matter of time. Relativity is riddled with holes — black holes. The theory is incomplete. A natural way to overcome its limitations would be to subsume it in a quantum theory of gravity, such as string theory.
11. Quantum theory turns the clock back to a pre-Einsteinian conception of space and time. Quantum theory says, that an eight-liter bucket can hold eight times as much as a one-liter bucket.
12. Several researchers have proposed rounding out quantum mechanics with "hidden variables".

Reconstruct the text *Was Einstein Right* into a dialogue. One of the interlocutors stands for the viewpoint of Einstein's proponents, the other supports the viewpoint of quantum mechanics advocates. Interrupt your partner if you don't agree. Write questions and correct answers.

X Writing

Outline the main ideas and write an abstract (a brief and concise summary) of the text.

a. Give your abstract a title.

b. Begin the abstract with one of the introductory general phrases: the text deals with, points out, discusses, surveys, outlines the developments of..., gives an overview, renders etc.

c. The principle part must not exceed 8-10 sentences generalizing the main idea of the text in a logical sequence.

Text II

Read and translate an abstract from the article *A Cosmic Conundrum* by L.M. Krauss and M.S. Turner. Outline the main ideas and summarize the text.

A COSMIC CONUNDRUM[3]

A new incarnation of Einstein's cosmological constant may point the way beyond general relativity

by Lawrence M. Krauss and Michael S. Turner

THE AUTHORS

Lawrence M. Krauss and Michael S. Turner were among the first cosmologists to argue that the universe is dominated by a cosmological term that is radically different from the one introduced and then repudiated by Einstein. Their 1995 prediction of cosmic acceleration was confirmed by astronomical observations three years later. Chair of the physics department at Case Western Reserve University, Krauss has also written seven popular books, including The Physics of Star Trek and the soon-to-be-released Hiding in the Mirror: The Mysterious Allure of Extra Dimensions. Turner, who is Rauner Distinguished Service Professor at the University of Chicago, is now serving as the assistant director for mathematical and physical sciences at the National Science Foundation.

[3]Scientific American, September 2004, pp. 71–72

Word Combinations

the soon-to-be-released book	at play
to face a problem	to move beyond one's theory
to be inconsistent with an equation	the biggest blunder ever made
the limited understanding of smth	to be convinced that
to counterbalance gravity	to allow for smth
to be far from static	at a rate of
proportional to smth	in the sense that
to abandon a concept	to arise from
no matter what its rotation is	to single out a direction

In 1917 Albert Einstein faced a confusing problem as he tried to reconcile his new theory of gravity, the general theory of relativity, with the limited understanding of the universe at the time. Like most of his contemporaries, Einstein was convinced that the universe must be static — neither expanding nor contracting — but this desired state was not consistent with his equations of gravity. In desperation, Einstein added an extra, ad hoc cosmological term to his equations to counterbalance gravity and allow for a static solution.

Twelve years later, though, American astronomer Edwin Hubble discovered that the universe was far from static. He found that remote galaxies were swiftly receding from our own at a rate that was proportional to their distance. A cosmological term was not needed to explain an expanding universe, so Einstein abandoned the concept. Russian-American physicist George Gamow declared in his autobiography that "when I was discussing cosmological problems with Einstein, he remarked that the introduction of the cosmological term was the biggest blunder he ever made in his life".

In the past six years, however, the cosmological term — now called the cosmological constant — has reemerged to play a central role in 21st-century physics. But the motivation for this resurrection is actually very different from Einstein's original thinking; the new version of the term arises from recent observations of an accelerating universe and, ironically, from the principles of quantum mechanics, the branch of physics that Einstein so famously abhorred. *Many physicists now expect the cosmological term to provide the key* to moving beyond Einstein's theory to a deeper understanding of space, time, and gravity and perhaps to a quantum theory that unifies gravity with the other laws of physics at play, no matter what her orientation (rotation) and no matter what her velocity (boost). When Lorentz symmetry holds, spacetime is isotropic in the sense that all directions and all uniform motions are equivalent, so none are singled out as being special.

I Translate the italicized sentence into Russian. Explain the grammar construction.

II Look up the new words and answer the following questions.

a. Why did Einstein add an extra ad hoc cosmological term to his equation?
b. Why did Einstein consider the introduction of the cosmological term now called the cosmological constant the biggest blunder he ever made in his life?
c. What does the new version of the term arise from?
d. What do many physicists now expect the cosmological term to provide?

III Vocabulary Notes

(Macmillan English Dictionary for Advanced Learners)
To abhor — (verb) to feel disgust for smb/at smth; *abhorrent* (adj.); *abhorrence* (noun)
a blunder — (noun) a mistake
a conundrum — (noun) a riddle, a confusing problem that is difficult to solve
incarnate (adj. following nouns to give emphasis) in physical human form: the devil incarnate, virtue incarnate; *incarnation* — (noun) the embodiment and symbol of smth; *to incarnate* — (verb) to be the human form of a quality or an idea, to personify, to embody
to recede from smth — (verb) to move backwards from a previous position or away from the observer; *recession* (noun)
to reconcile — (verb) to find a way to make two or more ideas,

situations etc., agree with each other when actually they seem to be in opposition; *reconciliation* (noun)
to reemerge — (verb) to appear again
to repudiate — (verb) to say formally that smth is not true, to reject; *repudiation* (noun)
to resurrect — (verb) to bring smb back to life, to bring smth back into use
resurrection (noun) — a new beginning

IV Key Terms

(Oxford Advanced Learner's Dictionary)
AN AD HOC TERM made or arranged for a particular purpose only, special
A COSMOLOGICAL CONSTANT — quantum mechanics and relativity, combined with recent evidence of an accelerating universe, have led physicists to resurrect the cosmological term that Einstein introduced and later repudiated. But this term now represents a mysterious form of energy that permeates empty space and drives an accelerated cosmic expansion. The efforts to explain the origin of this energy may help scientists move beyond Einstein's theory in ways that are likely to change our fundamental understanding of the universe. (Overview of L. M. Krauss and M. S. Turner)
AN ACCELERATING UNIVERSE — exceeding the rate of expansion
A STATIC UNIVERSE — neither expanding nor contracting. Antonym: a dynamic universe

V Vocabulary Practice

Insert the missing words or word combinations from the active vocabulary. See key words below.

1. Research is being undertaken in how to ... conservation needs with growing demand for water.

2. What is ... ... is the government's unwillingness to ... the problem.
3. This ... theory should be ... by some other theory.
4. The ancient Greeks ... ... posing unsolved construction problems that challenge mathematicians and amateurs alike even today.
5. Galileo had to ... ... demands of Catholic church.
6. Galileo ... the traditional physics of his time chiefly because of its tendency to postulate universal laws without paying close attention to the actual world.
7. The method involves searching for celestial objects, called standard candles, whose ... brightness is known.
8. Einstein's search for ... ... is often remembered as ... .
9. ... ... some physicists' viewpoint string theory might ... a promising ... ... for the ... of quantum mechanics, general relativity and particle physics. ... ... is ... ...
10. I hope we can introduce some ... into these debates.
11. The existence of gravitational waves hasn't been ... yet.
12. In the past six years ... ... now called ... ... has ... to play ... ... in the XXI century.
13. The galaxies are ... ... at a speed of 70 km per second per megaparsec of distance between them (a megaparsec is 3.26 m light years).
14. ... ... Einstein spent his final decades in ... ... of a unified theory of physics.
15. Einstein has become such ... ... that it ... ... to suggest he was wrong.
16. His ... ... remained ....
17. ... ... to an incomplete theory is to try to ... it.
18. Since 1920s several researchers have proposed ... ... quantum mechanics with ... .
19. The cosmological term now represents a mysterious form of energy that ... empty space and drives an accelerated cosmic expansion. The efforts to explain the origin of this energy

may help scientists ... ... Einstein's theory to a deeper understanding of space, time and gravity.

Key words: swiftly receding from each other, reconcile, a central role, at issue, reemerged, to handle, the cosmological constant, inconsistent, the cosmological term, superseded, confirmed, are given credit for, rationality, yield to, a matter of time, repudiated, intrinsic, total victory, a unified theory, unification, a failure, theoretical framework, according to, offer, move beyond, estranged from the quantum mainstream, permeates, quixotic pursuit, hidden variables, an icon, rounding out, sounds sacrilegious, complete it, aura of infallibility, the obvious response, impeccable.

VI Render the following text.

ОБЩАЯ ТЕОРИЯ ОТНОСИТЕЛЬНОСТИ

Материал из Википедии — свободной энциклопедии

Общая теория относительности (ОТО) — геометрическая теория тяготения, развивающая специальную теорию относительности, опубликованная Альбертом Эйнштейном в 1915–1916 годах. В рамках ОТО, как и в других метрических теориях, постулируется, что гравитационные эффекты обусловлены не силовым взаимодействием тел и полей, находящихся в пространстве-времени, а деформацией самого пространства-времени, которая связана, в частности, с присутствием массы-энергии. ОТО отличается от других метрических теорий тяготения использованием уравнений Эйнштейна для связи кривизны пространства-времени с присутствующей в нем материей.

ОТО в настоящее время — самая успешная теория, хорошо подтвержденная наблюдениями. Первый успех ОТО состоял в объяснении аномальной прецессии перигелия Меркурия. Затем, в 1919 году, Артур Эддингтон сообщил о наблюдении отклонения света вблизи Солнца в момент полного затмения, что качественно и количественно подтвердило предсказания ОТО.

С тех пор многие другие наблюдения и эксперименты подтвердили значительное количество предсказаний теории, включая гравитационное замедление времени, гравитационное красное смещение, задержку сигнала в гравитационном поле и, пока лишь косвенно, гравитационное излучение. Кроме того, многочисленные наблюдения интерпретируются как подтверждения одного из самых таинственных и экзотических предсказаний ОТО — существования черных дыр.

Несмотря на ошеломляющий успех ОТО, в научном сообществе существует дискомфорт, связанный, во-первых, с тем, что ее не удается переформулировать как классический предел квантовой теории, а во-вторых, с тем, что сама теория указывает границы своей применимости, так как предсказывает появление неустранимых физических расходимостей при рассмотрении черных дыр и вообще сингулярностей пространства-времени. Для решения этих проблем был предложен ряд альтернативных теорий, некоторые из которых также являются квантовыми. Современные экспериментальные данные, однако, указывают, что любого типа отклонения от ОТО должны быть очень малыми, если они вообще существуют.

Unit II

Text I

THE STRING THEORY LANDSCAPE[4]

The theory of strings predicts that the Universe might occupy one random "valley" out of a virtually infinite selection of valleys in a vast landscape of possibilities.

by Raphael Bousso and Joseph Polchinski

THE AUTHORS

Raphael Bousso and Joseph Polchinski's work together began at a workshop on string duality in Santa Barbara. It grew out of the synergy between Bousso's background in quantum gravity and inflationary cosmology and Polchinski's background in string theory. Bousso is assistant professor of physics at the University of California, Berkeley. His research includes a general formulation of the holographic principle, which relates spacetime geometry to its information content. Polchinski is a professor at the Kavli Institute for Theoretical Physics at the University of California, Santa Barbara. His contributions to string theory include the seminal idea that branes constitute a significant feature of the theory.

[4]Scientific American, September 2004, pp. 79–81

Word Combinations

to obtain a theory	to come to play a vital role in smth
the possibility of extra dimensions	to leave an imprint on smth
to be particularly attracted to work by smb	to be governed by smth
to achieve an understanding of smth	the underlying mathematical structure
to resurrect and extend an idea	a feature of a theory
a promising framework for smth	a leading approach to smth
to put forth an idea	to depend on the geometry of hidden extra dimensions
experimental and recent theoretical developments	to provide a connection
to fall off inversely proportional to the square of the distance	in effect
to have important indirect effects	to be immersed in spacetime
to split the geometry of 5-D spacetime into three elements	at least so far
for the theory's equations to be mathematically consistent	given the success

I Read the questions and find answers in the text that follows.

1. What was Einstein's idea formulated by him in 1915?
2. What did T. Kaluza and O. Klein propose?

According to Albert Einstein's theory of general relativity, gravity arises from the geometry of space and time, which combine to form spacetime. Any massive body leaves an imprint on the shape of spacetime, governed by an equation Einstein formulated in 1915. *The earth's mass, for example, makes time pass slightly more rapidly for an apple near the top of a tree than for a physicist working in its shade.* When the apple falls, it is actually responding to this warping of time. The curvature of spacetime keeps the earth in its orbit around the sun and drives distant galaxies ever farther apart. This surprising and beautiful idea has been confirmed by many precision experiments.

Given the success of replacing the gravitational force with the dynamics of space and time, why not seek a geometric explanation for the other forces of nature and even for the spectrum of elementary particles? Indeed, this quest occupied Einstein for much of his life. He was particularly attracted to work by German Theodor Kaluza and Swede Oskar Klein, which proposed that whereas gravity reflects the shape of the four familiar spacetime dimensions, electromagnetism arises from the geometry of an additional fifth dimension that is too small to see directly (at least so far). Einstein's search for a unified theory is often remembered as a failure. In fact, it was premature: physicists first had to understand the nuclear forces and the crucial role of quantum field theory in describing physics — an understanding that was only achieved in the 1970s.

The search for a unified theory is a central activity in theoretical physics today, and just as Einstein foresaw, geometric concepts play a key role. The Kaluza — Klein idea has been resurrected and extended as a feature of string theory, a promising framework for the unification of quantum mechanics, general relativity and particle physics. In both the Kaluza — Klein conjecture and string theory, the laws of physics that we see are controlled by the shape and size of additional microscopic dimensions. What determines this shape? Recent experimental and theoretical developments suggest a striking and controversial answer that greatly alters our picture of the universe.

KALUZA-KLEIN THEORY AND STRINGS

Kaluza and Klein put forth their concept of a fifth dimension in the early part of the 20th century, when scientists knew of two forces — electromagnetism and gravity. Both fall off inversely proportional to the square of the distance from their source, so it was tempting to speculate that they were connected in some way. *Kaluza and Klein noticed that Einstein's geometric theory of gravity might provide this connection if an additional spatial dimension existed, making spacetime five-dimensional.*

This idea is not as wild as it seems. If the extra spatial dimension is curled up into a small enough circle, it will have eluded our best microscopes — that is, the most powerful particle accelerators. Moreover, we already know from general relativity that space is flexible. The three dimensions that we see are expanding and were once much smaller, so it is not such a stretch to imagine that there is another dimension that remains small today.

Although we cannot detect it directly, a small extra dimension would have important indirect effects that could be observed. General relativity would then describe the geometry of a five-dimensional spacetime. We can split this geometry into three elements: the shape of the four large spacetime dimensions, the angle between the small dimension and the others, and the circumference of the small dimension. The large spacetime behaves according to ordinary four-dimensional general relativity. At every location within it, the angle and circumference have some value, just like two fields permeating spacetime and taking on certain values at each location. *Amazingly, the angle field turns out to mimic an electromagnetic field living in the four-dimensional world.* That is, the equations governing its behavior are identical to those of electromagnetism. The circumference determines the relative strengths of the electromagnetic and gravitational forces. Thus, from a theory of gravity alone in five dimensions, we obtain a theory of both gravity and electromagnetism in four dimensions.

The possibility of extra dimensions has also come to play a vital role in unifying general relativity and quantum mechanics. In string theory, a leading approach to that unification, particles are in actuality one-dimensional objects, small vibrating loops or strands. The typical size of a string is near the Planck length, or 10^{-33} centimeter (less than a billionth of a billionth of the size of an atomic nucleus). Consequently, a string looks like a point under anything less than Planckian magnification.

For the theory's equations to be mathematically consistent, a string has to vibrate in 10 spacetime dimensions, which implies that six extra dimensions exist that are too small to have yet been detected. Along with the strings, sheets known as "branes" (derived from "membranes") of various dimensions can be immersed in spacetime. *In the original Kaluza-Klein idea, the quantum wave functions of ordinary particles* *would fill the extra dimension — in effect, the particles themselves would be smeared across the extra dimension.* Strings, in contrast, can be confined to lie on a brane. String theory also contains fluxes, or forces that can be represented by field lines, much as forces are represented in classical (nonquantum) electromagnetism.

Altogether the string picture looks more complicated than Kaluza — Klein theory, but the underlying mathematical structure is actually more unified and complete. The central theme of Kaluza — Klein theory remains: the physical laws that we see depend on the geometry of hidden extra dimensions.

II Translate the italicized sentences into Russian. Explain the use of the grammar constructions.

III Vocabulary Notes

(Oxford Advanced Learner's Dictionary)
to confirm — (verb) 1. to provide evidence or state that a report, an opinion etc. is true or correct, to establish the truth of smth; 2. a. to confirm smth, to confirm smb (in smth) — to make smb feel or believe smth more strongly; 2. b. to make position or agreement more definite or official; *confirmation* (noun)
to elude — (verb) 1. to escape smb or smth especially by a clever trick, to avoid smth; 2. to be forgotten; elusive (adj.) tending to escape, difficult to find or capture
a feature — (noun) a distinctive characteristic, an aspect; (verb) — to feature in smth — to have a prominent part in smth; *featureless* (adj.) not interesting
to govern (verb) — to control or influence smth or smb, to determine smth; *government* (noun) — a group of people governing a country
imprint (noun) on smb or smth — a lasting characteristic mark or effect; *to imprint* (verb) — to imprint smth/itself in or on smth a. to press hard onto a surface, leaving a mark; b. to fix smth firmly in smb's mind
a landscape (noun) — all the features of an area that aren't seen when looking across it
to permeate (verb) — to spread to every part of smth; *permeable*

(adj.) that can be permeated by liquids and gases, porous; *permeability* (noun); *permeation* (noun)
premature — (adj.) 1. happening before the proper or expected time; 2. premature in doing smth — happening, done, made too soon: *a premature* decision/judgement or conclusion
to relate (verb) — to show or make a connection between two different things; *related* (adj.) — environmentally related deseases/closely/directly/intimately related; *relation* (noun) — a connection between two or more things or people: to bear no relation to smth; *relative* (adj.) — having a particular quality when compared to smth else; *relative to* — compared to; relatively (adv.); *relativity* (noun)
seminal (adj.) — a seminal piece of writing or music is new and different and influences other literature or music that comes after it
synergy (noun) — the extra energy or effectiveness that people or businesses create when they combine their efforts. Profitability is expected to benefit from synergies between the two operations
a valley (noun) — an area of land between hills or mountains often with the river flowing through it
whereas (conj.) — used for comparing two things, people, situations etc. and showing that there is an important difference between them; e.g.: whereas knowledge can be acquired from books, skills must be learned through practice

IV Comprehension Exercises

Answer the following questions.

1. How does gravity arise according to A. Einstein's theory of general relativity?
2. What keeps the earth in its orbit around the sun?
3. What kind of quest occupied Einstein for much of his life?
4. Why was Einstein's search for a unified theory premature?
5. Why was Einstein particularly attracted to work by T. Kaluza and O. Klein?

6. What concepts play a key role in the search for a unified theory in theoretical physics today?
7. What constitutes a promising framework for the unification of quantum mechanics, general relativity and particle physics?
8. What directed scientists on the chain of thoughts to speculate that electromagnetism and gravity were connected in some way?
9. Why is the idea of an extra spatial dimension not as wild as it seems?
10. What important indirect effects could be observed if a small extra dimension was proved to exist?
11. What do particles in string theory look like?
12. What is the typical size of a string? What does it look like?
13. What does it imply that six extra dimensions exist that are too small to have yet been detected?
14. What else besides the strings can be immersed in spacetime?
15. According to the original Kaluza-Klein idea what would fill the extra dimension?
16. Where can strings be confined to lie?
17. What other elements does string theory also contain?
18. What is the central theme of Kaluza-Klein theory?

V Grammar

1. Give the three forms of the irregular verbs: to split, to seek, to foresee, to fall, to take, to put, to drive, to leave, to bear, to keep, to arise, to wind, to spread, to hit, to hide.
2. Find in the text conditional sentences in the Indicative Mood and in the Subjunctive Mood. Translate them into Russian. Pay attention to the difference in grammar constructions. Give your own examples. Put the verbs given in brackets in the required form.

   The Indicative Mood. Conditionals. Type I. Real Condition.

   a. Particles or even worlds of matter (keep) flying through empty space forever until something (to compel) them to change their motion.

b. This law states a fact which can upset many calculations unless it (to take into account).
c. If a spark (to have) enough energy, an explosion (to be set off).
d. The fuel material is cooled when it (to pass) down through the steam generator.
e. The computer enables the user to see text displayed on a screen, so that words can be revised and reviewed before they (to be) ever committed to paper.
f. Maxwell was one of the most promising and honoured molecularists. His device of the "sorting demon" (to be remembered) as long as the kinetic theory of gases (to be studied).
g. The results of the experiment (to be published) as soon as they (to be verified).

The Subjunctive Mood. Conditionals. Type II. Unreal condition.

a. In the physical world man never (to get) anywhere if he (not to encounter) resistance on the way.
b. If the Moon, Triton, Pluto and Mercury (to be) all lumped together, you (to have) a body which (to be) nearly twice as massive as Mars.
c. If there (to be) no oxygen in the earth's atmosphere, life (to be) impossible.
d. In the original Kaluza-Klein idea, the quantum wave functions of ordinary particles (to fill) the extra dimension — in effect, the particles themselves (to be smeared across) the extra dimension.

3. Here are given two pairs of irregular verbs: one of them is transitive, that is followed by a direct object; the other — intransitive.

Arise-arose-arisen	raise-raised-raised
Lie-lay-lain	lay-laid-laid

Give the correct form of the missing verbs in the following sentences.

a. Gravity … from the geometry of space and time.

b. Electromagnetism ... from the geometry of an additional fifth dimension.
c. Contradictions ... (*past tense*) due to the lack of rigorous foundations of set theory.
d. The idea of unification of general relativity and quantum mechanics ... heated debates.
e. T. Kaluza and O. Klein ... the foundation of the geometry of hidden extra dimensions.
f. The possibility of extra dimensions ... at the basis of the possible future unification of the two theories.
g. The originality of the idea of unification ... in the attempt to unify incompatible essences.

4. Pay attention to the difference in using the active and the passive construction: to make smb do smth — smb is made to do smth.

   Complex Object (The Objective with the Infinitive)

   After the verbs: to see, to watch, to hear, to let, to observe, to feel, to make the particle "to" is not used. Open the brackets and put the verbs in the correct form.

   a. The force that causes bodies (to fall) to earth is called gravity.
   b. Heat and cold make all parts of the structure (to expand) and (to contract).
   c. Some forces tend to make an object's centre of gravity (to move) along some line.
   d. Galileo stated that if a body is moving freely in any direction, something must happen to stop it or to make it (to change) direction.
   e. Galileo believed the three stars (to belong) to the number of the fixed stars.
   f. While Galileo was viewing the constellations of the heavens through a telescope he noticed three little stars (to shine) brightly near the planet Jupiter. From their motion he correctly deduced that they travel in orbit around the planet.

g. We observe the volume as a given mass of a gas (to decrease) as the temperature decreases.
h. While making out his weekly pay-roll and coming to the end of his long computation Gerhard Gauss was startled to hear his little son (to say): “Father, the reckoning is wrong”.
i. The earth’s mass, for example, makes time (to pass) slightly more rapidly for an apple near the top of a tree than for a physicist working in its shade.

Use *Complex Subject* instead of the subordinate clause.

a. It is known that light carries energy.
b. It is conjectured that the very centre of the Milky Way harbours a black hole.
c. It was found that the rings rotate about Saturn at a rate different from that of the atmosphere of the planet.
d. It is assumed that the nebula has been rotating.
e. It is said that the molecule has six degrees of freedom.
f. It is unlikely that this method will yield the result desired.
g. For nearly two thousand years it was believed that all heavy objects fell faster than light ones.
h. It was acknowledged that the problem was becoming increasingly urgent.
i. It is asserted that space-time has four dimensions, the three familiar spatial ones of length, breadth and height, and time.
j. It is believed that the universe began with the Big Bang.

5. Give degrees of comparison of the following adjectives and adverbs.

Little	good
Much	bad
Far (two variants)	late (two variants)

Fill in the correct form of the adjectives and adverbs.

a. Of the two approaches the (late) is (much) promising.
b. On a (much) or (little) intuitive basis, early in the 20th century the great Henry Poincaré and others built a fascinating edifice of topological theory.

c. Pluto is one of the (little) known members of the Solar system.
d. The two (much) widespread elements in the universe are hydrogen and helium.
e. The Earth is eight times (much) massive than the Moon.
f. For (little) values of the coefficients of friction the angles lie between these extremes.
g. The device should be put to (good) use.
h. The (late) achievements in science and technology give an opportunity for (far) investigations in the field of molecular physics.
i. During the (late) century geometry was (far) extended to include the study of abstract spaces.
j. Iron is (bad) than copper as a conductor.

6. Fill in the necessary prepositions or adverbs.
   a. According … Albert Einstein's theory of general relativity, gravity arises … the geometry of space and time, which combine to form spacetime.
   b. Any massive body leaves an imprint … the shape … spacetime, governed … an equation formulated … Einstein in 1915.
   c. When the apple falls, it is actually responding … this warping … time.
   d. The curvature … spacetime keeps the earth … its orbit … the sun and drives distant galaxies ever farther….
   e. Given the success … replacing the gravitational force … the dynamics … space and time, why not seek a geometric explanation … the other forces … nature and even … the spectrum … elementary particles?
   f. Indeed, this quest occupied Einstein … much … his life.
   g. He was particularly attracted … work by German T. Kaluza and Swede O. Klein.
   h. Einstein's search … a unified theory is often remembered as a failure. In fact, it was premature: physicists had to

understand the nuclear forces and the crucial role … quantum field theory … describing physics.

i. The laws … physics that we see are controlled … the shape and size … additional microscopic dimensions.
j. … the early part … the 20th century scientists knew … two forces — electromagnetism and gravity. Both fall … inversely proportional … the square … the distance … their source.
k. We can split this geometry … three elements: the shape … the four large spacetime dimensions, the angle … the small dimension and the others, and the circumference … the small dimension.
l. The large spacetime behaves according … ordinary four-dimensional general relativity. … every location … it, the angle and circumference have some value.
m. The possibility … extra dimensions have come to play a vital role … unifying general relativity and quantum mechanics.
n. String theory is a leading approach … that unification.
o. The typical size … a string is … the Planck length, or 10^{-33} centimeter. Consequently, a string looks like a point … anything less than Planckian magnification.
p. Along … the strings, sheets known as branes (derived … membranes) … various dimensions can be immersed … spacetime.
q. String theory also contains fluxes, or forces that can be represented … field lines, much as forces are represented … classical (nonquantum) electromagnetism.
r. The physical laws that we see depend … the geometry … hidden dimensions.

VI Phrasal Verbs and Idioms

to come across smb or smth — to meet or find smb or smth by chance
to grow out of smth — to develop from smth or exist as a result
to point smth out to smb — to direct attention to smth

to relate to smth — to be about smth or connected with smth
to turn out to be smth, turn out that — to be discovered to be smth/smb, to prove to be: the job turned out to be harder than we thought
to put forth — to put forth a concept, a theory
to fall off — to decrease in quality or quantity
to curl up — to form or make smth form into a curved shape, especially so that the edges are rolled up
to take on smth — to begin to have a particular characteristic, quality or appearance, to assume smth: the chameleon can take on the colours of its background
to smear smth across/over smth — to spread an oily or sticky substance (e.g.: paint, mud, grease) on smth or smb in a rough and careless way
to drive further apart — 1. to force smth to move in a particular direction; 2. (of wind, water) to carry smth along; to drive smth off — to force smth away
it is not such a stretch to imagine — easy to imagine

VII Exercises

a. Give English equivalents to the following words and word combinations.

подтверждать	поиск единой теории
погружать	раскалывать
проникать	приближаться
увеличивать	мельчайшие вибрирующие петли или пряди
представлять	противоречивая гипотеза
предвидеть	усложнять
искушать	оставить след
размышлять	избегать
ускользать	воскрешать
преждевременное предложение	многообещающая структура

b. Give Russian equivalents to the following words and word combinations.

to respond	the quantum wave functions of ordinary particles
to leave an imprint	an additional spatial dimension
so far	experimental and theoretical developments
in contrast	particle accelerator
slightly	a circumference
virtually	an atomic nucleus
a flux	an angle field
in actuality	ordinary 4-D general relativity

c. Give synonyms to the following words.

to control	to choose
to distort	to account for
additional	to guess
to fill	to discover
inconsistent	to imitate
to link	to assemble
a search for	to revive
to restrict	to calculate
to escape	similar
to define	a conjecture
to play a key role	strength

d. Give antonyms to the following words.

to attract	familiar
natural	dependent
to remember	controversial
powerful	simple
permeable	to unite
to hide	

e. Match a phrasal verb in the left column with its equivalent in the right one.

1. to point out	a. to force smth to move in different directions
2. to fall off	b. to prove to be
3. to curl up	c. to assume
4. to take on	d. to produce
5. to turn out	e. to decrease
6. to drive apart	f. to roll up
7. to grow out of	g. to meet
8. to relate to	h. to spread an oily substance on smth
9. to come across	i. to be connected with
10. to put forth	j. to direct attention
11. to smear across	k. to develop

VIII Vocabulary Practice

Replace the Russian words and word combinations in the sentences given below with their English equivalents.

1. Every massive body (оставляет отпечаток на) the shape of spacetime, (контролируемого уравнением, которое) Einstein (сформулировал) in 1915.
2. The curvature of spacetime (удерживает Землю на ее орбите) around the sun and drives (далекие галактики еще дальше). This (эпохальная) idea has been (подтверждена многими точными экспериментами).
3. (В то время, как) gravity (отражает) the shape of the four (знакомых измерений пространства-времени), electromagnetism (возникает из) the geometry of an (дополнительного) fifth dimension that is too small to see (непосредственно, по крайней мере до сих пор).
4. (Поиск Эйнштейном единой теории) was (преждевременным). Physicists first (должны были понять ядерные силы и решающее значение) of quantum field theory (в описании физики — понимание, которое было достигнуто) in the 1970s.
5. Kaluza-Klein idea has been (восстановлена и расширена) as (особенность) of string theory.

6. Kaluza and Klein (выдвинули свое понятие пятого измерения в начале XX века) when scientists knew of two forces — electromagnetism and gravity.
7. Both (уменьшаются) inversely proportional to the square of the distance from their source.
8. It was (заманчиво предположить) that they were (связаны каким-то образом).
9. Kaluza and Klein noticed that Einstein's geometric theory of gravity might (обеспечить эту связь) if an additional spatial dimension existed, making spacetime five-dimensional.
10. (Не трудно себе представить, что существует) another dimension that remains small today.
11. (Оказывается, угловое поле подобно) an electromagnetic field living in the four dimensional world.
12. The equations (управляющие) its behaviour are (идентичны уравнениям электромагнетизма).
13. Thus, (из одной только теории гравитации) in five dimensions, we (получаем как) a theory of (гравитации, так и электромагнетизма) in four dimensions.
14. (Возможность существования) of extra dimensions (также стала играть чрезвычайно важную роль в объединении) general relativity and quantum mechanics.
15. (Для того, чтобы уравнения теории были математически последовательны) a string (должна вибрировать) in ten spacetime dimensions, which (подразумевает) that six extra dimensions exist that are too small (чтобы уже быть обнаруженными).
16. (Наряду со струнами), sheets known as “branes” of various dimensions can be (помещены) in spacetime.
17. Altogether the string picture (выглядит более сложной, чем) Kaluza — Klein theory, but (лежащая в ее основе математическая структура) is (фактически) more unified and complete.
18. Although we cannot (обнаружить) it directly, a small extra dimension (имело бы важные косвенные воздействия) that could be observed. General relativity (тогда описывало бы)

the geometry of a 5-D spacetime.

IX Key Terms

(Chambers Dictionary of Science and Technology)
THE CURVITURE OF SPACE-TIME – warping
PRECISION EXPERIMENTS – experiments conducted with very accurate instruments or tools, designed for very accurate work, measurements etc
THE SPECTRUM OF ELEMENTARY PARTICLES – a complete and wide range of related qualities of different types of tiny pieces of matter smaller than an atom
QUEST 1. quest for smth – the act of seeking smth, a long search for smth; 2. to quest – to try to find smth, to search
QUANTUM FIELD THEORY – the overall theory of fundamental particles and their interactions. Each type of particle is represented by appropriate operators which obey certain commutation laws. Particles are the quanta of fields in the same way as photons are the quanta of the electromagnetic fields. So gluon fields and intermediate vector boson fields can be related to strong and weak interactions. Quantum field theory accounts for the Lamb shift
QUANTUM GRAVITY – the theory that would unify gravitational physics with modern quantum field theory
QUANTUM MECHANICS – a generally accepted theory replacing classical mechanics for microscopic phenomena. Quantum mechanics also gives results consistent with classical mechanics for microscopic phenomena. Two equivalent formalisms have been developed: matrix mechanics (developed by W. Heisenberg) and wave mechanics (developed by E. Schroedinger). The theory accounts for a very wide range of physical phenomena
QUANTUM ELECTRODYNAMICS – a relativistic quantum theory of electromagnetic interactions. It provides a description of the interaction of electrons, muons and photons and hence the underlying theory of all electromagnetic phenomena
ELECTROMAGNETISM – the science of the properties and relations between magnetism and electric currents; ELECTRO-MAGNETIC – having both electric and magnetic properties (e.g.:

x-rays, radiowaves and light waves are all types of electromagnetic radiation)
PARTICLE PHYSICS — scientific study of any of various types of small pieces of matter of which atoms are composed
A CIRCUMFERENCE — a. a line that marks out a circle or that goes round any other curved shape; b. the length of this line
ORDINARY 4-D GENERAL RELATIVITY — 3 ordinary space dimensions plus time
A LOOP — 1. a shape, produced by a curve that bends right round and crosses itself; 2. a length of rope, wire in such a shape, usually fastened in a knot where it crosses itself; to loop the loop — idiom — to fly or make an aircraft fly in a complete vertical circle
A STRAND — each of the threads, wires, etc, twisted together to form a rope or cable
PLANCK LENGTH — the possible values of volume and area are measured in units of quantity called the Planck length; this length is related to the strength of gravity, the size of quanta and the speed of light. Planck length is a length scale thought to be of importance in quantum gravity which may represent the shortest possible distance between points; equals $\sqrt{\frac{Gh}{2\pi c^3}}$, where G is the gravitational constant, h is Planck's constant and c is the speed of light; value $1,62 \times 10^{-35}$ m. The corresponding PLANCK MASS is $2,1 \times 10^{-8}$ kg
PLANCK'S CONSTANT — the fundamental constant which is the basis of Planck's law. It has the dimensions of energy $\times$ time, i.e. action. The present accepted value is $6,626 \times 10^{-34}$ J s
PLANCK'S LAW — the basis of quantum theory, that the energy of electromagnetic waves is confined in indivisible packets or quanta, each of which has to be related or absorbed as a whole, the magnitude being proportional to frequency; if E is the value of the quantum expressed in energy units and v is the frequency of the radiation, then $E = h\nu$, where h is known as Planck's constant and has dimension of energy $\times$ time, i.e. action, and is $6,626 \times 10^{-34}$ J s
AN ATOMIC NUCLEUS — the positively charged central part of an atom containing most of its mass
SHEETS or BRANES (derived from membranes) a flat thin piece

of any material usually square or rectangular; a membrane is a piece of thin tissue that connects, covers or lines parts inside a plant or the body of an animal, a thin layer of material (e.g.: to protect smth against damp)
A FLUX (of neutrons) — continuous change, a flow or act of flowing; the rate at which matter or energy flows across a surface or area

X Conversational Practice

a. Agree or disagree with the statements. Justify your assertions. Add some sentences to develop your idea. The following phrases may be helpful:

I'm sure/certain about...	Sorry, I'm not really sure about...
I've no doubt about it.	I can't make up my mind.
I think...	I'm in two minds about it.
As I see it...	Surely not, I mean...
In my view/opinion	Yes, but on the other hand...
Personally I believe/feel	Let me explain my point.

1. According to Einstein's theory of general relativity, gravity arises from the geometry of space and time, which combine to form spacetime. Any massive body leaves an imprint on the shape of spacetime, governed by an equation Einstein formulated in 1915.
2. Given the success of replacing the gravitational force with the dynamics of space and time, why not seek a geometric explanation for the other forces of nature and even for the spectrum of elementary particles?
3. Einstein's search for a unified theory is often remembered as a failure.
4. The search for a unified theory is the central activity in the theoretical physics today, and just as Einstein foresaw, geometric concepts play a key role.
5. Kaluza and Klein put forth their concept of a fifth dimension in the early part of the 20th century, when scientists knew

of two forces — electromagnetism and gravity. Both fall off inversely proportional to the square of the distance from their source, so it was tempting to speculate that they were connected in some way.

6. The idea of 5-dimensional spacetime seems wild.
7. The possibility of extra dimensions has also come to play no essential role in unifying general relativity and quantum mechanics, and string theory is not a leading approach to that unification.
8. For the theory's equations to be mathematically consistent, a string has to vibrate in 10 spacetime dimensions, which implies that six extra dimensions exist that are too small to have yet been detected.
9. The string picture looks simple.

b. Prepare a mini-report. Express your opinion in favour of or against string theory as a promising framework for the unification of quantum mechanics, general relativity and particle physics. Write a plan of your reasoning.

XI Writing

Write an abstract of the text. It should consist of no more than 7–8 sentences.

Text II

THE GEOMETER OF PARTICLE PHYSICS[5]

Alain's Connes's noncommutative geometry offers an alternative to string theory. In fact, being directly testable, it may be better than string theory

by Alexander Hellemans

[5]Scientific American, August 2006, pp. 36–38

Word Combinations

the refinements of geometry	an extra discrete (noncontinuous) space
to succeed in doing smth	the recipe to eliminate infinities
layers of a continuum	a more subtle geometry
to mediate the weak force	to hide mathematical jewels
to peer into the apparent complexity	to reveal molecular structure
to come across smth	to hit an obstacle
to introduce a mathematical technique	to correspond to reality
to give smth a mathematically rigorous underpinning	fractional dimensions
to serve as a starting point	to couple with smth
to contend that...	to point out that...
to argue that...	to extend one's work to smaller scales
to be halfway	to look for the mathematics behind the physical phenomena

Alain Connes refers to the way particle physics has grown: the concept of spacetime was derived from electrodynamics, but electrodynamics is only a small part of the Standard Model. New particles were added when required, and confirmation came when these predicted particles emerged in accelerators.

But the spacetime used in general relativity, also based on electrodynamics, was left unchanged. Connes proposed something quite different: "Instead of having new particles, we have a geometry that is more subtle, and the refinements of this geometry generate these new particles." In fact, he succeeded in creating a noncommutative space that contains all the abstract algebras (known as symmetry groups) that describe the properties of elementary particles in the Standard Model.

The picture that emerges from the Standard Model, then, is that of spacetime as a noncommutative space that can be viewed as consisting of two layers of a continuum, like the two sides of a piece of paper. The space between the two sides of the paper is an extra discrete (noncontinuous), noncommutative space. The discrete part creates the

Higgs, whereas the continuum parts generate the gauge bosons, such as the W and Z particles, which mediate the weak force.

Connes has become convinced that physics calculations not only reflect reality but hide mathematical jewels behind their apparent complexity. All that is needed is a tool to peer into the complexity, the way the electron microscope reveals molecular structure, remarks Connes, whose "electron microscope" is noncommutative geometry. "What I'm really interested in are the complicated computations performed by physicists and tested by experiment," he declares. *"These calculations are tested at up to nine decimals, so one is certain to have come across a jewel, something to elucidate."*

One jewel held infinities. *Although the Standard Model proved phenomenally successful, it quickly hit an obstacle: infinite values appeared in many computations.* Physicists, including Gerard't Hooft and Martinus Veltman of the University of Utrecht in the Netherlands, solved this problem by introducing a mathematical technique called renormalization. By tweaking certain values in the models, physicists could avoid these infinities and calculate properties of particles that corresponded to reality.

Although some researchers viewed this technique as a bit like cheating, for Connes renormalization became another opportunity to explore the space in which physics lives. But it wasn't easy. "I spent 20 years trying to understand renormalization. Not that I didn't understand what the physicists were doing, but I didn't understand what the meaning of the mathematics was that was behind it," Connes says. He and physicist Dirk Kreimer of the Institut des Hautes 'Etudes Scientifiques near Paris soon realized that the recipe to eliminate infinities is in fact linked to one of the 23 great problems in mathematics formulated by David Hilbert in 1900 — one that had been solved. The linkage gave renormalization a mathematically rigorous underpinning — no longer was it "cheating."

The relation between renormalization and noncommutative geometry serves as a starting point to unite relativity and quantum mechanics and thereby fully describe gravity. "We now have to make a next step — we have to try to understand how space with fractional dimensions," which occurs in noncommutative geometry, "couples with gravitation," Connes asserts. He has already shown, with physicist Carlo Rovelli of the University of Marseille, that time can emerge naturally from the noncommutativity of the observable quantities of gravity. Time can be compared with a property such as temperature, which needs atoms to exist, Rovelli explains.

What about string theory? Doesn't that unify gravitation and the quantum world? Connes contends that his approach, looking for the mathematics behind the physical phenomena, is fundamentally different from that of string theorists. Whereas string theory cannot be tested directly — it deals with energies that cannot be created in the laboratory — Connes points out that noncommutative geometry makes testable predictions, such as the Higgs mass (160 billion electron volts), and he argues that even renormalization can be verified.

The Large Hadron Collider will not only test Connes's math but will also give him data to extend his work to smaller scales. "Noncommutative geometry now supplies us with a model of spacetime that reaches down to 10^{-16} centimeter, which still is a long way to go to reach the Planck scale, which is 10^{-33} centimeter," Connes says. That is not quite halfway. *But to Connes, the glass undoubtedly appears half full.*

I Translate the italicized sentences into Russian. Explain the grammar constructions.

II Comprehension Exercises

Look up the new words and word combinations and answer the following questions.

1. What did Alain Connes manage to create?
2. How can spacetime in a noncommutative space be viewed?
3. What mathematical jewels did the scientists hit upon?
4. What is renormalization?
5. What was the recipe to eliminate infinities linked to?
6. What did this linkage give to renormalization?
7. What will the next step be?
8. What is Conne's point of view concerning the difference between string theory and noncommutative geometry?

9. Which theory appeals to you more?

III Vocabulary Notes

(Macmillan English Dictionary for Advanced Learners)

to contend (verb) — 1. to claim that smth is true; 2. to compete against someone; 3. to struggle to overcome a difficulty; *contention* (noun) — disagreement; *contentious* (adj.) — causing disagreement, enjoying quarelling
to mediate (verb) — to influence or to cause a process or event; *mediation* (noun); *mediator* (noun)
to occur (verb) — to happen especially unexpectedly; *to occur to smb* — to come to one's mind, to realize an idea; *occurrence* (noun) — an occasion, an event
a recipe ['resipi] (noun) — a set of instructions
to refine (verb) — to make some changes to smth in order to improve it; *refinement* (noun) — a small change that is made to improve smth; *refined* (adj.) — a substance that is refined is now pure, because other things have been removed from it: refined oil/sugar
rigour (noun) — the quality of being strict or severe; the quality of being thorough and careful; *rigorous* (adj.) — thorough and careful; strict and severe; *rigorously* (adv.)
subtle (adj.) — delicate, complicated or difficult to notice, showing an ability to understand small things that other people do not: subtle observations; *subtlety* (noun); *subtly* (adv.)
underpinning (noun) — 1. an important basic part of smth that allows it to succeed or continue to exist; 2. a strong piece of metal or concrete that supports smth such as a wall; *to underpin* (verb) — 1. to be an important basic part of smth, allowing it to succeed or continue to exist; 2. to support smth such as a wall by putting a strong piece of metal or concrete under it
undoubted (adj.) — accepted or agreed by everyone; *undoubtedly* (adv.) — used by saying that smth is certainly true or is accepted by everyone

IV Exercises

a. Give synonyms to the following words.

to eliminate	to elucidate
to emerge	to argue
to link	to come across
to improve	to assist
to happen	severe

b.Give antonyms to the following words.

To agree, concrete, dubious

c.Fill in the missing prepositions or adverbs.

1. Alain Connes refers ... the way particle physics has grown: the concept ... spacetime was derived ... electrodynamics but new particles were added when required and confirmation came when these predicted particles emerged ... accelerators.
2. The spacetime used ... general relativity, also based ... electrodynamics was left unchanged.
3. "Instead ... having new particles, we have a geometry that is more subtle, and the refinements ... this geometry generate these new particles."
4. ... fact, he succeeded ... creating a noncommutative space that contains all the abstract algebras (known as symmetry group) that describe the properties ... elementary particles ... the Standard Model.
5. Connes has become convinced that physics calculations not only reflect reality but hide mathematical jewels ... their apparent complexity. All that is needed is a tool to peer ... the complexity.
6. "What I'm really interested ... are the complicated computations performed ... physicists and tested ... experiment", he declares. "These calculations are tested ... ... nine decimals, so one is certain to have come ... a jewel, something to elucidate."
7. Physicists solved the problem ... infinite values ... introducing a mathematical technique called renormalization. ...

tweaking certain values ... the models, physicists could avoid these infinities and calculate properties ... particles that correspond ... reality.

8. The recipe to eliminate infinities is ... fact linked ... one ... the 23 great problems ... mathematics formulated ... David Hilbert ... 1900.
9. The relation ... renormalization and noncommutative geometry serves as a starting point to unite relativity and quantum mechanics and thereby fully describe gravity.
10. Connes contends that his approach, looking ... the mathematics ... the physical phenomena, is fundamentally different ... that ... string theory.
11. "We now have to make a next step — we have to understand how space ... fractional dimensions", which occurs ... noncommutative geometry, "couples ... gravitation", Connes asserts.

V Key Terms

ELECTRODYNAMICS — the study of the motion of electric charges caused by electric and magnetic fields

NONCOMMUTATIVE SPACE — that contains all the abstract algebras (known as symmetry groups) that describe the properties of elementary particles in the Standard Model

RENORMALIZATION — introducing a mathematical technique called renormalization, physicists could avoid the infinities in many computations and calculate properties of particles that correspond to reality

THE HIGGS MASS — 160 billion electron volts; the Higgs is the still missing crowning piece of the so-called Standard Model — the theoretical framework that describes subatomic particles and their interactions; the discovery of the Higgs, which supposedly endows the other particles with mass, is crucial: its existence and even its mass emerges from the mysterious equations of a new form of mathematics called noncommutative geometry

A GAUGE BOSON — a particle that mediates the interaction between two fundamental particles; these are four types: photons for electromagnetic interactions, gluons for strong interactions, intermediate vector bosons for weak interactions and gravitons for gravitational interactions

VI Express your opinion about the ideas expounded in the article. Compare them with the ideas of string theory. Which of them appeals to you more and seems more consistent?

VII Render the following text.

КВАНТОВАЯ МЕХАНИКА

Материал из Википедии — свободной энциклопедии

Квантовая механика (КМ) (волновая механика), теория, устанавливающая способ описания и законы движения микрочастиц в заданных внешних полях; один из основных разделов квантовой теории. КМ впервые позволила описать структуру атомов и понять их спектры, установить природу химической связи, объяснить периодическую систему элементов и т.д. Т.к. свойства макроскопических тел определяются движением и взаимодействием образующих их частиц, законы КМ лежат в основе понимания большинства макроскопических явлений. Так, КМ позволила понять многие свойства твердых тел, объяснить явления сверхпроводимости, ферромагнетизма, сверхтекучести и многие другие; квантовомеханические законы лежат в основе ядерной энергетики, квантовой электроники и т.д. В отличие от классической теории, все частицы выступают в КМ как носители и корпускулярных, и волновых свойств, которые не исключают, а дополняют друг друга. Волновая природа электронов, протонов и других «частиц»подтверждена опытами по дифракции частиц. Корпускулярно-волновой дуализм материи потребовал нового подхода к описанию состояния физических систем и их изменения со временем. Состояние квантовой системы описывается волновой функцией, квадрат модуля которой определяет вероятность данного состояния и, следовательно, вероятности для значений физических величин, его характеризующих; из КМ вытекает, что не все физические величины могут одновременно иметь точные значения. Отличительная черта квантовой теории — дискретность возможных значений для ряда физических величин: энергии электронов в атомах, момента количества движения и его проекции на произвольное направление и т.д.; в классической теории все эти величины могут изменяться лишь непрерывно. Фундаментальную роль в КМ играет постоянная Планка — один из основных масштабов природы, разграничивающий области явлений, которые можно описывать классической физикой, от областей, для правильного истолкования которых необходима квантовая теория. Нерелятивистская (относящаяся к малым скоростям движения частиц по сравнению со скоростью света) КМ — законченная, логически непротиворечивая теория, полностью согласующаяся с опытом для того круга явлений и процессов, в которых не происходит рождения, уничтожения или взаимопревращения частиц.

Unit III

Text

ATOMS OF SPACE AND TIME[6]

We perceive space and time to be continuous, but if the amazing theory of loop quantum gravity is correct, they actually come in discrete pieces

by Lee Smolin

THE AUTHOR

Lee Smolin is a researcher at the Perimeter Institute for theoretical physics in Waterloo, Ontario, and an adjunct professor of physics at the University of Waterloo. He has a B. A. from Hampshire College and a Ph. D. from Harvard University and has been on the faculty of Yale, Syracuse and Pennsylvania State Universities. In addition to his work on quantum gravity, he is interested in elementary particle physics, cosmology and the foundations of quantum theory. His 1997 book, The Life of the Cosmos (Oxford University Press), explored the philosophical implications of developments in contemporary physics and cosmology.

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[6]Scientific American, February 2004, pp. 45–48

Word Combinations

continuous and smooth space	reliable calculations
to make an assumption	beyond the experimentally well tested principles
an evolving dynamical quantity	the visible universe
a predetermined classical spacetime	to be closely related to smth
to lay the foundation of smth	the theory of loop quantum gravity
a healthy field of research	combined efforts
to give one confidence in smth	at the smallest size scales
to specify precisely	to be marked out by a boundary
a cast-iron shell	the event horizon of a black hole
to escape the black hole's gravitational clutches	a discrete set of numbers
in between those values	specific quantum units of area and volume
to return an unambiguous result	distinct pieces

I Read the questions and find answers in the text that follows.

1. Which two key principles of general relativity carefully combined with the standard techniques of quantum mechanics allowed the scientists to determine that space is quantized?
2. What was the unambiguous result that the calculations using the loop quantum gravity revealed?

A BIG LOOPHOLE

In the mid-1980s *a few of us* — including Abhay Ashtekar, now at Pennsylvania State University, Ted Jacobson of the University of Maryland and Carlo Rovelli, now at the University of the Mediterranean in Marseille — *decided to reexamine the question of whether quantum mechanics could be combined consistently with general relativity using the standard techniques*. We knew that the negative results from the 1970s had an important loophole. Those calculations assumed that the geometry of space is continuous and smooth, no matter how minutely we examine it, just as *people had expected matter to be* before the discovery of atoms. *Some of our teachers and mentors had pointed out that if this assumption was wrong, the old calculations would not be reliable.*

So we began searching for a way to do calculations without assuming that space is smooth and continuous. We insisted on not making any assumptions beyond the experimentally well tested principles of general relativity and quantum theory. In particular, we kept two key principles of general relativity at the heart of our calculations.

The first is known as background independence. This principle says that the geometry of spacetime is not fixed. Instead the geometry is an evolving, dynamical quantity. *To find the geometry, one has to solve certain equations that include all the effects of matter and energy.* Incidentally, string theory, as currently formulated, is not background independent; the equations describing the strings are set up in a predetermined classical (that is, nonquantum) spacetime.

The second principle, known by the imposing name diffeomorphism invariance, is closely related to background independence. *This principle implies that, unlike theories prior to general relativity, one is free to choose any set of coordinates to map spacetime and express the equations*. A point in spacetime is defined only by what physically happens at it, not by its location according to some special set of coordinates (no coordinates are special). Diffeomorphism invariance is very powerful and is of fundamental importance in general relativity.

By carefully combining these two principles with the standard techniques of quantum mechanics, we developed a mathematical language that allowed us to do a computation to determine whether space is continuous or discrete. That calculation revealed, to our delight, that space is quantized. We had laid the foundations of our theory of loop quantum gravity. The term "loop," by the way, arises from how some computations in the theory involve small loops marked out in spacetime.

The calculations have been redone by a number of physicists and mathematicians using a range of methods. Over the years since, the study of loop quantum gravity has grown into a healthy field of research, with many contributors around the world; our combined efforts give us confidence in the picture of spacetime I will describe.

Ours is a quantum theory of the structure of spacetime at the smallest size scales, so to explain how the theory works we need to consider what it predicts for a small region or volume. *In dealing with quantum physics, it is essential to specify precisely what physical quantities are to be measured.* To do so, we consider a region somewhere that is marked out by a boundary, B. The boundary may be defined by some matter, such as a cast-iron shell, or it may be defined by the geometry of spacetime itself, as in the event horizon of a black hole (a surface from within which even light cannot escape the black hole's gravitational clutches).

What happens if we measure the volume of the region? What are the possible outcomes allowed by both quantum theory and diffeomorphism invariance? If the geometry of space is continuous, the region could be of any size and the measurement result could be any positive real number; in particular, it could be as close as one wants to zero volume. But if the geometry is granular, then the measurement result can come from just a discrete set of numbers and it cannot be smaller than a certain minimum possible volume. *The question is similar to asking how much energy electrons orbiting an atomic nucleus have.* Classical mechanics predicts that an electron can possess any amount of energy, but quantum mechanics allows only specific energies (amounts in between those values do not occur). *The difference is like that between the measure of something that flows continuously, like the 19th-century conception of water, and something that can be counted, like the atoms in that water.*

The theory of loop quantum gravity predicts that space is like atoms: there is a discrete set of numbers that the volume-measuring experiment can return. Volume comes in distinct pieces. Another quantity we can measure is the area of the boundary B. Again, calculations using the theory return an unambiguous result: the area of the surface is discrete as well. In other words, space is not continuous. It comes only in specific quantum units of area and volume.

The possible values of volume and area are measured in units of a quantity called the Planck length. This length is related to the strength of gravity, the size of quanta and the speed of light. It measures the scale at which the geometry of space is no longer continuous. The Planck length is very small: 10^{-33} centimeter. The smallest possible nonzero area is about a square Planck length, or 10^{-66} cm^2. The smallest nonzero volume is approximately a cubic Planck length, 10^{-99} cm^3. Thus, the theory predicts that there are about 10^{99} atoms of volume in every cubic centimeter of space. The quantum of volume is so tiny that there are more such quanta in a cubic centimeter than there are cubic centimeters in the visible universe (10^{85}).

II Translate the italicized sentences into Russian. Explain the use of the grammar constructions.

III Vocabulary Notes

(Oxford Advanced Learner's Dictionary)

ambiguous — (adj.) 1. that can be interpreted in more than one way; 2. not clearly stated or defined; *ambiguity* (noun)

to discourage — (verb) 1. (smb from doing smth) to take away smb's confidence or hope of doing smth; 2. to try to stop smth by showing disapproval or creating difficulties; *discouraging* (adj.): discouraging results

to distort — (verb) 1. to pull or twist smth out of its usual shape; 2. to give a false account of smth: to distort facts

a loophole — (noun) a way of avoiding smth, especially because the words of a law, a contract, etc. are not clear: to find or exploit a loophole in the rules

minute — (adj.) 1. very small in size and amount; 2. containing much detail, careful and accurate: a minute examination or inspection, study the contract in minutest detail; *minutely* — (adv.) very carefully, with a lot of attention to detail: a minutely detailed report; *minuteness* (noun)

to perceive — (verb) to become aware of smth or smb, to notice

or observe smb or smth: we had already perceived how the temperature fluctuated; *perception* — (noun) the ability to see, hear or understand things, awareness; *perceptible* — (adj.) that can be felt or noticed with the senses: perceptible sounds; a perceptible change, improvement; *perceptive* — (adj.) having or showing understanding or insight: a perceptive judgement or comment
to specify — (verb) to state smth clearly and definitely: the regulations specify that calculators may not be used in the examination; *specification* — (noun) a description of what is required: the offer didn't meet our specifications; *specific* — (adj.) detailed and exact: specific instructions

IV Comprehension Exercises

Answer the following questions.

1. Why did the physicists in the mid-1980s decide to reexamine the question of whether quantum mechanics could be combined consistently with general relativity using the standard techniques?
2. What had their teachers and mentors pointed out?
3. What kind of assumptions did the scientists insist on not making?
4. What is the first key principle of general relativity that the physicists of loop quantum gravity kept at the heart of their calculations?
5. What is the second key principle of general relativity closely related to the first one?
6. What did the combination of these two principles with the standard techniques of quantum mechanics allow the scientists to determine?
7. The foundation of what theory did they lay?
8. Why is the term "loop" involved in the theory?
9. By whom have the calculations been redone and confirmed?
10. What does this fact manifest?
11. How did it happen that the study of loop quantum gravity has grown into a vast and healthy field of research?

12. What does the structure of spacetime look like in the loop quantum theory?
13. What is the difference between the measurement results if the geometry of space is continuous and if the geometry is granular?
14. Compare what classical mechanics and quantum mechanics predict by asking how much energy electrons orbiting an atomic nucleus have.
15. What result did the volume-measuring experiment return?
16. What did the area of the surface-measuring experiment show?
17. In what units are the possible values of volume and area measured?
18. What does the loop quantum gravity theory predict?

V Grammar

1. Give the three forms of the verbs (one of them is regular): to choose, to keep, to set, to deal, to flow, to fly, to know, to begin, to make, to say, to find, to lay, to do, to grow, to give, to have.
2. Insert the proper prepositions from the text:
   a. So we began searching ... a way to do calculations ... assuming that space is smooth and continuous.
   b. We insisted ... not making any assumptions ... the experimentally well tested principles of general relativity and quantum theory.
   c. ... particular, we kept two key principles ... general relativity ... the heart of our calculations.
   d. The second principle known ... the imposing name diffeomorphism invariance is closely related ... background independence.
   e. This principle implies that, unlike theories prior ... general relativity, one is free to choose any set ... coordinates to map spacetime.
   f. A point in spacetime is defined only ... what physically happens ... it, not ... its location according ... some special set ... coordinates.

g. Diffeomorphism invariance is very powerful and is … fundamental importance … general relativity.
h. … carefully combining these two principles … the standard techniques … quantum mechanics, we developed a mathematical language that allowed us to do a computation to determine whether space is continuous or discrete.
i. We had laid the foundations … our theory of loop quantum gravity.
j. The term "loop" … the way arises … how some computations … the theory involve small loops marked … … spacetime.
k. If the geometry is granular, then the measurement result can come … just a discrete set … numbers and it cannot be smaller than a certain minimum possible volume.
l. The question is similar … asking how much energy electrons orbiting an atomic nucleus have.
m. Classical mechanics predicts that an electron can possess any amount … energy, but quantum mechanics allows only specific energies (amounts … … those values do not occur).
n. The difference is like that … the measure of something that flows continuously, like the 19th century conception … water and something that can be counted, like the atoms … that water.
o. The Planck length measures the scales … which the geometry … space is no longer continuous.

3. Few/a few, little/a little

   Few is used with plural nouns, *little* is used with singular uncountable nouns. Without articles *few* and *little* have rather negative meanings. They often suggest "not as much/many as one would like", or "not as much/many as expected", or a similar idea.
   He has little interest in politics.
   Few people can speak a foreign language perfectly.

A few and *a little* are more positive: their meaning is closer to "some". They often suggest ideas like "better than nothing" or "more than expected". "Quite a few" suggests a considerable number of smth;
Compare. His theory is very difficult, few people understand it. His theory is very difficult, but a few people understand it (Michael Swan. Practical English Usage). A little more information concerning the results of the experiment might come in handy. So far little information has been obtained.

Choose the correct indefinite pronoun: few/a few, little/a little.

a. The Greek philosophers had … idea that the earth was round and that "down" meant towards its centre.
b. … objects in the heavens have been treated with such unmerited neglect as the Great Nebula in Andromeda.
c. This controversial theory finds … scientific support.
d. Although since ancient times some philosophers and scientists had speculated that if matter were broken up into small enough bits, it might turn out to be made up of very tiny atoms, … thought the existence of atoms could ever be proved.
e. We conclude this article with … observations.
f. … doubt arises whether this theory holds true.
g. This approach has gained … followers so far.

The Comparative Degrees of "few" and "little".

a. The coalescence of two black holes would create even stronger gravitational waves, but physicists believe that there are … black holes than neutron stars, so such events would be rarer.
b. Of the two theories — Big Bang theory and Steady State theory — the latter has … scientific support.

4. Indefinite pronoun ONE

"One" is used instead of "you" in general statements, i.e. when you are making a statement about people in general, which

also applies to yourself.
One cannot always be right, can one?
One must bring one's own talents to every single task. One cannot be sure what lies ahead.
(Michael Swan. Practical English Usage)

Translate into English.

a. Нельзя забывать, что честь создания аналитической геометрии принадлежит П. Ферма и Р. Декарту.
b. Можно понять титанические усилия, предпринятые Галилеем в попытке поддержать картину вселенной Коперника.
c. Этот принцип подразумевает, что вы свободны в выборе любой системы координат, чтобы описать пространство-время и вывести уравнения.

5. "Have to" can be used with a particle *to* with the infinitive to express the idea of obligation; "to be to" is often used to talk about arrangements which have been planned for the future.

   Open the brackets using the correct forms of the verbs *to have to*, *to be to*.

   a. In 1872 Cantor published a paper that included a very general solution to his problem of number continuum together with the seeds of what later (to become) the theory of transfinite sets.
   b. For such new theories to be viable they (to meet) criteria that are steadily becoming more rigorous.
   c. Planck (to find) some theoretical justification for his radiation formula.
   d. The problem is so important that it is not easy even to assess the revolution in physics, if the gravitational waves (to discover).

6. Translate into Russian the sentences with Modal Verbs + Present or Perfect Infinitive Constructions.

   If a supernova with a given redshift looks dimmer than expected, then the supernova must be farther away than astronomers thought. Its light has taken longer to reach us and hence the universe must have taken longer to grow to its current size. Consequently, the expansion rate of the universe must have been slower in the past than previously was expected. In fact, the distant supernovae are dim enough so that the expansion of the universe must have accelerated to have caught up with its current expansion rate.

7. Open the brackets using Modal Verbs with the Perfect Infinitive.
   a. You (to notice) that the rational numbers include both positive and negative integers.
   b. There are only two basic ways a terrestrial planet (to form). It appears quite likely, however, that the terrestrial planets (to form) from planetesimals.
   c. Everyone realizes that the simplicity of Newton's great discovery is only apparent. The actual events (to be) much more complex.
   d. In the book "The Dialogue" there is a demonstration that hardly (to fail) to interest Newton.
   e. A passage Galileo wrote and particularly a diagram he drew (to apply) by Newton to a purpose that never occurred to Galileo.
8. The Subjunctive Mood. Conditionals. Unreal conditions. Type III.

   Translate the following sentences containing the Subjunctive Mood. Explain the use of the corresponding grammar forms.
   a. If the column had been smaller but of the same relative proportions, it would not have failed.
   b. If Einstein had done no more than to find an alternative and neater expression for gravitation than Newton, he would have been the Copernicus of the new era; but he did more — he showed that the new method gave results in better agreement with experiment.

   Open the brackets putting the verb in the required form.
   a. Unless the scientists (to develop) atomic clocks, we (not to have) so accurate a standard of time.

b. Like Gauss, Jacobi (can make) easily a high reputation in philology, unless maths (to attract) him more strongly.
c. These examples may suggest that the whole subject is trivial. But if it (to be), Gauss (not to attach) the extraordinary importance to it that he did.

Explain the use of the mixed case in the following paragraph containing a conditional sentence.

Gauss remarked that he couldn't understand how Archemedes failed to invent the decimal system of numeration or its equivalent which in his opinion was in Archemedes's hands. This oversight Gauss regarded as the greatest calamity in the history of science. "To what height would science now be raised if Archemedes had made that discovery!" — he exclaimed.

VI Phrasal Verbs and Idioms

to mark out — to draw lines to show the boundaries of smth
to set up — 1. to place or build up smth; 2. to make a piece of equipment, a machine ready for use; 3. to make the necessary preparations so that smth could take place (to set up an experiment); 4. to establish or create smth (to set up business); 5. to cause a process or a series of events to begin and continue
down the line — to pursue an activity without evident results

VII Exercises

1. Give synonyms to the following words.

minute	prior
to involve	to require
to perceive	to apply
distinct	to favour
to occur	an ally
precise	to encourage
an outcome	to reveal
to evolve	to probe

2.Give antonyms to the following words.

to split	to agree
a foe	to reveal
ambiguous	tiny
to encourage	compatible
to be aware of smth	exact

VIII Key Terms

BACKGROUND INDEPENDENT — this means that the theorists working on loop quantum gravity believe the laws of nature can be stated without making any prior assumptions about the geometry of space and time

THE EVENT HORIZON OF A BLACK HOLE — the boundary of the black hole: no light can escape from inside this boundary

A SET OF COORDINATES — an ordered set of numbers which specify the position or orientation of a point or geometric configuration relative to a set of axes

THEORY OF LOOP QUANTUM GRAVITY — the theory that would unify gravitational physics with modern quantum field theory

IX Vocabulary Practice

Fill in the gaps using the key words given below.

From the early part of the 20th century scientists of physics have (усилили) their efforts to see if general relativity and quantum mechanics could be (стать совместимой). The physicists assume that the universe (должна управляться) by a single set of rules and are thus disturbed that at the moment they have (полагаться на) two sets. One, called quantum mechanics, (описывает) the small fundamental particles of which matter (состоит) and the forces by which these particles (взаимодействуют). The other — general relativity — describes the force of gravity which (удерживает) big objects together. (Совмещение) these two universal descriptions has exercised (некоторые самые гениальные умы в области физики) but has yet (предоставить неоспоримый результат). Until recently the wide spread expectation was that some version of the idea called string theory would (доминировать). The string theory theorists think that the world is made of matter that (существует независимо от пространства-времени). (Материя, о которой идет речь, состоит из частиц) that are formed from (различных вибраций струн). According to string theory space and time are (фиксированный фон) that has a geometric structure — an unchanging stage on which (разыгрывается спектакль природы).

Loop quantum gravity (быстро стала популярной) as an alternative to string theory and (становится все более успешной). The main idea of the theory (подразумевает) that space and time are not smooth, as general relativity (требует) but come in (крошечными отдельными кусками). Loop quantum gravity is (независима от фона). The theorists believe that the laws of nature can be stated without (не делая никаких предварительных предположений) about the geometry of space and time. Space and time are (всего лишь следствия) of these laws. Loop quantum gravity can (быть представлена) as (сетка из петель). Theorists working on loop quantum gravity think that matter itself is merely a result of (скручивания и переплетения) ribbons of space and time. A fundamental particle is created when three ribbons (соединены) in a plait. Though string theory is (более устоявшаяся) of the two, some 90% of theoretical physicists (заняты) in developing it. But string theory has been around for decades (не принеся обещанных результатов), and that failure (вдохновила) the protagonists of the alternative explanation (ринуться вперед). Nevertheless, both string theory and loop quantum gravity (содержат неразрешенные проблемы). Most important, neither has been tested experimentally. Nor, (несмотря на обнадеживающие разговоры о противоположном), is there (больших перспектив того, что эксперимент будет произведен). Having two candidates for a theory of everything is almost as (обескураживающее) to physicists as their inability to reconcile quantum mechanics and quantum gravity in the first place. They (намного больше хотели бы) have just one theory. (К сожалению), 20 years down the line, exactly how this may be done (остается туманным).

Key words: remains elusive, reinforced, made compatible, unfortunately, must be governed, would far rather, to rely on, discouraging, describes, much prospect of an experiment being devised, consists, despite hopeful talk to the contrary, interact, harbour unresolved problems, holds, to push themselves forward, reconciling, has encouraged, some of physics' most brilliant minds, without delivering the goods, to provide an uncontested result, are engaged, exists independently of space and time, the more established, the matter in question consists of particles, are joined, different vibrations of strings, a result of twisting and braiding, a fixed background, a mesh of loops, be visualized, mere consequences, nature's play takes place, making any prior assumptions, took off, background independent, is gaining ground, tiny distinct chunks, implies, requires, dominate.

X Conversational Practice

Agree or disagree with the statements. Justify your judgements. Add some sentences to develop your idea. The following sentences can be useful.

I will start by saying, ...	But the point is ...
In this connection I would like to mention ...	Far from that.
The simple reason is that ...	What is lacking in the statement is that...
I have a similar view.	There is no point in denying that ...

1. The negative results concerning the possibility of unification of general relativity with quantum mechanics using the standard techniques from the 1970s had an important loophole.
2. The scientists decided to reexamine the problem by assuming that space is smooth and continuous and by making any assumptions beyond the experimentally well tested principles of general relativity and quantum theory.
3. The scientists kept two key principles of general relativity at the heart of their calculations.

4. A point in spacetime is defined by its location according to some special set of coordinates.
5. By carefully combining these two principles with the standard techniques of quantum mechanics the scientists developed a maths language that allowed them to do a computation to determine whether space is continuous or discrete.
6. Over the years since the study of loop quantum gravity has failed.
7. Loop quantum gravity is a quantum theory of the structure of spacetime at the largest size scales.
8. If we measure the volume of the region and the geometry of space is taken to be continuous, the region could be of any size and the measurement result could be any positive real number, in particular, it could be as close as one wants to zero volume.
9. Volume comes in distinct pieces.
10. The Planck length is very large. It measures the scale at which the geometry of space is continuous.
11. The theory predicts that there are about 10^{99} atoms of volume in every cubic centimeter of space.

XI Write a mini-report concerning the hot topics of nowadays physics: string theory, non-commutative geometry, loop quantum gravity. Give your view point and substantiate it. The following expressions may be helpful.

In this abstract I review/I concentrate on the features/characteristics of...
There is currently great interest in...
My analysis focuses on/ outlines/ tackles/ elucidates...
When we compare the theories, further questions arise.
I argue that...
This latter point requires justification.
The idea fits into contemporary speculation.
This idea is a useful starting point in investigating...
The theory commands wide support/ gains ground.

To lend support to the hypotheses we require the knowledge of…
To bridge the gap in our knowledge we should pay attention to…
The problem presupposes minute analysis.
My argument is based on considerations that…
The idea still generates controversy/raises many questions.
I have sufficient ground to assume that…
The approach is more flexible/ creative/ effective/ sound.
Theoretically important here is the clear demarcation between the theories.
The studies have reached widely differing conclusions.
The results are in agreement/ accordance/ conflict with …
The theory fails to verify … / to find a correlation between …
The reason for rejecting the idea in favour of … comes from the fact that…
The mechanism involved in … is complex and still poorly understood.
I conclude this paper by stressing/ emphasizing that…
The challenges deserve closer examination.

XII Render the following texts.

ТЕОРИЯ СТРУН

Материал из Википедии — свободной энциклопедии

Теория струн — направление математической физики, изучающее динамику и взаимодействия не точечных частиц, а одномерных протяженных объектов, так называемых квантовых струн. Теория струн сочетает в себе идеи квантовой механики и теории относительности, поэтому на ее основе, возможно, будет построена будущая теория квантовой гравитации.

Теория струн основана на гипотезе, что все элементарные частицы и их фундаментальные взаимодействия возникают в результате колебаний и взаимодействий ультрамикроскопических квантовых струн на масштабах порядка планковской длины 10^{-35} м. Данный подход, с одной стороны, позволяет избежать таких трудностей квантовой теории поля, как перенормировка, а с другой стороны, приводит к более глубокому взгляду на структуру материи и пространства-времени.

Квантовая теория струн возникла в начале 1970-х годов в результате осмысления формул Габриэле Венециано, связанных со струнными моделями строения адронов. Середина 1980-х и середина 1990-х ознаменовались бурным развитием теории струн, ожидалось, что в ближайшее время на основе теории струн будет сформулирована так называемая «единая теория», или «теория всего», поискам которой Эйнштейн безуспешно посвятил десятилетия. Но, несмотря на математическую строгость и целостность теории, пока не найдены варианты экспериментального подтверждения теории струн. Возникшая для описания адронной физики, но не вполне подошедшая для этого, теория оказалась в своего рода экспериментальном вакууме описания всех взаимодействий.

ПЕТЛЕВАЯ КВАНТОВАЯ ГРАВИТАЦИЯ

В ней делается попытка сформулировать квантовую теорию поля без привязки к пространственно-временному фону, пространство и время по этой теории состоят из дискретных частей. Эти маленькие квантовые ячейки пространства определенным способом соединены друг с другом, так что на малых масштабах времени и длины они создают пеструю, дискретную структуру пространства, а на больших масштабах плавно переходят в непрерывное гладкое пространство-время. Хотя многие космологические модели могут описать поведение вселенной только от планковского времени после Большого взрыва, петлевая квантовая гравитация может описать сам процесс взрыва, и даже заглянуть раньше. Петлевая квантовая гравитация позволяет описать все частицы стандартной модели, не требуя для объяснения их масс введения бозона Хиггса.

Unit IV

Text

INFORMATION IN THE HOLOGRAPHIC UNIVERSE[7]

Theoretical results about black holes suggest that the universe could be like a gigantic hologram

by Jacob D. Bekenstein

THE AUTHOR

Jacob D. Bekenstein has contributed to the foundation of black hole thermodynamics and to other aspects of the connections between information and gravitation. He is Polak Professor of Theoretical Physics at the Hebrew University of Jerusalem, a member of the Israel Academy of Sciences and Humanities, and a recipient of the Rothschild Prize. Bekenstein dedicates this article to John Archibald Wheeler (his Ph.D. supervisor 30 years ago).

[7] Scientific American, February 2004, pp. 32–34

Word Combinations

to leave traces	to forbid an inverse process
in accordance with Einstein's $E = mc^2$	a clue to resolving a puzzle
to circle smth	to exceed the star's entropy
to preserve a law	to cope with smth
to violate a law	to bar information
to make a law irrelevant	to undergo a process
an irreversible process	to set bounds on the information capacity
to reach an impasse	to generate a full 3D image on its 2D boundary

I Read the questions and find answers in the text that follows.

1. What does the generalized second law of thermodynamics hold?
2. What does information capacity depend on?
3. What does holographic principle state?

BLACK HOLE THERMODYNAMICS

A central player in the developments of gravitational physics is the black hole. Black holes are a consequence of general relativity, Albert Einstein's 1915 geometric theory of gravitation. *In this theory, gravitation arises from the curvature of spacetime, which makes objects move as if they were pulled by a force.* Conversely, the curvature is caused by the presence of matter and energy. According to Einstein's equations, a sufficiently dense concentration of matter or energy will curve spacetime so extremely that it rends, forming a black hole. The laws of relativity forbid anything that went into a black hole from coming out again, at least within the classical (nonquantum) description of the physics. The point of no return, called the event horizon of the black hole, is of crucial importance. In the simplest case the horizon is a sphere, whose surface area is larger for more massive black holes.

It is impossible to determine what is inside a black hole. No detailed information can emerge across the horizon and escape into the outside world. *In disappearing forever into a black hole, however, a piece of matter does leave some traces.* Its energy (we count any mass as energy in accordance with Einstein's $E = mc^2$) is permanently reflected in an increment in the black hole's mass. If the matter is captured while circling the hole, its associated angular momentum is added to the black hole's angular momentum. Both the mass and angular momentum of a black hole are measurable from their effects on spacetime around the hole. In this way, the laws of conservation of energy and angular momentum are upheld by black holes. *Another fundamental law, the second law of thermodynamics, appears to be violated.*

The second law of thermodynamics summarizes the familiar observation that most processes in nature are irreversible: a teacup falls from the table and shatters, but no one has ever seen shards jump up of their own accord and assemble into a teacup. The second law of thermodynamics forbids such inverse processes. It states that the entropy of an isolated physical system can never decrease; at best, entropy remains constant, and usually it increases. *This law is central to physical chemistry and engineering; it is arguably the physical law with the greatest impact outside physics.*

As first emphasized by Wheeler, when matter disappears into a black hole, its entropy is gone for good, and the second law seems to be transcended, made irrelevant. A clue to resolving this puzzle came in 1970, when Demetrious Christodoulou, then a graduate student of Wheeler's at Princeton, and Stephen W. Hawking of the University of Cambridge independently proved that in various processes, such as black hole mergers, the total area of the event horizons never decreases. The analogy with the tendency of entropy to increase led me to propose in 1972 that a black hole has entropy proportional to the area of its horizon. I conjectured that when matter falls into a black hole, the increase in black hole entropy always compensates or overcompensates for the "lost" entropy of the matter. More generally, the sum of black hole entropies and the ordinary entropy outside the black holes can not decrease. This is the generalized second law — GSL for short.

The GSL has passed a large number of stringent, if purely theoretical, tests. When a star collapses to form a black hole, the black hole entropy greatly exceeds the star's entropy. In 1974 Hawking demonstrated that a black hole spontaneously emits thermal radiation, now known as Hawking radiation, by a quantum process. The Christodoulou-Hawking theorem fails in the face of this phenomenon (the mass of the black hole, and therefore its horizon area, decreases), but the GSL copes with it: the entropy of the emergent radiation more than compensates for the decrement in black hole entropy, so the GSL is preserved. *In 1986 Rafael D. Sorkin of Syracuse University exploited the horizon's role in barring information inside the black hole from influencing affairs outside to show that the GSL (or something very similar to it) must be valid for any conceivable process that black holes undergo. His deep argument makes it clear that the entropy entering the GSL is that calculated down to level X, whatever that level may be.*

Hawking's radiation process allowed him to determine the proportionality constant between black hole entropy and horizon area: black hole entropy is precisely one quarter of the event horizon's area measured in Planck areas. (The Planck length, about 10^{-33} centimeter, is the fundamental length scale related to gravity and quantum mechanics. The Planck area is its square.) Even in thermodynamic terms, this is a vast quantity of entropy. The entropy of a black hole one centimeter in diameter would be about 10^{66} bits, roughly equal to the thermodynamic entropy of a cube of water 10 billion kilometers on a side.

THE WORLD AS A HOLOGRAM

The GSL allows us to set bounds on the information capacity of any isolated physical system, limits that refer to the information at all levels of structure down to level X. *In 1980 I began studying the first such bound, called the universal entropy bound, which limits how much entropy can be carried by a specified mass of a specified size.* A related idea, the holographic bound, was devised in 1995 by Leonard Susskind of Stanford University. It limits how much entropy can be contained in matter and energy occupying a specified volume of space.

In his work on the holographic bound, Susskind considered any approximately spherical isolated mass that is not itself a black hole and that fits inside a closed surface of area A. If the mass can collapse to a black hole, that hole will end up with a horizon area smaller than A. The black hole entropy is therefore smaller than $A/4$. What if the mass does not spontaneously collapse? *In 2000 I showed that a tiny black hole can be used to convert the system to a black hole not much different from the one in Susskind's argument.* The bound is therefore independent of the constitution of the system or of the nature of level X. It just depends on the GSL.

We can now answer some of those elusive questions about the ultimate limits of information storage. A device measuring a centimeter across could in principle hold up to 10^{66} bits — a mind-boggling amount. The visible universe contains at least 10^{100} bits of entropy, which could in principle be packed inside a sphere a tenth of a light-year across. *Estimating the entropy of the universe is a difficult problem, however, and much larger numbers, requiring a sphere almost as big as the universe itself, are entirely plausible.*

But it is another aspect of the holographic bound that is truly astonishing. Namely, that the maximum possible entropy depends on the boundary area instead of the volume. Imagine that we are piling up computer memory chips in a big heap. *The number of transistors — the total data storage capacity — increases with the volume of the heap. So, too, does the total thermodynamic entropy of all the chips.* Remarkably, though, the theoretical ultimate information capacity of the space occupied by the heap increases only with the surface area. *Because volume increases more rapidly than surface area, at some point the entropy of all the chips would exceed the holographic bound. It would seem that either the GSL or our commonsense ideas of entropy and information capacity must fail. In fact, what fails is the pile itself: it would collapse under its own gravity and form a black hole before that impasse was reached. Thereafter each additional memory chip would increase the mass and surface area of the black hole in a way that would continue to preserve the GSL.*

This surprising result — that information capacity depends on surface area — has a natural explanation if the holographic *principle* (proposed in 1993 by Nobelist Gerard't Hooft of the University of Utrecht in the Netherlands and elaborated by Susskind) is true. In the everyday world, a hologram is a special kind of photograph that generates a full three-dimensional image when it is illuminated in the right manner. All the information describing the 3-D scene is encoded into the pattern of light and dark areas on the two-dimensional piece of film, ready to be regenerated. The holographic principle contends that an analogue of this visual magic applies to the full physical description of any system occupying a 3-D region: it proposes that another physical theory defined only on the 2-D boundary of the region completely describes the 3-D physics. *If a 3-D system can be fully described by a physical theory operating solely on its 2-D boundary, one would expect the information content of the system not to exceed that of the description on the boundary.*

II Translate the italicized sentences into Russian. Explain the use of the grammar constructions.

III Vocabulary Notes

(Oxford Advanced Learner's Dictionary)
to argue — (verb) 1. (with smb about/over smth) — to express an opposite opinion, to exchange angry words; 2. (for/against smth) — to give reasons for or against smth, especially with the aim of persuading smb to share one's own opinion; *arguable* — (adj.) 1. that can be argued or asserted; 2. that can be questioned, not obviously correct, e.g.: the account contains many arguable points/statements; *arguably* — (adv.) one could give reasons to support a point of view, e.g.: it is arguably the most important aspect of the discussion; *argument* — (noun) 1. with smb about smth — a disagreement, especially an angry one; 2. discussion based on reasoning; 3. a reason put forward: accept or reject an argument
to bound — (verb, usually passive) to form the boundary of smth, to limit smth; *boundary* (noun) — a line that marks a limit, a dividing line, e.g.: scientists continue to push back the boundaries of knowledge; *bounds* — (noun, pl.) the accepted or furthest limits of smth, e.g.: the idea is beyond the bounds of possibility
to conceive — (verb) to form an idea, a plan etc. in the mind, to

imagine smth, e.g.: the ancients conceived (of) the world as (being) flat; *conceivable* — (adj.) that can be conceived or believed, e.g.: the GSL must be valid for every conceivable process
to estimate — (verb) to form a rough and general idea of smth, to calculate roughly the cost, size, value of smth; *estimate* (noun) — judgement or calculation not necessarily detailed or accurate
impasse (noun) — a difficult situation from which there is no way out, e.g.: break/resolve the impasse; *impassable* (adj.) — (of a road/route etc.) impossible to travel on or over
to merge (verb) — with/into smth, together — to combine or to make two or more things come together and combine; *merger* (noun)
to transcend (verb) — to be or go beyond the normal limits of smth; *transcendental* (adj.) — going beyond the limits of human knowledge, e,g.: transcendental experience
to undergo (verb) — to be put through a process, etc, e.g.: the GSL must be valid for any conceivable process the black holes undergo
to uphold (verb) — to support or confirm a decision, a belief which has been questioned, e.g.: to uphold an appeal/a principle; *upholder* (noun) — upholders of tradition

IV Comprehension Exercises

Answer the following questions.

1. What is the curvature of spacetime caused by?
2. How do black holes form?
3. What do the laws of relativity forbid?
4. What is the point of no return called?
5. As no detailed information can emerge across the horizon and escape into the outside world, why can one say that a piece of matter does leave some traces?
6. While the laws of conversation of energy and angular momentum are upheld by black holes, another fundamental law (the second law of thermodynamics) appears to be violated. Why?
7. How did a clue to resolving this puzzle come?

8. What does the Christodoulou-Wheeler theorem state?
9. What did J. D. Bekenstein propose in 1972? What did he conjecture?
10. What happens when a star collapses to form a black hole? What did Stephen W. Hawking demonstrate in 1974? Why did the Christodoulou-Hawking theorem fail in the face of this phenomenon?
11. In what way did the GSL cope with it?
12. What was the deep argument Rafael D. Sorkin of Syracuse University put forward?
13. What did the Hawking radiation process allow him to determine?
14. What does the GSL allow one to set bounds on?
15. What do the universal entropy bound and a related idea, the holographic bound, specify?
16. What did L. Susskind consider in his work on the holographic bound?
17. What was J. Bekenstein's contribution to the determination of the holographic bound?
18. Explain why the maximum possible entropy depends on the boundary area instead of the volume.
19. How does the holographic principle work?

V Grammar

1. Give the three forms of the verbs: to fit, to forbid, to lose, to lend, to hold, to undergo, to rend, to undertake, to uphold.
2. Compare the difference in the accent in the verbs and the nouns: to in´crease — an ´increase, to de´crease — a ´decrease, to im´pact — an ´impact.
3. Mind the difference between “to influence smth” and “to have an influence on smth”.

   Translate the sentences giving two variants:

   a. Transfinite numbers (оказали огромное влияние) the further development of mathematics.

b. The honour of creating the differential and integral calculus belongs to Newton. This (оказало огромное влияние) the entire subsequent development of physics.
c. No other discovery in physics (не оказало такого огромного влияния) all the subsequent development of science as Newton's law of universal gravitation.

4. Insert the missing prepositions.
   a. I conjectured that when matter falls … a black hole, the increase … black hole entropy always compensates or overcompensates … the lost energy of the matter.
   b. The Christodoulou-Hawking theorem fails … the face … this phenomenon (the mass … the black hole, and therefore its horizon area decreases) but the GSL copes … it: the entropy of the emergent radiation more than compensates … the decrement in black hole entropy, so the GSL is preserved.
   c. The GSL allows one to set bounds … the information capacity … any isolated physical system, limits that refer … the information … all levels … structure down … level X.
5. Insert that, those, one.
   a. The example illustrates three advantages that algebraic programs have over purely numerical … .
   b. Supermassive holes are the collapsed remnants of a mass several million times … of the Sun.
   c. The story of Galois known to most people today is derived from popular accounts, such as … by the physicist Leopold Infeld and the astronomer Fred Hoyle. The most influential version of the story has been … of Eric Temple Bell.
   d. A tiny black hole can be used to convert the system to a black hole not much different from the … in Susskind's argument.
6. Fill in the forms of the Gerund with the preceding prepositions where necessary.

a. The Green Peace activists insist ... (to take) urgent measures to reduce air pollution.
b. The Greeks had several ways ... (to write) their numbers.
c. The mystery of the origin of the universe is far ... (to be) solved.
d. Innumerable experiments performed by Newton resulted ... his (to invent) a reflecting telescope.
e. The theorem may be stated in somewhat different form, in which it is capable ... (to be proved) in a simple manner.
f. ... (to invent) his reflecting telescope, Newton could perform a series of experiments with light.
g. We began (to search) for a way to do calculations ... (to assume) that space is smooth and continuous.
h. ... carefully (to combine) these two principles with the standard techniques of quantum mechanics, we developed a mathematical language that allowed us to do a computation to determine whether space is continuous or discrete.
i. ... (to deal) with quantum physics, it is essential to specify precisely what physical quantities are to be measured.
j. ... (to be appointed) professor at Cambridge Newton continued (to work) on the problem of gravitation.
k. ... (to disappear) forever into a black hole, however, a piece of matter does leave some traces.
l. Newton succeeded ... (to complete) his whole theory in 1673.
m. Galileo's (to be persecuted) by Church darkened the last years of his life.
n. Archimedes's (to overlook) the decimal system of numeration or its equivalent was in Gauss's opinion the greatest calamity in the history of science.
o. Given the success ... (to replace) the gravitational force with the dynamics of space and time, why not seek a

geometric explanation for the other forces of nature and even for the spectrum of elementary particles?

p. In the "Principia" Newton credited Galileo ... (to rely) on the law of inertia.

V Phrasal Verbs and Idioms

1. of one's own accord — without being asked or forced
2. to be gone for good — forever
3. a mind-boggling amount — one can hardly accept or imagine a particular idea, suggestion, amount, etc
4. in the face of this phenomenon — in spite of smth: to succeed in the face of danger
5. by leaps and bounds — very quickly
6. to be beyond the bounds of possibility — beyond the conceivable limits
7. to end up — to reach or come to a certain place, especially by a long route or process
8. to pile up — to increase, to accumulate in quantity
9. to hold up — to delay or block the movement
10. to push back the boundaries of knowledge — to make efforts to enlarge the area of knowledge

VI Exercises

1.Give synonyms to the following words.

to emerge	to preserve
to avoid	to bar
to seize	to regard
to influence	to contend
to elaborate	to convert
to uphold	to conjecture
to (re)generate	a deadlock
to bound	to exploit
to compensate	to argue
to surpass	to contain

2.Give antonyms to the following words.

decrement	reversible	outside	to fail
relevant	temporary	possible	valid
to encode	to appear	plausible	visible
to permit	to pull	permeable	to pack

3.Match an idiom or a phrasal verb in the left column with its equivalent in the right one.

1. By leaps and bounds	a. forever
2. To set bounds on	b. to increase in quantity
3. Of one's own accord	c. to authorize the accepted limits
4. To make it clear	d. to establish smth
5. To hold up	e. to reach or come to a certain place
6. To mark out	f. in spite of smth
7. To point out	g. to draw lines
8. To set up	h. to direct attention to smth
9. To relate to smb/smth	i. easy to understand; not causing confusion
10. To end up	j. to block the movement
11. To pile up	k. to refer to smth
12. In the face of smth	l.without being asked or forced
13. To push back the boundaries	m. very rapidly
14. To be gone for good	n. to make efforts to enlarge the area of smth

VIII Key Terms

ANGULAR MOMENTUM — the quantity of motion of a moving object measured as its mass multiplied by its speed
BLACK HOLE — a region in space from which no matter or radiation can escape; the point of no return is called the event horizon of the black hole
BLACK HOLE MERGERS — combining of two or more black holes into one
HAWKING RADIATION process allowed R. Sorkin to determine proportionality constant between black hole entropy and horizon area: black hole entropy is precisely a quarter of the event horizon's area measured in Planck area (the Planck length about 10^{-33} centimeter, the fundamental length scale related to gravity and quantum mechanics); the Planck area is its square

THE HOLOGRAPHIC BOUND was devised in 1995 by L. Susskind of Stanford University; it limits how much entropy can be contained in matter and energy occupying a specified volume of space

THE HOLOGRAPHIC PRINCIPLE was proposed in 1993 by Nobelist G. Hooft and elaborated by L. Susskind; in the every day world, a hologram is a special kind of photograph that generates a full three-dimensional image when it is illuminated in the right manner. All the information describing the 3-D scene is encoded into the pattern of light and dark areas on the two-dimensional piece of film, ready to be regenerated. The holographic principle contends that an analogue of this visual magic applies to the full physical description of any system occupying a 3-D region: it proposes that another physical theory defined only on the 2-D boundary of the region completely describes the 3-D physics. If a 3-D system can be fully described by a physical theory operating solely on its 2-D boundary, one would expect the information content of the system not to exceed that of the description on the boundary

THE LAW OF ENERGY CONSERVATION – the principle that the total quantity of energy in the universe never varies

THE SECOND LAW OF THERMODYNAMICS states that the sum of black hole entropies and the ordinary entropy outside the black hole can not decrease

THERMAL RADIATION – Hawking radiation

THE ULTIMATE LIMITS OF INFORMATION STORAGE – a device measuring a centimeter across could in principle hold up to 10^{66} bits – a mind-boggling amount; the visible universe contains at least 10 100 bits of energy which could in principle be packed inside a sphere a tenth of a light-year across; estimating the entropy of the universe is a difficult problem, however, and much larger numbers requiring a sphere almost as big as the universe itself are entirely plausible

THE UNIVERSAL ENTROPY BOUND limits how much entropy can be carried by a specified mass of a specified size

IX Vocabulary Practice

Fill in the gaps using the key words given below.

Black hole is a region of space-time from which matter and energy cannot .... A black hole ... ... from a star which ... ... in on itself to the ... where its gravity is so strong that nothing, not even light, can ... from it.

Large stars, about ... ... the mass of the Sun, ... as supernovae at the end of their life. Enormous amounts of energy ... ... into space but the ... of the star can collapse under its own ... ... and begins ... ... into itself surrounding gases and other matter ... light and radiation. Some smaller stars have ... gravity to collapse to a singularity and instead ... their protons and electrons into a mass of neutrons only ... ... across to form neutron stars.

Black holes cannot be seen ... but can be ... because well over half of the stars ... as binary stars in which each ... around the other ... characteristic ... in their orbits. Since black holes and neutron stars ... their gravitational fields, these perturbations persist after the star ... ... and an ... number of such objects have now been ... and studied.

Key words: has collapsed, escape (2), is formed, increasing, point, are radiated, ten times, gravitational field, including, core, insufficient, to pull, identified, directly, rotates, detected, perturbations, retain, causing, has disappeared, explode, exist, a few kilometers, compress.

X Conversational Practice

Agree or disagree with the statements. Justify your judgements. Add some sentences to develop your idea. The following sentences can be useful:

True enough.	I think I disagree (I'm afraid).
I can't help thinking the same.	Yes, up to a point, but ...
That's just what I was thinking.	I don't entirely agree with you.
I couldn't agree more.	That's one way of looking at it, but...
That's the way it should be.	I don't think so.
It sounds just right.	I am afraid, it's wrong.

1. Black holes are the consequence of general relativity.
2. In disappearing forever into a black hole, however, a piece of matter does leave some traces.
3. The laws of conservation of energy and angular momentum are upheld by black holes.
4. The second law of thermodynamics allows inverse processes.
5. In 1970 D. Christodoulou and S.W. Hawking independently proved that in various processes, such as black hole mergers, the total area of the event horizons always decreases.
6. The analogy with the tendency of entropy to increase led Jacob Bekenstein to propose in 1972 that a black hole has entropy proportional to the area of its horizon.
7. The Christodoulou-Hawking theorem fails in the face of the phenomenon of Hawking radiation as well as the GSL.
8. In 1986 R. Sorkin exploited the horizon's role in barring information inside the black hole from influencing affairs outside it.
9. Hawking radiation process allowed R. Sorkin to determine the proportionality constant between black hole entropy and horizon area.
10. The GSL forbids us to set bounds on the information capacity of any isolated physical system, limits that refer to the information at all levels of structure down to level X.
11. In 1980 J. Bekenstein began studying the first such bound.
12. The holographic bound was devised in 1995 by L. Susskind and developed by J. Bekenstein.
13. We cannot answer some of those elusive questions about the

ultimate limits of information storage.

14. The maximum possible entropy depends on the boundary area instead of the volume.
15. This surprising result — that information capacity depends on surface area has a natural explanation if the holographic principle is true.

XI Write an abstract of the text. Outline the main ideas and express your point of view. Consult Unit III for reference.

XII Render the following text.

ЧЕРНЫЕ ДЫРЫ

Материал из Википедии — свободной энциклопедии

Черная дыра — область, ограниченная так называемым горизонтом событий, которую не может покинуть ни материя, ни информация. Предполагается, что такие области могут образовываться, в частности, как результат коллапса массивных звезд. Поскольку материя может попадать в черную дыру (например, из межзвездной среды), но не может ее покидать, масса черной дыры со временем может только возрастать.

Стивен Хокинг, тем не менее, показал, что черные дыры могут терять массу за счет излучения, названного излучением Хокинга. Излучение Хокинга представляет собой квантовый эффект, который не нарушает классическую ОТО.

Известно много кандидатов в черные дыры, в частности сверхмассивный объект, связанный с радиоисточником Стрелец A^* в центре нашей Галактики. Большинство ученых убеждены, что наблюдаемые астрономические явления, связанные с этим и другими подобными объектами, надежно подтверждают существование черных дыр, однако существуют и другие объяснения: например, вместо черных дыр предлагаются бозонные звезды и другие экзотические объекты.

Unit V

Text I

TO THE BOTTOM OF THE SEA[8]

Offshore structures have been built in more than 3,000 feet of water. How much deeper can the technology be pushed?

By José M. Roesset

THE AUTHOR

José M. Roesset is director of the Offshore Technology Research Center, which is jointly operated by Texas A&M University and the University of Texas at Austin.

Word Combinations

to push the technology	to endure waves and currents
to withstand gravity	civil engineering efforts
to affect offshore structures	shallow and intermediate waters
to be a major consideration	to neglect dynamic effects
to be rigid against the dynamic forces	in synchronicity with motion
with the beats spaced one second apart	to secure the assembly to smth
to become amplified through resonance	an upside-down pendulum
to be susceptible to dynamic effects	a buoyant platform
to be limited in the ability to do smth	to take into account
to be associated with smth	to be referred to as

I Read the questions and find answers in the text that follows.

1. Why are complex dynamic analyses required to determine the wave and current forces?
2. Why did engineers neglect dynamic effects in the past when designing shallow water steel jackets?
3. What solutions are proposed for constructions in deeper waters?

Like skyscrapers and bridges, an offshore platform must withstand gravity (a structure's own dead weight could, for example, cause it to collapse on itself), wind and — depending on its location — ice, snow and even earthquakes. *But deep-sea structures must also endure waves and currents, and it is these hydrodynamic forces that make such projects different from most other civil engineering efforts.*

Waves and currents affect offshore structures differently. The action of waves is concentrated near the water surface, and the forces associated with them dissipate rapidly with depth. Current forces, on the other hand, subside much more slowly. Thus, although wave forces may be more significant for traditional jackets in shallow and intermediate waters, the relative importance of currents grows with greater depths. In the Gulf of Mexico, strong loop currents and the subeddies they spawn, as well as recently detected currents at great depths, are a major consideration.

To determine the wave and current forces requires knowledge of the water particle velocities and accelerations as well as the motions of the main structural elements and other basic components, including the pipes, risers, mooring lines and tethers. Obviously, the loads vary with time, so the accurate prediction of how the structure will react to them requires, in principle, complex dynamic analyses.

In the past, engineers typically neglected dynamic effects when designing shallow-water steel jackets. This omission was acceptable because the structures were very rigid against the dynamic forces. In engineering parlance, the natural period of a steel jacket in shallow waters is about one second or less. (In other words, the structure would have a tendency to vibrate with the beats spaced roughly one second apart, just as a guitar string of a specific length and material will emit a note of a certain pitch.) *The period of the design waves, on the other hand, is normally around eight to 14 seconds, depending on the part of the world where the platform is installed.*

But construction in deeper waters has led to taller — and inherently less stiff — structures that are much more susceptible to dynamic effects such as those caused by waves. *For instance, the natural period of Shell's Cognac platform was reported to be roughly four seconds. For greater depths, the natural period of conventional steel jackets would approach that of the waves, and thus the dynamic effects would become amplified through resonance. (Think of a child soaring higher and higher on a swing because her parent pushes her in synchronicity with her motion.)*

Because building a very rigid structure in deep water would be prohibitively expensive, engineers chose a different solution: making the platforms more flexible so that their periods far exceeded those of the waves. This approach led to Exxon's Lena (built in some 1,000 feet of water in 1983), Amerada Hess's Baldpate (1,700 feet in 1997) and Texaco's Petronius (1,800 feet in 1998). For stability, Baldpate relies on mooring lines and Petronius on piles extending to more than one third the structure's depth.

A more recent alternative has been the use of floating structures tied to the ocean floor. One such solution is a tension leg platform (TLP), which typically consists of a rectangular deck supported by four columns at the corners. Below the water surface, pontoons connect the columns, and four bunches of multiple vertical tendons, one for each column, secure the entire assembly to the sea bottom. The buoyancy of the structure creates tension in the tendons, and the structure behaves as an upside-down pendulum. TLPs have played an important role in the deep waters of the Gulf of Mexico, as evidenced by Auger (installed in 2,860 feet in 1994), Mars (2,958 feet in 1995), Ram-Powell (more than 3,000 feet in 1997) and Ursa (3,800 feet in 1998). *Many variations of the classical TLP with different sizes and numbers of legs or tether bunches have been proposed and used recently, such as in British-Borneo's Morpeth field (1,700 feet in 1998).*

Another variation is the spar concept, which consists of a cylindrical hull anchored with mooring lines that radiate from the center of the floating structure. Two spars have been installed in the Gulf of Mexico: Oryx's Neptune (1,900 feet in 1997) and Chevron's Genesis (2,600 feet in 1998), with several others under design or construction. Still another option is to use a semisubmersible structure (referred to as a floating production system) that has a hull like a TLP's but is held in place with catenary mooring lines. *Also, modified tankers (called floating production storage and offloading systems) secured to the sea bottom with mooring lines are being used in many parts of the world but not in the Gulf of Mexico.*

The new structures are very pliant, with natural periods much longer than those of ocean waves. Such flexibility, however, leads to other potential problems. Engineers must consider that a structure — particularly when it is limber — can vibrate at frequencies higher than the one associated with its natural period (just as overblowing into a flute results in higher notes). For TLPs, spars and other buoyant platforms, various nonlinear effects must be investigated.

Vibrations can also be caused by vortex shedding, which occurs when waves and current move around an object, spawning vortices that can make the body undulate. Even small waves cause periodic movements that can contribute to fatigue failure, similar to the way a metal paper clip will eventually snap if a part of it is bent back and *forth repeatedly.*

To study such effects, researchers must develop more accurate methodologies to compute the nonlinear wave kinematics, hydrodynamic forces and structural responses. Much has been accomplished recently in these fields, but numerous problems require further study.

In addition to computational analyses, scale models in wave tanks have been used to study structures that were later installed at great depths in the Gulf of Mexico and in the North Sea. *Similar to wind-tunnel tests for aircraft, such experiments helped to validate proposed designs by yielding results that were then compared with analytical predictions.* Tests of North Sea platforms led to the discovery of previously unknown phenomena, such as ringing and springing of TLPs, in which nonlinear effects cause the structure to vibrate vertically. Yet even model tests are limited in their ability to determine the true behavior of a platform in the ocean. Researchers are currently developing computer simulations that fully take into account nonlinear hydrodynamics to complement the wave-tank experiments.

A factor that must be considered in such analyses is damping — the ability of a structure to dissipate energy while vibrating, thus minimizing the effects of dynamic forces. But damping for offshore platforms is normally very small; it is mainly associated with vortex shedding around the hull, tethers and mooring lines. These effects are difficult to reproduce in lab experiments and to incorporate in computer models. Although numerical solutions are under development, much work remains before they can be validated and incorporated into wave-tank simulations.

II Translate the italicized sentences into Russian. Explain the use of the grammar constructions.

III Vocabulary Notes

(Oxford Advanced Learner's Dictionary)
to amplify (verb) — to increase smth in strength or intensity, especially a sound; amplifier (noun)
a beat (noun) — a stroke of a drum, the sound of this; a rhythm

to buoy (verb) smb or smth up (especially passive) — to keep smb or smth floating; *buoyant* (adj.) — of an object that can float or continue to float; *buoyancy* (noun) — the quality of being able to float
an eddy (noun) — a circular movement of water, air, dust etc.; *to eddy* (verb) — to move in or like an eddy (eddying currents)
to endure (verb) — to suffer smth unpleasant or difficult in a patient way over a long period; *endurance* (noun)
limber (adj.) — able to bend and move easily
to omit (verb) — to exclude smth, to leave smth; *omission* (noun)
parlance (noun) — a particular way of speaking or of using words: in common, modern, official parlance
a pitch (noun) — the quality of a musical note, a voice etc., especially how high or low it is
to secure (verb) — 1. to fix smth firmly, to fasten smth; 2. to obtain smth, sometimes with difficulty; 3. to make smth safe, to protect smth; *secure* (adj.) — firmly fixed, not likely to fail, be broken etc.: a secure foundation
to soar (verb) — to rise quickly high into the air
to space (verb) — to arrange things with regular spaces between; *spacing* (noun) — the amount of space left between objects, words, etc. in laying or setting smth out
to spawn (verb) — to produce smth, often in great numbers
to subdue (verb) — to bring smth under control by force, to defeat smb or smth; *subdued* (adj.) — not very loud, intense, noticeable
to subside (verb) — 1. to become less violent, active, intense; 2. to sink to a lower or to the normal level (of water)
submersible (adj.) — that can be submerged in water
subsidiary (adj.) to smth — connected to but of less importance, etc. than smth else: a subsidiary question, quest
susceptible to smth (adj.) — easily influenced or harmed by smth; *susceptibility to smth* (noun) — the state of being susceptible
to swing (verb) — to move or make smb or smth move backwards and forwards or round and round while hanging or supported; *a swing* (noun) — a swinging movement, action or rhythm: the swing of a pendulum
to validate (verb) — to show that smth is reasonable or logical: to

validate a theory or an argument; *validity* (noun)
to withstand (verb) — to be strong enough not to be harmed or destroyed by smth

IV Comprehension Exercises

Answer the following questions.

1. What makes deep sea projects different from most other civil engineering efforts?
2. How do wave and currents affect offshore structures?
3. What is required to determine the wave and current forces?
4. Why was the omission of dynamic effects acceptable when designing shallow water steel jackets?
5. What did construction in deeper waters lead to?
6. What is the length of the natural period of Shell's Cognac platform?
7. How long is the natural period of conventional steel jackets for greater depths?
8. What solution was chosen instead of building a very rigid structure in deep water?
9. What technical means are used for stability in this case?
10. What is a more recent alternative?
11. What does a tension leg platform (TLP) look like?
12. What other options have been proposed and used recently?
13. What potential problems can arise due to great flexibility of the new structures?
14. What else can cause vibrations?
15. What do computational analyses include?
16. What has been used in addition to computational analyses to study structures that were later installed at great depths in the Gulf of Mexico and in the North Sea?
17. What tests are being currently developed to complement the wave-tank experiments?

V Grammar

1. Give the three forms of the verbs: to bend, to build, to grow, to lead, to choose, to withstand, to withdraw, to hold, to blow, to ring, to spring, to let, to shed, to swing, to beat.
2. Put in the missing prepositions and adverbs.
   a. For stability Baldpate relies ... mooring lines and Petronius ... piles extending ... more than one third the structure's depth.
   b. Still another option is to use a semisubmersible structure (referred ... as a floating production system) that has a hull like a TLP's but is held ... place ... catenary mooring lines.
   c. Even small waves cause periodic movements that can contribute ... fatigue failure, similar ... the way a metal paper clip will eventually snap if a part ... it is bent ... and ... repeatedly.
   d. Obviously, the loads vary ... time, so the accurate prediction ... how the structure will react ... them requires, ... principle, complex dynamic analyses.
   e. This omission was acceptable because the structures were very rigid ... the dynamic forces.
   f. ... other words, the structure would have a tendency to vibrate ... the beats spaced roughly one second ..., just as a guitar string ... a specific length and material will emit a note ... a certain pitch.
   g. Another variation is the spar concept, which consists ... a cylindrical hull anchored ... mooring lines that radiate ... the center ... the floating structure.
   h. Similar ... wind-tunnel tests ... aircraft, such experiments helped to validate proposed designs ... yielding results that were then compared ... analytical predictions.
   i. Engineers must consider that a structure — particularly when it is limber — can vibrate ... frequencies higher than the one associated ... its natural period (just as overblowing ... a flute results ... higher notes).
3. Fill in the forms of the Participle

a. The action of waves (to concentrate) near the water surface, and the forces (to associate) with them dissipate rapidly with depth.
b. An offshore platform must withstand gravity, wind and — (to depend) on its location — ice, snow and even earthquakes.
c. (To invent) his first telescope Galileo made a series of discoveries.
d. (To realize) the structure and mechanics of the Universe, Newton laid down the Law of Universal Gravitation.
e. (To invent) simultaneously though independently by Newton and Leibnitz the differential calculus became a subject of bitter argument between the supporters and opponents of the two scientists.
f. (To heat) to a sufficient temperature any body becomes a source of light.
g. (To ask) how he had made discoveries in astronomy (to surpass) those of all his predecessors, Newton replied: "By always thinking about them."
h. (To set) once in motion, a ball will travel with a uniform speed and in a straight line for an indefinite period of time.

VI Phrasal Verbs and Idioms

1. To space out smth apart — to arrange things with regular spaces between
2. To refer to smb or smth — to mention or speak of smb/smth

VII Exercises

1.Give synonyms to the following words.

to release	an eddy	to emit	to soar
to spawn	a beat	to vary	to yield
to resist	pliant	to neglect	to contribute
to affect	rigid	to undulate	to validate
to subside	external	to secure	roughly
to subdue	susceptible	to amplify	to endure

2. Give antonyms to the following words.

To prohibit, to dismantle, flexible, to decrease, to reject, to loosen.

VII Key Terms

BUNCHES OF MULTIPLE VERTICAL TENDONS — bunches of multiple vertical cords or ropes
CATENARY MOORING LINES — несущие тросы швартовых[9]
A CYLINDRICAL HULL ANCHORED WITH MOORING LINES — цилиндрический корпус, крепящийся с помощью швартовых
DAMPING — the ability of a structure to dissipate energy while vibrating
DEAD WEIGHT — a structure's own weight
FATIGUE FAILURE — an accident connected with the wear of a construction and the deterioration of technical performance
LOOP CURRENTS AND SUBEDDIES - powerful spinning currents of water that pull everything down inside them and currents that move against the main current in a circular pattern
OFFSHORE STRUCTURES — at sea not far from the land: offshore rig/anchorage
A PILE — a heavy column of wood, metal or concrete placed upright in the ground, a river, etc; e.g.: as a foundation for a building or support for a bridge
A PONTOON — any of several boats or hollow metal structures joined together to support a temporary road over a river or a bridge
RINGING AND SPRINGING OF TLPs — the excessive oscillation and vertical jumping of a platform
RISERS - vertical pipes that transport the petroleum products up

[9]Russian translation is given in singular cases to ease understanding.

from the well
A SPAR CONCEPT — a strong wooden or metal pole used to hold the sails, etc., on a ship
TETHERS — ropes or chains used for tying smth so that it will stay in a particular place
TRADITIONAL STEEL JACKETS in shallow and intermediate waters: a steel jacket is a steel outer cover round a tank, pipe, etc., used to reduce loss of heat
VORTEX SHEDDING — vortex creation
WIND TUNNEL — an aerodynamic tube

IX Vocabulary Practice

Fill in the gaps using the key words given below.

One ... for building TLPs and other ... floating platforms is to use ... ... that are ... to corrosion and fatigue failure. These materials ... ... for a particular purpose ... ... specific stiffnesses and strengths, ... weight reductions that then ... to greater overall economy. ... ..., a hull that is ... can be made smaller with the resulting structure still ... even though it ... less water. The size decrease has ... ...: waves will have less surface area ... ... on, and the structure will thus ... less extensive mooring systems and anchor piles for ....

Phenolic materials have already been ... for the floor gratings, stairs, partitions and even ... ... of TLPs, saving millions of dollars. More substantial cost reductions could ... ... if the tethers, mooring lines and risers (vertical pipes that ... the petroleum products up from the well) could also be made of composites ... of a resin matrix with glass or carbon fibers, or ... ... of both.

The main obstacle is a lack of knowledge about the ... ... of these materials. Much ... remains to be done to determine their ... and degradation, among other effects. The impracticality of ... ... 30 or 50 years to gain ... ... before using the new materials ... ... the development of instrumentation and nondestructive evaluation techniques that can ... their performance as they are being used underwater. This capability is ... because a composite pipe, for example, can ... significant internal damage and deterioration before any ... ... become visible.

Key words: used, has motivated, long-term underwater behavior, suffer, stability, be achieved, to push, lead, to provide, resistant, buoyant, deepwater, are made, an advantage, lighter, approach, composite materials, resulting in, for one thing, displaces, require, bearing walls, consisting, research, monitor, crucial, transport, a combination, having to wait, the necessary experience, aging, external symptoms.

X Conversational Practice

Agree or disagree with the statements. Justify your judgements. Add some sentences to develop your idea. The following sentences can be useful.

I absolutely agree.	To a certain extent, yes, but...
I'm very much in favour of that.	I see your point, but ...
That is just what I had in mind.	It is absolutely wrong.

1. The only forces an offshore platform must withstand are the forces of gravity, wind, ice and earthquakes.
2. Waves and currents affect offshore structures in the same way.
3. To determine the wave and current forces complex dynamic analyses are required.
4. In the past the omission of dynamic effects when designing shallow-water steel jackets was acceptable.
5. Construction in deeper waters has led to taller — and inherently less stiff — structures that are more susceptible to dynamic effects such as those caused by waves.
6. Building a very rigid structure in deep water would be cheap.
7. TLPs have played no role in deep water constructions.
8. Three other variations have been proposed and used recently.
9. For TLPs, spars and other buoyant platforms, various nonlinear effects may be neglected.
10. In addition to computational analyses, scale models in wave tanks have been used to study structures that were later

installed at great depths in the Gulf of Mexico and in the North Sea.
11. Model tests are limited in their ability to determine the true behaviour of a platform in the ocean.
12. Damping is the ability of a structure to conserve energy.

XI Outline the main ideas and write a summary.

XII Render the following text.

Нефтяная платформа "Deepwater Horizon" затонула 22 апреля 2010 года после 36-часового пожара, последовавшего вслед за мощным взрывом. После взрыва и затопления нефтяная скважина была повреждена и нефть из нее стала поступать в воды Мексиканского залива.

Нефтяное пятно окружностью 965 километров приблизилось на расстояние примерно 34 километра к побережью штата Луизиана, создало угрозу пляжам и районам рыболовного промысла, которые играют важнейшую роль в экономике прибрежных штатов. 26 апреля четыре подводных робота компании BP безуспешно пытались устранить утечку. Работе флотилии, состоящей из 49 буксиров, барж, спасательных катеров и других судов, мешали сильные ветры и волнение на море.

В обнародованном 20 июня внутреннем отчете BP сообщается, что объем утечки может составлять до 100 тысяч баррелей (около 14 000 тонн или 16 000 000 литров) ежедневно без учета объемов нефти, которую удается собрать при помощи защитного купола (а это около 15 тысяч баррелей в день). Для сравнения: объем разлива нефти, произошедшей в результате аварии на танкере Эксон Вальдез, которая ранее считалась наиболее разрушительной для экологии катастрофой, которая когда-либо происходила на море, составил около 260 тыс. баррелей нефти (около 36 000 тонн или 40 900 000 литров).

По состоянию на 16 июля 2010 года основная скважина загерметизирована, и по сообщениям BP выброс нефти в открытый океан прекращен. Однако надежность конструкции находится под вопросом, и представители BP подтверждают, что она является временным решением. В результате установки защитного купола возможно появление дополнительных утечек, в случае, если подземная часть скважины тоже повреждена. В нескольких километрах от скважины 18-го числа была обнаружена новая утечка. Несмотря на герметизацию, на протяжении 85 дней утечки мировой океан был загрязнен более чем 4 миллионами баррелей нефтепродуктов (примерно 0.54 млн тонн), и последствия катастрофы еще сложно оценить. Представитель правительства США, отвечающий за устранение последствий утечки нефти в Мексиканском заливе, сообщил в воскресенье 19 сентября, что поврежденная подводная скважина была перекрыта навсегда — через пять месяцев после взрыва на нефтяной платформе, который привел к крупнейшей утечке нефти в истории США.

Материал из Википедии — свободной энциклопедии

Unit VI

Text

WHY THINGS BREAK[10]

Scientists have known for most of this century that chemistry is responsible for whether a solid shatters or bends. But only now are they finding a way to predict which type of failure will win

by Mark E. Eberhart

THE AUTHOR

Mark E. Eberhart became intrigued with applying chemistry fundamentals to problems of materials failure as an undergraduate chemistry major at the University of Colorado. His interest grew out of attempts to strengthen the kayaks he built, making them less likely to shatter against river boulders. This interest carried him to the Massachusetts Institute of Technology, where he received a Ph.D. in materials science in 1983. Since that time, he has worked to develop more robust models of chemical bonding useful in the design of materials with predictable intrinsic properties. Now an associate professor of chemistry and geochemistry at the Colorado School of Mines, he directs the school's Center for Computation and Simulation for Materials and Engineering.

[10] Scientific American, October 1999, pp. 71–73

Word Combinations

to drop below the elevation	to favour one process over the other
to cease to exist	to identify the critical points
relevant experiments	thinking back to the analogy
to gain or lose altitude	to have the predicted effect
to run through the points	iron substituted for nickel
the flip side of smth	equal charge density

I Read the questions and find answers in the text that follows.

1. When does a bond break?
2. How can a bond form?

FIRST PREDICTIONS

Associating bonds with a well-characterized feature of the charge density made possible the first description of bond breaking as a topological process. When two bound atoms inside a solid are pulled apart, the curvatures along the bond and in two perpendicular directions change. *When the curvature along one or both of these directions vanishes, so does the topological connection between the atoms.* The key: a bond is broken not when the charge density between atoms vanishes but when the two atoms lose their topological connection.

Using the topological description of bonding, along with the magnitude of the principal curvatures involved, we can form a more quantitative analysis of fracture. Consider a saddle point in two dimensions using the analogy of the mountain range. *Starting at the pass between two mountains, you could walk in any of four directions, two around each peak, along which your altitude (and therefore the charge density) would not change. If four people started at the pass, and each took off in a different one of these directions, their paths as seen from above would form an X.* A plane containing these X-shaped paths makes an acute angle with the direction that most steeply descends toward a lake in the basin below, which is the area of least charge density. *This angle turns out to be related to the ratio of the two principal curvatures.*

Pulling the two peaks (or atoms) apart removes charge from the bond, just as blasting away rock and dirt would lower the elevation of the pass. The size of the original angle tells us how much dirt can be moved, and as excavation progresses that angle becomes smaller and smaller. As this angle approaches zero, the pass drops below the elevation of the lake surface, which begins to drain. The bond breaks — and the pass ceases to exist — when the angle is equal to zero. *By that time the pass has reached the same elevation as the lowest point in the basin, and the last drop of lake water has drained away.*

Similarly, a bond could form by adding charge to a minimum. *This bond-building process is like trucking in dirt from the excavated pass to form an earth embankment, or ridgeline, through the center of the lake.* In short, a bond breaks when charge is taken away from the area around a saddle point; a bond can form when charge is added near a minimum.

The mountain pass analogy is more complex when used to characterize the charge density in three dimensions. The angles used to measure the charge density must now be defined by geometric shapes. *(In this case, charge density is more like moving through a bottomless ocean of molasses that is stickier in some directions than others.) Instead of a flat plane containing the four directions you could walk without gaining or losing altitude, we must now visualize a shape that would contain all the directions in which the charge density is equivalent.*

If you take the X formed by the two-dimensional directions of equal charge density and rotate it around its axis along the chemical bond, you get two cones positioned point to point. *The outside edge of the cone makes an acute angle with a plane positioned perpendicular to the bond and running through the points of the cones.* This is the angle that provides a measure of the amount of charge that must be lost from the saddle point to cause the bond to break. As the angle gets smaller, the bases of the cone approach each other and eventually form a disk. *As in the two-dimensional scenario, the larger the starting angle, the more charge must be removed to reduce the angle to zero and break the bond.*

The flip side of bond breaking is bond formation, and we must understand both to describe failure. Just as a cone can represent a bond, other geometric shapes can represent other critical points. A minimum, which can become a bond if enough charge is added near the point, is represented by an ellipsoid. In this case, two angles are necessary to specify its shape and to measure the amount of charge, or dirt, that must be transferred from a saddle point to form a bond. *The angles also tell you whether it will be easier to build an embankment across the lake in one direction than another.*

With unique geometric representations for all a solid's critical points, we can measure exactly when and in what amounts the charge density is changing during bond formation and bond breaking. *Whether a material fails by brittle or ductile means depends on which of these processes dominates, so it follows that we should be able to favor one over the other.* I applied this line of reasoning to explain the failure properties of nickel aluminide and two closely related alloys, the aluminides of iron and cobalt.

All three of these compounds have identical structures and thus provided the ideal test case for the new approach to describe materials failure. I wanted to explain the difference in properties of the three alloys, which had not been done using conventional models, and to suggest elements that could be added to nickel aluminide to make it more ductile. *That meant I had to get original bonds to stay around as long as possible and to encourage new bonds to form along the slip plane as early as possible. That trade-off would entail taking charge from the breaking bonds to form new ones. To figure out in what instances this was possible, I needed new computer programs that would generate the numbers required to map out the charge density and to evaluate its changing topology.*

James M. MacLaren of Tulane University developed just the tools that I required to calculate the charge density for the three aluminides and, most important, to identify the critical points and the various angles needed to describe them. *What I first discovered in the computer simulations was consistent with the failure properties of these metals that had been discovered in experiments.* For example, iron aluminide, known to be the most ductile of the three alloys, showed the most charge in its bond around the saddle point between iron and aluminium atoms. *This aluminide also showed the flattest minimum between adjacent aluminum atoms, thereby requiring the least charge to build a bond there.*

The suggestion that the failure properties of these three alloys could be reduced to knowing the shape of the charge density around only two points allowed me to take the next step. I predicted that I could alter the failure properties of nickel aluminide by substituting an element for some of the nickel atoms that directed more charge along the nickel-aluminum bond to be available for building new bonds between aluminum atoms in the minimum. This charge redistribution would refine the shape of the charge density to that of a more ductile material.

Because every element has a specific shape to its charge in a given environment, it was a simple matter to identify iron as the best substitute. *Thinking back to the analogy of the mountain range, I knew that every element makes a mountain with different slopes falling away from its peak. Standing next to a mountain of aluminum, a mountain of iron puts more rock into the pass and forms a flatter basin than does a nickel mountain.* With iron, I have enough rock to remove it from the bond and build a new ridgeline between aluminum atoms in the basin. A cobalt mountain, on the other hand, contributes too little rock to the pass to build the ridgeline.

By the time I had made my predictions, the empirical search for alloying elements to improve nickel aluminide had been under way for nearly 15 years, so there was every reason to believe that other researchers already knew whether iron produced improvements in its ductility. At a meeting late last year, I discovered that relevant experiments showed that 10 percent iron substituted for nickel has exactly the predicted effect.

II Translate the italicized sentences into Russian. Explain the use of the grammar constructions.

III Vocabulary Notes

(Oxford Advanced Learner's Dictionary)
adjacent (adj.) — situated near or next to smth
elevated (adj.) — higher than the area around; *elevation* (noun)

— the height of the place, especially above the level of the sea; *to elevate* (verb)
to entail (verb) — to involve smth as a necessary or inevitable part of consequence
an embarkment (noun) — a wall or ridge of earth, stone, etc. made especially to keep water back or to carry a railway or road over low ground
relevant (adj.) to smth/smb — closely connected with smth appropriate in the circumstances; *relevance* (noun)
to shatter (verb) — to break or make smth break suddenly into pieces; *shattering* (adj.) — shocking or very disturbing; *shatterproof* (adj.) — designed not to shatter
to substitute (verb) — smb/smth for smb/smth — to put or use smb/smth instead of smb/smth else: ten per cent of iron substituted for nickel has exactly the predicted effect; *a substitute* (noun)
to visualize (verb) — to form a mental picture of smb/smth in one's mind

IV Comprehension Exercises

Answer the following questions.

1. What made it possible to describe bond breaking as a topological process for the first time?
2. What can be formed with the help of the topological description of bonding and the magnitude of the principal curvatures?
3. Can you consider a saddle point in two dimensions using the analogy of the mountain range?
4. What does pulling the two peaks (or atoms) apart initiate?
5. What happens to the pass as the size of the original angle approaches zero?
6. When does the pass cease to exist?
7. Why is the mountain pass analogy more complex when used to characterize the charge density in 3-D?
8. How must the angles used to measure the charge density be defined now?

9. What will you get if you take the X formed by the two directions of equal charge density and rotate it around its axis along the chemical bond?
10. What does the acute angle made by the outside edge of the cone with a plane, positioned perpendicular to the bond and running through the points of the cone, provide?
11. By what figure is a minimum which can become a bond represented?
12. In which case can a minimum become a bond?
13. What will be necessary in this case?
14. When and in what amounts is the charge density changing during bond breaking and formation?
15. What line of reasoning did the author apply to explain the failure properties of the three alloys?
16. What was discovered in computer simulations?
17. What did the author predict?
18. Why was iron chosen as the best substitute?

V Grammar

1. Give the three forms of the verbs: to break, to bound, to lose, to take, to see, to tell, to make, to begin, to get, to run, to understand, to become, to build, to mean, to know, to show, to give, to think, to fall, to stand, to do.
2. Put in the missing prepositions and adverbs.
   a. When two bound atoms … a solid are pulled …, the curvatures … the bond and … two perpendicular directions change.
   b. When the curvature … one or both … these directions vanishes, so does the topological connection … the atoms.
   c. Using the topological description … bonding, along … the magnitude … the principal curvatures involved, we can form a more quantitative analysis … fracture.
   d. Starting … the pass … two mountains, you could walk … any … four directions, two … each peak, … which

your altitude (and therefore the charge density) would not change.

e. If four people started ... the pass, and each took ... in a different one ... these directions, their paths as seen from ... would form an X.

f. A plane containing these X-shaped paths makes an acute angle ... the direction that most steeply descends ... a lake ... the basin ..., which is the area ... least charge density.

g. This angle turns out to be related ... the ratio ... the two principal curvatures.

h. Pulling the two peaks (or atoms) ... removes charge ... the bond, just as blasting ... rock and dirt would lower the elevation ... the pass.

i. This bond-building process is like trucking ... dirt ... the excavated pass to form an earth embankment, or ridgeline, ... the center ... the lake.

j. ... short, a bond breaks when charge is taken ... ... the area ... a saddle point; a bond can form when charge is added ... a minimum.

k. If you take the X formed ... the two-dimensional directions ... equal charge density and rotate it ... its axis ... the chemical bond, you get two cones positioned point ... point.

l. The outside edge ... the cone makes an acute angle ... a plane positioned perpendicular ... the bond and running ... the points ... the cones.

m. Whether a material fails ... brittle or ductile means depends ... which ... these processes dominates, so it follows that we should be able to favor one ... the other.

3. Put the sentences in the proper tense and mood.

   a. If four people (to start) at the pass, and each (to take off) in a different one of these directions, their paths as (to see) from above (to form) an X.

   b. The bond (to break) — and the pass (to cease) to exist — when the angle (to be) equal to zero.

   c. By that time the pass (to reach) the same elevation as the lowest point in the basin, and the last drop of lake water (to drain) away.
   d. By the time I (to make) my predictions, the empirical search for alloying elements to improve nickel aluminide (to be) under way for nearly 15 years, so there (to be) every reason to believe that other researchers already (to know) whether iron (to produce) improvements in its ductility.

4. Make up sentences according to the pattern: As in the two-dimensional scenario, *the larger* the starting angle, *the more* charge must be removed to reduce the angle to zero and break the bond.
   a. (Fast) the particle is moving, (steep) the slope of the tangent line.
   b. Aristotle thought (heavy) an object was (much) of this force it possessed.
   c. (Small) the particle, (fast) the decay of its orbit.
   d. (Large) the redshift, (small) the universe was when the supernova occurred and hence (much) the universe has expanded between then and now.
   e. (Far) an object falls, (fast) it moves.
5. Translate into Russian.
   a. Whether gravitational waves will be detected remains to be seen.
   b. Sceptics must be forgiven for wondering whether this really is the end of the matter.
   c. There is a wide-spread misconception, however, that the curvature of the universe determines whether the universe is finite or infinite in extent.
   d. These analyses will show whether the solution is adequate.
6. Give the Russian equivalents to the following parenthetical words. Go on with your own examples.

   By the same token, thereby, hence, therefore, however, thus, although, consequently, conversely, in particular, basically, in essence, nevertheless, in short, in fact, finally, besides, further on, moreover, so far, ultimately, on the whole, in the meantime, obviously, eventually.

VI Phrasal Verbs and Idioms

to pull apart — to break apart
to take off — to start moving or running suddenly and in a hurry; about a plane — to rise into the air
to turn out to be smth — to be discovered to be, to prove to be
to blast away — to damage or destroy smth by an explosion or a powerful movement of sudden air
to drain away — to flow away or to make a liquid flow away
to take away — to remove smth away from smth
to run through smth — to pass quickly through smth
the flip side of smth — another aspect of a situation
to stay around — to remain or continue to be in the same place
to trade smth off — to exchange smth for smth else which one wants very much but which one can not have or do both
to figure out — to understand smth by thinking about it; to calculate smth
to map smth out — to plan or arrange smth in detail
to think back to smth — to recall smth in the past
to fall away — to leave, to desert

VII Exercises

1.Give synonyms to the following words.

to bind	to contribute	to entail	to investigate
to vanish	to provide	adjacent	flexible
to excavate	to gain	to refine	the main
to cease	to specify	to substitute	inherent
to prevail	to position	elevation	
to visualize	to encourage	to foretell	
to demand	to shatter	to transfer	

2. Give antonyms to the following words.

Relevant, to degenerate, to diminish, to reduce, to approach, to ascend, favourable, to gain, limber, secure, consistent.

3. Match up the phrasal verb or the idiom in the left column with its equivalent in the right one.

1. to figure out	a. to take into account
2. to blast away	b. to leave, to desert
3. to map out	c. to remain in the same place
4. to think back	d. to plan or arrange smth in detail
5. to pull apart	e. to flow away
6. to take off	f. to damage or destroy smth
7. to fall away	g. to start moving or running
8. to stay around	h. to prove to be
9. to drain away	i. to break apart
10. to run through smth	j. to remove smth away from smth
11. to take into consideration	k. to exchange smth for smth
12. to turn out to be	l. another aspect of a situation
13. the flip side of smth	m. to pass quickly through smth
14. to trade off	n. to calculate
15. to take away	o. to recall smth in the past

VIII Key Terms

AN ALLOY — a metal formed of a mixture of metals or of metal and another substance: brass is an alloy of copper and zinc

A BOND — a force that holds atoms together

BRITTLE MATERIALS — hard but easily broken, fragile

CHARGE DENSITY — an amount of electricity contained in a substance

A COMPOUND — a substance consisting of two or more elements in a chemical combination in mixed proportions

A CONE — a solid figure that slopes up to a point from a circular flat base

DUCTILE METALS — metals such as copper or alluminium that can be pressed or pulled in two different shapes

A FRACTURE — an instance of breaking smth

A PASS — a road or way over or through mountains
A RATIO — a relationship between two things expressed as two numbers or amounts
A RIDGELINE — a line along the top, where two sloping surfaces meet

IX Vocabulary Practice

Fill in the gaps using the key words given below.

A theory for ... materials that behave as they are intended could revolutionize — even replace - the conventional ... ... that ... ... billions of dollars and years of researchers' time.

The search has already ... for new ... that are even ... and ... - and more capable of ... these properties at even higher temperatures. These ... alloys will find uses in supersonic and ... aircraft sometime after the year 2010. But the development program for these materials will ... differently than all others in human history.

... ... searching blindly for a base alloy with the ideal set of ... ..., materials designers will use computers to calculate the ... ... of candidate base alloys. From this information they will ... how the charge density must ... ... to produce desired properties and then ... ... as to which alloying elements will produce these changes. ... ..., a new alloy will be designed beginning with its ... .

Key words: for the first time, determine, rather than, lighter, eat up, proceed, trial-and-error searches, begun, retaining, charge density, alloys, make predictions, stronger, improved, hypersonic, intrinsic properties, be changed, electronic structure, creating.

X Conversational Practice

Agree or disagree with the statements. Develop your idea. Use the following expressions.

That's quite right/true.	Not really.
Yes, perhaps you have a point there.	No, I don't think...
Yes, of course.	I see what you mean, but...
Yes, that's quite correct.	There's a lot in what you say, but...
Exactly.	Yes, maybe/perhaps, but ...

1. A bond is broken when the charge density between atoms vanishes.
2. Using the topological description of bonding along with the magnitude of the principal curvatures involved, we can form a more quantitative analysis of fracture.
3. If four people started at the pass and each took off in a different one of these directions their paths as seen from above would form an X.
4. A plane containing these X-shaped paths makes an acute angle with the direction that most steeply descends toward a lake in the basin below, which is the area of most charge density.
5. Pulling the two peaks (or atoms) apart removes charge from the bond, just as blasting away rock and dirt would lower the elevation of the pass.
6. The bond breaks — and the pass ceases to exist — when the angle is equal to zero.
7. A bond couldn't form by adding charge to a minimum.
8. The mountain pass analogy is not more complex when used to characterize the charge density in three dimensions.
9. As in the two-dimensional scenario, the larger the starting angle, the more charge must be removed to reduce the angle to zero and break the bond.
10. The flip side of bond breaking is bond formation.
11. A minimum, which can become a bond, if enough charge is added near the point, is represented by an ellipsoid.
12. With unique geometric representations for all a solid's critical points, we can measure exactly when and in what amounts the charge density is changing during bond formation and

bond breaking.

13. The author applied this line of reasoning to explain the failure properties of nickel aluminide and two closely related alloys, the aluminides of iron and cobalt.
14. What the author first discovered in the computer simulations wasn't consistent with the failure properties of these metals that had been discovered in the experiments.
15. The author predicted that he could alter the failure properties of nickel aluminide by substituting an element for some of the nickel atoms that directed more charge along the nickel aluminium bond to be available for building new bonds between aluminium atoms in the minimum.
16. It was a complex matter to identify iron as the best substitute.
17. Thinking back to the analogy of the mountain range, the author knew that every element makes a mountain of equal slopes falling away from its peak.

XI Outline the main ideas and write an abstract.

XII Render the following text.

КОМПОЗИЦИОННЫЙ МАТЕРИАЛ

Композиционный материал (композит, КМ) — искусственно созданный неоднородный сплошной материал, состоящий из двух или более компонентов с четкой границей раздела между ними. В большинстве композитов (за исключением слоистых) компоненты можно разделить на матрицу и включенные в нее армирующие элементы. В композитах конструкционного назначения армирующие элементы обычно обеспечивают необходимые механические характеристики материала (прочность, жесткость и т.д.), а матрица (или связующее) обеспечивает совместную работу армирующих элементов и защиту их от механических повреждений и агрессивной химической среды.

Механическое поведение композиции определяется соотношением свойств армирующих элементов и матрицы, а также прочностью связи между ними.

Эффективность и работоспособность материала зависят от правильного выбора исходных компонентов и технологии их совмещения, призванной обеспечить прочную связь между компонентами при сохранении их первоначальных характеристик.

В результате совмещения армирующих элементов и матрицы образуется комплекс свойств композиции, не только отражающий исходные характеристики его компонентов, но и включающий свойства, которыми изолированные компоненты не обладают. В частности, наличие границ раздела между армирующими элементами и матрицей существенно повышает трещиностойкость материала, и в композициях, в отличие от однородных металлов, повышение статической прочности приводит не к снижению, а, как правило, к повышению характеристик вязкости разрушения.

Для создания композиции используются самые разные армирующие наполнители и матрицы. Это — гетинакс и текстолит (слоистые пластики из бумаги или ткани, склеенной термореактивным клеем), стекло- и графитопласт (ткань или намотанное волокно из стекла или графита, пропитанные эпоксидными клеями), фанера... Есть материалы, в которых тонкое волокно из высокопрочных сплавов залито алюминиевой массой. Булат — один из древнейших композиционных материалов. В нем тончайшие слои (иногда нити) высокоуглеродистой стали «склеены»мягким низкоуглеродным железом.

В последнее время материаловеды экспериментируют с целью создать более удобные в производстве, а значит — и более дешевые материалы. Исследуются саморастущие кристаллические структуры, склеенные в единую массу полимерным клеем (цементы с добавками водорастворимых клеев), композиции из термопласта с короткими армирующими волоконцами и пр.

Материал из Википедии — свободной энциклопедии

Unit VII

Text

HARDER THAN ROCKET SCIENCE[11]

If launching a rocket to the moon sounds tough, try flying an aircraft into space at speeds topping Mach 20

by Ken Howard

THE AUTHOR

Ken Howard is a freelance writer based in New York City. He would like to be a passenger on the inaugural hypersonic flight from Tokyo to Washington, D.C., but only if he has sufficient legroom.

Word Combinations

to sound tough	to mount an engine
to operate at low speeds	to take advantage of smth
to break through a limit	to be accompanied by smth
to break free of Earth's atmosphere	to surge to a point
to be inherently limited	a multimode operation
to handle speeds	a paradigm shift
to enable a leap in speed	relatively low maneuverability
to generate tremendous heat	to yield significant advances
not to do any good	a drop in airflow speed
to bring new potentials	state-of-the-art turbine materials
to access space	under such conditions
to provide a thrust	at speeds topping Mach 20

I Read the questions and find answers in the text that follows.

1. How does a conventional turbojet engine create a thrust with a maximum performance of Mach 3–4?
2. How does a ramjet achieve a leap in speed to about Mach 6?
3. In what way was a new engine redesigned?

For the past 30 years McClinton, the NASA engineer, has been trying to break through one limit, working to build a jet aircraft capable of hypersonic speeds so far reached only by rockets. Early next year NASA's Hyper-X program, on which McClinton serves as technology manager, will test the world's first air-breathing — that is, nonrocket — engine to be propelled by its own power to Mach 7, or seven times the speed of sound.

If this new type of jet engine succeeds, the implications could be huge. "The paradigm shift could be as significant as the shift from propellers to jets," asserts Hyper-X program manager Vincent Rausch. "It brings new potentials to access space and get from one place to another faster."

Air-breathing engines are what conventional military and passenger aircraft use for propulsion: air is sucked into an engine to be mixed with burning fuel, creating thrust, which propels the aircraft forward. Most of these engines are turbojets, which have a maximum performance of between Mach 3 and 4. The fastest aircraft propelled by an air-breathing engine, the SR-71 Blackbird, reached speeds of just over Mach 3. The Concorde can fly at Mach 2 and an F-15 fighter at Mach 2.5, whereas a 747 limps along at a relatively sedate Mach 0.8, or about 550 miles per hour (880 kilometers per hour).

But to break free of Earth's atmosphere and enter space, a vehicle must reach the range of Mach 20 to 25. For satellite launches and the space shuttle, giant rockets provide this thrust. But rockets are heavy and nonreusable, and they have relatively low maneuverability and require vertical takeoffs. Safety is another issue. *"There is a great advantage in getting away from solid rockets, where you're basically lighting a Roman candle and letting it burn," notes Laurence R. Young, Apollo Professor of Astronautics at the Massachusetts Institute of Technology.*

Well aware of the disadvantages of rockets, scientists at NASA, the U.S. Air Force and many foreign laboratories have been trying to develop an alternative. Their efforts have yielded significant advances in engine design over the past 40 years. In conventional turbojets, turbines compress the incoming air, putting it under great pressure as it is fed to burning fuel. The combustion products then expand back to atmospheric pressure as they exit the engine, thus creating thrust. But turbines are inherently limited in how fast they can power a plane. As the blades spin faster, they bring in more air and create greater thrust. With the increase in plane speed, however, the air hitting the turbines dissipates more heat. The danger with supersonic flight is that the engine could literally melt away. According to McClinton, even state-of-the-art turbine materials can handle speeds only up to about Mach 3.5.

For faster vehicles, engineers have taken advantage of the supersonic airflow into the engine by designing the system to act as its own compressor. Turbines and a mechanical compressor are replaced by an inlet valve that funnels the air, ramming it into a space so quickly that it compresses itself. These engines, called ramjets, have enabled a leap in speed up to about Mach 6. *They have been used with missiles in which propulsion is switched to ramjets once the rockets have achieved supersonic velocities.*

Under such conditions, however, the air is moving so fast that when it hits the combustion chamber to mix with fuel, the resulting drop in airflow speed generates tremendous heat. At Mach 6, the temperature reaches 6,000 degrees Fahrenheit (3,300 degrees Celsius), leading to chemical dissociation. Combustion begins, but instead of water forming — which would be accompanied by a tremendous rise in pressure and enormous thrust — the reaction produces free radicals at much lower pressure and thrust. In other words, the aircraft slows.

To prevent that, engineers again redesigned the engine, changing the inlet valve so that the decrease in airflow speed is less severe. As a result, the temperature does not surge to the point at which the combustion process breaks down. *Because this new design relies on the supersonic combustion of the rammed airflow, the engine was dubbed a scramjet.*

But solving one problem — high temperatures — led to another. Now the challenge was to get the supersonically moving air to mix uniformly with the fuel and combust within milliseconds. The perfection of this technology, details of which are currently classified, finally allowed for the construction of a functional scramjet, McClinton says. *According to him, the theoretical maximum speed has been upped again, this time to at least Mach 20 to 25 needed to reach orbit and perhaps higher, as an upper limit has yet to be determined.*

One drawback with scramjets (as well as with ramjets) is that they cannot operate at low speeds. "A scramjet doesn't do any good on the runway; it needs compressed air going into it," explains Joel Sitz, NASA project manager for X-43 flight research. One solution being investigated is multimode operation, with an aircraft being propelled first by an advanced turbine engine (for speeds up to about Mach 2 or 3), then a ramjet (to roughly Mach 6) and next a scramjet. "You then reach a point in the atmosphere where you run out of oxygen and a rocket would take over," Sitz says.

Such plans aside, the actual operation of a scramjet remains theoretical. Although researchers have performed flight tests, most recently by Russia in conjunction with NASA in 1998, those experiments never used a vehicle flown under scramjet power. The engines, which were mounted on rockets, did provide thrust, so their aerodynamics, combustion and propulsion could be studied, but they never flew at hypersonic speeds (above Mach 5) under their own power.

In addition to rocket-assisted tests, vehicles and engines have been evaluated with models, both in wind tunnels and in computer simulations. *But such investigations are restricted to about Mach 7, says Jack L. Kerrebrock, professor of aeronautics and astronautics at M.I.T. "As you go up in the Mach numbers," he explains, "the stagnation temperature, where the airflow is stopped at the nose of the vehicle, has to be simulated, and it gets to be very high. For Mach 10, it would be more than 4,000 kelvins.* We don't know how to heat air to that temperature in a stationary facility sufficient for wind-tunnel tests."

Modern understanding of fluid dynamics is likewise limited, because above Mach 7 the physical phenomena, including the airflow through the engine, become too complex to model, even on powerful computers. "It's a very difficult flow to calculate accurately," Kerrebrock says, "and we don't have experimental data to validate the calculations, which is what the Hyper-X program will provide."

II Translate the italicized sentences into Russian. Explain the use of the grammar constructions.

III Vocabulary Notes

(Macmillan English Dictionary for Advanced Learners)

To dissipate — (verb) to gradually disappear by becoming less strong or to make smth do this; *dissipation* (noun) — the process by which a substance, a feeling or energy gradually disappears by becoming less strong

To dub — (verb) (mainly journalism) to give smb or smth a particular name or description, often a humorous one

To evaluate — (verb) to think carefully about smth before making a judgement about its value, importance or quality; *evaluation* (noun) — the evaluation of the data

Implication (noun) — 1. a possible effect or result; 2. smth that you suggest is true, although you don't say it directly

Inaugural (adj.) — 1. an inaugural speech is one made by smb

to celebrate the start of an important new job; 2. an inaugural event is the first of a series or the first one to be held by members of a new organization; *inauguration* (noun) — an inauguration ceremony; *to inaugurate* (verb) — to start or introduce smth new and important
To ram (verb) — if a vehicle or boat rams smth, it hits it very hard, usually when it is moving very fast
To validate (verb) — 1. to officially prove that smth is true or correct; 2. to officially state that smth is of a suitable standard; 3. to make a document legally valid; *validation* (noun)

IV Comprehension Exercises

Answer the following questions.

1. What ambitious project has Mc Clinton, the NASA engineer, been trying to implement for the past 30 years?
2. How do scientists assess the implications of this achievement if this new type of jet engine succeeds?
3. How do air-breathing engines generate propulsion?
4. What provides thrust for satellite launches and the space shuttle?
5. What are the disadvantages of rockets?
6. Why are turbines in conventional turbojets inherently limited in producing greater increase in plane speed?
7. How do ramjets that enable a leap in speed up to about Mach 6 function?
8. What effect was achieved when the engine was redesigned again? How was it dubbed?
9. Although one problem of high temperatures was solved, what was another challenge that the engineers were faced with?
10. What is one drawback with scramjets (as well as with ramjets)?
11. Why does the actual operation of a scramjet remain theoretical?
12. What kind of tests and investigations are being carried out to evaluate the vehicles and the engines. What problems do

scientists face?
13. What will the Hyper-X program provide?

V Grammar

1. Give the three forms of the verbs: to fly, to hit, to get, to burn, to bring, to break, to fight, to let, to put, to spin, to feed, to go, to run, to write, to say.
2. Put in the missing prepositions and adverbs.
   a. Air-breathing engines are what conventional military and passenger aircraft use … propulsion: air is sucked … an engine to be mixed … burning fuel, creating thrust, which propels the aircraft … .
   b. Most … these engines are turbojets, which have a maximum performance … … Mach 3 and 4.
   c. But to break free … Earth's atmosphere and enter space, a vehicle must reach the range … Mach 20 … 25.
   d. … satellite launches and the space shuttle, giant rockets provide this thrust.
   e. Their efforts have yielded significant advances … engine design … the past 40 years.
   f. … faster vehicles, engineers have taken advantage … the supersonic airflow … the engine … designing the system to act as its own compressor.
   g. These engines, called ramjets, have enabled a leap … speed … … … Mach 6.
   h. … such conditions, however, the air is moving so fast that when it hits the combustion chamber to mix … fuel, the resulting drop … airflow speed generates tremendous heat.
   i. … Mach 6, the temperature reaches 6,000 degrees Fahrenheit (3,300 degrees Celsius), leading … chemical dissociation.
   j. Combustion begins, but … … water forming — which would be accompanied … a tremendous rise …

pressure and enormous thrust — the reaction produces free radicals … much lower pressure and thrust.

k. … other words, the aircraft slows.
l. To prevent that, engineers again redesigned the engine, changing the inlet valve so that the decrease … airflow speed is less severe.
m. As a result, the temperature does not surge … the point … which the combustion process breaks … .
n. Because this new design relies … the supersonic combustion … the rammed airflow, the engine was dubbed a scramjet.
o. Now the challenge was to get the supersonically moving air to mix uniformly … the fuel and combust … milliseconds.
p. The perfection … this technology, details … which are currently classified, finally allowed … the construction … a functional scramjet, McClinton says.
q. According … him, the theoretical maximum speed has been upped again, this time … … least Mach 20 … 25 needed to reach orbit and perhaps higher, as an upper limit has yet to be determined.
r. One drawback … scramjets (as well as … ramjets) is that they cannot operate … low speeds.

3. Put the verbs in the proper tense and voice form.

a. For the past 30 years McClinton, the NASA engineer, (to try) to break through one limit, working to build a jet aircraft capable of hypersonic speeds so far reached only by rockets.
b. Air Force and many foreign laboratories (to try) to develop an alternative.
c. Their efforts (to yield) significant advances in engine design over the past 40 years.
d. For faster vehicles, engineers (to take) advantage of the supersonic airflow into the engine by designing the system to act as its own compressor.

e. These engines, called ramjets, (to enable) a leap in speed up to about Mach 6.
f. They (to use) with missiles in which propulsion (to switch) to ramjets once the rockets (to achieve) supersonic velocities.
g. Although researchers (to perform) flight tests, most recently by Russia in conjunction with NASA in 1998, those experiments never (to use) a vehicle flown under scramjet power.
h. In addition to rocket-assisted tests, vehicles and engines (to evaluate) with models, both in wind tunnels and in computer simulations.

VI Phrasal Verbs and Idioms

to break through — to make new important discoveries, to make a way through smth using force to penetrate smth
to break free — to get released with an effort using a force
to limp along — to walk with difficulty, especially when one's leg or foot is hurt or stiff
to get away from — to succeed in leaving a place
to be fed to — to serve as food for smb/smth
to bring in — to carry in, to introduce smth
to melt smth away — to disappear or make smth disappear by melting or dissolving
to break down — to stop working because of mechanical etc. fault, to fail, to collapse (negotiations, law, etc.)
to be upped — to be increased
to put smth aside — to ignore or forget smth, to disregard; to put aside/by — to reserve smth
to take smth over — to gain control of smth (a party, a country, business, a company), to acquire control, responsibility
to run out of smth (a supply of smth) — to be used up or finished

VII Exercises

1.Give synonyms to the following words.

to evaluate	to propel
to mount	to design
a limit	to power
to ram	an issue
advances	moderate
to achieve	to progress
to test	basically
to draw into	a shift
to melt	research
to run out	conventional

2. Give antonyms to the following words.

A drawback, a merit, solid, to allow for, to diminish, to exit, to turn on, reusable, modern, inlet, dismantle.

3. Match up the phrasal verb or the idiom in the left column with its equivalent in the right one.

1. to limp along	a. to disappear by melting or dissolving
2. to get away	b. to stop working
3. to break through	c. to ignore or forget smth
4. to bring in	d. to be increased
5. to break free	e. to walk with difficulty
6. to melt away	f. to gain control
7. to break down	g. to introduce smth, to carry in
8. to put aside	h. to be finished
9. to run out	i. to make a way through smth
10. to take over	j. to succeed in leaving a place
11. to be upped	k. to get released using a force

VIII Key Terms

(Oxford Advanced Learner's Dictionary)

AN AIR-BREATHING ENGINE — a nonrocket

THE COMBUSTION PRODUCTS — substances produced in the process of burning

A COMPRESSOR — a machine that compresses air or other gases

A FIGHTER — a fast military aircraft designed to attack other aircraft

AN INLET/OUTLET VALVE — a mechanical device for controlling the flow of air, liquid or gas allowing it to move in one direction only
A JET — a strong narrow stream of gas, liquid, flame, forced out of a small opening
A JET ENGINE — an engine that gives forward movement by a stream of gases at high speed behind it
A JET AIRCRAFT — an aircraft with one or more jet engines
TO LAUNCH — to put smth into motion, to send smth on its course: to launch a missile/a rocket/ a satellite into orbit
TO MANOEUVRE — to move about or make smth move about by using skill and care
A MISSILE — an explosive weapon directed at a target automatically or by means of an electronic device
TO MOUNT — to organize smth or to arrange smth
TO PROPEL — to drive, move or push smth/smb forward mechanically
PROPULSION — the action or process of driving smth forward
A TURBOJET — a turbine jet engine that produces forward movement by means of a jet of hot exhaust gases

IX Vocabulary Practice

Fill in the gaps using the key words given below.

The vehicle, called the X-43, is aircraft and engine as ... ... Because of the extreme ... ... and the need to decrease them by fine-tuning the ..., there is no ... ... between aircraft and engine. The 12-foot-long (3.5-meter-long) ..., weighing 3000 pounds (1,400 kilograms), ... to minimize weight while ... maximum thermal protection. Specifically, the X-43 must ... intense heat ... from combustion and the resulting shock waves ... by the aircraft's hypersonic movement ... the atmosphere.

The five-foot wingspan is constructed from ... ..., and the structural components and outer surface are a combination of titanium, steel and aluminum ... ... the same thermal-protection tiles used on the space shuttle. The wing, tail and vehicle nose ... ... with carbon-fiber composite material, which actually ... as the temperature rises. Gaseous hydrogen will serve ... ..., with silane, a chemical that ... on contact with air, acting as the spark plug. ... ... will come principally from more than 500 gauges on the vehicle, which measure pressure, temperature and ....

Key words: the test data, as the fuel, generated, a high-temperature alloy, providing, vehicle, aerodynamics, are reinforced, withstand, hypersonic stresses, caused, a single unit, functional difference, was designed, through, lined with, strengthens, ignites, strain.

X Conversational Practice

Agree or disagree with the statements. Develop your idea. Use the following expressions.

Surely, ... but as far as I know...	Surely not, I mean ...
Well, as a matter of fact...	In my view, you are wrong.
It is absolutely right.	Well, that's very surprising.
How right that is!	Yes, but on the other hand...

1. For the past thirty years Mc Clinton, the NASA engineer, has been trying to break through one limit, working to build a jet aircraft capable of hypersonic speeds so far reached only by rockets.
2. If this new type of jet engine succeeds, the implications could be minute.
3. Air-breathing engines are what only military aircraft use for propulsion.
4. Most of these engines are turbojets, which have a maximum performance of between Mach 3 and 4.
5. To break free of Earth's atmosphere and enter space, a vehicle must reach the range of Mach 7.
6. Solid rockets have no disadvantages.
7. In conventional turbojets, turbines are inherently not limited in how fast they can power a plane.
8. For faster vehicles, engineers have taken advantage of the supersonic airflow into the engine.

9. Turbines and a mechanical compressor are replaced by an inlet valve that funnels the air, ramming it into a space so quickly that it compresses itself.
10. These engines, called ramjets, have enabled a leap in speed up to about Mach 6 and have been used with missiles in which propulsion is switched to ramjets once the rockets have achieved supersonic velocities.
11. Under such conditions, however, the air is moving so fast that when it hits the combustion chamber to mix with fuel, the resulting drop in airflow speed generates tremendous heat, leading to chemical dissociation.
12. Engineers again redesigned the engine, changing the inlet valve so that the decrease in airflow speed is more severe.
13. Because this new design relies on the supersonic combustion of the rammed airflow, the engine was dubbed a scramjet.
14. One drawback with scramjets (as well as with ramjets) is that they cannot operate at high speeds.
15. One solution being investigated is multimode operation, with an aircraft being propelled first by an advanced turbine engine, then a ramjet (to roughly Mach 6) and next a scramjet.
16. The actual operation of a scramjet remains theoretical.
17. Modern understanding of fluid dynamics is likewise limited.

XI Outline the main ideas and write an abstract.

XII Render the following text.

ГИПЕРЗВУКОВОЙ ПРЯМОТОЧНЫЙ ВОЗДУШНО-РЕАКТИВНЫЙ ДВИГАТЕЛЬ

Материал из Википедии — свободной энциклопедии

«Гиперзвуковой двигатель» ГПВРД (англ. Supersonic Combustion RAMJET - scramjet) — вариант прямоточного воздушно-реактивного двигателя (ПВРД), который отличается от обычного сверхзвуковым сгоранием. На больших скоростях для сохранения эффективности двигателя необходимо избегать торможения приходящего воздуха и производить сжигание топлива в сверхзвуковом воздушном потоке.

Верхний предел скорости гиперзвукового ПВРД (ГПВРД) без использования дополнительного окислителя оценивается в M=12 – M=24. Исследования в рамках проекта «X-30»фирмы Роквелл в 80-х годах XX-го века установили верхнее значение скорости для работы ГПВРД, соответствующей M=17 в связи с обеспечением условий для сгорания в двигателе. Для сравнения, самый быстрый пилотируемый самолет со сверхзвуковым прямоточным воздушно-реактивным двигателем (СПВРД) «SR-71»(англ. Black Bird, «Черный дрозд») компании Локхид достигает скорости не выше M=3,4 из-за торможения воздушного потока в двигателе до дозвуковой скорости. Кроме этого, так как ГПВРД использует не окислитель, транспортируемый вместе с аппаратом, а атмосферный воздух, он обладает гораздо более высоким показателем эффективности двигателя — удельным импульсом по сравнению с любым из существующих ракетных двигателей.

Так же как и сверхзвуковой ПВРД, гиперзвуковой ПВРД состоит из имеющего сужение воздуховода, в котором поступающий воздух претерпевает сжатие из-за высокой скорости аппарата; камеры сгорания, где происходит сжигание топлива; сопла, через которое происходит выход выхлопного газа со скоростью, большей скорости поступающего воздуха, что и создает тягу двигателя. Опять же, как и СПВРД, ГПВРД имеет мало движущихся частей или вовсе их лишен. В частности, в нем отсутствует высокоскоростная турбина, которая присутствует в турбореактивном двигателе (ТРД) и является одной из самых дорогих частей такого двигателя, являясь при этом потенциальным источником проблем при использовании.

Для работы гиперзвуковой ПВРД нуждается в проходящем сквозь него сверхзвуковом воздушном потоке, поэтому, так же как и сверхзвуковой ПВРД, этот тип двигателя имеет минимальную скорость, при которой он может функционировать, примерно равную M=7–8. Таким образом, аппарат с ГПВРД нуждается в другом способе ускорения до скорости, достаточной для работы гиперзвукового двигателя. Гибридный сверхзвуковой/гиперзвуковой ПВРД должен иметь меньшее значение минимальной рабочей скорости и некоторые источники указывают, что экспериментальный гиперзвуковой самолет «X-43»(Боинг/НАСА) имеет именно такой двигатель. Последние испытания «X-43»производились с помощью ракетного ускорителя, запускаемого с самолета, который разгонял этот аппарат до M=7,8.

Гиперзвуковые аппараты имеют большие проблемы, связанные с их весом и сложностью. Перспективность ГПВРД активно обсуждается в основном по той причине, что многие параметры, которые в конечном итоге определят эффективность самолета с таким двигателем, остаются неопределенными. Это, в частности, также связано со значительными затратами на испытания таких аппаратов. Такие хорошо финансируемые проекты, как X-30, были отменены до создания экспериментальных моделей.

Unit VIII

Text

POWERING NANOROBOTS[12]

Catalytic engines enable tiny swimmers to harness fuel from their environment and overcome the weird physics of the microscopic world

by Thomas E. Mallouk and Ayusman Sen

THE AUTHORS

Thomas E. Mallouk is DuPont Professor of Materials Chemistry and Physics at Pennsylvania State University. His research focuses on the synthesis and properties of nanoscale inorganic materials.

Ayusman Sen, who was born in Calcutta, India, is professor of chemistry at Penn State. His research focuses on catalysis and inorganic and organic materials. Sen numbers ecological and gastronomical explorations among his favorite pastimes. The authors first realized in a casual conversation that Sen's idea for a catalytic motor could be effected with nanorods that had already been made in Mallouk's laboratory.

[12] Scientific American, May 2009, pp. 72–74

Word Combinations

to fix invisible cracks	an array of molecular-scale structures
to feature as wheels of 4 buckyballs	at the scales of living cells or smaller
to militate against smth	the task poses some unique challenges
to provide an example	nanoscales versions of motors
to facilitate chemical reactions	the corkscrew motion of bacterial flagella
to make exciting progress	the bulk solution
to convert chemical energy into mechanical energy	on small length scale
to give a rocket forward thrust	a gold surface patterned with silver
to think differently about smth	in turn
to make good sense	with respect to smth
to scale down/up	an immobilized metal structure
to generate an excess of smth/a dearth of smth	a fluid-pumping effect
to bear an eerie resemblance to smth	at the macroscale

I Read the questions and find answers in the text that follows.

1. What is the biggest current problem with molecular machines?
2. What did researchers notice while observing the work of a living cell?
3. As the principle of recoil fails at the microsize scale how do swimming nanorobots work?

Imagine that we could make cars, aircraft and submarines as small as bacteria or molecules. Microscopic robotic surgeons, injected in the body, could locate and neutralize the causes of disease — for example, the plaque inside arteries or the protein deposits that may cause Alzheimer's disease. And nanomachines — robots having features and components at the nanometer scale — could penetrate the steel beams of bridges or the wings of airplanes, fixing invisible cracks before they propagate and cause catastrophic failures.

In recent years chemists have created an array of remarkable molecular-scale structures that could become parts of minute machines. James Tour and his co-workers at Rice University, for instance, have synthesized a molecular-scale car that features as wheels of four buckyballs (carbon molecules shaped like soccer balls), 5,000 times as small as a human cell.

But look under the hood of the nanocar, and you will not find an engine. *Tour's nanocars so far move only insofar as they are jostled by random collisions with the molecules around them, a process known as Brownian motion.* This is the biggest current problem with molecular machines: we know how to build them, but we still do not know how to power them.

At the scales of living cells or smaller, that task poses some unique challenges. Air and water feel as thick as molasses, and Brownian motion militates against forcing molecules to move in precise ways. In such conditions, nanoscale versions of motors such as those that power cars or hairdryers — assuming that we knew how to build them that small — could never even start.

Nature, in contrast, provides many examples of nanomotors. To see the things they can do, one need only look at a living cell. The cell uses nanoengines to change its shape, push apart its chromosomes as it divides, construct proteins, engulf nutrients, shuttle chemicals around, and so on. All these motors, as well as those that power muscle contractions and the corkscrew motion of bacterial flagella, are based on the same principle: they convert chemical energy — usually stored as adenosine triphosphate, or ATP — into mechanical energy. And all exploit catalysts, compounds able to facilitate chemical reactions such as the breakdown of ATP. Researchers are now making exciting progress toward building artificial nanomotors by applying similar principles.

In 2004 we were part of a team at Pennsylvania State University that developed simple nanomotors that catalytically convert the energy stored in fuel molecules into motion. We took inspiration from a considerably larger catalytic motor reported in 2002 by Rustem Ismagilov and George Whitesides, both at Harvard University. The Harvard team had found that centimeter-scale "boats" with catalytic platinum strips on their stern would spontaneously move on the surface of a tank of water and hydrogen peroxide (H_2O_2). *The platinum promoted the breakup of* H_2O_2 *into oxygen and water, and bubbles of oxygen formed that seemed to push the boats ahead by recoil, the way the exhaust coming out the back of a rocket gives it forward thrust.*

CREDIBLE SHRINKING

Our miniaturized version of the Harvard engine was a gold-platinum rod about as long as a bacterial cell (two microns) and half as wide (350 nanometers). Our rods were mixed into the solution, rather than floating on the surface. Like the ATP-powered molecular motors inside the cell, these tiny catalytic cylinders were essentially immersed in their own fuel. And they did indeed move autonomously, at speeds of tens of microns per second, bearing an eerie resemblance under the microscope to live swimming bacteria.

As often happens in science, however, the hypothesis that led to the experiment was wrong. *We had imagined our nanorods spewing tiny bubbles off their back and being pushed along by recoil.* But what they actually do is more interesting, because it reminds nanotechnologists that we must think very differently about motion on small length scales.

At the macroscale, the notion of recoil makes good sense. When someone swims or rows a boat, their arms, legs or oars push water backward, and the recoil force pushes the body or boat forward. In this way, a swimmer or boat can glide forward even after one stops pushing. How far an object glides is determined by the viscous force, or drag, and by the inertia, a body's resistance to changes in its velocity. The drag is proportional to the object's width, whereas the inertia is proportional to the object's mass, which in turn is proportional to the width to the third power. For smaller objects, inertia scales down much faster than drag, becoming negligible, so that drag wins out. On the micron scale, any gliding ends in about one microsecond, and the glide distance is less than one 100th of a nanometer. Hence, for a micronize body in water, swimming is a bit like wading through honey. A nanomotor has no memory of anything that pushed on it — no inertia — and inertial propulsion schemes (such as drifting after the recoil from bubbles) are hopeless.

The way our nanorods actually work is that they apply a continuous force to prevail over the drag with no need for gliding. At the platinum end, each H_2O_2 molecule is broken down into an oxygen molecule, two electrons and two protons. At the gold end, electrons and protons combine with each H_2O_2 molecule to produce two water molecules. These reactions generate an excess of protons at one end of the rod and a dearth of protons at the other end; consequently, the protons must move from platinum to gold along the surface of the rod.

Like all positive ions in water, protons attract the negatively charged regions of water molecules and thus drag water molecules along as they move, propelling the rod in the opposite direction, as dictated by Newton's law of motion that every action has an equal and opposite reaction.

Once this principle was established (with the help of our students and our Penn State collaborators Vincent H. Crespi, Darrell Velegol and Jeffrey Catchmark), several other catalytic nanomotor designs followed. And Adam Heller's research group at the University of Texas at Austin and Joseph Wang's group at Arizona State University showed that mixtures of different fuels — glucose and oxygen or H_2O_2 and hydrazine — could make motors run faster than they do with a single fuel.

Whereas freely suspended metal nanorods move with respect to the bulk solution, an immobilized metal structure in the presence of H_2O_2 will induce fluid flows at the interface between the structure and the fluid, thereby potentially powering the motion of something else immersed in the fluid. We have demonstrated this fluid-pumping effect on a gold surface patterned with silver.

II Translate the italicized sentences into Russian. Explain the use of the grammar constructions.

III Vocabulary Notes

(Oxford Advanced Learner's Dictionary)
to enable (verb) — to make smb able to do smth by giving them the necessary authority or means
to facilitate (verb) — to make a process easier
to harness (verb) — 1. to put a harness on a horse; 2. to control and use a natural force to produce electrical power etc.: to harness a river, a waterfall, the sun's rays as a source of energy
to immerse (verb) — to put smth under the surface
to induce (verb) — to persuade or influence smb to do smth, to cause smth; *inducement* (noun) — a thing that persuades smb to do smth
in so far as — to the extent that
molasses (noun) — a thick dark sweet liquid obtained from sugar while it is being refined
to pattern (verb) — to use smth as a model for smth, to create a pattern on smth; *a pattern* (noun)
to power (verb) — to supply smth with the energy that enables it to operate
to promote (verb) — to help the progress of smth, to encourage or support smth; *promotion* (noun)
to shrink (verb) — to become smaller in size or amount; *shrinkage* (noun)
to wade (verb) — to walk with an effort, especially through water or mud

IV Comprehension Exercises

Answer the following questions.

1. What are the advantages of using nanotechnology in comparison with conventional engineering?
2. How do nanocars so far move? What principle is involved here?

3. What is the biggest current problem with molecular machines?
4. How does nature manage to build nanomotors? What examples does nature provide if one looks at a living cell?
5. How were simple nanomotors developed? What principles were used then?
6. What are catalysts?
7. What idea did the authors of the article take inspiration from?
8. What was the idea of their miniaturized version of the Harvard engine?
9. Why does the notion of recoil not work at the microsize scale while at the macroscale the notion of recoil makes good sense?
10. In what way do nanorods actually work?
11. Why were different fuels used in the catalytic nanomotor designs that followed?

V Grammar

1. Give the three forms of the verbs: to shrink, to spend, to feel, to take, to find, to bear, to win, to run, to fall, to fly, to thrust, to see.
2. Put in the missing prepositions and adverbs.
   a. Microscopic robotic surgeons, injected ... the body, could locate and neutralize the causes ... disease — ... example, the plaque ... arteries.
   b. And nanomachines — robots having features and components ... the nanometer scale — could penetrate the steel beams ... bridges or the wings ... airplanes, fixing invisible cracks before they propagate and cause catastrophic failures.
   d. ... recent years chemists have created an array ... remarkable molecular-scale structures that could become parts ... minute machines.
   e. Tour's nanocars ... ... move only insofar as they are jostled ... random collisions ... the molecules ... them, a process known as Brownian motion.

f. Air and water feel as thick as molasses, and Brownian motion militates … forcing molecules to move … precise ways.
g. The cell uses nanoengines to change its shape, push … its chromosomes as it divides, construct proteins, engulf nutrients, shuttle chemicals …, and … ….
h. Researchers are now making exciting progress … building artificial nanomotors … applying similar principles.
i. The platinum promoted the breakup … H_2O_2 … oxygen and water, and bubbles … oxygen formed that seemed to push the boats ahead … recoil, the way the exhaust coming … the back … a rocket gives it forward thrust.
j. Like the ATP-powered molecular motors … the cell, these tiny catalytic cylinders were essentially immersed … their own fuel.
k. And they did indeed move autonomously, … speeds … tens … microns … second, bearing an eerie resemblance … the microscope to live swimming bacteria.
l. We had imagined our nanorods spewing tiny bubbles … their back and being pushed … … recoil.
m. A nanomotor has no memory … anything that pushed … it — no inertia — and inertial propulsion schemes (such as drifting … the recoil … bubbles) are hopeless.
n. The way our nanorods actually work is that they apply a continuous force to prevail … the drag … no need … gliding.
o. These reactions generate an excess … protons … one end … the rod and a dearth … protons … the other end; …, the protons must move … platinum … gold … the surface … the rod.
p. Like all positive ions … water, protons attract the negatively charged regions … water molecules and thus drag water molecules … as they move, propelling the

rod ... the opposite direction, as dictated ... Newton's law ... motion that every action has an equal and opposite reaction.

q. Whereas freely suspended metal nanorods move ... respect ... the bulk solution, an immobilized metal structure ... the presence ... H_2O_2 will induce fluid flows ... the interface ... the structure and the fluid, thereby potentially powering the motion ... something else immersed ... the fluid.

r. We have demonstrated this fluid-pumping effect ... a gold surface patterned ... silver.

3. The Verb *Need*

Need has two sets of forms: those of a "modal auxiliary verb" and those of an ordinary verb. The ordinary forms of need are much more common than the modal auxiliary forms. The only modal form which is often used is *needn't*.
Affirmative modal forms are possible after negative verbs and in sentences which express doubt or negative ideas: e.g., I don't think he need go just yet; the only thing you need do is fill in this form.
Note that these affirmative modal forms are mainly used in a formal style. (Michael Swan. Practical English Usage)

Explain the use of the verb *need* in the following sentences.

a. She needn't dwell long on the problem in question.
b. You needn't go into detail. Just outline the problem.
c. Need we perform this operation?
d. To see the things they can do one need only look at a living cell.

In what respect do the following sentences differ from the sentences given above?

e. Much needs to be done to satisfy these requirements.
f. All one needs to do is to apply the above rule.
g. This relationship does not need clarification.
h. We are aware of the need to protect the ecological balance.

VI Phrasal Verbs and Idioms

to militate against smth (of evidence, facts, etc.) — to have great force or influence to prevent smth
to shuttle around — to travel between two places
to push along — to leave the place
to push forward — to move forward by using a force; to advance quickly through an area
to push apart — to separate with a force
to push ahead — to continue as fast as possible on one's way
to take inspiration from — to draw inspiration from
to spew off — to make smth rush out in a stream
to glide forward — to move along smoothly and continuously, especially in a specified direction
to win out — to come successfully through a difficult period, to achieve success eventually
to drag along — to pull along with effort and difficulty
to bear resemblance to — to be similar to another person or thing
to scale down/up — to reduce/increase the number or size of smth

VII Exercises

1.Give synonyms to the following words.

to jostle	to exploit
to affect	to shrink
to prevent smth	weird
to engulf	a dearth of smth
to facilitate	power
to break up	a pattern
to promote	a compound

2.Give antonyms to the following words.

Artificial, to expand, visible, mobile, mobilized, activate, a miniaturized version, an excess of smth.

3.Match up the phrasal verb or the idiom in the left column with its equivalent in the right one.

1. to militate against smth	a. to be similar to
2. to push apart	b. to reduce the number or size of smth
3. to shuttle around	c. to move along smoothly and continuously
4. to spew off	d. to come successfully through a difficult period
5. to drag along	e. to continue as fast as possible on one's way
6. to push ahead	f. to pull along with effort or difficulty
7. to win out	g. to make smth rush out in a stream
8. to glide forward	h. to travel between two places
9. to scale down	i. to separate with a force
10. to take inspiration from	j. to prevent smth
11. to bear resemblance to	k. to draw inspiration from

VIII Key Terms

(Oxford Advanced Learner's Dictionary)
A BEAM — a long piece of wood, metal, concrete
BULK — 1. size, quantity or volume; 2. the most part of smth; in bulk — in large amounts
CATALYST — a compound able to facilitate chemical reactions
THE COCKSCREW MOTION — spiral motion
A DEPOSIT — a layer of matter deep under the earth or laid down by a river
A DRAG — a person or thing that makes progress difficult
TO DRIFT — to be carried along gently, especially by a current of air or water
AN EXHAUST — waste gases, steam, etc., that are released from an engine or machine: exhaust fumes/emissions
AN INTERFACE — a point where two subjects, systems, processes, etc., meet and affect each other: the man-machine interface

TO RECOIL — to move suddenly backwards
A SOLUTION — a liquid in which smth is dissolved, the process of dissolving, a solid or a gas in liquid
TO SUSPEND — 1. to hang up; 2. to stop; suspended — kept floating in air, liquid: particles suspended in water
A THRUST —the forward force produced by a jet engine, a rocket
VISCOUS — not flowing freely, thick and sticky

IX. Vocabulary Practice

Fill in the gaps using the key words given below.

Over the next ... ..., nanotech will ... through four overlapping ... of industrial prototyping and early commercialization. The first one, which began after 2000, ... the development of passive nanostructures: materials with steady structures and functions, often ... as parts of a product. These can be as modest as the particles of zinc oxide in sunscreens, but they can also be reinforcing ... in new composites or carbon nanotube wires in ... electronics.

The second stage, which began in 2005, ... on active nanostructures that change their ..., ..., ... or other properties during use. New drug-delivery particles could ... therapeutic molecules in the body only after they reached their targeted diseased tissues. Electronic components such as transistors and amplifiers with adaptive functions could be ... to single, complex molecules.

Starting around 2010, workers will cultivate expertise with systems of nanostructures, ... large numbers of intricate components to specified ends. One application could ... the guided self-assembly of nanoelectronic components into three-dimensional circuits and whole devices. Medicine could ... such systems to improve the tissue compatibility of implants, or to create scaffolds for tissue regeneration, or perhaps even to build ... organs.

After 2015-2020, the field will ... to include molecular nanosystems — heterogeneous networks in which molecules and supramolecular structures ... as distinct devices. The molecular nanosystems will be able ... ... in a far wider ... of environments and should be much faster. Computers and robots could be reduced to ... small sizes. Medical applications might be as ... as new types of genetic therapies and antiaging treatments. New ... linking people directly to electronics could change telecommunications.

Key words: interfaces, artificial, reduced, extraordinarily, fibers, involves, involve, ultraminiaturized, evolve, size, shape, conductivity, directing, expand, couple of decades, ambitious, stages, used, focuses, release, employ, range, serve, to operate.

X Conversational Practice

Agree or disagree with the statements. Develop your idea. Use the following expressions.

I agree with much of what you say.	Well, I must say...
Yes, you could well be right.	Really?
I have no doubt about it.	Sorry, I am not really sure about...
I am quite certain that ...	Another way of looking at it would be that...

1. Nanomachines — robots having features and components at the nanometer scale — could not penetrate the steel beams of bridges or the wings of airplanes, fixing invisible cracks before they propagate and cause catastrophic failures.
2. Brownian motion militates against forcing molecules to move in precise ways.
3. Nature doesn't provide any examples of nanomotors.
4. All these motors, as well as those that power muscle contractions and the corkscrew motion of bacterial flagella, are based on different principles.
5. Catalysts are compounds able to facilitate chemical reactions such as the breakdown of ATP.
6. The researchers took inspiration from a considerably larger catalytic motor reported in 2002 by the Harvard team.
7. The hypothesis that led to the experiment was correct.
8. Both at the macroscale and microscales the notion of recoil makes good sense.
9. The way our nanorods actually work is that they apply a continuous force to prevail over the drag with no need for

gliding.

10. Like all positive ions in water, protons attract the negatively charged regions of water molecules and thus drag water molecules along as they move, propelling the rod in the opposite direction, as dictated by Newton's law of motion that every action has an equal and opposite reaction.

XI Read, translate and summarize the following text.

RETURN OF THE ROBOTS[13]

By Alun Anderson

It will be the 50th anniversary of the construction of the sci-fi world's first real robot hero in 2005. Robby the Robot was the lumbering giant who starred in the cult film "Forbidden Planet". Standing seven and a half feet (2.3 metres) tall with a transparent domed head and spinning antennae, he provided inspiration for the robot heroes of "Star Trek" and other movies to come. And like all good robots he was there to ensure humans came to no harm. Posters of Robby, cradling the film's heroine in his bulging steel arms, still adorn student rooms around the world.

Fifty years on, real robots that can save human lives are at long last beginning to appear. But what exactly do the new robots of 2005 look like? Can you expect help from an intelligent humanoid that walks on two legs and is always there to protect its master (or mistress)? Should you instead be waiting for rescue by a comic-strip giant robot that can rip the doors off cars with giant claws? Perhaps your imagination runs to something stranger: a robot that looks more like a giant spider but with arms tipped with super-sharp steel blades and metal pincers? Or even a long, flexible robot that crawls along the ground like a snake?

If you bet on having help from an intelligent humanoid, you are going to be disappointed. Even getting a two-legged robot to walk effortlessly in a straight line on a smooth laboratory floor is proving much harder than scientists thought. But if you backed any of the

[13] Economist, December 2005, pp. 125–126

other three robots, you are on to a winner. All will be out there in 2005.

First, the clear leader: that's the spider-like robot equipped with knives and pincers. It is a surgical robot that is now spreading rapidly to hospitals around the world. The robot is called da Vinci and is built by Intuitive Surgical of Sunnyvale, California. In 2005 we can expect more surgical robots to be working harder and to be licensed to carry out more types of operation.

A robot does not operate like a conventional surgeon. It has no need to open up your chest or abdomen to let in big human hands. Instead, the robot's long, spidery arms roam deep into your body through a set of tiny incisions, called "ports". Inside your body it can wield instruments to repair heart valves or remove diseased prostate glands. Its tiny robot hands don't tremble as they work and can twist and turn with a dexterity that beats the limitations of a human wrist. When it's finished, it can withdraw leaving just some small holes needing a few stitches.

A robot-equipped operating room is a strange sight. The robot sits alongside the operating table with its long arms bent down over the patient. One arm carries a miniature stereoscopic camera. Others carry blades, pincers and surgical instruments needed to cut, clamp and suture. An anaesthetist and nurses will be present as usual. But the surgeon is not towering over the patient, calling for forceps and scalpels. He or she will be sitting at a distance, at a console that looks like a sophisticated computer-games machine. The surgeon's eyes will be locked on a colour display providing a three-dimensional view from within the patient. The machine gives a remarkable feeling, almost as if the surgeon has been miniaturized and stepped inside the patient's body.

Patients often recover much faster than after surgery requiring the body to be opened up. After a conventional heart-valve repair, for example, a patient may need to spend weeks recovering in hospital, not because of the work performed on the heart itself but because their chest had to be cracked open and a large incision made in order to give access to the heart.

The da Vinci is descended from robots that the US Department of Defence began working on in the 1980s to enable surgeons to operate on soldiers at a safe distance from the battlefield. At a little over \$1m, it is still too expensive for many hospitals. But so-called "minimally invasive surgery", which includes conventional keyhole surgery where the surgeon peers into the body through a small incision, is taking off. New research and training centres around the world will drive demand for the more sophisticated view and capabilities that a robot can provide. Robot-assisted surgeons have already taken on heart-valve repairs, coronary artery bypass operations, prostate removal and oesophageal surgery. Expect other machines to appear in other specialities, such as neurosurgery, where a robot has the potential to provide absolute precision, as well as in relatively standard operations, such as the removal of kidney stones.

Robots don't always need precision and delicacy to be helpful. You might also encounter the giant super-strong clawed robot in 2005. It is called Enryu (meaning "rescue dragon") and stands 3.5 metres tall. During recent trials in Kitakyushu in Japan, Enryu did indeed behave like a comic-strip hero, ripping a door from a car, waving an iron girder and tossing heavy objects out of its way. The caterpillar-tracked monster can lift 500 kilos (1,100 pounds) in each of its claws and comes from a company called Tmsuk that has already created home-guard robots and robot receptionists. Enryu was developed with co-operation from Japan's National Research Institute of Fire and Disaster and is planned to go on the market in 2005, ready to roll in the event of a major disaster, such as an earthquake or nuclear accident, when it can enter a danger zone and clear rubble from collapsed buildings.

In the hunt for survivors it might want to call on the last of the robot menagerie. Snake robots are now gliding around laboratories, and tethered versions that look more like elephants' trunks are also under test. Several are being designed to worm their way into confined spaces, such as collapsed buildings, and search out survivors. Others will do more conventional tasks, including cleaning out pipes.

None of these robots is terribly intelligent. All require human guidance. An autonomous robot like Robby won't escape from the sci-fi movies for many years yet.

Appendix

Texts for home reading and abstracting

BIG SCIENCE[14]

A giant particle accelerator will help physicists better understand the workings of nature

by Alison Goddard

The most complex scientific instrument ever constructed will start up in 2007. The particle accelerator being built at CERN, the European particle-physics laboratory near Geneva, will dominate international fundamental physics for the next 15 years.

Over the centuries scientists have refined their understanding of exactly what makes up the universe. Since the 1960s the existence of different particles, each now thought to be fundamental, has been postulated and observed. So far physicists have seen 16 of them. The problem is that none of these particles confers mass on the others — yet we know from nature that something must do this.

The likeliest explanation is that there is a 17th fundamental particle that has not yet been seen. According to this theory, an invisible field fills the whole of space. When different particles interact with this field, they gain mass, much as anything moving through treacle gets slowed down by it. The larger the interaction, the more mass the particle would have.

[14] The Economist, 2007, p. 143

As the universe is pervaded by such fields that convey other characteristics, the proposal is plausible. It was first made in the 1960s by Peter Higgs of the University of Edinburgh in Scotland. The Higgs field cannot be observed directly, yet, as with other fields, there should be a particle associated with it that can be detected. In this case, it is a particle called the "Higgs boson". Unfortunately no one has ever seen one.

That may soon change. Deep underground at CERN lies what will be the world's most powerful particle accelerator. By the end of 2007 two tubes within the 27km-long (17-mile) circular tunnel will have the air pumped out of them to create the most perfect vacuum on the planet, comparable with that of outer space. The tubes will then be filled with pulses of fast-moving protons, a familiar (albeit non-fundamental) particle. The protons will be accelerated to speeds marginally below that of light itself. Two beams, each containing billions of protons, will circulate in opposite directions in the two separate tubes. But four experiments will run in cavernous halls on the ring, where the beams will collide with such energy that the impact will resemble the universe a split second after the Big Bang.

The four experiments are known by their acronyms. The biggest two are called ATLAS and CMS. Each employs roughly 2,000 scientists and engineers from at least 150 institutions in 35 countries (the best American particle physicists will work at CERN, as will the top Russian, Chinese and Indian scientists). In terms of volume, ATLAS is the bigger: its equipment is the size of a five-storey house and occupies eight times as much space as CMS. But CMS, which weighs about the same as 40 large aircraft, is twice as heavy as ATLAS. These are general-purpose experiments, designed to find the Higgs particle or, failing that, to tell physicists what it is that they see in the extreme conditions created by the impacts.

Such collisions produce a plethora of new and exotic particles that exist fleetingly before they themselves decay into other items of interest that soon settle back down into everyday matter. Both ATLAS and CMS almost completely cover the point at which the protons smash into one another, maximizing their chances of detecting interesting events. Each performs the same set of measurements on the particles emerging from the impact, capturing their paths, energies and identities. But each experiment does this differently.

Scientists working on each obviously want to be the first to see incontrovertible evidence of the existence of the Higgs particle. Nobel prizes are awarded for such things. But the healthy competition between the two experiments is tempered by the need for collaboration. Both experiments share the same accelerator technology and the extraordinarily fast data analysis needed to distinguish between collisions that are interesting and ones that are not. Moreover, any glimpse of new physics would need to be confirmed by the other experiment.

The other two experiments each have a specific goal. In the Big Bang matter and antimatter were created in equal amounts but somehow the antimatter disappeared. An experiment called LHCb will examine why.

Then there's ALICE, "a large ion collider experiment". At times the protons will be removed from the ring and lead ions will be injected instead. Many of those entities thought to be fundamental have never been seen alone, only in combination with other fundamental particles. Although the lead collisions will be far messier than those between protons, the result may be to see isolated basic building blocks of nature for the first time.

As well as the hunt for the Higgs particle, the new machine will look for evidence that will help scientists distinguish between theories of what lies just beyond their present understanding of the world. These include "supersymmetry" — the idea that every matter particle has a partner force particle — and "dark matter", thought to be more abundant than the stuff scientists can now see. Such discoveries will be for 2008 and beyond.

BUILDING THE NEXT-GENERATION COLLIDER[15]

By Barry Barish, Nicholas Walker and Hitoshi Yamamoto

THE INTERNATIONAL LINEAR COLLIDER (ILC) IN A NUTSHELL

The ILC design team has already established the basic parameters for the collider. The machine will be about 31 kilometers long, with most of that length taken up by the two superconducting linacs that will set up electron-position collisions with 500 GeV energies. (A 250-GeV electron striking a 250-GeV positron moving in the opposite direction will result in a collision with a center-of-mass energy of 500 GeV.) At a rate of five times per second, the ILC will generate, accelerate and collide nearly 3,000 electron and positron bunches in a one-millisecond-long pulse, corresponding to an average total power of about 10 megawatts for each beam. The overall efficiency of the machine — that is, the fraction of electrical power converted to beam power — will be about 20 percent, so the two linacs will require a total of about 100 megawatts of electricity to accelerate the particles.

To produce the electron beam, a laser will fire at a target made of gallium arsenide, knocking off billions of electrons with each pulse. These particles will be spin-polarized — all their spin axes will point in the same direction — which is important for many particle physics investigations. The electrons will be rapidly accelerated in a short superconducting radio-frequency (SCRF) linac to an energy of 5 GeV, then injected into a 6.7-kilometer storage ring at the center of the complex. As the electrons circulate and emit synchrotron radiation, the bunches of particles will be damped — that is, their volume will decrease, and their charge density will increase, maximizing the intensity of the beam.

When the electron bunches exit the damping ring 200 milliseconds later, each will be about nine millimeters long and thinner than a human hair. The ILC will then compress each electron bunch to a length of 0.3 millimeter to optimize its acceleration and the dynamics of its subsequent collisions with the corresponding positron bunch

[15] Scientific American, February 2008, pp. 54–59

inside the detector. During the compression, the bunches will be boosted to an energy of 15 GeV, after which they will be injected into one of the main 11.3-kilometer-long SCRF linacs and accelerated to 250 GeV.

Midway through the linac, when the particles are at an energy of 150 GeV, the electron bunches will take a small detour to produce the positron bunches. The electrons will be deflected into a special magnet known as an undulator, where they will radiate some of their energy into gamma rays. The gamma photons will be focused onto a thin titanium alloy target that rotates about 1,000 times per minute, and the impacts will produce copious numbers of electron-positron pairs. The positrons will be captured, accelerated to an energy of 5 GeV, transferred to another damping ring and finally sent to the other main SCRF linac at the opposite end of the ILC. Once the electrons and positrons are fully accelerated to 250 GeV and rapidly converging toward the collision point, a series of magnetic lenses will focus the high-energy bunches to flat ribbon beams about 640 nanometers (billionths of a meter) wide and six nanometers high. After the collisions, the bunches will be extracted from the interaction region and removed to a so-called beam dump, a target that can safely absorb the particles and dissipate their energy.

Every subsystem of the ILC will push the technological envelope and present major engineering challenges. The collider's damping rings must achieve beam qualities several times better than those of existing electron storage rings. What is more, the high beam quality must be preserved throughout the compression, acceleration and focusing stages. The collider will require sophisticated diagnostics, state-of-the-art beam-tuning procedures and a very precise alignment of its components. Building the positron production system and aiming the nanometer-size beams at the collision point will be demanding tasks.

Developing detectors that can analyze the collisions in the ILC will also be challenging. To determine the strengths of the interactions between the Higgs boson and other particles, for example, the detectors will need to measure the momentum and creation points of charged particles with resolutions that are an order of magnitude better than those of previous devices. Scientists are now working on new tracking and calorimeter systems that will allow researchers to harvest the rich physics of the ILC.

THE NEXT STEPS

Although the ILC team has chosen a design for the collider, much more planning needs to be done. Over the next few years, while the LHC starts collecting and analyzing data from its proton-proton collisions, we will strive to optimize the ILC design to ensure that the electron-positron collider achieves the best possible performance at a reasonable cost. We do not yet know where the ILC will be located; that decision will most likely hinge on the amount of financial support that governments are willing to invest in the project. In the meantime, we will continue to analyze the sample ILC sites in Europe, the U.S. and Japan. Differences in geology, topography, and local standards and regulations may lead to different construction approaches and cost estimates. Ultimately, many details of the ILC design will depend on exactly where the collider is built.

In any event, our planning will allow us to move forward at full speed as soon as the scientific discoveries at the Large Hadron Collider (LHC) reveal the best targets for follow-up research. In parallel with the technical design work, we are creating models for dividing the governance of the ILC project so that each constituency of physicists will have a say. This ambitious undertaking has been truly global in its conception, development and design, and we expect it to be thoroughly international in its construction and operation as well.

THE HAMMER AND THE SCALPEL

To understand the complementary relation between the LHC and the proposed ILC, imagine the former as a hammer that breaks open a walnut and the latter as a scalpel that carefully slices the bits of meat inside. The LHC will accelerate protons to energies of seven trillion electron volts (TeV), giving each head-on proton-proton collision a total energy of 14 TeV and providing researchers with their first direct look at physics at this energy scale. The collisions may generate the production of particles whose existence has been hypothesized but not yet observed. One such particle is the Higgs boson. (According to the

Standard Model — the widely accepted theory of particle physics that can explain electromagnetism and the weak and strong nuclear forces — the Higgs endows all other particles with mass.) Other examples are the supersymmetric particles, which are hypothesized partners of the known particles. (The putative partner of the electron, for example, is called the selectron; the photon's partner is the photino.) Furthermore, the LHC may find evidence for extra dimensions that can be detected only by observing high-energy events.

If the Higgs boson does exist, physicists expect that the LHC will detect the particle, measure its mass and determine its interactions with other particles. But scientists will not be able to specify the detailed properties of the Higgs from the LHC's messy proton-proton collisions. The more precise ILC would be needed to measure important characteristics such as the strength of the Higgs's interactions. This information would be invaluable to physicists because it could test the validity of the Standard Model: Does it correctly describe high-energy events, or are other theories needed? Investigations of supersymmetric particles in the ILC could also help physicists flesh out the details of new theories. The results may reveal whether some of these particles could be constituents of the so-called dark matter that makes up one quarter of the energy content of the universe.

Yet another particle that could be revealed by the LHC is the hypothesized Z-prime boson, a counterpart to the Z boson, which is one of the carriers of the weak nuclear force. Because the discovery of the Z-prime particle would indicate the existence of a new fundamental force of nature, physicists would be very interested in determining the properties of this force, its origins, its relation to the other forces in a unified framework and its role in the earliest moments of the big bang. The ILC would play a definitive role in addressing such issues. Finally, if history is any guide, it seems very likely that the LHC and the ILC will discover unanticipated new phenomena that are at least as interesting and important as the ones already discussed.

THE LHC IS NOW OPERATING IN EARNEST[16]

Eighteen months ago CERN, Europe's particle-physics laboratory, based near Geneva, switched on its latest toy. The toy in question was the LHC, and it was going to find all sorts of wonderful things, ranging from the Higgs boson (which is needed to explain why mass exists in the first place) via dark matter (which is needed to explain why the universe is as massive as it is) to miniature black holes (the densest concentrations of mass possible, which journalists of a more scaremongering disposition confidently predicated would eat the Earth up as soon as the machine was switched on).

Nine days after the fanfare, however, a leak in the cooling system put things on hold and they did not restart until last November, with a few gentle collisions between low-energy protons.

Since then, the LHC has been cranking up for serious operation and on March 30th it passed a milestone. There was less trumpeting this time, but protons were made to hit each other at energies higher than any accelerator had managed before. The Tevatron, in America, has officially been relegated to second place.

Once, that might have been a signal for a bit of quiet European gloating. Hubris, however, has been followed by nemesis rather too often in this field for anybody to be making a song and dance about things. Though there was cheering and champagne in the control room when the first high-energy beams collided, sighs of relief are more the order of the day.

Assuming there are no further glitches, the energy of the collisions will be cranked up over the next few months and the new subatomic goodies will start pouring out of the machine and into the pages of physics journals. Finding the Higgs boson is as near a racing certainty as exists in science. For the rest, those who fancy pitting their knowledge of physics against the pros can do so. Paddy Power, an online bookmaker, is offering odds of 11 to 10 that dark matter will be found before black holes and 8 to 1 that black holes will be first. Dark energy, a mysterious force thought to drive the expansion of the universe, trails at 12 to 1. And for those who fancy a real outside bet,

[16]The Economist, 3rd, April, 2010

the firm is also offering 100 to 1 that the machine will discover God.

GOTCHA![17]

ANTIHYDROGEN ATOMS ARE CAPTURED FOR THE FIRST TIME

The history of physics is littered with the detritus of once-sacred assumptions. As better technology enables more exacting experiments, phenomena that were once scoffed at as impossible become the new norm. For this reason, physicists have long been searching for more sensitive means of probing the realm of antimatter, which theory holds should mirror the familiar world of matter. If precise comparisons of the two were to turn up differences, that would signal a fundamental flaw in understanding of the universe.

Now, a team of scientists working at CERN, Europe's particle-physics laboratory, has announced a breakthrough in the quest for such tests. In the current issue of Nature, members of the ALPHA experiment report that they have been able to trap a very small amount of antihydrogen — the simplest type of anti-atom — for the first time. Since the hydrogen atom is one of the best-measured systems in all of science, this opens the door to a series of experiments testing just how similar matter and antimatter really are.

The symmetry between particles and antiparticles is woven deep into the foundations of physics. For each particle there should be a corresponding antiparticle with exactly the same mass and lifetime but with an opposite electrical charge. Bring the two together and they annihilate each other in a flash of energy. When antielectrons (or positrons, as they are usually called) orbit antiprotons and antineutrons, the resulting anti-atoms should have the same energy levels as the common or garden variety. Furthermore, it is thought that gravity should pull on matter and antimatter in just the same way.

[17] The Economist, November 20th, 2010, pp. 84–85

In reality, no one has ever been able to drop an anti-apple and watch it fall down (or up), and the antimatter produced in particle colliders is so energetic that it is hard to examine with the tools of precision physics. For decades, physicists at CERN and elsewhere have been trying to overcome these limitations with antihydrogen, which consists of a single positron orbiting a single antiproton. By shining laser light onto hydrogen or antihydrogen and observing which wavelengths are absorbed, the energy levels of the two can be compared in detail. And since hydrogen is electrically neutral, it should be possible to observe gravity's tiny tug on it without the confounding effects of electrostatic attraction to other particles.

Antihydrogen atoms were produced in the past by several experiments at CERN. But they were so energetic that they immediately bumped into the walls of the experimental apparatus and were annihilated. Since then several teams have been trying to make colder antihydrogen and to hold on to it using clever configurations of electrical and magnetic fields. This is what ALPHA has just succeeded in doing.

Coaxing hot and bothered antiprotons and positrons to couple is quite a task. The magnetic traps employed to hold the antihydrogen are only strong enough to confine it if it is colder than around half a degree above absolute zero. The antiprotons themselves, which are produced by smashing regular protons into a piece of iridium, are around 100 billion times more energetic than this. Several stages of cooling are needed to slow them down before they can be trapped, forming a matchsticksized cloud of around 30, 000 particles. The positrons, produced by the decay of radioactive sodium, are cooled into a similarly sized cloud of around 1m particles and held in a neighbouring trap.

The antiprotons are then pushed into the same trap as the positrons and left to mingle for a second or so. In that time some of the particles get together and form antihydrogen. Next, an electrical field is used to kick out any remaining positrons and antiprotons. The electrically neutral antihydrogen atoms are left behind.

To test whether any antihydrogen was actually formed and captured in their trap, the ALPHA team turned off its trapping magnet. The antihydrogen was then free to wander towards the walls, and thus annihilation. The detectors duly observed 38 bursts of energy which the team concluded came from antihydrogen atoms hitting the wall of the trap.

Although the number of trapped atoms recorded was small, the team is optimistic. It has developed better techniques for cooling both positrons and antiprotons, which should allow it to trap more anti-atoms. Soon it will be able to see just how contrarian antimatter really is.

Part Two

Unit IX

Text I

THE SHAPES OF SPACE[18]

A Russian mathematician has proved the century-old Poincaré conjecture and completed the catalogue of three-dimensional spaces. He might earn a $1-million prize

by Graham P. Collins

THE AUTHOR

Graham P. Collins, a staff writer and editor, has degrees in mathematics and physics. For additional information on the Poincaré conjecture visit `www.sciam.com`

[18] Scientific American, July 2004, pp. 100–103

Word Combinations

to withstand close scrutiny	to be assigned to smth
to be related to a procedure	to gain a sense of smth
to have curvature evenly spread throughout the manifold	in the late 1970s
to remain beyond smb's grasp	to make a name for oneself
to introduce the innovative technique of analysis	to go unanswered
to run into a stumbling block	beyond proving smth
at the turn of the 20th century	to acknowledge support
to perform a surgery	to enable smb to do smth
to eliminate the troubles	to disappear from mathematicians' radar screens
it remains to be seen	to be named after smb
the large-scale structure of the universe	to apply a procedure
to take any of eight canonical geometries	to geometrize a manifold
to smooth out all the irregularities	one way to do smth
to have a similar effect on smth	to examine a process

I Read the questions and find answers in the text that follows.

1. What problem was formulated in the Poincaré conjecture?
2. What solution was suggested by Perelman?

GEOMETRIZATION

Perelman's proof is the first to withstand close scrutiny. His approach to analyzing three-dimensional manifolds is related to a procedure called geometrization. Geometry relates to the actual shape of an object or manifold: for geometry, an object is made not of play dough but of ceramic. A cup, for example, has a different geometry than a doughnut; its surface curves in different ways. It is said that the cup and the doughnut are two examples of a topological torus (provided the cup has one handle) to which different geometries have been assigned.

To gain a sense of how geometrization served to help Perelman, consider how geometry can be used to classify 2-manifolds, or surfaces. *Each topological surface is assigned a special, unique geometry: the one for which the curvature of the surface is spread completely evenly about the manifold.* For the sphere, that unique geometry is the perfectly spherical sphere. An eggshell shape is another possible geometry for a topological sphere, but it does not have curvature evenly spread throughout: the small end of the egg is more curved than the big end.

The 2-manifolds form three geometric types. The sphere has what is called positive curvature, the shape of a hilltop. The geometrized torus is flat; it has zero curvature, like a plain. All the other manifolds, with two or more handles, have negative curvature. Negative curvature is like the shape of a mountain pass or a saddle: going from front to back, a saddle curves up; from left to right, it curves down. Poincaré (who else?), along with Paul Koebe and Felix Klein (after whom the Klein bottle is named), contributed to this geometric classification, or geometrization, of 2-manifolds.

It is natural to try to apply similar methods to 3-manifolds. Is it possible to find unique geometries for each topological 3-manifold, for which curvature is spread evenly throughout the manifold?

It turns out that 3-manifolds are far more complicated than 2-manifolds. Most 3-manifolds cannot be assigned a uniform geometry. Instead they have to be cut up into pieces, each piece having a different canonical geometry. Furthermore, instead of three basic geometries, as with 2-manifolds, the 3-manifold pieces can take any of eight canonical geometries. The cutting up of each 3-manifold is somewhat analogous to the factorization of a number into a unique product of prime factors.

This classification scheme was first conjectured by Thurston in the late 1970s. He and his colleagues proved large swaths of the conjecture, but crucial points that the entire system depended on remained beyond their grasp, including the part that embodied the Poincaré conjecture. Was the 3-sphere unique? An answer to that question and completion of the Thurston program have come only with Perelman's papers.

How might we try to geometrize a manifold — that is, give it a uniform curvature throughout? One way is to start with some arbitrary geometry, perhaps like an eggshell shape with various lumps and indentations, and then smooth out all the irregularities. Hamilton began such a program of analysis for 3-manifolds in the early 1990s, using an equation called the Ricci flow (named after mathematician Gregorio Ricci-Curbastro), which has some similarities to the equation that governs the flow of heat. *In a body with hot and cold spots, heat naturally flows from the warmer regions to the cooler ones, until the temperature is uniform everywhere. The Ricci flow equation has a similar effect on curvature, morphing a manifold to even out all the bumps and hollows.* If you began with an egg, it would gradually become perfectly spherical.

Hamilton's analysis ran into a stumbling block: in certain situations the Ricci flow would cause a manifold to pinch down to a point. (This is one way that the Ricci flow differs from heat flow. The places that are pinched are like points that manage to acquire infinite temperature.) One example was when the manifold had a dumbbell shape, like two spheres connected by a thin neck. The spheres would grow, in effect drawing material from the neck, which would taper to a point in the middle. Another possible example arose when a thin rod stuck out from the manifold; the Ricci flow might produce a trouble called a cigar singularity. When a manifold is pinched in this way, it is called singular — it is no longer a true three-dimensional manifold. In a true three-dimensional manifold, a small region around any point looks like a small region of ordinary three-dimensional space, but this property fails at pinched points. *A way around this stumbling block had to wait for Perelman.*

Perelman came to the U.S. as a postdoctoral student in 1992, spending semesters at New York University and Stony Brook, followed by two years at the University of California at Berkeley. He quickly made a name for himself as a brilliant young star, proving many important and deep results in a particular branch of geometry. He was awarded a prize from the European Mathematical Society (which he declined) and received a prestigious invitation to address the International Congress of Mathematicians (which he accepted). In spring 1995 he was offered positions at a number of outstanding mathematics departments, but he turned them all down to return to his home in St. Petersburg. "Culturally, he is very Russian," commented one American colleague. "He's very unmaterialistic."

Back in St. Petersburg, he essentially disappeared from mathematicians' radar screens. The only signs of activity, after many years, were rare occasions when he e-mailed former colleagues, for example, to point out errors in papers they had posted on the Internet. E-mails inquiring about his pursuits went unanswered.

Finally, in late 2002 several people received an e-mail from him alerting them to the paper he had posted on the mathematics server — just a characteristically brief note saying they might find it of interest. That understatement heralded the first stage of his attack on the Poincaré conjecture. In the preprint, along with his Steklov Institute affiliation, Perelman acknowledged support in the form of money he had saved from his U.S. postdoctoral positions.

In his paper, Perelman added a new term to the Ricci flow equation. The modified equation did not eliminate the troubles with singularities, but it enabled Perelman to carry the analysis much further. *With the dumbbell singularities he showed that "surgery" could be performed: Snip the thin tube on each side of the incipient pinch and seal off the open tube on each dumbbell ball with a spherical cap. Then the Ricci flow could be continued with the surgically altered manifold until the next pinch, for which the same procedure could be applied. He also showed that cigar singularities could not occur. In this way, any 3-manifold could be reduced to a collection of pieces, each having a uniform geometry.*

When the Ricci flow and the surgery are applied to all possible 3-manifolds, any manifold that is as "simple" as a 3-sphere (technically, that has the same homotopy as a 3-sphere) necessarily ends up with the same uniform geometry as a 3-sphere. That result means that topologically, the manifold in question is a 3-sphere. Rephrasing that, the 3-sphere is unique.

Beyond proving Poincaré's conjecture, Perelman's research is important for the innovative techniques of analysis it has introduced. Already mathematicians are posting papers that build on his work or apply his techniques to other problems. In addition, the mathematics has curious connections to physics. The Ricci flow used by Hamilton and Perelman is related to something called the renormalization group, which specifies how interactions change in strength depending on the energy of a collision. For example, at low energies the electromagnetic interaction has a strength characterized by the number 0.0073 (about

1/137). If two electrons collide head-on at nearly the speed of light, however, the strength is closer to 0.0078.

Increasing the collision energy is equivalent to studying the force at a shorter distance scale. The renormalization group is therefore like a microscope with a magnification that can be turned up or down to examine a process at finer or coarser detail. Similarly, the Ricci flow is like a microscope for looking at a manifold at a chosen magnification. Bumps and hollows visible at one magnification disappear at another. Physicists expect that on a scale of about 10^{-35} meter, or the Planck length, the space in which we live will look very different — like a "foam" with many loops and handles and other topological structures. The mathematics that describes how the physical forces change is very similar to that which describes geometrization of a manifold.

Another connection to physics is that the equations of general relativity, which describe the workings of gravity and the large-scale structure of the universe, are closely related to the Ricci flow equation. Furthermore, the term that Perelman added to the basic flow used by Hamilton arises in string theory, which is a quantum theory of gravity. It remains to be seen if his techniques will reveal interesting new information about general relativity or string theory. If that is the case, Perelman will have taught us not only about the shapes of abstract 3-spaces but also about the shape of the particular space in which we live.

II Translate the italicized sentences into Russian. Explain the use of the grammar constructions.

III Vocabulary Notes

(Macmillan English Dictionary for Advanced Learners)

to acknowledge — (verb) 1. to accept or admit that smth exists, is true or is real; to know or recognize that smth is important; 2. to thank smb for smth they have done or given to you especially in writing or by saying it publicly; *acknowledgement* — (noun) 1. (sing.) smth that you say or do in order to show that you accept that smth exists or is true; 2. a statement of thanks for smth that

smb has done; 2.(a) (plur.) a statement of thanks at the beginning of a book, made by the writer to people who have helped
to alert — (verb) 1. to tell smb in authority about a danger or problem so that they can take action to deal with it, to inform; 2. (formal) to tell smb about smth that may affect them, to warn: to alert smb to smth; *alert* (noun) — a warning; *on the alert* — paying attention to what is happening and ready to react quickly if necessary
to herald — (verb) 1. to announce smth or to be a sign that smth is going to happen soon; 2. to praise smth loudly or in a public way; *herald* — (noun + of) a sign that smth is going to happen soon
incipient — (adj.) just beginning to appear or develop
to inquire — (verb + about/whether/why/when etc.) to ask smb for information about smth; *inquiry* — (noun) a question intended to get information about smb or smth: to make inquiries; inquiring — (adj.): inquiring mind
to morph — (verb) (computing) to gradually change one image into another, using computer technology, or to be changed in this way
to pinch — (verb) to squeeze smb's skin between your thumb and finger so that it hurts them; *a pinch* (noun) 1. a small amount of smth that you can hold between your thumb and finger, for example, salt; 2. the action of squeezing smb's skin between your thumb and finger so that it hurts them
to provide — (verb) 1. (smb with smth) to give smb smth that they want or need; 1. (a) to cause smth to exist or be available; 2. (+that) to contain statements or plans that set conditions for dealing with a particular issue; *provided/providing* or *provided/providing that* — (conjunction) only if a particular thing happens or is done
to scrutinize — (verb) to examine smth very carefully; *scrutiny* — (noun) careful examination of smb or smth: to come under close scrutiny, to be subject to public/parliamentary/judicial scrutiny
to snip — (verb) to cut smth in a short quick movement using scissors; *a snip* (noun) — a small quick cut made with scissors
to specify — (verb) to explain smth in an exact and detailed way; *specification* — (noun)
to swathe — (verb) to completely cover smth in smth; *a swath* — (noun) 1. a large area of land; 2. a large number of people or a large

amount of smth
to taper — (verb) to gradually become narrower towards one end or make smth narrower towards one end; *taper off* — (phrasal verb) to gradually become less
an understatement — (noun) a statement that makes smth seem less important, serious, big, etc. than it really is; antonym: *an overstatement*

IV Comprehension Exercises

Answer the following questions.

1. What procedure is Perelman's approach to analyzing three-dimensional manifolds related to? What does it imply?
2. How can geometry be used to classify 2-manifolds or surfaces?
3. How many geometric types do the 2-manifolds form?
4. Who contributed to this geometric classification or geometrization of 2-manifolds?
5. Is it possible to find unique geometries for each topological 3-manifold, for which curvature is spread evenly throughout the manifold?
6. What is the cutting up of each 3-manifold analogous to?
7. When and by whom was the classification scheme for 3-manifolds first conjectured?
8. How might we try to geometrize a manifold — that is to give it a uniform curvature throughout?
9. When Hamilton began such a program of analysis for 3-manifolds in the early 1990s, what equation underlay his research?
10. The Ricci flow has some similarities to the equation that governs the flow of heat but in certain situations the Ricci flow differs from heat flow. What are these situations?
11. How did Perelman manage to find a way around this stumbling block and prove the Poincaré conjecture?
12. Why is Perelman's research so important beyond proving the Poincaré conjecture?
13. What does the renormalization group specify? What is it like?
14. What is the Ricci flow like?

15. What do physicists expect to see on a scale of about 10^{-35} meter or the Planck length?
16. What other connection to physics did Perelman reveal?

V Grammar

1. Give the three forms of the verbs: to stick, to withstand, to shrink, to underlie, to mean, to flow, to teach, to fly, to grow, to arise, to spread, to hold, to find, to take, to get, to go.
2. *Absolute Participle Construction.* Translate the following sentences into Russian.
   a. In this way, any 3-manifold could be reduced to a collection of pieces, each having a uniform geometry.
   b. Most 3-manifolds cannot be assigned a uniform geometry. Instead they have to be cut up into pieces, each piece having a different canonical geometry.
   c. There being no alternative, we have to take this implicit concept for granted.
   d. Hundreds of scientific papers have been written on the pioneer anomalies, many of them trying to find explanations beyond the current laws of gravity.
   e. Pluto orbits the Sun in a period of just less than 250 years. It moves some 25 times slower than an asteroid in the main belt. All things being equal, it would collide with other planetesimals 25 times less often than if it were in the main belt.
3. Translate the following sentences into Russian and comment on the use of the grammar constructions.
   a. It remains to be seen if his techniques will reveal interesting new information about general relativity or string theory.
   b. If that is the case, Perelman will have taught us not only about the shapes of abstract 3-spaces but also about the shape of the particular space in which we live.
   c. If you began with an egg, it would gradually become perfectly spherical.

   d. Hamilton's analysis ran into a stumbling block: in certain situations the Ricci flow would cause a manifold to pinch down to a point.
   e. The spheres would grow, in effect drawing material from the neck, which would taper to a point in the middle.

4. *Verbal Noun.* Explain the use of the corresponding grammar construction in the following sentence.

   The cutting up of each 3-manifold is somewhat analogous to the factorization of a number into a unique product of prime factors.

5. Open the brackets, putting the verbs in the required form.
   a. The most important outstanding problems in the development of the theory concern (to understand) and classification of generalized catastrophies and the more subtle catastrophies that arise when symmetry conditions are imposed.
   b. Herivel showed conclusively that Newton took the law of inertia from (to write) of René Descartes.
   c. The final section of Newton's Principia develops the law of universal gravitation and shows how it explains (to fall) of objects to the earth, (to orbit) of the moon, the motion of the planets and the phenomenon of tides.

6. Mind the difference between the words *affect* and *effect*. *Affect* is a verb, it means "cause a change in", e.g.: The cold weather affected everybody's work. *Effect* is a noun, it means "result" or "change". It is often used in the expression "have an effect on", which means "change" or "influence", e.g.: His meeting with Stravinsky had a great effect on his musical development. Note that *affect* means "have an effect on". (M. Swan. Practical English Usage)

7. *Each* and *every* do not mean quite the same. *Every* puts people or things into a group, like "all". We often use *every* to generalize. *Each* separates, when we say "each violinist, each child, each player", for example, we think of the people doing things differently, separately, or one at a time. Compare: We want every child to succeed. Each child will find his own personal road to success. Every player was on top form. The

Queen shook hands with each player in turn after the game. When we are stressing the idea of a whole group, *each* is not used. *Each* is not used with words and expressions like "almost", "practically", "nearly" or "without exception". Note that *each* can be used to talk about two or more people or things, but *every* always refers to three or more, never to two. The idea of "every two" is given by "both". (M. Swan. Practical English Usage)

8. Fill in the necessary prepositions and adverbs.

   a. Negative curvature is like the shape ... a mountain pass or a saddle: going ... front ... back, a saddle curves ... ; ... left ... right, it curves down. Poincaré (who else?), along ... Paul Koebe and Felix Klein (... whom the Klein bottle is named), contributed ... this geometric classification, or geometrization, ... 2-manifolds.
   b. It is natural to try to apply similar methods ... 3-manifolds.
   c. Is it possible to find unique geometries ... each topological 3-manifold, ... which curvature is spread evenly ... the manifold?
   d. It turns ... that 3-manifolds are far more complicated than 2-manifolds.
   e. Most 3-manifolds cannot be assigned a uniform geometry. ... they have to be cut ... ... pieces, each piece having a different canonical geometry.
   f. ..., instead ... three basic geometries, as ... 2-manifolds, the 3-manifold pieces can take any ... eight canonical geometries.
   g. The cutting ... ... each 3-manifold is somewhat analogous ... the factorization ... a number ... a unique product ... prime factors.
   h. This classification scheme was first conjectured ... Thurston ... the late 1970s. He and his colleagues proved large swaths ... the conjecture, but crucial points that the entire system depended ... remained ... their grasp, including the part that embodied the

Poincaré conjecture.

i. Was the 3-sphere unique? An answer ... that question and completion ... the Thurston program have come only ... Perelman's papers.

VI Phrasal Verbs

to cut up into — to cut smth into several pieces
to smooth out — to move your hand across the surface of smth until it is flat and even
to even out — if things even out or you even them out, they show fewer or smaller changes or differences
to stick out — to continue further than the end of a surface or the main part of an object
to seal off — to prevent people from entering an area or a building
to end up — to be in a particular place or state after doing smth or because of doing it
to turn up — to increase the amount of sound, heat or light produced by a piece of equipment by pressing a button or moving a switch
to turn down — a. opposite to turn up; b. to refuse to accept an offer or request

VII Exercises

a. Give synonyms to the following words.

similarity	to grasp
to govern	to embody
to acquire	to inquire
to admit	to eliminate
to specify	to withstand
to decline	to occur
to scrutinize	to investigate

b. Give antonyms to the following words.
Visible, a regularity, an overstatement, to acquire, necessarily, coarse, to reject

c. Match a phrasal verb in the left column with its equivalent in the right one.

1. to even out	a. to be in a particular place or state after doing smth
2. to stick out	b. to move your hand across the surface of smth until it is even
3. to seal off	c. to refuse to accept an offer or request
4. to turn down	d. to prevent people from entering an area or a building
5. to smooth out	e. to continue further than the end of a surface
6. to end up	f. if things even out, they show fewer or smaller changes
7. to turn up	g. to cut smth into several pieces
8. to cut up	h. to increase the amount of sound, heat or light produced by a piece of equipment by pressing a button or moving a switch

VIII Key Terms

Geometrization — geometric classification of manifolds
Homotopy — a measure of an object's topology
The renormalization group specifies how interactions change in strength depending on the energy of a collision. For example, at low energies the electromagnetic interaction has a strength characterized by the number 0.0073 (about 1/137). If two electrons collide head-on at nearly the speed of light, however, the strength is closer to 0.0078.
Planck length — the possible values of volume and area are measured in units of quantity called the Planck length; this length is related to the strength of gravity, the size of quanta and the speed of light. Planck length is a length scale thought to be of importance in quantum gravity which may represent the shortest possible distance between points; equals $\sqrt{\frac{Gh}{2\pi c}}$, where G is the gravitational constant, h is Planck's constant and c is the speed

of light; value 1.62×10^{-35} m. The corresponding Planck mass is 2.1×10^{-8} kg.

IX Conversational Practice

Agree or disagree with the statements. Justify your choice. Add some sentences to develop your idea. Use the introductory phrases.

Right it is. Quite so.	I am afraid, it is wrong.
Absolutely correct.	On the contrary. Far from it.
I quite agree.	Not at all.
What I mean to say is...	Not quite so. My point is that...
I think it is right.	It is not the case.
In a sense, it is true.	Just the other way round.
I share this viewpoint.	It is unlikely. There is one more point.

1. Geometry relates to the actual shape of an object or manifold.
2. Perelman's approach to analyzing three-dimensional manifolds is related to a procedure called geometrization.
3. Each topological surface is not assigned a special, unique geometry: the one for which the curvature of the surface is spread completely evenly about the manifold.
4. The 2-manifolds form 8 geometric types.
5. It is possible to find unique geometries for each topological 3-manifold, for which curvature is spread evenly throughout the manifold.
6. Instead of three basic geometries, as with 2-manifolds, the 3-manifold pieces can take any of 8 canonical geometries.
7. The classification scheme was first conjectured by Thurston in the late 1970s. He and his colleagues proved a small part of the conjecture but crucial points that the entire system depended on remained beyond their grasp including the part that embodied the Poincaré conjecture.
8. Hamilton began his program of analysis for 2- and 3-manifolds in the early 1990s, using an equation called the

Ricci flow, which has no similarities to the equation that governs the flow of heat.

9. Hamilton's analysis ran into a stumbling block.
10. Adding a new term to the Ricci flow equation eliminated the troubles with singularities.
11. When the Ricci flow and the surgery are applied to all possible 3 manifolds, any manifold that is as "simple" as a 3-sphere unnecessarily ends up with the same uniform geometry as a 3-sphere.
12. Beyond proving Poincaré's conjecture, Perelman's research is of no importance for the innovative techniques of analysis it has introduced.
13. The mathematics has no curious connections to physics.
14. Physicists expect that on a scale about 10^{-35}, or the Planck length, the space in which we live will look the same.
15. Another connection is that the equations to physics of general relativity, which describe the workings of gravity and the large-scale structure of the universe, are closely related to the Ricci flow equation.

X Vocabulary Practice

Try to recollect how these phrases are used in the text.
To withstand close scrutiny..., a procedure called geometrization..., geometry relates to..., to gain a sense of how geometrization served..., is assigned a special, unique geometry; the 2-manifolds form 3 geometrical types..., contributed to this geometric classification..., it is natural to apply similar methods..., it turns out that 3-manifolds..., instead they have to be cut up ..., remained beyond their grasp..., using an equation called the Ricci flow..., ran into a stumbling block..., when the manifold had a dumbbell shape..., a trouble called a cigar singularity..., Perelman added a new term..., surgery could be performed..., in this way any 3-manifold could be reduced to..., when the Ricci flow and the surgery are applied to..., beyond proving Poincaré's conjecture..., another connection to physics..., it remains to be seen....

XI Writing

Outline the main ideas and write an abstract (a brief and concise summary) of the text.

a. Give your abstract a title.
b. Begin the abstract with one of the introductory general phrases: *the text deals with, the author points out, discusses, surveys, gives an overview*, etc.
c. The principal part must not exceed 8-10 sentences generalizing the main idea of the text in a logical sequence.

XII Text II

Read the text and discuss H. Poincaré's contribution to science.

LOST IN EINSTEIN'S SHADOW

by Tony Rothman

PRINCIPLE OF RELATIVITY

Einstein didn't call his creation "the theory of relativity," but it was indeed based on two postulates, the first being the "principle of relativity," the supposition that any experiment done on a train moving with constant velocity should give the same result as an identical experiment done on the ground.

It wasn't Einstein's idea. The great French mathematician Henri Poincaré enunciated the principle of relativity at least as early as 1902 in his popular book *Science and Hypothesis*. We know from Einstein's friend Maurice Solovine that the two pounced on Poincaré's book, indeed that it kept them "breathless for weeks on end." It should have. In *Science and Hypothesis*, Poincaré declares: "1) There is no absolute space, and we can only conceive of relative motion; 2) There is no absolute time. When we say that two periods are equal, the statement has no meaning; 3) Not only have we no direct intuition of the equality of two periods, but we have not even direct intuition of the simultaneity of two events occurring in two different places."

These ideas lie at the heart of relativity, and it is hard to imagine that they did not have a profound effect on Einstein's thinking. But Poincaré not only speculated — he calculated, and in the same weeks that Einstein was writing his paper on relativity, Poincaré completed a pair of his own. The major one is quite remarkable. Mathematically, he has more than Einstein does. Among other things, he notes that time can be viewed as a fourth dimension (something Einstein doesn't do, by the way), he predicts the existence of gravitational waves 10 years before Einstein does and, perhaps most remarkable of all, he writes down an expression exactly equivalent to $E = mc^2$ several months before his rival. But he fails to interpret it.

Poincaré's paper, alas, is that of a mathematician. Right at the start he sets the speed of light equal to a constant, "for convenience." The second, and revolutionary, postulate at the basis of Einstein's relativity is in fact that the speed of light is always observed to be the same constant, regardless of the speed of the observer. Perhaps if Poincaré had been less a brilliant mathematician and more a dumb physicist he would have seen that the whole edifice stands or falls on this "convenience." He didn't.

XIII Render the following text.

Материал из Википедии — свободной энциклопедии

Математическая деятельность Пуанкаре носила междисциплинарный характер, благодаря чему за тридцать с небольшим лет своей напряженной творческой деятельности он оставил фундаментальные труды практически во всех областях математики. Работы Пуанкаре, опубликованные Парижской Академией наук в 1916–1956, составляют 11 томов. Это труды по созданной им топологии, автоморфным функциям, теории дифференциальных уравнений, интегральным уравнениям, неевклидовой геометрии, теории вероятностей, теории чисел, небесной механике, физике, философии математики и философии науки.

Во всех разнообразных областях своего творчества Пуанкаре получил важные и глубокие результаты. Хотя в его научном наследии немало крупных работ по «чистой математике» (абстрактная алгебра, алгебраическая геометрия, теория чисел и др.), все же существенно преобладают труды, результаты которых имеют непосредственное прикладное применение. Особенно это заметно в его работах последних 15-20 лет. Тем не менее открытия Пуанкаре, как правило, имели общий характер и позднее с успехом применялись в других областях науки.

Творческий метод Пуанкаре опирался на создание интуитивной модели поставленной проблемы: он всегда сначала полностью решал задачи в голове, а затем записывал решение. Пуанкаре обладал феноменальной памятью и мог слово в слово цитировать прочитанные книги и проведенные беседы (память, интуиция и воображение Анри Пуанкаре даже стали предметом настоящего психологического исследования). Кроме того, он никогда не работал над одной задачей долгое время, считая, что подсознание уже получило задачу и продолжает работу, даже когда он размышляет о других вещах. Свой творческий метод Пуанкаре подробно описал в докладе «Математическое творчество»(Парижское психологическое общество, 1908).

Поль Пенлеве так оценил значение Пуанкаре для науки:

“Он все постиг, все углубил. Обладая необычайно изобретательным умом, он не знал пределов своему вдохновению, неутомимо прокладывая новые пути, и в абстрактном мире математики неоднократно открывал неизведанные области. Всюду, куда только проникал человеческий разум, сколь бы труден и тернист ни был его путь — будь то проблемы беспроволочной телеграфии, рентгеновского излучения или происхождения Земли — Анри Пуанкаре шел рядом... Вместе с великим французским математиком от нас ушел единственный человек, разум которого мог охватить все, что создано разумом других людей, проникнуть в самую суть всего, что постигла на сегодня человеческая мысль, и увидеть в ней нечто новое”.

Unit X

Text

HOW TO KEEP SECRETS SAFE[19]

A versatile assortment of computational techniques can protect the privacy of your information and online activities to essentially any degree and nuance you desire

by Anna Lysyanskaya

THE AUTHOR

Anna Lysyanskaya is associate professor of computer science at Brown University, where she is a recipient of a National Science Foundation CAREER grant and a Sloan Research Fellowship. She earned her Ph.D. from the Massachusetts Institute of Technology, supervised by Ronald L. Rivest, the "R" of RSA encryption. Signature schemes and anonymous authorization protocols from her thesis are now a part of the Trusted Computing Group Standard. If you bought a new computer in the past couple of years, its microprocessor probably incorporates them.

[19] Scientific American, September 2008, pp. 91–94

Word Combinations

to encrypt one's message	to decrypt the resulting ciphertext
a function with a trap-door property	to recover the plain text
a fundamental cryptographic breakthrough	to be hard to invert
to fuel years of subsequent research in encryption	to verify a signature
to append a signature to one's message	to produce the valid signature
to underpin the security of a specific function	to combat spam
to envision digital-signature schemes	to include fake news reports
to trick people to act against their best interest	to match the message
to wrap one's message in layers	to handle the decryption
to route a message back	to participate as an intermediary
to forward the onion to smb in random order	to receive the onion core
to choose to reveal one's identity	to volunteer one's computers
to provide browsing over an encrypted channel	to remain untraceable

I Read the questions and find answers in the text that follows.

1. What kind of encryption has been known and practiced for centuries?
2. What discovery was hailed as a fundamental cryptographic breakthrough?
3. What do digital-signature schemes provide?

The oldest and one of the most fundamental problems studied in cryptography is that of encryption — the problem of how to communicate securely over an insecure channel (one on which an adversary can eavesdrop). Alice wants to send a message to Bob, but Eve has control over part of the channel (through the apartment's network) that Alice will use. Alice wants Bob, but not Eve, to be able to read the message.

In analyzing this problem, notice, first, that Bob must know something that Eve does not — otherwise Eve would be able to do whatever Bob can do. Bob's private knowledge is called his secret key (SK). Second, notice that Alice must know something about Bob's SK so that she can create a ciphertext — an encrypted message — specifically for Bob. If Alice knows the SK itself, the protocol is called secret-key encryption, the kind of encryption that has been known and practiced for centuries.

In 1976 Whitfield Diffie and Martin E. Hellman, both then at Stanford University, envisioned another possibility, called public-key encryption, in which Alice need not know the SK. All she needs is a public value related to the SK called Bob's public key (PK). Alice uses his PK to encrypt her message, and only Bob, with his SK, can decrypt the resulting ciphertext. It does not matter that Eve also knows Bob's PK because she cannot use it to decrypt the ciphertext. Diffie and Hellman proposed the public-key idea but did not know how to carry it out. That came a year later, when Ronald L. Rivest, Adi Shamir and Leonard M. Adleman, all then at the Massachusetts Institute of Technology, gave the first construction of a public-key cryptosystem: the RSA algorithm.

Their algorithm works for public-key encryption because it involves a so-called trapdoor function. *Such a function is easy to compute, to produce the ciphertext, yet hard to invert, to recover the plaintext, unless a special "trapdoor" is used.* The trapdoor serves as the secret key. The RSA algorithm was the first example of a function with a trapdoor property. For this work they won the 2002 A.M. Turing Award, the most prestigious prize in computer science.

The RSA discovery, hailed as a fundamental cryptographic breakthrough, fueled years of subsequent research in encryption and in cryptography more generally. *Much hard work on encryption* *still remains, from finding new trapdoor functions, to studying the mathematical assumptions that underpin the security of a specific function, to defining precisely what is required for an encryption system to be considered secure.*

Public-key encryption makes it possible to purchase things online without sending sensitive information such as credit-card numbers openly on the Internet. The customer's Web browser plays the role of Alice and the Web site the role of Bob. More generally, https, a protocol that most browsers now support, uses public-key encryption to provide Web browsing over an encrypted channel — look for `https://` in the URL (the address of the Web site) and an icon such as a closed padlock on the browser's status bar.

Many people also use public-key encryption for secure e-mail. Plenty of free software exists for that purpose, including the GNU Privacy Guard package (available at `www.gnupg.org`) first released by the Free Software Foundation a decade ago. If you do not encrypt your e-mail, it travels across the Internet in a form that is easy to read and may remain in that form on various hard drives along the way for some time afterward.

Closely associated with the problem of encryption is that of authentication. Suppose Alice receives the message "Alice, please send Eve $100. Love, Bob." How does she know that it really came from her boyfriend Bob and was not in fact fabricated by Eve?

Just as in the encryption scenario, Bob must know something that Eve does not so that he, but not Eve, can produce a message that Alice will accept. Thus, Bob again needs a secret key. Moreover, Alice needs to know something about Bob's SK to be able to verify that the message is from Bob. Once again, two varieties of protocol exist: secret-key authentication, more commonly known as a message authentication code, and public-key authentication, frequently referred to as a digital-signature scheme. Diffie and Hellman first envisioned digital-signature schemes at the same time that they proposed public-key encryption, and a scheme using the RSA algorithm was the first one constructed.

The chief idea is that Bob uses his SK to compute a "signature" that he appends to his message and that Alice or anyone else then uses his PK to verify that it matches the message itself. Alice knows the message must be from Bob because no one else has the SK needed to produce the valid signature.

Currently it is easy to trick an e-mail client into thinking that a message came from Bob when in fact it came from Eve. A spoofed e-mail may include fake news reports and incorrect stock quotes, tricking people to act against their best interest. *But if all e-mail communication were authenticated, such an attack would be impossible: your e-mail client would digitally sign all outgoing messages and would verify the digital signatures of all incoming messages. Authentication could also combat spam by having servers reject incoming e-mail that is not authenticated by its sender.* Authentication protocols did not exist when e-mail was developed in the 1970s, and many conventions from that era still prevail.

Software that everyone can use to sign their e-mail and verify signatures is freely available, for instance, as a part of the GNU Privacy Guard package mentioned earlier.

ONION ROUTING

By encrypting your messages, you can prevent Internet service providers (or any other eavesdropper) from discovering what you send and receive, but not to whom you are communicating. For example, Alice's ISP will know if she browses an Alcoholics Anonymous Web site. *Imagine if the ISP were to sell this information to car insurance companies. People would be less likely to seek help online because they would be worried that it would increase their insurance premium.*

This problem could be solved with SFE: Alice's private input would be the URL she wants to look at, and her private output would be the contents of the Web page she wants to see. Using SFE, however, would be highly inefficient. In 1981 David Chaum, then at the University of California, Berkeley, proposed a much simpler solution called anonymous channels, now also known as onion routing.

As the name suggests, Alice wraps her message in layers. She encrypts each layer (and everything inside it) with a different person's public key and then adds that person's address to the outside of the layer. A message from Alice to Bob could travel as follows: Alice sends the onion to Mark, who can peel off the outermost layer by decrypting the onion with his secret key. Inside, Mark finds a smaller onion and Lisa's address. He forwards that onion to Lisa, who can decrypt it with her key, and so on. Finally, Bob receives the onion core from someone, and he decrypts it to find Alice's message.

In practice, the intermediaries are part of a network of computers set up to handle the decryption and forwarding automatically. Ideally, each intermediary continually receives lots of onions and forwards them in random order. Even if an ISP is watching all the intermediaries at all times, it cannot tell where Alice's message went or where Bob's came from, provided there is enough onion traffic on the network.

Bob himself does not know who sent the message, unless Alice chooses to reveal her identity in the message. Yet even if she remains anonymous to him, he can still send her an anonymous reply if she includes a "reply onion" containing the layers of addresses and public keys needed to route a message back to her.

Alice's and Bob's messages can remain untraceable even if some of the intermediaries leak information about what they are doing. As more participants use this system and volunteer their computers to serve as intermediaries, it becomes harder to figure out who is talking to whom.

As with encryption and digital signatures for e-mail, free software is available for anyone to communicate over anonymous channels or to participate as an intermediary. The Onion Router (Tor) project, for instance, can be found at `www.torproject.org`.

II Translate the italicized sentences into Russian. Explain the use of the grammar constructions.

III Vocabulary Notes

(Macmillan English Dictionary for Advanced Learners)
to browse — (verb) (computing) 1. to look for information in a computer, especially on the internet, mobile phones that can browse the web; 1.(a) to look at a website on the internet, e.g.: an excellent graphical interface for browsing web pages; *browser* — (noun) (computing) a computer program that allows you to look at and search through information on the internet

cipher — (noun) a secret system of writing, used for sending messages so that no one can understand them unless they know the system code
to eavesdrop — (verb) to listen to other people's conversation without them knowing that you are listening
to encrypt — (verb) to put information into a form called a code that other people are unable to read; *encryption* — (noun)
to envision (AmE *to envisage*) — (verb) to consider smth as possible or what you intend
to forward — (verb) to send a letter, an e-mail, etc. that has been sent to your address to smb else at another address
to hail — (verb) to say publicly how good or important smth is
to intercept (verb) to stop, catch or take control of smb or smth before they can get to the place they are going to, e.g.: to intercept a message; *interception* — (noun)
an intermediary — (noun) smb who talks to each of the people or groups involved in smth, usually passing information from one to the other or trying to persuade them to agree with each other
to invert — (verb) to put smth in the opposite position to the one it was in before, especially by turning it upside down; *inverted* — (adj.) turned in the opposite direction, especially upside down
to leak information — (verb) to tell private or secret information to journalists or to the public
protocol — (noun) 1. a set of rules for the correct way to behave in formal occasions; 1.(a) (computing) a method of sending information between computers
to route — (verb) to send smb or smth along a particular route; *a route* — (noun) 1. a way that buses, trains, ships or planes travel regularly; 1.(a) the roads and paths that you use when you go from one place to another
spoof — (noun) a piece of entertainment that copies smth in a funny way intended to make it seem silly; *to spoof* — (verb)
to underpin — (verb) to be an important basic part of smth, allowing it to succeed or continue to exist; *underpinning* — (noun)
to verify — (verb) to check or prove that smth is true or correct; *verification* — (noun); *verifiable* — (adj.) able to be checked or proved

to volunteer — (verb) to offer or choose to do smth without being forced; *a volunteer* — (noun); *voluntary* — (adj.)

IV Comprehension Exercises

Answer the following questions.

1. What is one of the most fundamental problems studied in cryptography?
2. What is a cyphertext like?
3. What kind of encryption is called secret-key encryption?
4. What another kind of encryption was envisioned by W. Diffie and M.E. Hellman in 1976?
5. When and by whom was the public-key idea realized?
6. How will you decrypt the RSA algorithm?
7. What does this algorithm involve?
8. What prize did the scientists win in 2002?
9. What does public-key encryption make it possible to do?
10. What problem is closely associated with the problem of encryption?
11. What is the chief idea of the digital-signature scheme?
12. What problems would be eliminated if all e-mail communication were authenticated?
13. What can't you prevent from discovering by encrypting your message?
14. What solution was proposed?
15. In what way does "onion routing" work?

V Grammar

1. Give the 3 forms of the verbs: to seek, to know, to sell, to win, to send, to tell, to set, to choose, to become, to read, to give, to think, to undertake, to learn, to catch, to buy.
2. Find in the text *conditional sentences* in the Indicative Mood and in the Subjunctive Mood. Translate them into Russian. Pay attention to the difference in grammar constructions.
3. *The Indicative Mood. Conditionals. Type I. Real Condition.* Put the verbs given in brackets in the required form.

a. Such a function is hard to invert, to recover the plain text, unless a special trapdoor (to be used).
b. On the plane two geodesies intersect in exactly one point unless they (to be) parallel.
c. A moving body is "at rest" as far as its own inertia is concerned, as long as its motion (to continue) at the same speed and in the same direction.
d. If the string (to become) slack, the tension is supposed to vanish and no work is done until the string again (to become) tight.
e. The change of velocity is not constant unless the change (to be constant) both in magnitude and direction.
f. Galileo pointed out that if completed infinite sets (to be) admissible in maths, there must be as many even integers as there are even and odd integers together.
g. A car continues in motion unless a force (the brakes or the friction of the road surface or an uphill slope) (to stop) the car.
h. The relative velocity of two bodies in orbit around the Sun will tend to be great unless the orbits (to be similar) in size, shape and orientation.
i. Approximation necessarily introduces errors. If there (to be) many successive numerical operations, the errors can accumulate and make nonsense of the final result. Only if a careful error analysis (to be undertaken) can the final answer be stated with confidence and such error analysis is one of the most complex problems faced in many fields.
j. Bob himself doesn't know who sent the message unless Alice (to choose) to reveal her identity in the message.

4. *The Subjunctive Mood. Conditionals. Type II. Unreal Condition.*

Put the verbs given in brackets in the required form.

a. But if all e-mail communication (to be authenticated), such an attack (to be) impossible: your e-mail client (to digitally sign) all outgoing messages and (to verify) the digital signatures of all incoming messages

b. Imagine if the ISP (to be) to sell this information to car insurance companies. People (to be) less likely to seek help on line because they (to be) worried that it (to increase) their insurance premium.
c. The Ricci flow equation has a similar effect on curvature, morphing a manifold to even out all the bumps and hollows. If you (to begin) with an egg, it (to gradually become) perfectly spherical.
d. If there (to be) no slight but repeated gravitational tug between the two satellites (Io and Europa) that keeps their orbits elliptical, tidal forces from Jupiter (to drag) Io into a perfectly circular orbit in a few million years, and tidal heating then (to cease).
e. If it (not to be) for the radio, there (to be) little point in sending satellites into space.
f. But for Newton's gravitational theory, people (to think) of the world as two-dimentional.
g. Under current number-theoretical beliefs about the difficulty of cracking FEE codes, it (require) without knowing the secret key all the computing power on earth more than 10^{10000} years to decrypt the gibberish back to a meaningful magazine.

5. Fill in the necessary prepositions or adverbs.
   a. … encrypting your messages, you can prevent Internet service providers (or any other eavesdropper) … discovering what you send and receive, but not … whom you are communicating.
   b. … 1981 David Chaum, then … the University of California, Berkeley, proposed a much simpler solution called anonymous channels, now also known as onion routing.
   c. As the name suggests, Alice wraps her message … layers.
   d. She encrypts each layer (and everything … it) … a different person's public key and then adds that person's

address ... the outside ... the layer.

e. A message ... Alice ... Bob could travel as follows: Alice sends the onion ... Mark, who can peel ... the outermost layer ... decrypting the onion ... his secret key.
f. ..., Mark finds a smaller onion and Lisa's address.
g. He forwards that onion ... Lisa, who can decrypt it ... her key, and so .... Finally, Bob receives the onion core ... someone, and he decrypts it to find Alice's message.
h. ... practice, the intermediaries are part ... a network ... computers set ... to handle the decryption and forwarding automatically.
i. Ideally, each intermediary continually receives lots ... onions and forwards them ... random order.
j. Even if an ISP is watching all the intermediaries ... all times, it cannot tell where Alice's message went or where Bob's came ..., provided there is enough onion traffic ... the network.

VI Phrasal Verbs

to peel off — to remove a tight or wet piece of clothing
to set up — to start smth such as a business organization or institution; to organize or plan smth such as an event or system
to figure out — to be able to understand smth or solve a problem
to carry out — to do a particular piece of work, research etc.
to refer to smb/smth — to mention smb or smth when you are speaking or writing
to be referred to as — to be called

VII Exercises

a. Give synonyms to the following words.

to restore	to purchase	to proclaim
to greet	to associate	to obtain
to remove	to suggest	to disclose

b. Give antonyms to the following words.

To reveal, to encrypt, an adversary, secure, traceable, to prevent, available, compulsory, private, correct

VIII Key Terms

SK — secret key
PK — public key
The RSA algorithm — called so by the first letters in the surnames of the inventors
A message authentication code — SK authentication
GNUPG — Privacy Guard Package first released by the Free Software Foundation
ISP — Internet Service Provider
SFE — secure function evaluation. Suppose, for instance, that all the members of a group connected by the Internet want to compute smth that depends on data from each of them — data that each wants to remain private. The data could be their vote in an election and they want to know the outcome without revealing their individual votes. A procedure known as multiparty computation or SFE enables them to tally their votes in such a way that each participant learns the correct output and no one can learn anyone's individual vote — not even a coalition of malevolent insiders capable of intercepting messages on the network and substituting their own carefully crafted fake data. The SFE protocol can also provide each individual with a private output.

IX Conversational Practice

Agree or disagree with the statements. Justify your assertions. Add some sentences to develop your idea.

I'm sure/certain about the fact that…	Sorry, I'm not really sure.
I've no doubt that…	I'm in two minds about it.
I think…	Surely not. I mean…
As I see it…	Yes, but on the other hand…
In my view/opinion	Let me explain my point.

1. The oldest and one of the most fundamental problems studied in cryptography is that of encryption — the problem of how to communicate securely over an insecure channel (one on which an adversary can eavesdrop).
2. Bob's private knowledge is called his PK.
3. Alice must know smth about Bob's SK so that she can create a ciphertext — an encrypted message — specifically for Bob.
4. If Alice knows the SK itself, the protocol is called SK encryption.
5. PK encryption, the kind of encryption that has been known and practiced for centuries.
6. The protocol on PK encryption implies that Alice uses Bob's PK to encrypt her message and only Bob with his SK can decrypt the resulting ciphertext.
7. The PK idea was proposed by W. Diffie and M. Hellman and they knew how to carry it out.
8. R.L. Rivest, A. Shamir and L.H. Adelman, all then at the Massachusetts Institute of Technology, gave the first construction of a PK cryptosystem: the RSA algorithm.
9. The discovery of the RSA algorithm was insignificant.
10. The algorithm involves a so-called trapdoor function.
11. A protocol that most browsers now support uses SK encryption to provide web browsing over an encrypted channel.
12. Not so closely associated with the problem of encryption is that of authentication.
13. Once again, only one protocol exists, i.e. SK authentication, more commonly known as a message authentication code.
14. The chief idea is that Bob uses his PK to compute a "signature".

15. If all e-mail communication were authenticated, no spoofed e-mail containing fake news reports, incorrect stock quotes, etc. and tricking people to act against their best interest would be possible.

X Vocabulary Practice

Try to recollect how these phrases are used in the text.

The oldest and one of the most fundamental problems studied in cryptography..., the protocol is called SK encryption..., the first construction of a PK cryptosystem: the RSA algorithm..., it involves the so called trapdoor function..., hailed as a fundamental cryptographic breakthrough..., PK encryption makes it possible..., closely associated with the problem of encryption..., once again, two varieties of protocol exist..., a PK authentication frequently referred to as..., if all e-mail were authenticated....

Retell the text *"Onion Routing"* by using the following expressions as clues.

To prevent Internet Service providers..., a solution called anonymous channels..., as the name suggests.., with a different person's PK..., adds that person's address..., by decrypting the onion with his SK..., he forwards that onion to..., Bob finally receives the onion core from ..., part of a network of computers..., set up to handle the decryption..., in random order..., unless Alice chooses to reveal her identity..., to route a message back to her..., as more participants volunteer their computers....

XI Writing

Outline the main ideas and write an abstract (a brief and concise summary) of the text.

XII Render the following text

Анализ безопасности криптосистемы — это хорошо разработанная область науки. В отличие от общепринятого представления, криптография — это не игра в кошки-мышки, в которой предполагается, что система безопасна, только потому что никто не показал, как ее взломать. Напротив, многие фундаментальные понятия криптографии основываются на хорошо изученных математических проблемах. Криптографы не могут показать, возможно ли в принципе взломать некую криптосистему, но они показывают, что любой алгоритм ее взлома также позволил бы решить какую-либо фундаментальную проблему, которая ставит в тупик лучших математиков и кибернетиков.

Некоторые протоколы зависят только от существования математической функции определенного вида. Например, криптографы знают, как построить криптосистему с открытым ключом, используя любую одностороннюю (trapdoor) функцию. Таким образом, если бы кто-то взломал функции, используемые в протоколе РСА, мы могли бы заменить их другими односторонними функциями.

Лишь только изредка схема считается безопасной. Но это происходит только после того, как сотни ведущих исследователей по всему миру изучали алгоритм в течение нескольких лет. Криптографическое сообщество может себе позволить осуществить этот процесс только для нескольких важнейших фундаментальных понятий и протоколов (строительных блоков). Криптографы затем доказывают безопасность более крупных систем, полагаясь на безопасность строительных блоков.

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Unit XI

Text I

THE CHALLENGE OF LARGE NUMBERS[20]

As computer capabilities increase, mathematicians can better characterize and manipulate gargantuan figures. Even so, some numbers can only be imagined.

by Richard E. Grandall

THE AUTHOR

Richard E. Grandall is chief scientist in Next Software. He is also Vollum Adjunct Professor of Science and director of the Center for Advanced Computation at Reed College. Grandall is the author of seven patents, on subjects ranging from electronics to the East Elliptic Encryption system. In 1973 he received his Ph.D in physics from the Massachusetts Institute of Technology.

[20] Scientific American, February, 1997, pp. 76–77

Word Combinations

a workhorse of all engineering algorithms	more recently
to be thought of as a means for ascertaining smth	a record holder
to enhance a fundamental operation between numbers via FFT	by way of smth
to refine an astute observation into a rigorous theory	a gargantuan number
the one-billionth decimal place of π	current number-theoretical beliefs
to fall somewhere in the range of	to take considerable computational effort
a long-winded process	by any account
to be beyond the scope of smth	frequency bands
to decompose the signal into its spectral components	to treat smth as bipolar
an irrational-base discrete weighted transform	to optimize an algorithm

I Read the questions and find answers in the text that follows.

1. In what way can ordinary multiplication — a fundamental operation between numbers — be dramatically enhanced?
2. In what celebrated calculations has FFT multiplication been used
3. In which discoveries has FFT also been used?

ALGORITHMIC ADVANCEMENTS

Many modern results on large numbers have depended on algorithms from seemingly unrelated fields. One example that could fairly be called the workhorse of all engineering algorithms is the Fast Fourier Transform (FFT). The FFT is most often thought of as a means for ascertaining some spectrum, as is done in analyzing birdsongs or human voices or in properly tuning an acoustic auditorium. *It turns out that ordinary multiplication — a fundamental operation between numbers — can be dramatically enhanced via FFT.* Arnold Schoenage of the University of Bonn and others refined this astute observation into a rigorous theory during the 1970s.

FFT multiplication has been used in celebrated calculations of π to a great many digits. Granted π is not a bona fide large number, but to compute π to millions of digits involves the same kind of arithmetic used in large-number studies. In 1985 R. William Gosper, Jr., of Symbolics, Inc., in Palo Alto, Calif., computed 17 million digits of π. A year later David Bailey of the National Aeronautics and Space Administration Ames Research Center computed π to more than 29 million digits. More recently, Bailey and Gregory Chudnovsky of Columbia University reached one billion digits. And Yasumasa Kanada of the University of Tokyo has reported five billion digits. In case anyone wants to check this at home, the one-billionth decimal place of π, Kanada says, is nine.

FFT has also been used to find large prime numbers. Over the past decade or so, David Slowinski of Cray Research has made a veritable art of discovering record primes. Slowinski and his coworker Paul Gage uncovered the prime $2^{1,257,787} - 1$ in mid-1996. A few months later, in November, programmers Joel Armengaud of Paris and George F. Woltman of Orlando, Fla., working as part of a network project run by Woltman, found an even larger prime: $2^{1,398,269} - 1$. This number, which has over 400,000 decimal digits, is the largest known prime number as of this writing. It is, like most other record holders, a so-called Mersenne prime. These numbers take the form $2^q - 1$, where q is an integer, and are named after the 17th century French mathematician Marin Mersenne.

For this latest discovery, Woltman optimized an algorithm called an irrational-base discrete weighted transform, the theory of which I developed in 1991 with Barry Fagin of Dartmouth College and Joshua Doenias of NeXT Software in Redwood City, Calif. This method was actually a by-product of cryptography research at NeXT.

Blaine Garst, Doug Mitchell, Avadis Tevanian, Jr., and I implemented at NeXT what is one of the strongest — if not the strongest — encryption schemes available today, based on Mersenne primes. This patented scheme, termed Fast Elliptic Encryption (FEE), uses the algebra of elliptic curves, and it is very fast. Using, for example, the newfound Armengaud-Woltman prime $2^{1,398,269} - 1$ as a basis, the FEE system could readily encrypt this issue of Scientific American into seeming gibberish. *Under current number-theoretical beliefs about the difficulty of cracking FEE codes, it would require, without knowing the secret key, all the computing power on earth more than $10^{10,000}$ years to decrypt the gibberish back into a meaningful magazine.*

Just as with factoring problems, proving that a large number is prime is much more complicated if the number is arbitrary — that is, if it is not of some special form, as are the Mersenne primes. For primes of certain special forms, "large" falls somewhere in the range of $2^{1,000,000}$. But currently it takes considerable computational effort to prove that a "random" prime having only a few thousand digits is indeed prime. For example, in 1992 it took several weeks for Francois Morian of the University of Claude Bernard, using techniques developed jointly with A.O.L. Atkin of the University of Illinois, and others, to prove by computer that a particular 1,505-digit number, termed a partition number, is prime.

USING FAST FOURIER TRANSFORMS FOR SPEEDY MULTIPLICATION

Ordinary multiplication is a long-winded process by any account, even for relatively small numbers: To multiply two numbers, x and y, each having D digits, the usual, "grammar school" method involves multiplying each successive digit of x by every digit of y and then adding columnwise, for a total of roughly D^2 operations. During the 1970s, mathematicians developed means for hastening multiplication of two D-digit numbers by way of the Fast Fourier Transform (FFT). The FFT reduces the number of operations down to the order of $D \log D$. (For example, for two 1,000-digit numbers, the grammar school method may take more than 1,000,000 operations, whereas an FFT might take only 50,000 operations.)

A full discussion of the FFT algorithm for multiplication is beyond the scope of this article. In brief, the digits of two numbers, x and y (actually, the digits in some number base most convenient for the computing machinery) are thought of as signals. The FFT is applied to each signal in order to decompose the signal into its spectral components. This is done in the same way that a biologist might decompose a whale song or some other meaningful signal into frequency bands. These spectra are quickly multiplied together, frequency by frequency. Then an inverse FFT and some final manipulations are performed to yield the digits of the product of x and y.

There are various, powerful modern enhancements to this basic FFT multiplication. One such enhancement is to treat the digit signals as bipolar, meaning both positive and negative digits are allowed. Another is to "weight" the signals by first multiplying each one by some other special signal. These enhancements have enabled mathematicians to discover new prime numbers and prove that certain numbers are prime or composite (not prime).

II Translate the italicized sentences into Russian. Explain the use of the grammar constructions.

III Vocabulary Notes

(Macmillan English Dictionary for Advanced Learners)
astute — (adj.) good at judging situations and people quickly and able to use this knowledge for personal benefit; *astutely* — (adv.); *astuteness* — (noun)
to ascertain — (verb) to find out smth
bona fide — (Latin) a bona fide person or thing is really what they seem to be or what they claim to be
to enhance — (verb) to improve smth or make it more attractive or more valuable; *enhancement* — (noun) the process of improving smth
enigma — (noun) smb or smth that is mysterious and difficult to understand; *enigmatic* — (adj.); *enigmatically* — (adv)
gibberish — (noun) nonsense
longwinded — (adj.) using more words and taking more time than

necessary to say smth, e.g.: a longwinded computation
veritable — (adj.) real (used for emphasizing what you are saying)
to weight — (verb) to make smth heavier by putting a weight on it, especially in order to stop it from moving; *weighted* — (adj.) designed to produce a particular effect or result by giving more importance to one thing than another

IV Comprehension Exercises

Answer the following questions.

1. What have many modern results depended on?
2. What algorithm could fairly be called the workhorse of all engineering algorithms?
3. How can ordinary multiplication be enhanced via FFT?
4. What happened during the 1970s?
5. What kind of arithmetic was involved in celebrated calculations of π to a great many digits?
6. What discovery has taken place over the past decade or so?
7. What is the record holder called? After whom are these numbers named? What form do they take?
8. What algorithm did Woltman optimize for this latest discovery?
9. What is one of the strongest encryption schemes available today based on? What is it termed?
10. Having in view the difficulty of cracking FEE, how long would it take to decrypt the gibberish back into a meaningful magazine and how much computer power would it require without knowing the secret key?
11. In which case is it more complicated to prove that a large number is prime?

V Grammar

1. Give the three forms of the verbs: to make, to have, to say, to do, to fall, to run, can, may, to break.
2. Give the plural forms of the following nouns: torus, spectrum, belief, proof, helix, focus.

3. *The Subjunctive Mood. Conditionals. Type III. Unreal Condition.*

   a. Many discoveries jotted down in Gauss's diary suffice to establish his priority in fields — elliptic functions, for instance, were buried for years or decades in the diary that (to make) half a dozen great reputations if they (to publish) promptly.
   b. Again, a later entry shows that Gauss had recognized the double periodicity in the general case. This discovery of itself if he (to publish) it, (to make) him famous. But he never published it.
   c. The year 1811 (may) (to be) a landmark in mathematics comparable to 1801 — the year in which the *Disquisitions* appeared if Gauss (to make) public a discovery he confined to Bessel.
   d. For many years Gauss, aided by his friend Weber, sought a satisfactory theory for all electromagnetic phenomena. Failing to find one that he considered satisfactory, he abandoned his attempt. If he (to find) Clerk Maxwell's equation of the electromagnetic field, he (may) (to be satisfied).
   e. Perhaps if Poincaré (to be) less a brilliant mathematician and more a dumb physicist he (to see) that the whole edifice stands or falls on this "convenience."

4. Open the brackets, put the verbs in the required form and give your explanations. Account for the use of *the Present Perfect* or *the Past Simple forms.*
   a. Many modern results on large numbers (to depend) on algorithms from seemingly unrelated fields.
   b. Arnold Schoenage of the University of Bonn and others (to refine) this astute observation into a rigorous theory during the 1970s.
   c. FFT multiplication (to use) in celebrated calculations of π to a great many digits.
   d. In 1985 R. William Gosper, Jr., of Symbolics, Inc., in

Palo Alto, Calif., (to compute) 17 million digits of π.
e. A year later David Bailey of the National Aeronautics and Space Administration Ames Research Center (to compute) π to more than 29 million digits.
f. More recently, Bailey and Gregory Chudnovsky of Columbia University (to reach) one billion digits.
g. And Yasumasa Kanada of the University of Tokyo (to report) five billion digits.
h. FFT also (to use) to find large prime numbers.
i. Over the past decade or so, David Slowinski of Cray Research (to make) a veritable art of discovering record primes.
j. Slowinski and his coworker Paul Gage (to uncover) the prime $2^{1,257,787} - 1$ in mid-1996.

VI Exercises

a. Give synonyms to the following words.

to term	to treat	shrewd	to ascertain
to yield	current	celebrated	to enhance
to crack	to recur	to run	by way of
proper	to uncover	to require	random

b. Give antonyms to the following words.

To compose, to reduce, multiplication, positive, powerful, fruitful, to cover

VII Key Terms

FEE — Fast Elliptic Encryption
FFT — Fast Fourier Transform
The Mersenne primes — these numbers take the form $2^q - 1$, where q is an integer, and are named after the XVIIth century French mathematician Marin Mersenne. Marin Mersenne measured the speed of a sound in the air and proposed a scheme of a mirror telescope.

VIII Conversational Practice

Agree or disagree with the statements. Justify your choice. Add some sentences to develop your idea. Use the introductory phrases.

I fully agree to it.	But the point is...
That's right.	Far from that.
Certainly/exactly.	On the contrary.
I have a similar view.	What is lacking in the statement is that...

1. Many modern results on large numbers turned out to have depended on logarithms from seemingly unrelated fields.
2. Ordinary multiplication can not be enhanced via FFT.
3. To compute π to millions of digits does not involve the same kind of arithmetic used in large-number studies.
4. FFT has also been used to find large prime numbers.
5. The largest known prime number has over $400,000$ decimal digits, and it is as most other record holders, a so-called Mersenne prime.
6. The patented encryption scheme, termed FEE, uses the algebra of elliptic curves and it is very fast.
7. Proving that a large number is prime is not more complicated if the number is arbitrary, that is if it is not of some specific form as are the Mersenne primes.
8. Currently, it does not take considerable computational effort to prove that "random" prime having only a few thousand digits is indeed prime.
9. For primes of certain special forms "large" falls somewhere in the range of $21,000$.
10. It took considerable computational effort to prove by computer that a particular 1,505-digit number, termed a partition number, is prime.
11. In the 1970s mathematicians failed to develop means for hastening multiplication of two D-digit numbers by way of FFT.
12. The digits of two numbers, x and y aren't thought of as signals.

13. The FFT is applied to each signal in order to decompose the signal into its spectral components.
14. There are various modern powerful enhancements which have enabled mathematicians to discover new prime numbers.

IX Vocabulary Practice

Fill in the gaps using the key words given below.

Somewhat above the googol lie numbers that present a sharp ... to practitioners of the art of factoring: the art of ... numbers into their prime factors, where primes are themselves ... only by 1 and themselves. For example, 1,799,257 factors into 7,001x257, but ... ... a sufficiently large number into its prime factors can be so ... that computer scientists ... ... this difficulty ... ... data. Indeed, one ... encryption algorithm, called RSA, ... the problem of cracking ... messages into that of ... certain large numbers, called ... keys. (RSA is named after its ..., Ronald L. Rivest, Adi Shamir and Leonard M. Adleman.)

To demonstrate the strength of RSA, Rivest, Shamir and Adleman ... readers of Martin Gardner's column in the August 1977 issue of Scientific American ... ... a 129-digit number, dubbed RSA-129, and find a hidden message. It was not until 1994 that Arjen K. Lenstra, Paul Leyland, Derek Atkins and Michael Graff, working with hundreds of colleagues on the Internet, ... Current recommendations suggest that RSA encryption keys have at least 230 ... to be secure.

Key words: challenged, encrypted, prevailing, succeeded, factoring, have harnessed, public, divisible, to decompose, breaking, challenge, problematic, to encrypt, transforms, inventors, to factor, digits

X Writing

Outline the main ideas and write an abstract (a brief and concise summary) of the text.

XI Render the following texts.

A. Те, кто занимаются разложением чисел на множители, обычно обращаются к трем мощным алгоритмам. Первый из них, метод квадратичного решета, впервые примененный в 1980х годах Карлом Померансом из университета штата Джорджии, остается эффективным, универсальным методом для разложения на множители чисел больших, чем гугол. (Фактически этот метод разложил РСА-129.) Чтобы разложить некое число на множители, метод квадратичного решета делает попытку разложить на множители большое количество меньших, связанных с исходным числом чисел, получаемых в результате сложного процесса просеивания. Эти разложения меньших чисел на множители используются, чтобы в результате получить множитель искомого числа.

Более новый алгоритм, решето числового поля, смог разложить число в 155 знаков, F_9. Названное в честь великого французского теоретика Пьера де Ферма, n-ое число Ферма есть $F_n = 2^{2^n} + 1$. В 1990 году разложение F_9 было получено А. Ленстра, Х. Ленстра из университета штата Калифорнии в Беркли, М. Манассе из Корпорации цифрового оборудования и британским математиком Дж. Поллардом, при этом были снова использованы сетевые ресурсы. Это впечатляющее разложение на множители было успешно благодаря особой форме F_9. Но с тех пор Дж. Бухлер, Х. Ленстра и К. Померанс разработали вариацию решета числового поля для разложения на множители произвольных чисел. На данный момент этот метод может без труда разложить на множители произвольные числа до 130 знаков. В ретроспективе РСА-129 могли бы быть разложены таким образом на множители за меньшее время, чем были разложены методом квадратичного решета.

Третий общепринятый алгоритм разложения на множители, метод эллиптических кривых, разработанный Х. Ленстра, может разложить на множители намного большие числа при условии, что, по крайней мере, один из простых множителей числа достаточно мал. Например, Р. Брент из Австралийского национального университета недавно разложил на множители F_{10}, используя метод эллиптических кривых, перед этим получив один его простой множитель, длиной «всего лишь»в 40 знаков. Используя метод эллиптических кривых, трудно найти множители, имеющие большее количество знаков, чем 40. Для произвольных чисел в диапозоне от 10^{150} до $10^{1.000.000}$ метод эллиптических кривых является методом выбора, хотя нельзя ожидать, что данный метод сможет найти все множители таких огромных чисел.

Б. Большие числа явно притягательны. В каком-то смысле они лежат на границе человеческого воображения, поэтому они давно считаются более сложными для манипуляций. В последние десятилетия, однако, технические возможности резко возросли. Современные машины теперь обладают достаточной памятью и скоростью, чтобы работать с весьма внушительными числами. Например, можно перемножить числа, состоящие из миллионов цифр всего лишь за долю секунды. В результате этого мы теперь можем выяснить природу тех чисел, о которых математики раньше могли только мечтать.

Интерес к большим числам восходит к древним временам. Мы знаем, например, что древние индусы, разработавшие десятичную систему, размышляли о них. В нынешней общепринятой десятичной системе позиция цифры в числе обозначает ее порядок (scale). Используя этот экономный способ записи, индусы могли называть многие большие числа; одно из них, например, состоящее из 153 знаков — или как бы мы сказали теперь, число порядка 10^{153} — упоминается в мифе о Будде.

У римлян изначально не было терминов или символов для цифр, превышающих 100.000. Аналогично, греки обычно считали только до «мириады», 10.000. В самом деле, популярная в Древней Греции идея состояла в том, что нет большего числа, чем количество песчинок, необходимых, чтобы заполнить вселенную.

Ученые XVIII и XIX веков все еще рассматривали большие числа, имеющие практическую научную ценность. Рассмотрим число Авогадро, названное в честь итальянского химика XIX века Амедео Авогадро. Оно примерно равно $6,02 \times 10^{23}$ и представляет собой число атомов, содержащихся в 12 граммах чистого углерода. Один из способов представить себе число Авогадро, также именуемого молем, состоит в следующем: если бы всего лишь один грамм чистого углерода растянуть до размера планеты Земля, отдельный атом углерода выглядел бы как шар для игры в боулинг.

Другой интересный способ представить моль — это рассмотреть суммарное число компьютерных операций, то есть, арифметических операций, происходящих в компьютерной сети — когда-либо совершенных всеми компьютерами за всю историю. Даже слабый компьютер может выполнять миллионы операций в секунду, а мощный компьютер с несколькими подключенными к нему меньшими компьютерами может выполнять намного больше. Итак, общее число операций на настоящий момент, хотя его и невозможно точно оценить, должно примерно равняться числу Авогадро.

Сегодня ученые оперируют числами, намного превышающими моль. Число протонов в познанной вселенной, например, предполагается равным около 10^{80}. Но человеческое воображение может пойти дальше. Стало легендой, как девятилетний племянник математика Эдварда Каснера в 1938 году действительно ввел число гугол (googol), где за единицей следовало 100 нулей или 10^{100}. Что касается некоторых классов вычислительных проблем, гугол приблизительно очерчивает величины чисел, которые бросают серьезный вызов современным компьютерам. Но и в этом случае компьютеры могут ответить на некоторые вопросы о таких величинах, как мощный гуголплекс, то есть единица, за которой следует гугол нулей или $10^{10^{100}}$. Даже если бы вы использовали протон для каждого нуля, вы не могли бы вписать гуголплекс в познанную вселенную.

Scientific American, February 1997, pp. 74–76

XII Text II

Read the article, outline the main ideas and summarize the text.

CRACKING A CENTURY-OLD ENIGMA[21]

Mathematicians unearth fractal counting patterns to explain a cryptic claim

[21] Scientific American, April 2011, p. 15

by Davide Castelvecchi

For someone who died at the age of 32, the largely self-taught Indian mathematician Srinivasa Ramanujan left behind an impressive legacy. Number theorists have now finally managed to make sense of one of his more enigmatic statements, written just one year before his death in 1920.

The statement concerned the deceptively simple concept of partitions. Partitions are subdivisions of a whole number into smaller ones. For example, for the number 5 there are seven options:

$$5$$

$$1+1+1+1+1$$

$$1+1+1+2$$

$$1+1+3; 1+2+2$$

$$1+4; 2+3$$

Mathematicians express this by saying $p(5) = 7$. For the number 6 there are 11 possibilities: $p(6) = 11$. As the number n increases, the partition number $p(n)$ soon starts to grow very fast: for example, $p(100) = 190,569,292$, and $p(1,000)$ is a 32-figure number.

For centuries mathematicians have struggled to make sense of partitions, in part by hunting for patterns that link them together. Ramanujan noticed that if you started with the number 9 and kept adding 5's to that number, the partitions would all be divisible by 5. For example: $p(9) = 30$, $p(9+5) = 135$, $p(9+10) = 490$, and $p(9+15) = 1,575$. He posited that this pattern should go on forever and that similar patterns exist when 5 is replaced by 7 or 11, the next two prime numbers (primes are numbers that are divisible only by themselves or by 1), and also by powers of 5, 7 or 11. Thus, for instance, there should be an infinity of n's at intervals of 53 such that all the corresponding $p(n)$'s should be divisible by 125. Then, in a nearly oracular tone, Ramanujan wrote that there should be no corresponding "simple properties" involving larger primes — in other words, there is no sequence of $p(n)$'s that are all divisible by 13, 17 or

19 and so on. In the years since, researchers have looked fruitlessly for patterns linking these higher primes.

In January, Ken Ono of Emory University and his collaborators finally found a solution: they described for the first time formulas linking n's that come at intervals of the powers of 13 (13, 132, 133 ...) and of the higher primes. The formulas are not "simple", in the sense that they do not say that the $p(n)$'s are divisible by powers of 13; instead they reveal relations among the remainders of such divisions. For each prime, as the exponent grows, the formulas recur in ways that are reminiscent of fractals — structures in which patterns or shapes repeat identically at multiple different scales.

In a separate result also announced in January, Ono and another collaborator described the first formula that directly calculates $p(n)$ for any n, a feat that had eluded number theorists for centuries.

Will the new discoveries have any practical use? Hard to predict, says George E. Andrews of Pennsylvania State University. "Deep understanding of underlying pure mathematics may take a while to filter into applications."

XIII Vocabulary Notes

(Macmillan English Dictionary for Advanced Learners)

a claim — (noun) a statement without proof
cryptic — (adj.) expressing smth in a mysterious or indirect way so that it is difficult to understand
deceptive — (adj.) smth that is deceptive seems very different from the way it really is; *deception* — (noun)
a feat — (noun) smth impressive that smb does
legacy — (noun) smth that smb has achieved that continues to exist after they stop working or die
to posit — (verb) to say that smth is true or that smth should be accepted as true
reminiscent (of fractals) — (adj.) similar to smth else
to unearth — (verb) to discover smth that was not known before or that people had kept secret especially by searching very thoroughly

XIV Render the following text

Материал из Википедии — свободной энциклопедии

Шриниваса Рамануджан Айенгор (1887 - 1920) — индийский математик. Не имея специального математического образования, получил замечательные результаты в области теории чисел. Наиболее значительна его работа совместно с Г. Харди по асимптотике числа разбиений $p(n)$.

Сфера его математических интересов была очень широка. Это магические квадраты, квадратура круга, бесконечные ряды, гладкие числа, разбиение чисел, гипергеометрические функции, специальные суммы и функции, ныне носящие его имя, определенные интегралы, эллиптические и модулярные функции.

Он нашел несколько частных решений уравнения Эйлера, сформулировал около 120 теорем (в основном в виде исключительно сложных тождеств). Современные математики считают, что Рамануджан был и остается крупнейшим знатоком цепных дробей в мире. Одним из самых замечательных результатов Рамануджана в этой области является формула, в соответствии с которой сумма простого числового ряда с цепной дробью в точности равна выражению, в котором присутствует произведение e на π.

Г. Харди остроумно прокомментировал результаты, сообщенные ему Рамануджаном: «Они должны быть истинными, поскольку, если бы они не были истинными, то ни у кого не хватило бы воображения, чтобы изобрести их». Его формулы иногда всплывают в современнейших разделах науки, о которых в его время никто даже не догадывался.

Сам Рамануджан говорил, что формулы ему во сне внушает богиня Намагири.

Чтобы сохранить наследие этого удивительного, ни на кого не похожего математика, была издана книга с фотокопиями его черновиков.

«Наука ничего не выиграла от того, что Кумбаконамский колледж отверг единственного большого ученого, которого он имел, и потеря была неизмеримой. Судьба Рамануджана — худший известный мне пример вреда, который может быть причинен малоэффективной и негибкой системой образования. Требовалось так мало, всего 60 фунтов стерлингов в год на протяжении 5 лет и эпизодического общения с людьми, имеющими настоящие знания и немного воображения, а мир получил бы еще одного из величайших своих математиков...»

Г. Харди

Unit XII

Text

DOES INFINITY COME IN DIFFERENT SIZES?[22]

by John Matson

THE AUTHOR

John Matson is a copy editor at Scientific American.

Word Combinations

to be rooted in smth	unsurpassable absolute
to be put into a one-to-one correspondence	a sound assumption
for demonstration's sake	crafty math
a wily side	the logic of contradiction
to use an elegant argument to show smth	a variety of infinities

I Read the questions and find answers in the text that follows.

1. What did G. Cantor demonstrate in the late 19th century?

[22]Scientific American, January 2008

2. Cantor's argument used the logic of contradiction. What was Cantor's presumption?
3. What mathematical method did Cantor use to show that any one-to-one correspondence between the reals and the naturals fails, which means that the infinity of real numbers is somehow greater than the infinity of natural numbers?

In the 1995 film *Toy Story*, the gung-ho space action figure Buzz Lightyear tirelessly incants his catchphrase: "To infinity...and beyond!" The joke, of course, is rooted in the perfectly reasonable assumption that infinity is the unsurpassable absolute — that there is no beyond. That assumption, however, is not entirely sound. As German mathematician Georg Cantor demonstrated in the late 19th century, a variety of infinities exist — and they can be classified by their relative sizes.

NATURAL LOGIC

Take, for instance, the so-called natural numbers: 1, 2, 3, and so on. These numbers are unbounded, and thus the collection, or set, of all the natural numbers is infinite in size. But just how infinite is it? Cantor used an elegant argument to show that the naturals, though infinitely numerous, are actually less numerous than another common family of numbers: the real numbers. This set comprises all numbers that can be represented as a decimal, even if that decimal representation is infinite in length. Hence, pi (3.14159...) is a real number, as is 27 (which is both natural and real).

Cantor's argument used the logic of contradiction: he first assumed that these sets are the same size; next he followed a series of logical steps to find a flaw that would undermine that assumption. He reasoned that if the naturals and the reals have equally many members, then the two sets can be put into a one-to-one correspondence. That is, they can be paired so that every element in each set has one — and only one — "partner" in the other set.

Think of it this way: even in the absence of numerical counting, one-to-one correspondences can be used to measure relative amounts. Imagine two crates of unknown sizes, one of apples and one of oranges. *Withdrawing one apple and one orange at a time thus partners the* *two sets into apple-orange pairs. If the contents of the two crates are emptied simultaneously, the two boxes contain an equal number of fruits; if one crate is exhausted before the other, the one with remaining food is more plentiful.*

CRAFTY MATH

Cantor thus began by presuming that the naturals and the reals are in such a correspondence. Accordingly, every natural number n has a real partner r_n. The reals can then be listed in order of their corresponding naturals: r_1, r_2, r_3, and so on.

Then Cantor's wily side comes out. He created a real number, called p, by the following rule: make the digit n places after the decimal point in p something other than the digit in that same decimal place in r_n. A simple method would be: choose 3 when the digit in question is 4; otherwise, choose 4.

For demonstration's sake, say the real-number partner for the natural number 1 is 27 (or 27.00000...), the pair for 2 is pi (3.14159...) and that of 3 is President George W. Bush's share of the popular vote in 2000 (0.47868...). Now create p following Cantor's construction: the digit in the first decimal place of p should not be equal to that in the first decimal place of r_1 (27), which is 0. Therefore, choose 4, and p begins 0.4.... (The number before the decimal can be anything; 0 is used here for simplicity.) Then choose the digit in the second decimal place of p so that it does not equal that in the second decimal place of r_2 (pi), which is 4. Select 3, and now p = 0.43.... Finally, choose the digit in the third decimal place of p so that it does not equal the one in the corresponding decimal place of r_3 (President Bush's percentage), which is 8. Write 4 again, making $p = 0.434\ldots.$ Thus, you have:

$$r1 = 27.00000\ldots \text{——} p = 0.4\ldots$$

$$r2 = 3.14159\ldots \text{——} p = 0.43\ldots$$

$$r3 = 0.47868\ldots \text{——} p = 0.434\ldots$$

This mathematical method (called diagonalization), continued infinitely down the list, generates a real number (p) that, by the rules of its construction, differs from every real number on the list in at least one decimal place. Ergo, it cannot be on the list.

In other words, for any pairing of naturals and reals, there exists a real number p without a natural-number partner — an apple without an orange. Therefore, any one-to-one correspondence between the reals and the naturals fails, which means that the infinity of real numbers is somehow greater than the infinity of natural numbers.

II Translate the italicized sentences into Russian. Explain the use of the grammar constructions.

III Vocabulary Notes

(Macmillan English Dictionary for Advanced Learners)

to exhaust — (verb) to use all you have of smth; *exhausted* — (adj.) empty or finished because a supply of smth has all been used; *exhaustion* — (noun) the use of all you have of smth
share — (noun) a part of a total number or amount of smth that is divided between several people or things; *to share* — (verb) to use or have smth at the same time as smb else
to undermine — (verb) 1. to make smth or smb become gradually less effective, confident or successful; 2. to dig under smth especially so that it becomes weaker

IV Comprehension Exercises

Answer the following questions.

1. What perfectly reasonable assumption underlay the joke in the 1995 film *Toy Story*?
2. What elegant argument did G. Cantor use to show that the naturals, though infinitely numerous, are actually less numerous than another common family of numbers — real numbers?
3. What logic did Cantor's argument use?
4. What did Cantor assume first?

5. How did he reason then?
6. How can a one-to-one correspondence be used to measure relative amounts?
7. What was Cantor's presumption concerning the naturals and the reals?
8. What clever trick did Cantor use in his reasoning trying to substantiate his conception?

V Grammar

1. Give the three forms of the verbs: to put, to have, to make, to choose, to begin, to withdraw, to mean, to set.
2. *Gerund, Participle* or *Verbal Noun*

   Open the brackets and put the verbs in the required form. Comment on the use of the corresponding grammar constructions.

   a. The horizon indicator or gyro vertical indicates the horizon without the pilot's (to have to) look at the ground.
   b. In this article the current (to understand) of the phenomenon will be discussed.
   c. In (to use) the first principle, it should be noticed that the (to impress) forces are (to apply) at the center of gravity.
   d. Few would admit that the technical definition of an infinite set expresses their intuitive (to understand) of the concept.
   e. A circle is a closed curve (to lie) in a plane and so (to construct) that all its points are equally distant from a (to fix) point in the plane.
   f. He made a calculation (to base) on the weakenings (to be) proportional to the square of the distance.
   g. In fact, Cantor borrowed the paradox (to cite) by Galileo and turned it into a means of (to compare) the size of infinite sets. He defined two sets as equivalent if a one-to-one correspondence can (to be established) between

the members of each set.

h. Why does a stone hit the ground sooner than a feather in spite of their (to drop) at the same time and from the same height?

i. These forces do not prevent molecular motion within the liquid itself, but prevent (to escape) of molecules from the surface of the liquid.

j. (To warm) to 0^o ice begins to melt.

3. Fill in the necessary prepositions and adverbs.

   a. This mathematical method (called diagonalization), continued infinitely ... the list, generates a real number (p) that, ... the rules ... its construction, differs ... every real number ... the list ... ... least one decimal place.

   b. Ergo, it cannot be ... the list.

   c. ... other words, ... any pairing ... naturals and reals, there exists a real number p ... a natural-number partner — an apple ... an orange.

   d. Therefore, any one-to-one correspondence ... the reals and the naturals fails, which means that the infinity ... real numbers is somehow greater than the infinity ... natural numbers.

VI Phrasal Verbs

To come out — to become easy to notice

VII. Exercises

a. Give synonyms to the following words.

tireless, reasonable, an argument, to withdraw, abundant, sound, to comprise, identical, to exhaust, numerous, ergo, to demonstrate, a series of, to undermine.

b.Give antonyms to the following words.

Reasonable, escapable, plentiful, equal, to converge, real

c. Match a phrasal verb in the left column with its equivalent in the right one.

1. to refer to smb/smth	a. to start to be seen
2. to figure out	b. to remove a tight or wet piece of clothing
3. to set up	c. to do a particular piece of work
4. to come out	d. to be able to understand and solve the problem
5. to peel off	e. to mention smb or smth when you are speaking or writing
6. to carry out	f. to start, plan, organize smth such as a business, institution

VIII Key Terms

The logic of contradiction — ad absurdum
Diagonalization — Cantor's theorem — that no set has as many members as it has subsets — is proved by diagonalization which creates an extra subset. Each subset of the set of positive integers is represented as a series of yeses or noes. A "yes" indicates that the integer belongs to the subset, a "no" that it does not. Replacing each "yes" with a "no", and vice versa, down the diagonal creates another subset.

IX Conversational Practice

Agree or disagree with the statements. Justify your choice. Add some sentences to develop your idea. Use the introductory phrases.

True enough.	I think, I disagree (I'm afraid).
I can't help thinking the same.	Yes, up to a point, but...
That's just what I was thinking...	I don't entirely agree with you.
I couldn't agree more.	That's one way of looking at it, but...
That's the way it should be.	I don't think so.
It sounds just right.	It's wrong, I'm afraid.

1. The joke of the catchphrase “To infinity and beyond” is rooted in the perfectly reasonable assumption that infinity is unsurpassable absolute — that there is no beyond.
2. G. Cantor demonstrated in the late 19th century that a variety of infinities exist.
3. The natural numbers are unbounded and the collection or set of all the natural numbers is infinite in size.
4. Cantor used an elegant argument to show that the real numbers are actually less numerous than the natural numbers.
5. Cantor’s argument used the logic of contradiction.
6. A one-to-one correspondence cannot be used to measure relative amounts.
7. Cantor began by presuming that the naturals and the reals are in such a correspondence.
8. Then Cantor’s wily side comes out.
9. The mathematical method (called diagonalization), continued infinitely down the list, generates a real number (p) that, by the rule of its construction, differs from every real number on the list in at least one decimal place.
10. No one-to-one correspondence between the reals and the naturals fails.

X Vocabulary Practice

Try to recollect how these phrases are used in the text.

“To infinity and beyond. . . ”, a variety of infinities exist. . . , the set of all the natural numbers is . . . , less numerous than another common family of numbers. . . , pi (3.14159. . .) is a real number. . . , the logic of contradiction. . . , he followed a series of logical steps. . . , . . . can be put into a one-to-one correspondence. . . , to measure relative amounts. . . , . . . are emptied simultaneously. . . , Cantor began by presuming . . . , Cantor’s wily side ..., for demonstration’s sake. . . , this mathematical method (called diagonalization) . . . , a real number p without a natural-number partner. . . , the infinity of real numbers . . . .

XI Writing

Outline the main ideas and write an abstract (a brief and concise summary) of the text. Express your point of view.

Unit XIII

Text

A BRIEF HISTORY OF INFINITY[23]

The infinite has always been a slippery concept. Even the commonly accepted mathematical view, developed by Georg Cantor, may not have truly placed infinity on a rigorous foundation

by A. W. Moore

THE AUTHOR

A.W. Moore is a tutorial fellow in philosophy at St. Hugh's College of the University of Oxford. He studied for his Ph.D. in the philosophy of language at Balliol College at Oxford. His main academic interests are in logic, metaphysics and the philosophies of I. Kant and L. Wittgenstein, all of which have informed his work on the infinite. He is at work on a book about metaphysics of objectivity and subjectivity.

[23] Scientific American, April 1995, pp. 115–116

Word Combinations

to settle an issue	to remain beyond smb's grasp
there is smth dubious about it	to come into being
in any view of smth	a temporal metaphor
but given Cantor's picture	to have best claim to smth
ad hoc reasoning	to lend considerable substance to smth
to be at variance with smth	to articulate a result
to be forced on smb	the task at hand
to advocate using anything other than	to go with smth
to be averse to doing smth	to tame the actual infinite
to absorb the shock	to escape the trap

I Read the questions and find answers in the text that follows.

1. What problem did Cantor's continuum hypothesis tackle?
2. What was Cantor's assertion concerning the set of all sets?
3. What did B. Russel's paradox reveal?
4. What do some scholars object to?

ARE THERE ANY SETS OF INTERMEDIATE SIZE? CANTOR'S CONTINUUM HYPOTHESIS

Cantor's own hypothesis, his famous "continuum hypothesis," was that there are not. *But he never successfully proved this idea, nor did he disprove it. Subsequent work has shown that the situation is far graver than he had imagined.* Using all the accepted methods of modern mathematics, the issue cannot be settled. This problem raises philosophical questions about the determinacy of Cantor's conception. *Asking whether the continuum hypothesis is true may be like asking whether Hamlet was left-handed.* It may be that not enough is known to form an answer. If so, then we should rethink how well Cantor's work tames the actual infinite.

Of even more significance are questions surrounding the set of all sets. Given Cantor's theorem, this collection must be smaller than the set of sets of sets. But wait! Sets of sets are themselves sets, so it follows that the set of sets must be smaller than one of its own proper subsets. That, however, is impossible. The whole can be the same size as the part, but it cannot be smaller. How did Cantor escape this trap? With wonderful pertinacity, he denied that there is any such thing as the set of sets. His reason lay in the following picture of what sets are like. There are things that are not sets, then there are sets of all these things, then there are sets of all those things, and so on, without end. Each set belongs to some further set, but there never comes a set to which every set belongs.

Cantor's reasoning might seem somewhat ad hoc. But an argument of the sort is required, as revealed by Bertrand Russell's memorable paradox, discovered in 1901. This paradox concerns the set of all sets that do not belong to themselves. Call this set R. The set of mice, for example, is a member of R; it does not belong to itself because it is a set, not a mouse. *Russell's paradox turns on whether R can belong to itself. If it does, by definition it does not belong to R. If it does not, it satisfies the condition for membership to R and so does belong to it.* In any view of sets, there is something dubious about R. *In Cantor's view, according to which no set belongs to itself, R, if it existed, would be the set of all sets. This argument makes Cantor's picture, and the rejection of R that goes with it, appear more reasonable.*

But is the picture not strikingly Aristotelian? Notice the temporal metaphor. Sets are depicted as coming into being "after" their members — in such a way that there are always more to come. Their collective infinitude, as opposed to the infinitude of any one of them, is potential, not actual. *Moreover, is it not this collective infinitude that has best claim to the title? People do ordinarily define the infinite as that which is endless, unlimited, unsurveyable and immeasurable. Few would admit that the technical definition of an infinite set expresses their intuitive understanding of the concept.* But given Cantor's picture, endlessness, unlimitedness, unsurveyability and immeasurability more properly apply to the entire hierarchy than to any of the particular sets within it.

In some ways, then, Cantor showed that the set of positive integers, for example, is "really" finite and that what is "really" infinite is something way beyond that. *(He himself was not averse to talking in these terms.) Ironically, his work seems to have lent considerable* *substance to the Aristotelian orthodoxy that "real" infinitude can never be actual.*

Some scholars have objected to my suggestion that, in Cantor's conception, the set of positive integers is "really" finite. *They complain that this assertion is at variance not only with standard mathematical terminology but also, contrary to what I seem to be suggesting, with what most people would say.*

Well, certainly most people would say the set of positive integers is "really" infinite. But, then again, most people are unaware of Cantor's results. They would also deny that one infinite set can be bigger than another. My point is not about what most people would say but rather about how they understand their terms — and how that understanding is best able, for any given purpose, to absorb the shock of Cantor's results. Nothing here is forced on us. We could say some infinite sets are bigger than others. We could say the set of positive integers is only finite. We could hold back from saying either and deny that the set of positive integers exists.

If the task at hand is to articulate certain standard mathematical results, I would not advocate using anything other than standard mathematical terminology. But I would urge mathematicians and other scientists to use more caution than usual when assessing how Cantor's results bear on traditional conceptions of infinity. The truly infinite, it seems, remains well beyond our grasp.

II Translate the italicized sentences into Russian. Explain the use of the grammar constructions.

III Vocabulary Notes

(Macmillan English Dictionary for Advanced Learners)

to absorb — (verb) to reduce the harmful effects; *absorbtion* — (noun)
averse — (adj.) detesting; to be *averse* to doing smth — to hate doing smth; *aversion* — (noun)
to disprove — (verb) to prove that smth is not correct or true. Until now no one had been able to disprove the theory
grave — (adj.) so serious that you feel worried; *gravity* — (noun)

hierarchy — (noun) a system for organizing people according to their status in a society, organization or other group
pertinacious — (adj.) determined to continue doing smth; *pertinacity* — (noun)
proper — (adj. only before noun) suitable for the purpose or situation, understood in its most exact meaning; *properly* — (adv.)
a scholar — (noun) 1. a person who has a deep knowledge of an academic subject, e.g.: a Greek scholar
to tame — (verb) to train an animal to become calm when people are near it and make it used to being with them
to urge — (verb) to advise smb very strongly about what action or attitude they should take; *urgent* — (adj.); *urgency* — (noun)

IV Comprehension Exercises

Answer the following questions.

1. What does Cantor's continuum hypothesis assert concerning the idea of sets of intermediate size?
2. What are the questions surrounding the set of all sets?
3. What are sets like according to Cantor's view?
4. What was B. Russel's memorable paradox concerned with? What argument made Cantor's picture appear more reasonable?
5. What was Aristotle's conception of the infinite?
6. Given Cantor's picture does the characteristic of the infinite as endless, unlimited, unsurveyable and immeasurable more properly refer to the entire hierarchy or to any of the particular sets within it?
7. What is "really" finite in Cantor's conception and what is that "really" infinite?
8. What do some scholars object to?
9. What does the author of the article urge mathematicians and other scientists to do?

V Grammar

1. Give the three forms of the verbs: to lie, to raise, to rise, to rethink, to show, to hold, to come, to lend, to say, to understand, to bear.
2. *Either, neither, nor*

   As a pronoun *either* is used without a noun. When used as a pronoun *either* can be followed by "of + a noun phrase".
   Neither and *nor* are both used at the beginning of clauses and short answers to mean "also not". They are followed by inverted word-order (the same as in questions). There is no real difference of meaning between *neither* and *nor* in this construction. *Nor* is perhaps less common in a formal style. Instead of *neither... nor*, we can use "not either" (with normal word-order).
   (Michael Swan . Practical English Usage.)

   Translate the following examples.

   A. We could say some infinite sets are bigger than others. We could say the set of positive integers is only finite. We could hold back from saying either. *B.* Both string theory and loop quantum gravity harbour unresolved problems. Nor, despite the hopeful talk to the contrary, is there much prospect of the experiment being devised.
3. Fill in the gaps with *either, neither, either... or, neither... nor* and translate the sentences.
   a. It was argued, not entirely unreasonably that the surface of the earth must ... be indefinite ... have an edge.
   b. ... Henri Poincaré ... any other eminent mathematician came forward in support of Cantor's theory of transfinite numbers.
   c. A line is said to have length, but ... breadth ... thickness.
   d. Every mathematical problem must be settled ... in the form of a direct answer to the question posed ... by the proof of the impossibility of its solution.
   e. The ancient Greek mathematicians did not solve

the three famous construction problems by compass and straightedge alone and further generations of mathematicians could not solve them … .

f. Cantor did not prove the continuum hypothesis … did his successors.

g. In particular, if the axioms do not contradict one another, then that fact itself, suitably encoded as a numerical statement, will be "formally undecidable" — … provable … refutable — on the basis of those axioms.

h. So to draw any conclusions about the inability of science to deal with these questions, we must … justify the mathematical model as a faithful representation of the physical situation … abandon the mathematics altogether.

4. Fill in the necessary prepositions and adverbs.

a. … some ways, then, Cantor showed that the set … positive integers, … example, is "really" finite and that what is "really" infinite is something way … that.

b. He himself was not averse … talking in these terms.

c. Ironically, his work seems to have lent considerable substance … the Aristotelian orthodoxy that "real" infinitude can never be actual.

d. Some scholars have objected … my suggestion that, … Cantor's conception, the set … positive integers is "really" finite.

e. They complain that this assertion is … variance not only … standard mathematical terminology but also, contrary … what I seem to be suggesting, … what most people would say.

f. Well, certainly most people would say the set … positive integers is "really" infinite.

g. But, then again, most people are unaware … Cantor's results.

h. They would also deny that one infinite set can be bigger than another. My point is not … what most people would say but rather ... how they understand their terms — and how that understanding is best able, ... any given purpose, to absorb the shock ... Cantor's results.

i. Nothing here is forced ... us.

j. We could say some infinite sets are bigger than others. We could say the set ... positive integers is only finite.

k. We could hold ... ... saying either and deny that the set ... positive integers exists.

VI Phrasal Verbs and Idioms

to bear on/upon smth — to be connected with smth or to influence it

to turn on smth — if an event or a discussion turns on smth, whether it is accurate or has a good result depends completely on that thing

to hold back from smth — 1. to stop smb or smth from moving forwards; 2. to decide not to say or to do smth; 3. to not show what you are thinking or feeling

to have best claim — 1. to state that one has a right to smth; 2. to state that one has knowledge, understanding, skill

VII Exercises

a. Give synonyms to the following words.

to be conscious	to tame
to decide	to state
a problem	to discard
a scientist	doubtful
grave	suitable

b. Give antonyms to the following words.

To prove, to dissuade, to be aware of smth, to reject, grave, tamed, measurable, surveyable, limited.

c. Match a phrasal verb in the left column with its equivalent in the right one.

1. to have best claim	a. to be connected with smth or influence it
2. to hold back	b. to state that one has a right to smth
3. to turn on smth	c. to stop smb or smth from moving forwards
4. to bear on smth	d. whether it is accurate depends completely on it

VIII Key Terms

The Aristotelian view — Aristotle denied that infinitely many things can be gathered together all at once. He distinguished between two kinds of infinity. *The actual infinite* is that whose infinitude exists at some point in time. In contrast, *the potential infinite* is that whose infinitude is spread over time. All the objections to the infinite, Aristotle insisted, are objections to *the actual infinite. The potential infinite*, on the other hand, is a fundamental feature of reality. It deserves recognition in any process that can never end, including counting, the division of matter and the passage of time itself. This distinction between the two types of infinity provided a solution to Zeno's paradoxes. Traversing a region of space does not involve moving across *an actual infinity* of subregions which would be impossible. But it does mean crossing *a potential infinity* of subregions, in the sense that there can be no end to the process of dividing the space.

Scholars usually interpreted his reference to time as a metaphor for smth deeper and more abstract. Existing "in time" or existing "all at once" assumed much broader meanings. To take exception to *the actual infinite* was to object to the very idea that some entity could have a property that surpassed all finite measure. It was also to deny that *the infinite* was itself a legitimate object of study.

IX Conversational Practice

Agree or disagree with the statements. Justify your choice. Add some sentences to develop your idea. Use the introductory phrases.

I absolutely agree.	To a certain extent, yes, but...
I'm very much in favour of that.	I see your point, but...
That is just what I had in mind.	It is absolutely wrong.
I will start by saying that ...	The simple reason is that...
In this connection I would like to mention...	It's not the case.

1. Cantor's famous continuum hypothesis states that there are sets of intermediate size.
2. The determinancy of Cantor's conception is inviolable.
3. Cantor denied that there is any such thing as the set of sets.
4. Cantor's reasoning seems to be on an ad hoc basis.
5. B. Russel's memorable paradox concerns the set of all sets that belong to themselves.
6. Cantor's picture as well as the Aristotelian one more properly applies to any of the particular sets within the entire hierarchy.
7. Cantor showed that the set of positive integers is "really" infinite.
8. Most people would deny that one infinite set can be bigger than another.
9. The author asserts that the task at hand is to articulate certain standard mathematical results.

X Vocabulary Practice

Try to recollect how these phrases are used in the text.

He never successfully proved this idea..., the issue cannot be settled..., the problem raises philosophical questions..., of even more importance are questions..., it follows that the set of sets must be smaller than..., his reason lay in the following picture..., there never comes a set..., this paradox concerns..., Russel's paradox turns on..., there is smth dubious about R..., in Cantor's view according to which no set..., sets are depicted as coming into being..., as opposed to the infinitude of any one of them..., and what is really infinite is smth..., his work seems to have lent considerable substance to Aristotelian orthodoxy... .

XI Writing and Speaking

Write a mini-report on Cantor's conceptions concerning infinity on the basis of Units IV and V. Present it to your classmates. Do not read your report. Instead, speak from notes.

XII Render the following text.

Кантор бросил вызов концепции Аристотеля. В своей блестящей работе он рассмотрел его парадоксы и сформулировал связную, систематизированную и точную теорию актуальной бесконечности, готовую противостоять любому скептику. Кантор согласился с принципом «разбиения на пары» и с его обратным утверждением, а именно, что не существует двух равномощных множеств, если только их составляющие нельзя разбить на пары с взаимнооднозначным соответствием. Таким образом, он согласился с тем, что четных положительных чисел столько же, сколько натуральных чисел (подобное верно и в случае остальных парадоксов).

Давайте ради выяснения истины, следуя современной математической традиции, в этом случае поступим так же (to follow suit). Если этот принцип означает, что целое не больше, чем его части, пусть так оно и будет. Мы в самом деле можем воспользоваться этой идеей, чтобы определить актуальную бесконечность, по крайней мере применительно к множествам: множество бесконечно, если оно не больше, чем одна из его частей. Точнее, множество бесконечно, если у него столько же членов, сколько и у одного из его собственных подмножеств.

Если пользоваться такими аргументами, открытым остается вопрос: являются ли все бесконечные множества равномощными. Большое значение работы Кантора состояло в демонстрации того, что это не так. Существуют разные бесконечные множества. Это утверждение следует из теоремы Кантора: не существует такого множества, в частности бесконечного, которое имело бы столько же членов, сколько подмножеств. Иными словами, множество не равномощно множеству своих подмножеств. Но почему это так? Поскольку, если бы множество было таким большим, можно было бы взаимнооднозначно разбить на пары все его члены со всеми его подмножествами. Одни члены были бы таким образом включены в пары с подмножествами, в которые они входят, другие — с подмножествами, в которые они не входят. А что тогда делать со множеством тех членов, которые не включены в множество, с которым они поставлены в пару? Ни один член не мог бы быть разбитым на пары с этим подмножеством, не вызвав противоречия.

Scientific American, April 1995, p. 115

Unit XIV

Text I

GOEDEL AND THE LIMITS OF LOGIC[24]

Mathematical genius Kurt Goedel was devoted to rationality in his work but struggled with it in his personal life

by John W. Dawson

THE AUTHOR

John W. Dawson catalogued Kurt Goedel's papers at the Institute for Advanced Study in Princeton, N.J. He has served as co-editor of Goedel's Collected Works since the inception of that project. He received his doctorate in mathematical logic from the University of Michigan in 1972 and is a professor of mathematics at Pennsylvania State University at York. He has a particular interest in axiomatic set theory and the history of logic.

[24] Scientific American, June 1999, pp. 78–79

Word Combinations

to obey the axioms of number theory	a system of entities
to fail to behave like the natural numbers	in some other respects
to become a priori problematic	to justify the role of intuition
to be suitably encoded	to underlie all of modern computer science
The discipline of recursion theory	to derive the consistency of smth

I Read the questions and find answers in the text that follows

1. What does Goedel's completeness theorem state?
2. What did Goedel's 1931 paper show?

Goedel's completeness theorem states that one can prove all those statements that follow from the axioms. There is a caveat, however: if some statement is true of the natural numbers but is not true of another system of entities that also satisfies the axioms, then it cannot be proved. That did not seem to be a serious problem, because mathematicians hoped that entities that masqueraded as numbers but were essentially different from them did not exist. So Goedel's next theorem came as a shock.

In his 1931 paper Goedel showed that some statement that is true of the natural numbers must fail to be provable. (That is, objects that obey the axioms of number theory but fail to behave like the natural numbers in some other respects do exist.) *One could escape this "incompleteness theorem" if all true statements were taken to be axioms. In that case, however, deciding whether some statements are true or not becomes a priori problematic.* Goedel showed that whenever the axioms can be characterized by a set of mechanical rules, it does not matter which statements are taken to be axioms: if they are true of the natural numbers, some other true statements about those numbers will remain unprovable.

In particular, if the axioms do not contradict one another, then that fact itself, suitably encoded as a numerical statement, will be "formally undecidable" — neither provable nor refutable — on the basis of those axioms. Any proof of consistency must therefore appeal to stronger principles than the axioms themselves.

The latter result greatly dismayed David Hilbert, who had envisioned a program for securing the foundations of mathematics through a "bootstrapping" process, by which the consistency of complex mathematical theories could be derived from that of simpler, more evident theories. Goedel, on the other hand, saw his incompleteness theorems not as demonstrating the inadequacy of the axiomatic method but as showing that the derivation of theorems cannot be completely mechanized. He believed they justified the role of intuition in mathematical research.

The concepts and methods Goedel introduced in his incompleteness paper are central to the discipline of recursion theory, which underlies all of modern computer science. Extensions of his ideas have allowed the derivation of several other results about the limits of computational procedures. *One is the unsolvability of the "halting problem" — that of deciding, for an arbitrary computer with an arbitrary input, whether the computer will eventually halt and produce an output rather than becoming stuck in an infinite loop. Another is the demonstration that no program that does not alter a computer's operating system can detect all programs that do (viruses).*

II Translate the italicized sentences into Russian. Explain the use of the grammar constructions.

III Vocabulary Notes

(Macmillan English Dictionary for Advanced Learners)

a caveat — (noun) a warning of the limits of a particular agreement or statement
a priori — (adj., adv.) using knowledge or experience you already have in order to make a judgement or decision
to dismay — (verb) to make smb worried, disappointed or sad; *dismayed* — (adj.) very upset or annoyed about smth surprising or

shocking that has happened; *dismay* — (noun) the feeling of being very disappointed, worried, etc. about smth surprising or shocking that has happened
to justify — (verb) to show that there is a good reason for smth, especially smth that other people think is wrong; *justification* — (noun); *justifiable* — (adj.)
to masquerade — (verb) to pretend to be smb or smth you are not; *a masquerade* — (noun)

IV Comprehension Exercises

Answer the following questions.

1. What kind of a caveat is there in Goedel's completeness theory?
2. Why did mathematicians hope that it did not seem to be a serious problem?
3. Why did Goedel's 1931 paper come as a shock?
4. How could one escape this "incompleteness theorem"?
5. What principles must any proof of consistency appeal to?
6. Why did the latter result greatly dismay D. Hilbert?
7. How did Goedel assess his incompleteness theorems?
8. What discipline are the concepts and methods Goedel introduced in his incompleteness paper central to?
9. What did the extensions of his ideas lead to?

V Grammar

1. Give the three forms of the verbs: to lead, to deal, to see, to stick, to do.
2. Fill in the necessary prepositions and adverbs.
   a. The latter result greatly dismayed David Hilbert, who had envisioned a program … securing the foundations … mathematics … a "bootstrapping" process, … which the consistency … complex mathematical theories could be derived … that … simpler, more evident theories.

b. Goedel, ... the other hand, saw his incompleteness theorems not as demonstrating the inadequacy ... the axiomatic method but as showing that the derivation ... theorems cannot be completely mechanized.
c. He believed they justified the role ... intuition ... mathematical research.
d. The concepts and methods Goedel introduced ... his incompleteness paper are central ... the discipline ... recursion theory, which underlies all ... modern computer science.
e. Extensions ... his ideas have allowed the derivation ... several other results ... the limits ... computational procedures.
f. One is the unsolvability ... the "halting problem" — that ... deciding, ... an arbitrary computer ... an arbitrary input, whether the computer will eventually halt and produce an output rather than becoming stuck ... an infinite loop.

3. Insert the pronouns: *whenever, whoever, whatsoever*, etc.
   a. Goedel showed that ... the axioms can be characterized by a set of mechanical rules, it does not matter which statements are taken to be axioms: if they are true of the natural numbers, some other true statements about those numbers will remain unprovable.
   b. ... tried to solve Fermat's Last theorem, he failed.
   c. This principle is valid. There can be no doubt ... about it.
   d. ... one refers to computation, he can not do without the Hindu-Arabic system of numeration.

VI Exercises

a. Give synonyms to the following words.

a caveat	to dismay	enlargement	to deny
evident	to justify	to alter	to masquerade

b. Give antonyms to the following words.

Provable, to obey, decidable, refutable, to contradict, solvability

VIII Key Terms

Bootstrapping (Electronics) — the technique of using bootstrap feedback. A feedback circuit in which part of the output is fed back across the input, giving effectively infinite input impedance and unity gain. *A bootstrapping process* — a program for securing the foundations of maths through a "bootstrapping" process, by which the consistency of complex mathematical theories could be derived from that of simpler, more evident theories
A halting problem — extension of Goedel's ideas have allowed the derivation of several other results about the limits of computational problems. One is the unsolvability of the "halting problem" — that of deciding for an arbitrary computer with an arbitrary input, whether the computer will eventually halt and produce an output rather than becoming stuck in an infinite loop
Recursion (MathSci) — a process by which a term in a sequence may be computed from one or more of the preceeding terms. (Chambers Dictionary of Science and Technology)

IX Conversational Practice

Agree or disagree with the statements. Justify your choice. Add some sentences to develop your idea. Use the introductory phrases.

Surely, but as far as I know...	Surely not. I mean...
Well, as a matter of fact...	In my view, you are wrong.
It is absolutely right.	Well, that's very surprising.
I can't help thinking the same.	Yes, but on the other hand...
Yes, that's quite correct.	Not really. I don't think so.
Yes, perhaps you have a point there.	No, it's quite the reverse.
I couldn't agree more.	I think I disagree (I'm afraid).

1. Goedel's completeness theorem states that one can prove all those statements that follow from the axioms.

2. There is a caveat, however: if some statement is true of the natural numbers but is not true of another system of entities that also satisfies the axioms, it can, nevertheless, be proved.
3. In his 1931 paper Goedel showed that some statement that is true of the natural numbers must be provable.
4. One could escape this "incompleteness theorem" if all true statements were taken to be axioms.
5. Goedel showed that whenever the axioms can be characterized by a set of mechanical rules, it does not matter which statements are taken to be axioms: if they are true of the natural numbers, some other true statements about those numbers will remain unprovable.
6. The latter result greatly dismayed D. Hilbert.
7. Goedel, on the other hand, regarded his incompleteness theorems as demonstrating the inadequacy of the axiomatic method.
8. The concepts and methods Goedel introduced in his incompleteness paper are central to the discipline of recursion theory which underlies all modern science.
9. Among the several other results about the limits of computational procedures is that of the solvability of the "halting problem".
10. Another result is the demonstration that no program that does not alter a computer's operating system can detect all programs that do (viruses).

X Writing

Outline the main ideas and write an abstract (a brief and concise summary) of the text. Express your point of view.

XI Text II

Summarize the text.

DIAGONALIZATION AND GOEDEL'S THEOREM[25]

The diagonalization used in establishing Cantor's theorem also lies at the heart of Austrian mathematician Kurt Goedel's celebrated 1931 theorem. Seeing how offers a particularly perspicuous view of Goedel's result.

Goedel's theorem deals with formal systems of arithmetic. By arithmetic I mean the theory of positive integers and the basic operations that apply to them, such as addition and multiplication. The theorem states that no single system of laws (axioms and rules) can be strong enough to prove all true statements of arithmetic without at the same time being so strong that it "proves" false ones, too. Equivalently, there is no single algorithm for distinguishing true arithmetical statements from false ones. Two definitions and two lemmas, or propositions, are needed to prove Goedel's theorem. Proof of the lemmas is not possible within these confines, although each is fairly plausible.

Definition 1: A set of positive integers is arithmetically definable if it can be defined using standard arithmetical terminology. Examples are the set of squares, the set of primes and the set of positive integers less than, say, 821.

Definition 2: A set of positive integers is decidable if there is an algorithm for determining whether any given positive integer belongs to the set. The same three sets above serve as examples.

Lemma 1: There is an algorithmic way of pairing off positive integers with arithmetically definable sets.

Lemma 2: Every decidable set is arithmetically definable.

Given lemma 1, diagonalization yields a set of positive integers that is not arithmetically definable. Call this set D. Now suppose, contrary to Goedel's theorem, there is an algorithm for distinguishing between true arithmetical statements and false ones. Then D, by virtue of its construction, is decidable. But given lemma 2, this proposition contradicts the fact that D is not arithmetically definable. So Goedel's theorem must hold after all. Q.E.D.

[25]Scientific American, April 1995, p. 116

XII Vocabulary Practice

Fill in the gaps using the key words given below.

Goedel's dissertation ... that the principles of logic developed up to that time were adequate for their ... purpose, which was to prove everything that was true on the ... of a given set of axioms. It did not show, however, that every true statement ... the natural numbers could be proved on the basis of the accepted axioms of number theory.

Those axioms, ... by Italian mathematician Giuseppe Peano in 1889, ... the principle of induction. It asserts that any ... that is true of zero, and true of a natural number $n+1$ ... true of n, must be true of all natural numbers. Sometimes called the ... principle — because if you ... one over, the rest will ... — the axiom might seem ... . Yet mathematicians found it problematic because it ... not just to numbers themselves but to properties of numbers. Such a "second-order" statement was thought too vague and ... ... to serve as a basis for the theory of natural numbers.

As a result, the induction axiom was ... as an infinite schema of similar axioms that refer to specific formulas ... ... to general properties of numbers. Unfortunately, those axioms no longer uniquely ... the natural numbers, as Norwegian logician Thoralf Skolem ... a few years before Goedel's work: other structures ... them as well.

Key words: self-evident, satisfy, established, demonstrated, intended, characterize, basis, rather than, concerning, recast, proposed, ill defined, include, refers, property, topple, whenever, knock, domino

XIII Render the following text

В 1938 году Гёдель снова вернулся в Америку, где в Институте перспективных исследований он читал лекции о замечательных новых результатах, которые он получил в теории множеств.

Одним из достижений было разрешение некоторых противоречивых аспектов теории множеств. В конце XIX века немецкий математик Георг Кантор ввел понятие меры для бесконечных множеств. Согласно Г. Кантору, множество A меньше множества B, если, как бы ни сопоставляли взаимнооднозначно элементам A элементы B, некоторые элементы B всегда остаются без пары. Следуя этому, Кантор доказал, что множество натуральных чисел меньше, чем множество всех действительных чисел. Далее он предположил, что нет такого множества, которое имело бы размер, промежуточный между этими двумя множествами, - утверждение, получившее название континуум-гипотезы.

В 1908 году соотечественник Кантора Эрнест Цермело сформулировал ряд аксиом теории множеств. Среди них была аксиома выбора, которая утверждает (в одной из версий), что, если дан любой бесконечный набор (попарно) непересекающихся множеств, каждое из которых содержит по крайней мере один элемент, тогда существует множество, которое содержит в точности по одному элементу из каждого из этих множеств. Хотя эту аксиому, кажется, трудно оспорить (непонятно, по какой причине невозможно отобрать один элемент из каждого множества), аксиома выбора имеет множество следствий, сильно противоречащих интуиции. Одно из них состоит в том, например, что шар может быть разделен на конечное число частей, которые могут быть разъединены и вновь соединены при помощи только движений без деформации, при этом будет получен новый шар в два раза большего радиуса.

В результате этого, аксиома стала восприниматься как в высшей степени противоречивая. Математики подозревали и, как выяснилось, справедливо, что ни аксиома выбора, ни континуум-гипотеза не могут быть выведены из остальных аксиом теории множеств. Они боялись, что применение этих теорем в доказательствах может привести к противоречиям. Гёдель, однако, доказал, что оба принципа не противоречат остальным аксиомам.

Таким образом, результаты Гёделя по теории множеств ответили на вопрос, который Гильберт сформулировал в 1900 году в своем обращении к Международному конгрессу математиков.

Scientific American, June 1999, pp. 79–80

Unit XV

Text

CONFRONTING SCIENCE'S LOGICAL LIMITS[26]

The mathematical models now used in many scientific fields may be fundamentally unable to answer certain questions about the real world. Yet there may be ways around these problems.

by John L. Casti

THE AUTHOR

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[26]Scientific American, October 1996, pp. 103-104

Word Combinations

it is my belief that...	to hamper an ability to do smth
to bring the issue into sharper focus	to address an issue of how...
to be expelled from the system	to process all information affecting smth
one of the pillars on which smth rests	broadly speaking
a faithful representation of smth	the traveling-salesman problem
to constitute a discrete set of measurements	to be firmly rooted in smth
to take their values in some finite set of numbers	a way round a problem
to discount the effect of smth	to generate an answer
to move in an unpredictable, essentially random fashion	a daunting task
to entail the development of smth	to invoke the proof machinery of maths
to bear a relation to smth	to find compelling definitions

I Read and translate the text. Pay attention to the italicized grammar constructions

A TRIAD OF RIDDLES

It is my belief that nature is both consistent and complete. On the other hand, science's dependence on mathematics and deduction hampers our ability to answer certain questions about the natural world. To bring this issue into sharper focus, let us look at three well-known problems from the areas of physics, biology and economics.

Stability of the solar system. The most famous question of classical mechanics is the N-body problem. Broadly speaking, this problem looks at the behavior of a number, N, of point-size masses moving in accordance with Newton's law of gravitational attraction. *One version* *of the problem addresses whether two or more of these bodies will collide or whether one will acquire an arbitrarily high velocity in a finite time.* In his 1988 doctoral dissertation, Zhihong (Jeff) Xia of Northwestern University showed how a single body moving back and forth between two binary systems (for a total of five masses) could approach an arbitrarily high velocity and be expelled from the system. This result, which was based on a special geometric configuration of the bodies, says nothing about the specific case of our solar system. *But it does suggest that perhaps the solar system might not be stable.* More important, the finding offers new tools with which to investigate the matter.

Protein folding. The proteins making up every living organism are all formed as sequences of a large number of amino acids, strung out like beads on a necklace. *Once the beads are put in the right sequence, the protein folds up rapidly into a highly specific three-dimensional structure that determines its function in the organism. It has been estimated that a supercomputer applying plausible rules for protein folding would need* 10^{127} *years to find the final folded form for even a very short sequence consisting of just 100 amino acids.* In fact, in 1993 Aviezri S. Fraenkel of the University of Pennsylvania showed that the mathematical formulation of the protein-folding problem is computationally "hard" in the same way that the traveling-salesman problem is hard. How does nature do it?

Market efficiency. One of the pillars on which the classical academic theory of finance rests is the idea that financial markets are "efficient." That is, the market immediately processes all information affecting the price of a stock or commodity and incorporates it into the current price of the security. Consequently, prices should move in an unpredictable, essentially random fashion, discounting the effect of inflation. This, in turn, means that trading schemes based on any publicly available information, such as price histories, should be useless; there can be no scheme that performs better than the market as a whole over a significant interval. But actual markets do not seem to pay much attention to academic theory. The finance literature is filled with such market "anomalies" as the low price — earnings ratio effect, which states that the stocks of firms whose prices are low relative to their earnings consistently outperform the market overall.

THE UNREALITY OF MATHEMATICS

Our examination of the three questions posed above has yielded what appear to be three answers: the solar system may not be stable, protein folding is computationally hard, and financial markets are probably not completely efficient. But what each of these putative "answers" has in common is that it involves a mathematical *representation* of the real-world question, not the question itself. For instance, Xia's solution of the N-body problem does not explain how real planetary bodies move in accordance with real-world gravitational forces. Similarly, Fraenkel's conclusion that protein folding is computationally hard fails to address the issue of how real proteins manage to do their job in seconds rather than eons. And, of course, canny Wall Street operators have thumbed their noses at the efficient-market hypothesis for decades. *So to draw any conclusions about the inability of science to deal with these questions, we must either justify the mathematical model as a faithful representation of the physical situation or abandon the mathematics altogether.* We consider both possibilities in what follows.

What these examples show is that if we want to look for scientifically unanswerable questions in the real world, we must carefully distinguish between the world of natural and human phenomena and mathematical and computational models of those worlds. The objects of the real world consist of directly observable quantities, such as time and position, or quantities, such as energy, that are derived from them. Thus, we consider parameters such as the measured position of planets or the actual observed configuration of a protein. Such observables generally constitute a discrete set of measurements taking their values in some finite set of numbers. Moreover, such measurements are generally not exact.

In the world of mathematics, on the other hand, we have symbolic representations of such real-world observables, where the symbols are often assumed to belong to a continuum in both space and time. The mathematical symbols representing attributes such as position and speed usually have numerical values that are integers, real numbers or complex numbers, all systems containing an infinite number of elements. In mathematics the concept of choice for characterizing uncertainty is randomness.

Finally, there is the world of computation, which occupies the curious position of having one foot in the real world of physical devices and one foot in the world of abstract mathematical objects. If we think of computation as the execution of a set of rules, or algorithm, the process is a purely mathematical one belonging to the world of symbolic objects. But if we regard a computation as the process of turning switches on or off in the memory of an actual computing machine, then it is a process firmly rooted in the world of physical observables.

One way to demonstrate whether a given question is logically impossible to answer by scientific means is to restrict all discussion and arguments solely to the world of natural phenomena. If we follow this path, we are forbidden to translate a question such as "Is the solar system stable?" into a mathematical statement and thereby to generate an answer with the logical proof mechanism of mathematics. We then face the problem of finding a substitute in the physical world for the concept of mathematical proof.

A good candidate is the notion of causality. A question can be considered scientifically answerable, in principle, if it is possible to produce a chain of causal arguments whose final link is the answer to the question. *A causal argument need not be expressed in mathematical terms.* For example, the standard deductive argument "All men are mortal; Socrates is a man; therefore, Socrates is mortal" is a causal chain. There is no mathematics involved, just plain English. *On the other hand, constructing a convincing causal argument without recourse to mathematics may be a daunting task.* In the case of the stability of the solar system, for example, one must find compelling nonmathematical definitions of the planets and gravity.

Given these difficulties, it seems wise to consider approaches that mix the worlds of nature and mathematics. If we want to invoke the proof machinery of mathematics to settle a particular real-world question, it is first necessary to "encode" the question as a statement in some mathematical formalism, such as a differential equation, a graph or an N-person game. We settle the mathematical version of the question using the tools and techniques of this particular corner of the mathematical world, eventually "decoding" the answer (if there is one!) back into real-world terms. *One challenge here is establishing that* *the mathematical version of the problem is a faithful representation of the question as it arises in the real world.* How do we know that mathematical models of a natural system and the system itself bear any relation to each other? This is an old philosophical conundrum, entailing the development of a theory of models for its resolution. *Moreover, mathematical arguments may be subject to the constraints revealed by Goedel, Turing and Chaitin; we do not know yet whether the real world is similarly constrained.*

II Comprehension Exercises

Answer the following questions.

1. What are the three well-known questions from the areas of physics, biology and economics?
2. What does each of the putative answers to the questions have in common with the others?
3. Why must we carefully distinguish between the world of natural and human phenomena and mathematical and computational models of those worlds?
4. Why does the author believe that the world of computation occupies a curious position of having one foot in the real world of physical devices and one foot in the world of abstract mathematical objects?
5. What is the way to demonstrate whether a given question is logically impossible to answer by scientific means?
6. What problem do we face then?
7. In which case can a question be considered scientifically answerable?
8. As constructing a convincing causal argument without recourse to mathematics is a daunting task, what kind of approaches does it seem wise to consider?
9. What challenge arises here if we invoke mathematics to settle a particular real-world question?
10. How do we know that mathematical models of a natural system and the system itself bear any relation to each other?
11. Are mathematical arguments subject to constraints as well as the real world itself?

III Vocabulary Notes

(Macmillan English Dictionary for Advanced Learners)

an attribute — (noun) a quality or feature of smb or smth; *to attribute* — (verb) smth to smb/smth — to believe that smth is a result of a particular situation, event or person's actions; *attributable* — (adj.) caused by a particular event, situation, activity or person

to confront — (verb) (often passive) *to be confronted* with smth; 1. to deal with a difficult situation, e.g.: We need to confront this problem; 2. if a problem or a difficult situation confronts you, you have to deal with it, e.g.: the problems confronting science

to compel — (verb) to force smb to do smth; *compelling* — (adj.) 1. interesting or exciting enough to keep your attention completely; 2. able to persuade smb to do smth or persuade them that smth is true, e.g.: compelling evidence

to convince — (verb) 1. smb that/of smth — to make smb believe that smth is true; 2. to persuade smb to do smth; *convinced* — (adj.) certain that smth is true; *convincing* — (adj.) smth that is convincing makes you believe that it is true or persuades you to do smth, e.g.: a convincing argument/explanation

to daunt — (verb) (often passive) if smth daunts you, it makes you worried because you think it will be very difficult or dangerous to do; *daunting* — (adj.) smth that is daunting makes you very worried because you think it will be very difficult or dangerous to do, e.g.: a daunting task, challenge, prospect; *dauntless* — (adj.) brave, never frightened or worried

to discount — (verb) to consider that smth is not important, possible or likely, e.g.: to discount the possibility; *discount* — (noun)

to distinguish — (verb) to recognize the difference between things, to differentiate; *distinguishable* — (adj.) clearly different from other people or things of the same type

to entail — (verb) if a situation or action entails a particular thing, it involves having or doing that thing

to execute — (verb) to carry out; *execution* — (noun)

faithful — (adj.) showing or describing smth in a way that is exactly

correct; *faith* — (noun) a strong belief in or trust of smb/smth; *faithfully* — (adv.)
to hamper — (verb) (often passive) 1. to prevent smth from happening or progressing normally; 2. to limit smb's freedom to move
to outperform — (verb) to be better than smb else at doing smth
to perform — (verb) to complete an action or activity, especially a complicated one, e.g.: perform a task, duty, etc.; *performance* — (noun) the speed and effectiveness of a machine or a vehicle
recourse — (noun) the use of smth so that you can get what you want or need in a difficult situation
to subject — (verb) to make smb experience smth unpleasant; to be subject to smth — 1. likely to experience or be affected by smth; 2. in a situation when you have to obey a rule or law; *subjection* — (noun); *subjective* — (adj.)

IV Grammar

1. Give the three forms of the verbs: to string, to bear, to arise, to learn, to forbid, to deal, to speak, to pay, to say, to show, to do, to put, to drive.
2. Fill in the missing prepositions or adverbs.
   Protein folding. The proteins making ... every living organism are all formed as sequences ... a large number ... amino acids, strung ... like beads ... a necklace. Once the beads are put ... the right sequence, the protein folds ... rapidly ... a highly specific three-dimensional structure that determines its function ... the organism. It has been estimated that a supercomputer applying plausible rules ... protein folding would need 10^{127} years to find the final folded form ... even a very short sequence consisting ... just 100 amino acids. ... fact, ... 1993 Aviezri S. Fraenkel ... the University ... Pennsylvania showed that the mathematical formulation ... the protein-folding problem is computationally "hard" ... the same way that the traveling-salesman problem is hard. How does nature do it?
3. Use *a subordinate clause* instead of Complex Subject in the following sentences and translate them into Russian.

a. But actual markets do not seem to pay much attention to academic theory.
b. In the world of mathematics, on the other hand, we have symbolic representations of such real-world observables, where the symbols are often assumed to belong to a continuum in both space and time.
c. It does not seem to have occurred to Jacobi, as it did to Abel, that the general quintic might be unsolvable algebraically.
d. The history of elliptic functions is quite involved and, although of considerable interest to specialists, is not likely to appeal to the general reader.
e. The property appears to have been mentioned frequently in the past.
f. The rings of Uranus happened to have been discovered by accident.
g. Fermat appears to have known a proof before 1683.
h. Galileo's *Dialogue* turned out to have been pivotal for Newton's discovery of the law of universal gravitation.

4. Enlist all *the parenthetical words* you came across in the text: for example, broadly speaking, on the other hand, similarly, etc. and give their Russian equivalents.
5. Define the grammar construction in the following sentence. Translate it into Russian.
   The mathematical symbols representing attributes such as position and speed usually have numerical values that are integers, real numbers or complex numbers, all systems containing an infinite number of elements.

V Phrasal Verbs and Idioms

to make up smth — to combine together to form a whole
to string out — (usually passive) to arrange smth in a long line
to fold up — to make smth smaller by bending it over on itself more than once
to pay attention to smth — to listen, watch or consider smth very carefully

to bear no relation to smth or smb — to show no connection between two or more things or people
to thumb one's nose at smth or smb — to show no respect for a rule, law or person in authority
to bring smth into sharp focus — to make people pay particular attention to smth

VI Exercises

a. Give synonyms to the following words.

an attribute	loyal	to daunt
promptly	to emerge	to confine
to incorporate	to expel	to execute
a constraint	to hamper	plausible

b. Give antonyms to the following words.

Unable, real, random, to enroll, predictable, essential, uncertainty, faithful, accurate, answerable

c. Match a phrasal verb or an idiom in the left column with its equivalent in the right one.

1. to fold up	a. to arrange smth in a long line
2. to string out	b. to combine together to form a whole
3. to bear no relation to smth/smb	c. to show no respect for a rule or a law
4. to bring smth into sharp focus	d. to show no connection between two things
5. to make up	e. to make smth smaller by bending it over on itself more than once
6. to thumb one's nose at smth	f. to make people pay particular attention to smth

VII Key Terms

Traveling salesman problem — a traveling salesman would need the world's fastest computer running for billions of years to calculate the shortest route between 100 destinations. Scientists are now seeking ways to make such daunting problems more tractable

VIII Conversational Practice

Agree or disagree with the statements. Justify your choice. Add some sentences to develop your idea. Use the introductory phrases.

I have no doubt about it.	I see what you mean, but...
Yes, perhaps you have a point there.	There is a lot in what you say, but...
Yes, that's quite correct.	Surely not, I mean ...
How right you are!	Yes, maybe/perhaps, but ...

1. The mathematical models now used in many scientific fields may be fundamentally unable to answer certain questions about the real world.
2. Nature is both consistent and complete, but science's dependence on maths and deduction hampers our ability to answer certain questions about the natural world.
3. One version of the N-body problem addresses the issue whether two or more of these bodies will collide and acquire an arbitrary high velocity in a finite time.
4. The result suggests that the solar system is stable.
5. It has been estimated that a supercomputer applying plausible rules for protein folding would need 10 years to find the final folded form for a sequence consisting of 100 amino acids.
6. The mathematical formulation of the protein-folding problem is computationally hard in the same way that the traveling-salesman problem is hard.
7. There can be no scheme that performs better than the market as a whole over a significant interval.
8. If we want to look for scientifically unanswerable questions in the real world, we must carefully distinguish between the world of natural and human phenomena and mathematical and computational models of those worlds.
9. The objects of the real world consist of directly observable quantities.
10. Such observables generally constitute a discrete set of measurement taking their values in some finite set of numbers.

11. In the world of mathematics we have symbolic representations of such real-world observables, where the symbols are often assumed to belong to a continuum in both space and time.
12. The mathematical symbols representing attributes such as position and speed usually have numerical values that are integers, real numbers or complex numbers, all systems containing an infinite number of elements.
13. There is a world of computation, which occupies the curious position of having one foot in the real world of physical devices and one foot in the world of abstract mathematical objects.
14. One way to demonstrate whether a given question is logically impossible to answer by scientific means is to restrict all discussion and arguments solely to the world of mathematical models.
15. We face the problem of finding a substitute in the physical world for the concept of mathematical proof.
16. Constructing a convincing causal argument without recourse to mathematics may be an encouraging task.
17. Given these difficulties, it seems wise to consider approaches that do not mix the worlds of nature and mathematics.
18. .One challenge here is establishing that the mathematical version of the problem is a faithful representation of the question as it arises in the real world.

IX Vocabulary Practice

Fill in the gaps using the key words given below.

There may be ... to sidestep these ... . The problems ... by Goedel and others ... to number systems with ... elements, such as the set of all integers. But many ... ... problems, such as the traveling salesman problems ... a finite number of variables, each of which can take only a ... number of possible values.

Similarly, nondeductive models of ... — induction, for instance, in which we ... to a general ... on the basis of a finite number of specific ... — can take us ... the realm of logical ... . So, if we ... our mathematical formalisms to systems using ... sets of numbers or nondeductive ... or both, every mathematical question should be ...;

hence, we can ... the decoded real-world ... of such questions to be answerable as well.

Key words: answerable, observations, involve, jump, apply, undecidability, issues, real-world, restrict, conclusion, counterpart, finite (2), ways, identified, infinite, reasoning, beyond, logic, expect

X Writing and Speaking

Write a mini-report on the problems formulated by Goedel. Present it to your classmates. Do not read your report. Instead, speak from notes.

XI Render the following text

Проблемы, сформулированные Геделем и другими учеными, применимы к числовым системам с бесконечным числом элементов, таким, как множество всех целых чисел. Но многие задачи реального мира, например, проблема коммивояжера, зависят от конечного числа величин, каждая из которых может принимать только конечное число возможных значений.

Подобным же образом, недедуктивные способы мышления — индукция, например, при которой мы приходим к общему заключению на основании конечного числа экспериментов — могут вывести нас за пределы логической неразрешимости. Поэтому, если мы ограничим наш математический формализм системами, использующими конечные множества чисел или недедуктивную логику, или и то и другое, то каждый математический вопрос должен иметь ответ, следовательно, мы можем ожидать, что расшифрованные аналоги этих математических проблем в реальном мире тоже имеют решение.

Изучение человеческого разума может выявить другие способы обойти логические пределы. Некоторые исследователи искусственного интеллекта предложили считать наш мозг компьютером, хотя и чрезвычайно мощным, совершающим вычисления таким же логически поэтапным путем, как и традиционные компьютеры. Но разные теоретики, в первую очередь физик-математик Роджер Пенроуз из Оксфордского университета, утверждают, что человеческая мыслительная деятельность не построена ни на каких известных правилах дедукции и таким образом не подпадает под ограничения Геделя.

Недавно эта точка зрения была поддержана исследованиями, проведенными математиками Джоном Л. Касти и Дональьдом Т. Сари, психологом Маргарет А. Боден, экономистом Оке Е. Андерсеном и другими. Это исследование дает основания утверждать, что в искусстве, равно как и в естественных науках и математике, человеческие творческие способности не ограничиваются жесткими рамками математических вычислений. Пенроуз и другие теоретики высказали догадку, что человеческое творчество имеет некие все еще неизвестные механизмы или правила, возможно, связанные с квантовой механикой. Если ученые раскроют эти механизмы и включат их в научный метод, то они, возможно, смогут решить некоторые проблемы, кажущиеся сейчас неразрешимыми. Конечно, способность науки раскрывать секреты природы ограничена многими практическими аспектами — такими, как ошибки измерения, время вычислений, физические и экономические ресурсы, политическая воля и культурные ценности. Но ничто из этого не отвечает на вопрос, существует ли логический предел нашим ответам на определенный вопрос об окружающем мире. Предполагается, что не существует. Поэтому экскурс в математику XX века вселяет надежду.

Scientific American, October 1996, pp. 104–105

Appendix

Texts for home reading and abstracting

HYPERSPHERE EXOTICA[27]

A 45-year-old problem on higher-dimensional spheres is solved — probably

by Davide Castelvecchi

Relax. Until recently, lurking in the dark recesses of mathematical existence, there might have been a really weird sphere of 254 dimensions, or 510, or 1,026. in fact, for all you knew, you might have had to worry about weird spheres when visiting any space with numbers of dimensions of the type $2^k - 2$.

Not anymore. "We can all sleep a bit better tonight," joked mathematical physicist J. Baez of the University of California, Riverside, in his blog. Baez was referring to the announcement made by mathematicians Michael Hopkins of Harvard University, Michael Hill of the University of Virginia and Douglas Ravenel of the University of Rochester that they had cracked a 45-year-old question known as the Kervaire invariant problem. If confirmed, their result puts the finishing touch to a glorious piece of 1960s mathematics: the classification of "exotic," higher-dimensional spheres. The Kervaire problem was a major stumbling block in understanding multidimensional spaces, and its solution could have implications in equally exotic fields of physics such as string theory.

[27] Scientific American, August 2009, p. 22

When mathematicians talk about higher-dimensional spaces, they are referring to the number of variables, or dimensions, needed to locate a point in such a space. The surface of the earth is two-dimensional because two coordinates — latitude and longitude — are needed to specify any point on it. In more formal terms, the standard two-dimensional sphere is the set of points equidistant from a point in $2+1=3$ dimensions. More generally, the standard n-dimensional sphere, or n-sphere for short, is the set of points that are at the same distance from a center point in a space of $n+1$ dimensions. Spheres are among the most basic spaces in topology, the branch of mathematics that studies which properties are unchanged when an object is deformed without crushing or ripping it. Topology comes up in many studies, including those trying to determine the shape of our universe.

In recent years mathematicians have completed the classification of 3-D spaces that are "compact," meaning that they are finite and with no edges. (A sphere is compact, but an infinite plane is not.) Thus, they have figured out the topologies of all possible universes, as long as those universes are compact and three-dimensional. In more than three dimensions, however, the complete classification has turned out to be intractable and even logically impossible. Topologists had hoped at least that spaces as simple as spheres would be easy enough.

John Milnor, now at Stony Brook University, complicated matters somewhat in the 1950s, when he discovered the first "exotic" 7-sphere. An exotic n-sphere is a sphere from the point of view of topology. But it is not equivalent to a standard n-sphere from the point of view of differential calculus, the language in which physics theories are formulated. The discrepancy has consequences for equations such as those that describe the motion of particles or the propagation of waves. It means that solutions to such equations (or even their formulation) on one space cannot be mapped onto the other without developing kinks, or "singularities." Physically, the two spheres are different, incompatible worlds.

In 1963 Milnor and his colleague Michel Kervaire calculated the number of exotic 7-spheres and found that there were exactly 27 different ones. In fact, they calculated the number of n-spheres for any n from five up. Their counts, however, had an ambiguity — a possible factor of two — when n is an even number. William Browder of Princeton University later removed that ambiguity, except for dimensions of the type $n = 2^k - 2$, starting with $k = 7$ — specifically, 126, 254, 510, and so on. In other words, mathematicians could only guess the number of exotic spheres in these dimensions to within a factor of two, known as the Kervaire invariant because of its relation to an earlier concept invented by Kervaire.

Hopkins and his colleagues think that they have found a way to remove that ambiguity. In their proof, which involves an intricate hierarchy of algebraic systems called homology groups, they show that the factor of two did not exist in any of those dimensions except possibly in the case 126, which, for technical reasons, their proof strategy did not address. There is actually still another major exception: the 4-D case. Although there are no exotic 1-, 2- or 3-spheres, no one has any clue whether exotic 4-spheres exist or not.

Although the researchers have not yet published their proof, Hopkins says, "I'm as confident as I possibly could be" without peer review that the proof is correct. Gunnar Carlsson, a topologist at Stanford University, says he has only heard "the most cursory outline of the proposed proof" from Hopkins but is "optimistic that the ingredients may very well be there for a resolution of this problem." And not a moment too soon, if you've stayed up worrying about weird spheres.

BREAKING NETWORK LOGJAMS[28]

by Michelle Effros, Ralf Koetter and Muriel Medard

Claude E. Shannon, mathematician and engineer, launched one such revolution almost 60 years ago by laying the foundation of a new mathematical theory of communications — now known as information theory. Practical outgrowths of his work, which dealt with the compression and reliable transmission of data, can be seen today in the Internet, in landline and wireless telephone systems, and in storage devices, from hard drives to CDs, DVDs and flash memory sticks.

[28] Scientific American, June 2007, pp. 78–81

Shannon tackled communications over phone lines dedicated to individual calls. These days, information increasingly travels over shared networks (such as the Internet), in which multiple users simultaneously communicate through the same medium — be it a cable, an optical fiber or, in a wireless system, air. Shared networks can potentially improve the usefulness and efficiency of communications systems, but they also create competition for communal resources. Many people must vie for access to, say, a server offering downloadable songs or to a wireless hot spot.

The challenge, then, is to find ways to make the sharing go smoothly; parents of toddlers will recognize the problem. Network operators frequently try to solve the challenge by increasing resources, but that strategy is often insufficient. Copper wires, cables or fiber optics, for instance, can now provide high bandwidth for commercial and residential users yet are expensive to lay and difficult to modify and expand. Ultrawideband and multiple-antenna transmission systems can expand the number of customers served by wireless networks but may still fail to meet ever increasing demand.

Techniques for improving efficiency are therefore needed as well. On the Internet and other shared networks, information currently gets relayed by routers — switches that operate at nodes where signaling pathways, or links, intersect. The routers shunt incoming messages to links heading toward the messages' final destinations. But if one wants efficiency, are routers the best devices for these intersections? Is switching even the right operation to perform?

Until seven years ago, few thought to ask such questions. But then Rudolf Ahlswede of the University of Bielefeld in Germany, along with Ning Cai, Shuo-Yen Robert Li and Raymond W. Yeung, all then at the University of Hong Kong, published groundbreaking work that introduced a new approach to distributing information across shared networks. In this approach, called network coding, routers are replaced by coders, which transmit evidence about messages instead of sending the messages themselves. When receivers collect the evidence, they deduce the original information from the assembled clues.

Although this method may sound counterintuitive, network coding, which is still under study, has the potential to dramatically speed up and improve the reliability of all manner of communications systems and may well spark the next revolution in the field. Investigations are, of course, also exploring additional avenues for improving efficiency; as far as we know, though, those other approaches generally extend existing methods.

Ahlswede and his colleagues built their proposal in part on the idea, introduced by Shannon, that transmitting evidence about data can actually be more useful than conveying the data directly. They also realized that a receiver would be able to deduce the original data once enough clues had been gathered but that the receiver would not need to obtain all of the evidence emitted. One kind of clue could be replaced by another, and all that was important was receiving some combination of clues that, together, would reveal the original message. (Receivers would be able to make sense of the evidence if they were informed in advance about the rules applied to generate it or if instructions on how to use the evidence were included in the evidence itself.)

Network coding breaks with the classic view that communications channels are analogous to roads and that bits are like the cars that travel those roads. But an understanding of the transportation model of communications is useful for grasping how the new scheme works and why it has such promise.

Shannon proved mathematically that every channel has a capacity — an amount of information it can relay during any given time frame — and that communications can proceed reliably as long as the channel's capacity is not exceeded. In the transportation analogy, a road's capacity is the number of cars per second it can handle safely. If traffic stays below capacity, a car entering the road at one end can generally be guaranteed to exit at the other end unchanged (barring the rare accident). Engineers have built increasingly complex communications systems based on the transportation model. For example, the phone systems Shannon pondered dedicate a distinct "road" to every conversation; two calls over traditional phone lines never share a single line at the same time and frequency.

Computer networks — and the Internet in particular — are essentially a maze of merging, branching and intersecting roads. Information traveling from one computer to another typically traverses several roads en route to its destination. Bits from a single message are grouped into packets (the carpools or buses of the information superhighway), each of which is labeled with its intended destination. Routers sit at the intersections of the roads, examine each packet's header and forward that packet toward its destination.

Ironically, the very transportation model that fueled today's sophisticated communications systems now stands in the way of progress. After all, bits are not cars. When two vehicles converge on the same narrow bridge, they must take turns traversing the bottleneck. When two bits arrive at a bottleneck, however, more options are possible — which is where network coding comes in.

HOW TO STEAL SECRETS WITHOUT A NETWORK[29]

by W. Wayt Gibbs

Through the eyepiece of Michael Backes's small Celestron telescope, the 18-point letters on the laptop screen at the end of the hall look nearly as clear as if the notebook computer were on my lap. I do a double take. Not only is the laptop 10 meters (33 feet) down the corridor, it faces away from the telescope. The image that seems so legible is a reflection off a glass teapot on a nearby table. In experiments here at his laboratory at Saarland University in Germany, Backes has discovered that an alarmingly wide range of objects can bounce secrets right off our screens and into an eavesdropper's camera. Spectacles work just fine, as do coffee cups, plastic bottles, metal jewelry — even, in his most recent work, the eyeballs of the computer user. The mere act of viewing information can give it away.

The reflection of screen images is only one of the many ways in which our computers may leak information through so-called side channels, security holes that bypass the normal encryption and operating —system restrictions we rely on to protect sensitive data. Researchers recently demonstrated five different ways to surreptitiously capture keystrokes, for example, without installing any software on the target computer. Technically sophisticated observers can extract private data by reading the flashing light-emitting diodes (LEDs) on

[29] Scientific American, May 2009, pp. 58–61

network switches or by scrutinizing the faint radio-frequency waves that every monitor emits. Even certain printers make enough noise to allow for acoustic eavesdropping.

Outside of a few classified military programs, side-channel attacks have been largely ignored by computer security researchers, who have instead focused on creating ever more robust encryption schemes and network protocols. Yet that approach can secure only information that is inside the computer or network. Side-channel attacks exploit the unprotected area where the computer meets the real world: near the keyboard, monitor or printer, at a stage before the information is encrypted or after it has been translated into human-readable form. Such attacks also leave no anomalous log entries or corrupted files to signal that a theft has occurred, no traces that would allow security researchers to piece together how frequently they happen. The experts are sure of only one thing: whenever information is vulnerable and has significant monetary or intelligence value, it is only a matter of time until someone tries to steal it.

The idea of stealing information through side channels is far older than the personal computer. In World War I the intelligence corps of the warring nations were able to eavesdrop on one another's battle orders because field telephones of the day had just one wire and used the earth to carry the return current. Spies connected rods in the ground to amplifiers and picked up the conversations. In the 1960s American military scientists began studying the radio waves given off by computer monitors and launched a program, code-named "Tempest," to develop shielding techniques that are used to this day in sensitive government and banking computer systems. Without Tempest shielding, the image being scanned line by line onto the screen of a standard cathode-ray tube monitor can be reconstructed from a nearby room — or even an adjacent building — by tuning into the monitor's radio transmissions.

Many people assumed that the growing popularity of flat-panel displays would make Tempest problems obsolete, because flat panels use low voltages and do not scan images one line at a time. But in 2003 Markus G. Kuhn, a computer scientist at the University of Cambridge Computer Laboratory, demonstrated that even flat-panel monitors, including those built into laptops, radiate digital signals from their video cables, emissions that can be picked up and decoded from many meters away. The monitor refreshes its image 60 times or more each second; averaging out the common parts of the pattern leaves just the changing pixels — and a readable copy of whatever the target display is showing.

"Thirty years ago only military suppliers had the equipment necessary to do the electromagnetic analysis involved in this attack," Kuhn says. "Today you can find it in any well-equipped electronics lab, although it is still bulky. Sooner or later, however, it will be available as a plug-in card for your laptop."

Similarly, commonplace radio surveillance equipment can pick up keystrokes as they are typed on a keyboard in a different room, according to Martin Vuagnoux and Sylvain Pasini, both graduate students in computer science at the Swiss Federal Institute of Technology in Lausanne. The attack does not depend on fluctuations in the power supply, so it works even on the battery-powered laptops you see by the dozen in any airport terminal.

Vuagnoux and Pasini showed off the feat in an online video recorded last October. They are now preparing a conference paper that describes four distinct ways that keystrokes can be deduced from radio signals captured through walls at distances up to 20 meters. One of the newer methods is 95 percent accurate. "The way the keyboard determines which key is pressed is by polling a matrix of row and column lines," explains Kuhn, who proposed (but never demonstrated) one of these methods a decade ago. "The polling process emits faint radio pulses, and the position of those pulses in time can reveal which key was pressed."

Last May a group led by Giovanni Vigna of the University of California, Santa Barbara, published details of a fifth way to capture typing that does not require a fancy radio receiver; an ordinary webcam and some clever software will do. Vigna's software, called ClearShot, works on video of a victim's fingers typing on a keyboard. The program combines motion-tracking algorithms with sophisticated linguistic models to deduce the most probable words being typed. Vigna reports that ClearShot reconstructs the typed text about as quickly as human volunteers do, but not quite as accurately.

It might seem implausible that someone would allow their own webcam to be used against them in this way. It is not. Gathering video from a webcam can be as simple as tricking the user into clicking on an innocuous-looking link in a Web page, a process known as clickjacking. Last October, Jeremiah Grossman of WhiteHat Security and Robert Hansen of SecTheory revealed details of bugs they discovered in many Web browsers and in Adobe's Flash software that together allow a hostile Web site to collect audio and video from a computer's microphone and webcam. Just a single errant click launches the surveillance.

Still, Backes points out, "almost all these interception methods are accessible only to experts with specialized knowledge and equipment. What distinguishes the attack based on reflections is that almost anyone with a $500 telescope can do it, and it is almost impossible to defend against completely."

MASTERING CHAOS[30]

It is now possible to control some systems that behave chaotically. Engineers can use chaos to stabilize lasers, electronic circuits and even the hearts of animals

by William L. Ditto and Louis M. Pecora

What good is chaos? Some would say it is unreliable, uncontrollable and therefore unusable. Indeed, no one can ever predict exactly how a chaotic system will behave over long periods. For that reason, engineers have typically dealt with chaos in just one way: they have avoided it. We find that strategy somewhat shortsighted. Within the past few years we and our colleagues have demonstrated that chaos is manageable, exploitable and even invaluable.

Chaos has already been applied to increase the power of lasers, synchronize the output of electronic circuits, control oscillations in chemical reactions, stabilize the erratic beat of unhealthy animal hearts and encode electronic messages for secure communications. We anticipate that in the near future engineers will no longer shun chaos but will embrace it.

There are at least two reasons why chaos is so useful. First, the behavior of a chaotic system is a collection of many orderly behaviors,

[30]Scientific American, August 1993, p. 78

none of which dominates under ordinary circumstances. In recent years, investigators have shown that by perturbing a chaotic system in the right way, they can encourage the system to follow one of its many regular behaviors. Chaotic systems are unusually flexible because they can rapidly switch among many different behaviors.

Second, although chaos is unpredictable, it is deterministic. If two nearly identical chaotic systems of the appropriate type are impelled, or driven, by the same signal, they will produce the same output, even though no one can say what that output might be. This phenomenon has already made possible a variety of interesting technologies for communications.

For more than a century, chaos has been studied almost exclusively by a few theoreticians, and they must be credited for developing some of the concepts on which all applications are based. Most natural systems are nonlinear: a change in behavior is not a simple function of a change in conditions. Chaos is one type of nonlinear behavior. The distinguishing feature of chaotic systems is that they exhibit a sensitivity to initial conditions. To be more specific, if two chaotic systems that are nearly identical are in two slightly different states, they will rapidly evolve toward very different states.

To the casual observer, chaotic systems appear to behave in a random fashion. Yet close examination shows that they have an underlying order. To visualize dynamics in any system, the Irish-born physicist William Hamilton and the German mathematician Karl Jacobi and their contemporaries devised, more than 150 years ago, one of the fundamental concepts necessary for understanding nonlinear dynamics: the notion of state space.

Any chaotic system that can be described by a mathematical equation includes two kinds of variables: dynamic and static. Dynamic variables are the fundamental quantities that are changing all the time. For a chaotic mechanism, the dynamic variables might be the position of a moving part and its velocity. Static variables, which might also be called parameters, are set at some point but then are never changed. The static variable of a chaotic mechanism might be the length of some part or the speed of a motor.

State space is essentially a graph in which each axis is associated with one dynamic variable. A point in state space represents the state of the system at a given time. As the system changes, it moves from point to point in state space, defining a trajectory, or curve. This trajectory represents the history of the dynamic system.

Chaotic systems have complicated trajectories in state space. In contrast, linear systems have simple trajectories, such as loops. Yet the trajectory of a chaotic system is not random; it passes through certain regions of state space while avoiding others. The trajectory is drawn toward a so-called chaotic attractor, which in some sense is the very essence of a chaotic system. The chaotic attractor is the manifestation of the fixed parameters and equations that determine the values of the dynamic variables.

So if one measures the trajectory of a chaotic system, one cannot predict where it will be on the attractor at some point in the distant future. The chaotic attractor, on the other hand, remains the same no matter when one measures it. Once researchers have obtained information about the chaotic attractor of a system, they can begin to use chaos to their advantage.

PRACTICAL FRACTAL[31]

Mandelbrot's equations compress digital images

When IBM researcher Benoit B. Mandelbrot published The Fractal Geometry of Nature a decade ago, few imagined that the beautiful, infinitely detailed designs he called fractals might one day also improve television reception and help make pictures a part of everyday computing. Two who did were Michael F. Barnsley and Alan D. Sloan, mathematicians at the Georgia Institute of Technology. They reasoned that because images of the real world tend to consist of many complex patterns that recur at various sizes — in other words, fractals — there ought to be a way to translate pictures into fractal equations. Images so coded would require fewer data and thus less disk space to store and less time to transmit.

By 1987 the researchers had worked out enough details to patent their idea, garner $500,000 in start-up capital from Norwegian investors

[31] Scientific American, July 1993, p. 89

and form Iterated Systems in Norcross, Ga. But turning potential to profit proved difficult. Iterated found a formidable competitor in JPEG, an image compression technique developed by the International Standards Organization's Joint Photographic Experts Group. JPEG uses a well-understood mathematical procedure, the discrete cosine transform, to compress files by 90 to 95 percent — equivalent to compression ratios of 10:1 to 20:1. JPEG enjoys another advantage: because it is an industry standard, it is free.

The mathematics behind fractal compression, on the other hand, has only recently left the crib. "Relatively speaking, very little research has been done to date," Barnsley admits. "Two or three years ago, when people looked at my pictures, they said. This stuff looks terrible; it isn't going to work — you're dreaming. But we bet on continual dramatic improvement, and we've seen it."

Indeed, fractal compression has at last begun to challenge JPEG in the three areas that matter: speed, quality and strength. To a certain extent, the three are mutually exclusive — stronger compression yields a smaller image file but takes longer and creates more artifacts. JPEG takes as long to decompress an image as to compress it, and it produces blocky "pixelation" as compression ratios rise above about 20:1.

Iterated takes a different tack. Its algorithm works by treating an image as a jigsaw puzzle composed of many overlapping pieces, some of which are similar. The software takes each piece and, using a fractal formula, transforms its shape, size and color until it matches another part of the picture. To do this for each piece of the puzzle takes some time; fractal compression is quite slow. But it produces a much smaller image file, which contains just the numbers needed to specify the mathematical relations between the pieces, and not those needed to actually draw each piece.

This approach has some unique advantages. Reconstructing the image from the numbers is relatively quick work: Iterated's video software can decompress tens of images each second without any special hardware. Quality depends on the accuracy of the numbers; giving the compression algorithm more time or a dedicated computer processor thus yields better pictures. And the artifacts generated at higher compression ratios add an impressionistic blur, rather than blockiness, to the image. What is more, because fractal images are encoded by equations, they have no inherent size — an attractive quality to publishers who want their products to work as well on a laptop screen as on a 21-inch monitor. Barnsley expects that in the long term, such resolution independence will prove irresistible.

REPEALING THE LAW OF AVERAGES[32]

by Ian Stewart

Suppose I keep tossing a fair coin — one for which heads and tails are equally likely, each having probability ? - and maintain a running count of how many times each turns up. If at some stage I have tossed 100 more heads than tails, is there any tendency for tails to "catch up" in future tosses? Some people talk of a law of averages, based on the intuition that tosses of a fair coin ought to even out ultimately. Others assert that coins have no "memory" — so the probability of heads or tails always remains ? - and deduce that there is no tendency whatsoever for the numbers to even out.

The same issues arise in diverse circumstances. If airplane crashes happen on average once every four months and three months have passed without one, should you expect one soon?

In all such cases, the answer is "no". The random processes involved — or, more accurately, the standard mathematical models of those processes — do indeed have no memory.

Still, much depends on what you mean by catching up. A long run of heads does not affect the probability of getting tails later on. Even so, after a run of, say, 100 more heads than tails, the probability that at some stage the numbers will even up again is 1. A probability of 1 normally means certain, and a probability of 0 means impossible. (In this case, we are working with a potentially infinite list of tosses, so mathematicians prefer to say "almost certain" and "almost impossible.")

I hasten to add that there is also a sense in which coin tosses do not have a tendency to even out in the long run. For example, after a run of 100 more heads than tails, the probability that the cumulative number of heads gets at least a million ahead of tails is also 1.

[32] Scientific American, April 1998, pp. 102–104

To analyze these apparent contradictions, take a closer look at coin tossing. I flipped one 20 times, getting the result TTTTHTHH-HHHHTTTHTTTH, with 11 Ts and 9 Hs. According to the law of large numbers, the frequencies with which events occur should, in the long run, be very close to their probabilities. Here the frequencies are $11/20 = 0.55$ and $9/20 = 0.45$ — close to 0.50 but not equal to it. Perhaps my sequence doesn't look random enough. You'd probably be happier with something like HTHHTTHTTHTHHTHTHHTT, with frequencies $10/20 = 0.50$ for H or T. As well as getting the numbers spot on, the second sequence looks more random. But it isn't.

The first sequence looks nonrandom because of long strings of the same event, such as TTTT and HHHHHH, which the second sequence lacks. But our intuition is misleading: random sequences often show patterns and clumps. Don't be surprised by these. (Unless the coin goes HHHHHHHHHHHH. . . for a long time, in which case the shrewd guess is that it is double-headed.)

Suppose you toss four coins in a row. The illustration at the right summarizes the possible results. The first toss is either H or T (each with probability 1/2). Whichever of these happens, the second toss is also either H or T. And so on. So for four tosses we get a "tree" with 16 possible routes through it. According to probability theory, each route has probability ? x ? x ? x ? = 1/16. This result is plausible, because there are 16 routes, and each should be equally likely.

Notice that TTTT has probability 1/16, and HTHH, say, also has probability 1/16. So although HTHH looks more random than TTTT, they have the same probability.

Again, if you toss a coin four times, on average you get exactly two heads. Does this mean that two heads and two tails are highly probable? No. In the illustration below, there are 16 different sequences of Hs and Ts, and a total of six of them contain two heads: HHTT, HTHT, HTTH, THHT, THTH, TTHH. So the probability of exactly two heads is $6/16 = 0.375$. This is less than the probability of not getting exactly two heads, which is 0.625. With longer sequences, this effect becomes even more extreme.

Investigations of this kind make it clear that there is no law of averages, in the sense that the future probabilities of events are not changed in any way by what happened in the past. Still, there is an interesting sense in which things do tend to balance out in the long run. Plot the excess of the number of Hs over the number of Ts by drawing a graph of the difference at each toss. You can think of this construction as a curve that moves one step upward for each H and one down for each T. Such diagrams, in which the successive steps are randomly chosen, are known as random walks.

The graph on the next page shows a typical random walk corresponding to 10, 000 tosses. This kind of wildly unbalanced behavior is entirely normal. In fact, the probability that in 10, 000 tosses one side leads for 9, 930 tosses and the other for only 70 is about 1 in 10.

Random walk theory also tells us that the probability that the balance never returns to 0 (that is, that H stays in the lead forever) is 0. This is the sense in which the law of averages is true — but it carries no implications about improving your chances of winning if you're betting on whether H or T turns up. You don't know how long the long run is going to be — except that it is most likely to be very long indeed.

Suppose you toss a coin 100 times and get 55 Hs and 45 Ts — an imbalance of 10 in favor of Hs. Then random walk theory says that if you wait long enough, the balance will (with probability 1) correct itself. Isn't that the law of averages? No, not as that law is normally interpreted. If you choose a length in advance — say, a million tosses — then random walk theory says that those million tosses are unaffected by the imbalance. Moreover, if you made huge numbers of experiments with a million extra tosses, then on average you would get 500,055 Hs and 500,045 Ts in the combined sequence of 1,000,100 throws. On average, imbalances persist. Notice, however, that the frequency of H changes from $55/100 = 0.55$ to $500{,}055/1{,}000{,}100 = 0.500005$. The law of averages asserts itself not by removing imbalances but by swamping them.

. . . Instead of tossing a coin, imagine I roll a die and count how many times each face, 1 to 6, turns up. Assume each face has probability 1/6, equally likely. When I start, the cumulative numbers of occurrences of each face are equal — all 0. Typically, after a few throws, those numbers start to differ. Indeed, it takes at least six throws before there is any chance of them evening out again, at one of each. What is the probability that however long I keep throwing the die, the six numbers at some stage even out again? I don't know the exact value, so here's a gap for Feedback to fill. But I'll show you that it's certainly not 1.

For the die problem, we need to generalize the random walk to more dimensions. The simplest random walk in the plane, for example, takes place on the vertices of an infinite square grid. A point starts at the origin and successively moves one step either north, south, east or west, with probability ? for each. The graph on the preceding page shows a typical path. A three-dimensional random walk, on a cubic grid in space, is very similar, but now there are six directions — north, south, east, west, up, down — each with probability 1/6.

It can again be shown that for a two-dimensional random walk, the probability that the path eventually returns to the origin is 1. Stanislaw M. Ulam (formerly of Los Alamos National Laboratory and best known for his co-invention of the hydrogen bomb) proved that in three dimensions, the probability of eventually returning to the origin is about 0.35. (So if you get lost in a desert and wander around at random, you'll eventually get to the oasis; however, if you're lost in space, there is only a chance of one in three that you'll wander back to Earth.)

Suppose we label the six directions of a three-dimensional random walk according to the faces of a die — north = 1, south = 2, east = 3, west = 4, up = 5 and down = 6. Repeatedly roll the die and move through the grid in the specified direction. In this case, "return to the origin" means the same number of 1s as 2s, the same number of 3s as 4s, and the same number of 5s as 6s. The probability that this eventually happens is therefore 0.35. So the stronger condition that all six numbers occur equally often must have probability less than 0.35.

Even the simplest one-dimensional random walk has many other counterintuitive features. Suppose you choose a large number of tosses in advance — say, a million — and watch whether heads or tails is in the lead. What proportion of the time, on average, would you expect heads to take the lead? The natural guess is $1/2$. Actually, this proportion is the least likely. The most likely proportions are the extremes: heads stays in front the whole time or none of the time!

THE SCIENCE OF MURPHY'S LAW[33]

Life's little annoyances are not as random as they seem: the awful truth is that the universe is against you

by Robert A.J. Matthews

LOST ON THE FRINGES

One manifestation of the Murphy principle that is rather easy to explain is Murphy's Law of Maps, which might be expressed as, "If a place you're looking for can lie on the inconvenient parts of the map, it will." The reason turns out to involve an interesting combination of probability and optical illusion. Suppose that the map is square; the "Murphy Zone" consists then of those parts of the map close to its edges and down the central crease, where following roads to their destination is most awkward.

Simple geometry shows that if the width of the Murphy Zone makes up just one tenth of the width of the entire map, it nonetheless accounts for more than half the area of the map. Hence, a point picked at random on a map has a better than 50-50 chance of falling into the Murphy Zone. This surprising result stems from the fact that although the Murphy Zone looks rather narrow, its perimeter tracks the largest dimension of the map, so the total area of this zone is deceptively large.

Another example of Murphy's Law that is relatively easily explained is Murphy's Law of Queues: "The line next to you will usually finish first." Of course, if you stand in line behind a family of 12 shopping for the winter, it is hardly surprising if all the other queues finish before yours does. But what if your line is identical in length and makeup to all the others? Surely then you'll be safe from Murphy's Law?

Sorry, but the answer is no. It is true that, on average, all the queues will move at more or less the same rate — each being equally likely to suffer from the kind of random delays that occur when, for example, the cashier has to change the cash-register tape or a customer wants to use a personal check drawn on an obscure bank to pay for a pack of chewing gum. But during any one trip to the supermarket, we

[33] Scientific American, April 1997, pp. 89–91

don't care about averages: we just want our line to finish first on that particular visit. And in that case, the chances that we've picked the queue that will turn out to be the one least plagued by random delays is just $1/N$, where N is the total number of queues in the supermarket.

Even if we are concerned only about beating the queues on either side of ours, the chances we'll do so are only one in three. In other words, two thirds of the time, either the line to the left or the one on the right will beat ours.

Probability theory and combinatorics, the mathematical study of arrangements, hold the key to another notorious example of Murphy's Law: "If odd socks can be created, they will be." Anyone who has hunted through a drawer looking for a matching pair will have been struck by the ubiquity of odd socks. Popular folklore has blamed everything from gremlins to quantum black holes. Yet it is possible to probe the mystery of odd socks without knowing anything about where they go.

To see how, imagine you have a drawer containing only complete pairs of socks. Now suppose one goes missing; don't worry about where or how. Instantly you have an odd sock left behind in the drawer. Now a second sock goes missing. This can be either that odd sock just created or — far more likely — it will be a sock from an as yet unbroken complete pair, creating yet another odd sock in the drawer.

Already one can see signs of a natural propensity that can be confirmed by combinatoric analysis. Random sock loss is always more likely to create the maximum possible number of odd socks than to leave us free of the things. For example, if we started with 10 complete pairs, by the time half our socks have gone missing, it is four times more likely that we will be left with a drawerful of odd socks, rather than one containing only complete pairs. And the most likely outcome will be just two complete pairs lost among six odd socks. No wonder matching pairs can be so difficult to find in the morning.

Probability theory also casts light on Murphy's Law of Umbrellas: "Carrying an umbrella when rain is forecast makes rain less likely to fall." With meteorologists now claiming rain-forecast accuracy rates of more than 80 percent, it seems obvious that taking an umbrella on their advice will prove correct four times out of five. This reasoning, however, fails to take into account the so-called base rate of rain. If rain is pretty infrequent, then most of the correct forecasts that resulted in that impressive 80 percent accuracy figure were predictions of no rain. This is hardly impressive (especially in, say, Phoenix or San Diego).

DON'T TAKE THE UMBRELLA

Thus, when deciding whether to take an umbrella, you need to take into account the probability of rain falling during the hour or so you are on your walk, which is usually pretty low throughout much of the world. For example, suppose that the hourly base rate of rain is 0.1, meaning that it is 10 times more likely not to rain during your hour-long stroll. Probability theory then shows that even an 80 percent accurate forecast of rain is twice as likely to prove wrong as right during your walk — and you'll end up taking an umbrella unnecessarily. The fact is that even today's apparently highly accurate forecasts are still not good enough to predict rare events reliably.

Captain Murphy was perhaps justifiably irritated by what in his view was the trivialization of his worthy principle for safety-critical engineering. Nevertheless, I believe the popular version of his law is not without merits.

That many of the manifestations of Murphy's Law do have some basis in fact suggests that perhaps scientists should not be so hasty to explain away the experience of millions as mere delusion. And with many of the explanations based on disciplines ranging from rigidbody dynamics to probability theory, analysis of various manifestations of Murphy's Law may also help motivate students to study otherwise dry topics.

But perhaps the most important lesson behind Murphy's Law is its light-hearted demonstration that apparently trivial phenomena do not always have trivial explanations. On the whole, that is not such a bad legacy.

ROBOTICS IN THE 21ST CENTURY

Automatons may soon find work as subservient household help

by Joseph F. Engelberger

Since Unimation, Inc., installed the first industrial robot in 1961 to unload parts from a die-casting operation, more than 500,000 similar constructs have gone to work in factories around the world. They are common sights in chemical processing plants, automobile assembly lines and electronics manufacturing facilities, replacing human labor in repetitive and possibly dangerous operations. But how will robotics evolve in the immediate decades ahead? Can it move from the industrial setting to serve people in their daily lives?

In his story "There Will Come Soft Rains," Ray Bradbury forecast that our homes would become enveloping automaton systems that could outlast the human inhabitants. Isaac Asimov came to different conclusions. In his robot novels, Asimov envisioned stand-alone robots that would serve and mingle with humans to our everlasting mutual benefit. The answer can be gleaned from real-world experience coupled with the speculations of these two science-fiction giants.

Finding first for Bradbury, we already have the Smart House project, an (expensive) option for home buyers in which a central computer optimizes heat, light, air conditioning and security. Add automatic control of communications, entertainment, data seeking and shopping in cyberspace, and seemingly much of Bradbury's conjecture is justified.

But not completely. Bradbury's house went further, offering automated cooking, cleaning and personal hygiene. A slew of little robot mice, for instance, would dart out from the baseboards throughout the house to pick up dirt. Human occupants literally did not have to lift a finger.

Such physical intervention, however, is where Bradbury's vision loses some credibility. Although we already have automation in washing machines, dishwashers, coffeemakers and so forth, these devices are loaded manually, with human hands. Robotic mice that do away with dust might be technically feasible at great cost, but it seems more practical to push around a vacuum cleaner every so often.

In that regard, I think Asimov's scenario becomes more likely. Rather than a specialized device, a household robot would be a stand-alone automaton. It would do the chores just as we do, using the same equipment and similar tools and responding to spoken commands and supplying verbal reports.

Therefore, the robots that serve us personally in the near future will of necessity be somewhat anthropomorphic, just as Asimov envisioned. To share a household with a human, the robot must be able to travel autonomously throughout the living quarters, to see and interpret needs, and to provide materials and services with a gentle and precise touch.

It may be that before the early decades of the 21st century become history, some profound invention will alter robotics. But it behooves this would-be oracle to stay within the bounds of current technology and logical extensions thereof. And that is not much of a constraint! Roboticists have a substantial toolbox in hand today — low-cost electronics, servomechanisms, controllers, sensors and communications equipment, to name just a few categories. Moreover, these instruments of construction are steadily evolving, particularly those in sensory perception. Active and passive beacons, stereo vision and even a receiver for the Global Positioning System (a network of satellites that broadcasts positional information) will enable a robot to navigate its environment effortlessly. Voice synthesis and recognition will ensure understanding of the human overseer's needs. Safety precautions, such as rules similar to Asimov's three laws of robotics — which can be loosely paraphrased as "Protect humans; obey humans; protect yourself" — can readily be embedded.

WHAT IS THE SIGNIFICANCE OF $E = MC^2$? AND WHAT DOES IT MEAN?[34]

by Ronald C. Lasky

It is the most famous equation in the world. Many can recite it — and attribute it to Albert Einstein — but few know its significance.

It tells us that mass and energy are related, and, in those rare instances where mass is converted totally into energy, how much energy that will be. The elegance with which it ties together three disparate parts of nature — energy, the speed of light and mass — is profound.

Here is where the equation of all equations comes from:

[34] Scientific American, April 2007, p. 23

It was known for some time before Einstein's insights that electromagnetic radiation (light, for example) possessed momentum. This quality of radiation is small in magnitude — after all, you needn't worry about being knocked over by sunlight — but easily measurable. Applying an understanding of light's momentum within a little thought experiment, it is possible to see how $E = mc^2$ comes about.

Consider a cubic hollow box at rest in space with sides of length D and a mass of M. This box is also symmetrical in its mass distribution. One of the faces inside the box is coated with a fluorescing material, and, at a given moment, a photon (i.e., a particle of light) is emitted from that material, perpendicular to its surface. The momentum of this photon causes the box to move in the opposite direction as the photon, and it continues to move until the photon hits the opposite wall. During this time the box moves a very small distance, Δx.

Newton's laws of mechanics tell us that the center of mass cannot move, because the box *has* not been acted upon by an outside force. However, in order to keep the center of mass constant, since the box has moved, some mass must have been transferred from the fluorescing side of the box to the absorbing side in the process of generating the photon and its striking the opposite side. Therefore the photon must have a mass, m.

So the photon, which also possesses energy E, is emitted from the fluorescing side of the box. Its momentum, P_{photon}, is equal to its energy divided by the speed of light: $P_{photon} = E/c$. The photon will impart this momentum to the box, causing the box to move a small distance, Δx, during the time, t, in which the photon travels to the opposite side of the box. The momentum of the box, P_{box}, is also equal to its mass, M, times the velocity, v_{box}, at which it moves before the photon strikes its target. (Note: The box loses the photon's mass, m, during this process, but this slight loss can be neglected here.) Hence:

$P_{photon} = P_{box} = E/c = Mv_{box}$

Then $v_{box} = E/cM$ (1)

We can also determine the time it takes for the photon to travel across the box: it is equal to the length, between parallel faces, of the box (which is D), minus the amount the box moved in the opposite direction (Δx), divided by the speed of light, c. (The target will essentially have moved a slight distance closer, meaning the photon did not have to travel the full distance D.):

$t = (D - \Delta x)/c$

But, since Δx is a minute fraction of D, we essentially get:

$t = D/c$ (2)

Now, since $v_{box} = \Delta x/t$, using equation 2, v_{box} can be restated as:

$v_{box} = \Delta xc/D$ (3)

Substituting equation 3 for the term v_{box} in equation 1:

$\Delta xc/D = E/cM$

Next, we rearrange the terms to get:

$\Delta xM = ED/c^2$ (4)

Assuming the center of the box is initially at $x = 0$, this position is also the center of mass, x_m. After the photon event, the box moves Δx to the left, as shown in the figure below, and the equivalent mass of the photon, m, is deposited on the opposite side. As mentioned above, we recall from Newton's Laws that the center of mass must not change, because the box is not acted upon by an outside force. This concept is expressed in the center of mass equation below. The center of mass is at $x = 0$ in the left half of the equation and it is still at 0 after the photon strikes the opposite wall as described in the right half of the equation.

$x_{m,initial} = x_{m,final}$

$0 = (-M\Delta x - m\Delta x + mD)/M$

Grouping like terms:

$0 = (mD - (M + m)\Delta x)/M$

Solving for Δx:

$\Delta x = mD/(M + m)$

Since m is extremely small:

$\Delta x = mD/M$ (5)

Substituting equation 5 into equation 4:

$(mDM)/M = ED/c^2$

The mass of the box and D cancel out, leaving:

$m = E/c^2$

Which rearranges to:

$E = mc^2$.

SIERPINSKI'S UBIQUITOUS GASKET[35]

by Ian Stewart

Strange numbers, strange shapes: these are the things that give mathematics its allure. And, even more so, strange connections — topics that seem totally different yet possess a hidden, secret unity. One of my favorite examples is Sierpinski's gasket of a triangular shape. In the term made famous by mathematician Benoit B. Mandelbrot, the shape is a fractal — it can be divided into parts that are smaller versions of the whole. But Sierpinski's gasket also has connections with self-intersections of curves, Pascal's triangle, the Tower of Hanoi puzzle, and the curious number 466/885, whose numerical value is roughly 0,52655. This number should be on everyone's list of "numbers that are more significant than they seem," alongside π, e, the golden number and so on.

Polish mathematician Waclaw Sierpinski introduced his gasket in 1915. It's easy to draw one: split an equilateral triangle into four triangles by connecting the triangle's midpoints, then remove the central triangle and repeat the procedure on the remaining triangles. If you do this an infinite number of times, you will end up with a curve that crosses itself at every point — a classic instance of a geometric property so counterintuitive that such shapes were originally known as pathological curves. Strictly speaking, the Sierpinski gasket crosses itself at every point except the three corners of the largest triangle. Sierpinski's answer to this objection is that if six copies of this triangle are arranged to form a regular hexagon, then the result is a curve that crosses itself at every point. Recently researchers have designed antennas in the shape of Sierpinski's gasket to take advantage of its jagged form.

Earlier, in 1890, French mathematician E'douard Lucas discovered a theorem that provides a connection between Sierpinski's gasket and the celebrated Pascal's triangle, in which each number is the sum of the two above it. These numbers are more technically known as binomial coefficients, and the kth entry in row n (where we number the rows and entries starting with 0 rather than 1) is the number of different ways to

[35]Scientific American, August 1999, pp. 90–91

choose k objects out of n. Lucas asked, When is a number in Pascal's triangle even or odd? The results are striking and surprising. The odd binomial coefficients look extraordinarily like a discrete version of the Sierpinski gasket.

One curious consequence is that nearly all binomial coefficients are even — that is, as the size of Pascal's triangle gets ever larger, the ratio of odd coefficients to even coefficients gets closer and closer to zero. The reason is that since the gasket is a curve, its area, which in the limit represents the proportion of odd binomial coefficients, is zero. David Singmaster of London's South Bank University has taken this observation further, proving that for any m, almost all binomial coefficients are divisible by m.

Lucas seems to have been haunted, albeit unwittingly, by Sierpinski's gasket. In 1883 he marketed the famous puzzle known as the Tower of Hanoi under the pseudonym "M. Claus" (the surname being an anagram of his own.) The puzzle consists of eight (or fewer) disks mounted on three pins and it is an old favorite of recreational mathematicians. The disks are arranged on one pin in order of size, and they have to be moved one at a time so that no disk ever sits on top of a smaller one. The object of the puzzle is to move all the disks to a different pin from the one they started from.

It is well known that the solution has a recursive structure. That is, the solution of $(n + 1)$-disk Hanoi can be simply deduced from that for n-disk Hanoi. For instance, suppose you know how to solve three-disk Hanoi, and you are presented with the four-disk version. Start by ignoring the bottom disk and use your knowledge of three-disk Hanoi to transfer the top three disks to an empty pin. Then move the bottom disk to the other empty pin. Now use your knowledge of three-disk Hanoi to transfer the top three disks to that same pin, on top of the bottom disk.

We can interpret this recursive structure geometrically, which is where the connection with the gasket comes in. For any puzzle of this general type, with moving objects and a finite number of positions, we can draw a graph: a collection of nodes (dots) joined by edges (lines). In a Tower of Hanoi graph, the nodes are the possible legal positions of the disks, and the edges represent the legal moves between positions. For n-disk Hanoi, call this graph H_n. What does it look like? Consider H_3, which describes the positions and moves in three-disk Hanoi. Number the three disks 1, 2 and 3, with 1 being the smallest and 3 the largest. Number the pins 1, 2 and 3, from left to right. Suppose that disk 1 is on pin 2, disk 2 on pin 1, and disk 3 on pin 2. The rules imply that disk 3 must be under disk 1. Thus, we can represent this position in the game by the sequence 212, the three digits in turn representing the pins for disks 1, 2 and 3. Each position in three-disk Hanoi corresponds to a similar three-digit sequence. There are $3^3 = 27$ positions, because each disk can be on any pin, independent of the others.

What are the permitted moves from position 212? The smallest disk on any pin must be at the top; we cannot move disk 2 to pin 2, for example, because it would then lie on top of the smaller disk 1. From position 212 we can make legal moves only to 112, 312 and 232. The graph H_3 shows all the possible moves from all 27 positions. It consists of three copies of a smaller graph, H_2, linked by three edges to form a triangle.

Each smaller graph H_2 has a similar triple structure, and this is a consequence of the recursive solution. The edges that join the three copies of H_2 together are the stages at which the bottom disk is moved, and the three copies of H_2 are the ways you can move the top two disks only — one copy for each possible position of the third disk. The same goes for any H_n: it is made from three copies of H_{n-1}, linked in a triangular manner. As the number of disks becomes larger and larger, the graph looks more and more like Sierpinski's gasket.

We can use the H_n graph to answer all kinds of questions about the Tower of Hanoi puzzle. For example, the graph is clearly connected — all in one piece — so we can move from any position to any other. The minimum path from the usual starting position (one corner of the largest triangle) to the usual finishing position (another corner) runs straight along one side of the graph and consists of $2^n - 1$ edges. Hence, the puzzle can be solved in a minimum of $2^n - 1$ moves.

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