И.Ю. Коваленко,
А.В. Плотникова

Scientific English for Students of Physics

Московский государственный университет имени М.В. Ломоносова
Физический факультет
Кафедра английского языка

И.Ю. Коваленко, А.В. Плотникова

SCIENTIFIC ENGLISH
FOR STUDENTS OF PHYSICS

Учебник для студентов старших курсов
физического факультета

Москва
Физический факультет МГУ
2020

УДК 811.111
ББК 81.2 Англ.
К56

Коваленко И.Ю., Плотникова А.В.
Scientific English for Students of Physics / Учебник — М.: Физический факультет МГУ, 2020, 190 с.
ISBN 978-5-8279-0177-8

Учебник предназначен для студентов старших курсов по направлению подготовки “Физика”, продолжающих изучение английского языка для профессионального общения в диапазоне уровней В1-В2.

Основными целями учебника являются дальнейшее развитие коммуникативных компетенций на базе аутентичных материалов по физике, систематизация грамматического материала, расширение словарного запаса студентов за счёт общенаучной и терминологической лексики.

Печатается по рекомендации Учёного совета физического факультета МГУ им. М.В. Ломоносова

Рецензенты:
Е.Л. Агибалова, кандидат филологических наук, доцент;
О.Д. Шляхова, кандидат филологических наук, доцент.

ISBN 978-5-8279-0177-8

CONTENTS

ПРЕДИСЛОВИЕ

Учебник "Scientific English for Students of Physics" предназначен для студентов старших курсов физического факультета, продолжающих изучение английского языка для профессионального общения. Целью учебника является закрепление и дальнейшее развитие ранее приобретенных студентами коммуникативных компетенций на материале, знакомящем их с такими актуальными областями науки и техники, как оптика, фотоника, физика частиц, ядерная физика, физика звезд, нанотехнологии. Тщательно отобранные аутентичные тексты дают представление как об истории научных открытий, так и о современных достижениях ученых.

Работа с учебником позволяет решить следующие задачи:

- в области развития языковых компетенций:
  1) отработать правильное произношение и чтение общенаучной и терминологической лексики;
  2) повторить характерные для научного текста грамматические явления;
  3) активизировать общенаучную и терминологическую лексику по тематике уроков;
- в области развития речевых компетенций:
  1) совершенствовать навыки дифференцированного чтения научной литературы;
  2) развивать навыки устной монологической и диалогической научной речи;
  3) формировать навыки устного и письменного реферирования;
  4) развивать навыки продуктивного письма;
- в области перевода: отрабатывать навыки перевода текстов по специальности с учетом лексико-грамматических трансформаций.

В результате освоения учебного материала студенты должны:

знать: лексику и грамматику в объеме, предусмотренном учебником;

уметь: извлекать профессионально значимую информацию из научных текстов разной степени сложности, вести беседу в рамках пройденной научной тематики, участвовать в дискуссии, делать доклады и презентации, переводить научные тексты с английского языка на русский и с русского языка на английский в соответствии с нормами языка перевода;

владеть: английским языком для его эффективного использования в профессиональной и научной деятельности в диапазоне уровней B1 - B2.

Учебник состоит из шести уроков, соответствующих определенному разделу физики, и приложения Course Vocabulary. Каждый урок рассчитан на 6-8 часов аудиторной работы и включает тексты с заданиями, лексико-грамматические упражнения, проектные задания, а также список ключевых терминологических слов и выражений.

Типология упражнений предусматривает следующие виды работы:

1) поиск транскрипции и правильное воспроизведение слов и словосочетаний из базового текста;
2) нахождение лексических эквивалентов ключевых слов и словосочетаний;
3) создание собственных предложений с ключевыми словами и словосочетаниями;
4) вопросно-ответная форма работы с текстом;
5) составление плана текста и его последующий пересказ;
6) структурно-семантический анализ абзаца;
7) смысловой анализ текста по абзацам;
8) обучение навыкам устной и письменной компрессии текстов;
9) подготовка к выступлению на заданную тему, ведению дискуссии и др.

Помимо решения задач, связанных с углублением и совершенствованием знаний английского языка, учебник дает студентам возможность расширить представление о предмете своего профессионального изучения – физике.

UNIT 1. HOLOGRAPHY

TEXT 1

1. Check the pronunciation of these words in a dictionary. If necessary, specify their meaning.

although, coherent, component, confront, content, exhibit, focus, hologram, holography, illuminate, multitude, original, source, technique, transparent, trough, unique, utilize, whorl

2. Read the text and answer the questions below.

1) What does holography deal with?
2) How would you define a hologram?
3) What is the difference between an ordinary photographic image and a hologram?
4) How was holography invented?
5) How did the development of lasers advance holography?
6) What are the basic principles of holography?

1. Holography is a means of creating a unique photographic image without the use of a lens. The photographic recording of the image is called a hologram, which appears to be an unrecognizable pattern of stripes and whorls but which – when illuminated by coherent light, as by a laser beam – organizes the light into a three-dimensional representation of the original object.

2. An ordinary photographic image records the variations in intensity of light reflected from an object, producing dark areas where less light is reflected and light areas where more light is reflected. Holography, however, records not only the intensity of the light but also its phase, or the degree to which the wave fronts making up the reflected light are in step with each other, or coherent. Ordinary light is incoherent – that is, the phase relationships between the multitude of waves in a beam are completely random; wave fronts of ordinary light waves are not in step.

3. Dennis Gabor, a Hungarian-born scientist, invented holography in 1948, for which he received the Nobel Prize for Physics more than 20 years later (1971). Gabor considered the possibility of improving the resolving power of the electron microscope, first by utilizing the electron beam to make a hologram of the object and then by examining this hologram with a beam of coherent light. In Gabor's original system the hologram was a record of the interference between the light diffracted by the object and a collinear background. This automatically restricts the process to that class of objects that have considerable areas that are transparent. When the hologram is used to form an image, twin images are formed. The light associated with these images is propagating in the same direction, and hence in the plane of one image light from the other image appears as an out-of-focus component. Although a degree of coherence can be obtained by focusing light through a very small pinhole, this technique reduces the light intensity too much for it to serve in holography; therefore, Gabor's proposal was for several years of only theoretical interest. The development of lasers in the early 1960s suddenly changed the situation. A laser beam has not only a high degree of coherence but high intensity as well.

4. Of the many kinds of laser beam, two have especial interest in holography: the continuous-wave (CW) laser and the pulsed laser. The CW laser emits a bright, continuous beam of a single, nearly pure colour. The pulsed laser emits an extremely intense, short flash of light that lasts only about 1/100,000,000 of a second. Two scientists in the United States, Emmett N. Leith and Juris Upatnieks of the University of Michigan, applied the CW laser to holography and achieved great success, opening the way to many research applications.

5. In essence, the problem Gabor conceived in his attempt to improve the electron microscope was the same as the one photographers have confronted in their search for three-dimensional realism in photography. To achieve it, the light streaming from the source must itself be photographed. If the waves of this light, with their multitude of rapidly moving crests and troughs, can be frozen for an instant and photographed, the wave pattern can then be reconstructed and will exhibit the same three-dimensional character as the object from which the light is reflected. Holography accomplishes such a reconstruction by recording the phase content as well as the amplitude content of the reflected light waves of a laser beam. How this works is shown in Figure 1 on the left.

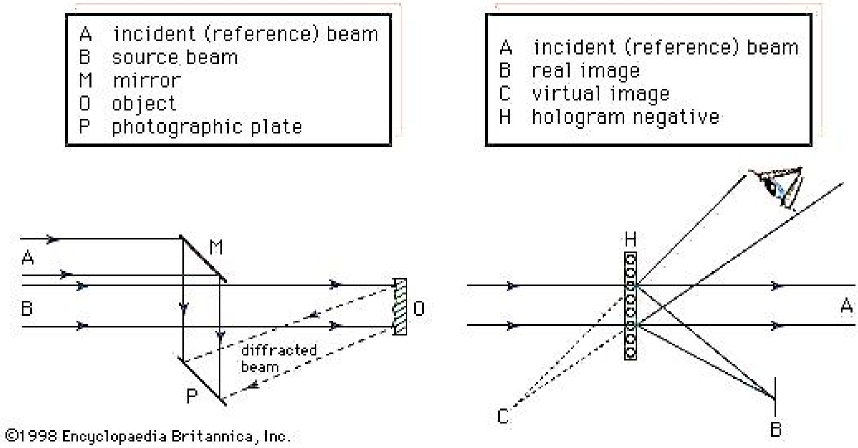


Figure 1. Arrangements for (left) creating a hologram and (right) reconstructing an image from a hologram. Encyclopædia Britannica, Inc.

LANGUAGE REVIEW

Focus on word formation

1. ***Review noun-forming suffixes and match the verbs with appropriate nouns.***

   accomplish, appear, apply, interfere, produce, propagate, reconstruct, reduce, reflect, represent, vary

2. ***Identify what part of speech the word 'record' represents in paragraphs 2 and 3, then check how it should be pronounced in each case.***

3. ***Give the negative form of the adjectives 'recognizable' and 'coherent'.***

Focus on grammar

1. ***Answer the questions.***

   1) How is the Passive Voice formed?
   2) What are the features of non-finite forms of the verb?
   3) What are the main functions of the Participle in the sentence?

4) What functions can the Gerund be used in?
5) What multifunctional words do you know? Can you name the functions of 'one', 'it' and 'that' in the sentence?
6) What is understood by asyndetic connection between clauses in complex sentences?

2. *Do the following tasks.*

1) Analyse the use of the Passive Voice forms in paragraphs 2 and 3.
2) Comment on the use of participles in paragraphs 1, 2 and 5.
3) State the functions of the Gerund in paragraphs 1 and 3.
4) Identify the function of 'one' in paragraphs 3 and 5 and the function of 'that' in paragraphs 3 and 4.
5) Find the referents of the word 'which' in paragraphs 1, 2 and 5.
6) Indicate the difference in the usage of the verb 'appear' in paragraphs 1 and 3.
7) Identify asyndetic attributive clauses in paragraph 5.

Focus on paragraph structure and content

1. *Answer the questions.*

1) What key terms and phrases provide an effective means of connecting the sentences in all the paragraphs of Text 1?
2) What parallel grammatical and structural forms (words, phrases, clauses) are used in paragraphs 2, 3 and 4 to add more clarity and emphasis to the text?
3) What does the pronoun 'it' in paragraph 5 refer to?

2. *Do the following tasks.*

1) Indicate the topic sentence in each paragraph of Text 1.
2) Develop the idea of each topic sentence.
3) Sum up the main points of Text 1.

3. *Study the list of connecting words and phrases. Which of them occur in Text 1?*

Enumeration: first, furthermore, finally; firstly, secondly, thirdly; first and foremost; to begin with, in the second place, moreover, and to conclude; next, then, afterward, lastly, finally, eventually
Addition: also, again, in addition, besides, above all, as well (as), too, not only...but also, either…or

Similarity: equally, likewise, similarly, correspondingly, in the same way
Transition: now, with respect to, regarding, as for/to, let us now turn to
Summation: in conclusion, to conclude, to sum up, in short/brief, altogether, thus
Apposition: that is, namely, in other words, or, or rather
Exemplification: for example, for instance
Result: so, therefore, as a result, consequently, because of this, hence, for this reason
Contrast: but, instead, conversely, on the contrary, on the one hand... on the other hand
Concession: besides, however, nevertheless, notwithstanding, only, still, while, (al)though, yet, in spite of, despite that, in any case, at any rate, after all
Emphasis: most importantly, indeed, in fact, certainly, truly

Focus on vocabulary

1. *Define or explain these terms.*

hologram, coherent light, wave front, ordinary light, interference, diffraction, continuous-wave laser, pulsed laser, wave pattern, real image, virtual image, photographic plate, source beam, incident beam, reference beam, crest, trough

2. *Give English equivalents for the following word combinations. Make up sentences with some of them.*

метод создания фотографического изображения, освещаться светом, регистрировать и восстанавливать трехмерное изображение, отраженный свет, дифрагированный свет, улучшить разрешающую способность электронного микроскопа, пучок когерентного света, воспроизведение голограммы, интерференция световых волн, амплитуда и фаза световых волн, мнимое изображение, действительное изображение, падающий луч (пучок), опорный луч (пучок), импульсный лазер, лазер непрерывного излучения

3. *Give Russian equivalents for the following word combinations.*

a pattern of stripes and whorls, a three-dimensional representation of the original object, variations in intensity of light reflected from an object, the phase relationships between the multitude of waves in a beam, to examine the hologram with a beam of coherent light, to form twin images, to focus light through a very small pinhole, to reduce the light intensity, to confront a problem, rapidly moving crests and troughs, to record the phase content and the amplitude content of the reflected light waves, to reconstruct an image from a hologram

TEXT 2

1. Write an outline of the text in the form of questions and discuss the basic principles of continuous-wave laser holography. Work in pairs.

Continuous-Wave Laser Holography

In a darkened room, a beam of coherent laser light is directed onto object O from source B (see Figure 1). The beam is reflected, scattered, and diffracted by the physical features of the object and arrives on a photographic plate at P. Simultaneously, part of the laser beam is split off as an incident, or reference, beam A and is reflected by mirror M also onto plate P. The two beams interfere with each other; that is, their respective amplitudes of waves combine, creating on the photographic plate a complex pattern of stripes and whorls called interference fringes. These fringes consist of alternate light and dark areas. The light areas result when the two beams striking the plate are in step – when crest meets crest and trough meets trough in the waves from the two beams; the beams are then in phase, and so reinforce each other. When the two waves are of equal amplitude but opposite phase – trough meeting crest and crest meeting trough – they cancel each other and a dark area results.

The plate, when developed, is called a hologram. The image on the plate bears no resemblance to the object photographed but contains a record of all the phase and amplitude information present in the beam reflected from the object. The two parts of the laser beam – the direct and the reflected beams – meet on the plate at a wide angle and are recorded as very fine and close-packed interference fringes on the hologram. This pattern of fringes contains all the optical information of the object being photographed.

By reversing the procedure, as shown on the right in Figure 1, an image of the original object can be reconstructed. The coherent light of a laser beam illuminates the hologram negative H. Most of the light from the laser passes through the film as a central beam A and is not used. The close-packed, fine-detailed fringes on the hologram negative act as a diffraction grating, bending or diffracting the remaining light to exactly reverse the original condition of the coherent light waves that created the hologram. The diffracted light is transmitted at a wide angle from that of the laser's reference beam.

On the light source side of the hologram, at C, a virtual image visible to the eye is formed. On the other side, at B, a real image that can be photographed is formed. Both these reconstituted images have a three-dimensional character because in addition to amplitude information, which is all that an ordinary photographic process stores, phase information also has been stored. This phase information is what provides the three-dimensional characteristics of the image, as it contains within it exact information on the depths and heights of the various contours of the object. It is possible to photograph the reconstituted image, at B, by ordinary photographic means, at a selected depth, in exact focus.

The real image from a hologram – that is, the one that can be photographed – appears pseudoscopic, or with a reversed curvature. This reversal can be eliminated by making a double hologram, first by preparing the single hologram and then by using it as an object in the creation of a second hologram. With a double reversal the image becomes normal again, as when a mirror image of writing is made legible by viewing it in a second mirror. The real image of a hologram has valuable properties. A viewing camera or microscope can be positioned and focused on various selected positions in depth. The original object also can be brought into the position in space.

The hologram not only offers images at different depths (different cross-sections of the object) but also images seen along different directions if the viewer moves off the axis on which the principal image is viewed. Direct images can be seen under these conditions. In holography it is also possible to record on the same plate a succession of numerous multiple images that can be reconstructed as one image, leading to the possibility of holography in colour. Three holograms could be superimposed on the same plate, using three lasers of different colours. Reconstruction with the three different lasers would produce an image in its natural colour, even though the hologram plate itself is black-and-white.

2. ***Here are the sentences from Text 2. Fill in the gaps with appropriate prepositions from memory.***

   1) In a darkened room, a beam … coherent laser light is directed … object O from source B.
   2) The two beams interfere … each other; that is, their respective amplitudes … waves combine, creating … the photographic plate a complex pattern … stripes and whorls called interference fringes.
   3) These fringes consist … alternate light and dark areas.
   4) When the two waves are … equal amplitude but opposite phase – trough meeting crest and crest meeting trough – they cancel each other and a dark area results.
   5) The image … the plate bears no resemblance … the object photographed but contains a record of all the phase and amplitude information present in the beam reflected … the object.
   6) By reversing the procedure, as shown … the right … Figure 1, an image … the original object can be reconstructed.
   7) The hologram not only offers images … different depths (different cross-sections of the object) but also images seen … different directions if the viewer moves off the axis … which the principal image is viewed.

3. ***Translate the following sentences. Identify the Passive Voice forms, the Participle, the Gerund, and multifunctional words.***

   1) The beam is reflected, scattered, and diffracted by the physical features of the object and arrives on a photographic plate at P.
   2) The plate, when developed, is called a hologram.
   3) This pattern of fringes contains all the optical information of the object being photographed.
   4) The close-packed, fine-detailed fringes on the hologram negative act as a diffraction grating, bending or diffracting the remaining light to exactly reverse the original condition of the coherent light waves that created the hologram.
   5) This phase information is what provides the three-dimensional characteristics of the image, as it contains within it exact information on the depths and heights of the various contours of the object.
   6) It is possible to photograph the reconstituted image, at B, by ordinary photographic means, at a selected depth, in exact focus.

7) The real image from a hologram – that is, the one that can be photographed – appears pseudoscopic, or with a reversed curvature.
8) This reversal can be eliminated by making a double hologram, first by preparing the single hologram and then by using it as an object in the creation of a second hologram.
9) This reversal can be eliminated by making a double hologram, first by preparing the single hologram and then by using it as an object in the creation of a second hologram.
10) Three holograms could be superimposed on the same plate, using three lasers of different colours.

4. ***Read the text again and trace connecting words and phrases. If necessary, check their meaning.***

TEXT 3

1. ***Read the text and highlight the advantages of pulsed laser holography.***

Pulsed-Laser Holography

A moving object can be made to appear to be at rest when a hologram is produced with the extremely rapid and high-intensity flash of a pulsed ruby laser. The duration of such a pulse can be less than 1/10,000,000 of a second; and, as long as the object does not move more than 1/10 of a wavelength of light during this short time interval, a usable hologram can be obtained. A continuous-wave laser produces a much less intense beam, requiring long exposures; thus it is not suitable when even the slightest motion is present.

With the rapidly flashing light source provided by the pulsed laser, exceedingly fast-moving objects can be examined. Chemical reactions often change optical properties of solutions; by means of holography, such reactions can be studied. Holograms created with pulsed lasers have the same three-dimensional characteristics as those made with CW sources.

Pulsed-laser holography has been used in wind-tunnel experiments. Usually high-speed air flow around aerodynamic objects is studied with an optical interferometer (a device for detecting small changes in interference fringes, in this instance caused by variations in air density).

Such an instrument is difficult to adjust and hard to keep stable. Furthermore, all of its optical components (mirrors, plates, and the like) in the optical path must be of high quality and sturdy enough to minimize distortion under high gas-flow velocities. The holographic system, however, avoids the stringent requirements of optical interferometry. It records interferometrically refractive-index changes in the air flow created by pressure changes as the gas deflects around the aerodynamic object.

2. ***On the Internet, look for information about other applications of pulsed-laser holography and share it with other students.***

TEXT 4

1. ***Read the text and identify the topic of each paragraph.***

Major Applications of Holography

1. Because the real image from the hologram can be viewed by a camera or microscope, it is possible to examine difficult and even inaccessible regions of the original object. This feature renders holography useful for many purposes. A deep, narrow depression on a plane, for example, cannot often be reached by a microscope objective because of working distance limitations. If the detail can be reached by coherent light, however, a hologram can be taken and its image reconstructed. Since this image is aerial, the microscope can be positioned in such a way that it can focus on the required region. In the same way, a camera also can be focused at the required depth and can photograph objects inside a deep transparent chamber.

2. Many holographic applications exploit the fact that composite repeat holograms of a surface tilted slightly after each exposure can be treated as composite, repeat wave patterns. If two such patterns are matched, a condition arises that is effectively the same as that which exists in ordinary classical two-beam interferometry, in which a single light source is split into two beams and the beams recombined to form interference patterns. Such an arrangement can be set up in several ways; in one, a holographic exposure is made of a surface, then, before the hologram is removed or developed, the surface is slightly tilted and a repeat hologram is made, superimposed on the first hologram. When this double hologram is reconstructed, the object as well as the surface

covered by the interference fringes caused by surface irregularities can be seen. These fringes reveal microtopographic information about the object.

3. Holographic interferometry can be applied successfully to any situation in which the wave front is modified slightly, no matter how complex the surface may be. Elastic deformation effects can be studied by superimposing the two wave fronts on the hologram, reflected before and after the elastic distortion effect has been introduced. When reconstructed, the hologram provides a clear picture of the object, crossed by interference fringes. Even highly complex shapes respond to this approach in a manner that would be impossible in classical interferometry. There is also great flexibility in the choice of methods used to apply distortions, and even these conditions alone often completely exclude optical interferometry. Not only static distortion but also slow dynamic variations can be studied in this manner. And with pulsed ruby lasers, very fast, short-time variations can be studied.

4. Time variations in the shape of an object are not usually studied with a single, double-exposure hologram but by an alternative method. First, a hologram is made of the object in its free, unstressed condition. Then the object is stressed and a new hologram made. The stressed hologram is viewed through the original unstressed hologram, and the superposition provides the interference fringe pattern that would have been produced by a double exposure. By such means, time variations can be studied. Valuable studies have been made of mechanically vibrating systems, such as diaphragms, musical instruments (e.g., the belly of a violin), vibrating steam-turbine blades, and the like. The examination of large engineering components, measuring as much as one metre (about three feet) in length, imposes special problems. The distance between the hologram plate and the object must be great enough to ensure that all of the object can be seen at once. In turn, laser power must be increased, high demands on the coherence of light are imposed, and mechanical stability of the whole setup must be exceptionally good.

5. When hologram interferometry is applied to the examination of vibrations set up in a rapidly rotating turbine blade, stroboscopic techniques aid the analysis. The laser light is stroboscopically interrupted at the same frequency as the rotation of the turbine blade, and, with the blade thus apparently at rest, a hologram is produced. Consequently, a holographic interferometric pattern is created for the blade whose motion is stopped by stroboscopic action. By slightly altering the frequency of the stroboscope arrangement, a slow scan can be made over the complete vibrational stress pattern to which the blade is subjected. Much

information about stresses in turbine blades and other rotating or vibrating objects can be obtained from such holograms.

6. Although holography can solve many problems, it still is a relatively expensive procedure. It has been used – or misused – in applications more amenable to simpler and cheaper methods. The laser system by itself is a fairly complex and costly piece of equipment, and costs are aggravated further by the additional equipment and the long exposure times required to produce holograms and reconstruct images. Aside from its uses in microscopy and interferometry, holography is therefore applied only when other methods have failed or are not precise enough.

2. Read the text again and say what makes holography useful in many applications, on the one hand, and what limits its utility, on the other.

TEXT 5

1. Read the text and answer the questions.

1) How is a hologram defined in the text below? Compare the description of a hologram in Text 1 with that in Text 5. Which do you think is better and why?
2) What is the most basic difference in the recording of reflection holograms and transmission holograms?
3) What hybrid holograms are mentioned in the text?

Types of holograms

A hologram is a recording in a two- or three-dimensional medium of the interference pattern formed when a point source of light (the reference beam) of fixed wavelength encounters light of the same fixed wavelength arriving from an object (the object beam). When the hologram is illuminated by the reference beam alone, the diffraction pattern recreates the wave fronts of light from the original object. Thus, the viewer sees an image indistinguishable from the original object.

There are many types of holograms, and there are varying ways of classifying them.

A. Reflection holograms

The reflection hologram, in which a truly three-dimensional image is seen near its surface, is the most common type shown in galleries. The hologram is illuminated by a "spot" of white incandescent light, held at a specific angle and distance and located on the viewer's side of the hologram. Thus, the image consists of light reflected by the hologram. Recently, these holograms have been made and displayed in color – their images optically indistinguishable from the original objects. If a mirror is the object, the holographic image of the mirror reflects white light; if a diamond is the object, the holographic image of the diamond is seen to "sparkle".

Although mass-produced holograms such as the eagle on the VISA card are viewed with reflected light, they are actually transmission holograms "mirrorized" with a layer of aluminum on the back.

B. Transmission holograms

The typical transmission hologram is viewed with laser light, usually of the same type used to make the recording. This light is directed from behind the hologram and the image is transmitted to the observer's side. The virtual image can be very sharp and deep. For example, through a small hologram, a full-size room with people in it can be seen as if the hologram were a window. If this hologram is broken into small pieces (to be less wasteful, the hologram can be covered by a piece of paper with a hole in it), one can still see the entire scene through each piece. Depending on the location of the piece (hole), a different perspective is observed. Furthermore, if an undiverged laser beam is directed backward (relative to the direction of the reference beam) through the hologram, a real image can be projected onto a screen located at the original position of the object.

C. Hybrid holograms

Between the reflection and transmission types of holograms, many variations can be made.

• Embossed holograms: To mass produce cheap holograms for security application such as the eagle on VISA cards, a two-dimensional interference pattern is pressed onto thin plastic foils. The original hologram is usually recorded on a photosensitive material called photoresist. When developed, the hologram consists of grooves on the surface. A layer of nickel is deposited on this hologram and then peeled off, resulting in a metallic "shim". More secondary shims can be produced from the first one. The shim is placed on a roller. Under high temperature and pressure, the shim presses (embosses) the hologram onto a roll of composite material similar to Mylar.

• Integral holograms: A transmission or reflection hologram can be made from a series of photographs (usually transparencies) of an object – which can be a live person, an outdoor scene, a computer graphic, or an X-ray picture. Usually, the object is "scanned" by a camera, thus recording many discrete views. Each view is shown on an LCD screen illuminated with laser light and is used as the object beam to record a hologram on a narrow vertical strip of holographic plate (holoplate). The next view is similarly recorded on an adjacent strip, until all the views are recorded. When viewing the finished composite hologram, the left and right eyes see images from different narrow holograms; thus, a stereoscopic image is observed. Recently, video cameras have been used for the original recording, which allows images to be manipulated through the use of computer software.

• Holographic interferometry: Microscopic changes on an object can be quantitatively measured by making two exposures on a changing object. The two images interfere with each other and fringes can be seen on the object that reveal the vector displacement. In real-time holographic interferometry, the virtual image of the object is compared directly with the real object. Even invisible objects, such as heat or shock waves, can be rendered visible. There are countless engineering applications in this field of holometry.

• Multichannel holograms: With changes in the angle of the viewing light on the same hologram, completely different scenes can be observed. This concept has enormous potential for massive computer memories.

• Computer-generated holograms: The mathematics of holography is now well understood. Essentially, there are three basic elements in holography: the light source, the hologram, and the image. If any two of the elements is predetermined, the third can be computed. For example, if we know that we have a parallel beam of light of certain wavelength and we have a "double-slit" system (a simple "hologram"), we can calculate the diffraction pattern. Also, knowing the diffraction pattern and the details of the double-slit system, we can calculate the wavelength of the light. Therefore, we can dream up any pattern we want to see. After we decide what wavelength we will use for observation, the hologram can be designed by a computer. This computer-generated holography (CGH) has become a sub-branch that is growing rapidly. For example, CGH is used to make holographic optical elements (HOE) for scanning, splitting, focusing, and, in general, controlling laser light in many optical devices such as a common CD player.

(Basic Principles and Applications of Holography - SPIE)

2. ***Give on overview of different types of holograms. Draw a mind-map to help you do the task.***

3. ***Find additional information on one of the hybrid holograms and share it with other students.***

CHECK YOURSELF

1. ***Translate the text at sight. State the functions of the Participle and the Gerund. Identify the Absolute Participial Construction.***

From 1960 onwards, holography grew rapidly, both in fields of display and scientific imagery. Two scientists working in a lab at the University of Michigan, Emmett Leith and Juris Upatnieks, developed the basics of the reflection hologram as we know it today. Meanwhile, in the Soviet Union, Yuri Denisyuk, who was also working on optical holography, invented another type of hologram which is also still in use.

People became interested in holography as a creative medium in the mid to late 60's, with focal points developing in San Francisco, New York and London. Leith and Upatnieks as well as Stephen A. Benton all developed processes for making holograms that were viewable using ordinary white light. Art holography was born.

A revolutionary technique for mass-producing holograms cheaply and in very large numbers was developed in the mid 1970's. Known as the embossed hologram, this is the type of holography that most of us are familiar with, seen on credit cards and bank notes.

2. ***Translate the text in writing. Time limit: 35 min.***

Interferometry and holography

The coherence of laser light is crucial for interferometry and holography, which depend on interactions between light waves to make extremely precise measurements and to record three-dimensional images. The result of adding light waves together depends on their relative phases. If the peaks of one align with the valleys of the other, they will interfere destructively to cancel each other out; if their peaks align, they will interfere constructively to produce a bright spot. This effect can be used for measurement by splitting a beam into two identical halves that follow different paths. Changing one path just half a wavelength from the other will shift the two out of phase, producing a dark spot. This technique has proved invaluable for precise measurements of very small distances.

Holograms are made by splitting a laser beam into two identical halves, using one beam to illuminate an object. This object beam then is combined with the other half – the reference beam – in the plane of a photographic plate, producing a random-looking pattern of light and dark zones that record the wave front of light from the object. Later, when laser light illuminates that pattern from the same angle as the reference beam, it is scattered to reconstruct an identical wave front of light, which appears to the viewer as a three-dimensional image of the object. Holograms now can be mass-produced by an embossing process, as used on credit cards, and do not have to be viewed in laser light.

3. *Translate the sentences into English.*

1) Голография как метод восстановления волнового фронта была предложена Д. Габором в 1947 году.
2) Д. Габор теоретически и экспериментально обосновал возможность записи и последующего восстановления амплитуды и фазы волны при использовании двумерной (плоской) регистрирующей среды.
3) Основы современной голографии были заложены в начале 1960-х годов благодаря появлению лазеров.
4) Э.Лейт и Ю.Упатниекс, разработавшие внеосевую схему записи голограмм (off-axis hologram recording scheme), а также Д.Н. Денисюк, предложивший голографический метод с записью в трехмерных средах, внесли значительный вклад в развитие голографии.
5) Для образования голограммы, которая, по сути, является интерференционной картиной, необходимо существование, по крайней мере, двух когерентных волн.
6) Основные свойства и особенности голограмм связаны с возможностью восстановления волны, неотличимой от исходной объектной волны, т.е. волны, сформированной объектом.
7) Лазер считается наиболее эффективным и применяемым источником света при голографической записи.
8) Информация об объекте, как известно, фиксируется на голограмме в виде совокупности интерференционных полос.

9) Существует много способов изготовления голограмм, и каждая из них имеет свои особенности.
10) Голография нашла применение в таких областях, как оптическое приборостроение, оптическая обработка информации, изобразительная техника, интерферометрия, лазерная техника, регистрация быстропротекающих процессов, неразрушающий контроль изделий и др.

4. *Render the text into English, either orally or in writing, and entitle it.*

Термин "голография", включающий в себя два греческих слова, означающих в переводе "весь, полный" и "рисую, отображаю", был введен в употребление венгерским ученым Д. Габором, предложившим в 1947 году метод записи волновых фронтов, позволяющий сохранить информацию как об амплитуде, так и о фазе регистрируемого излучения. Своим рождением голография обязана попыткам улучшить разрешающую способность электронного микроскопа, существенным образом ограниченную сферической аберрацией электронных фокусирующих систем. Предыстория голографии начинается с работ немецкого физика Е. Аббе (E. Abbe), создавшего теорию формирования изображения в микроскопе. В соответствии с ней процесс формирования изображения представляет собой последовательность актов дифракции и интерференции. Сначала излучение дифрагирует на структуре объекта. При этом за объектом формируется дифракционное поле, представляющее собой совокупность волн, дифрагированных на структуре объекта. После чего взаимная интерференция этих волн формирует изображение объекта. Последователи Аббе пытались решить задачу разделения указанных выше актов и их практического использования. В частности, М. Вольфке (M. Wolfke) в 1920 году хотел реализовать дифракционную часть процесса в рентгеновском излучении, а интерференционную часть – в видимом свете. Опыты Вольфке закончились неудачей, поскольку, регистрируя дифракционное поле на фотопластине, он терял информацию о фазовой составляющей поля. Позднее У. Л. Брэгг (W. L. Bragg), повторяя опыты Вольфке и используя слюдяные пластинки для внесения фазовых задержек в отдельные участки дифракционного поля, получил изображение распределения атомов в кристалле. В 1935 году Ф. Цернике (F. Zernike) предложил отказаться от подбора фазы и осуществлять её запись путем добавления когерентного фона, т.е. опорной волны, к дифракционной картине. Однако практически реализовать свое предложение он так и не смог. Лишь в 1948 году Д. Габору удалось с помощью излучения ртутной лампы (mercury-vapor lamp) зарегистрировать картину интерференции двух волн, обладающих относительно высокой степенью когерентности: волны, дифрагированной на объекте, и фоновой квазиплоской волны (quasi-plane wave), играющей роль когерентного фона. В качестве объекта он использовал бинарный транспарант (transparency), содержащий лишь прозрачные и непрозрачные участки. Сквозь непрозрачные участки проходил когерентный фон. Непрозрачные участки транспаранта формировали дифракционное поле объекта. Зарегистрированная таким образом интерференционная картина получила название голограммы. Д. Габору за эту работу в 1971 году была присуждена Нобелевская премия по физике.

(Корешев С.Н. Основы голографии и голограммной оптики)

FOCUS ON PRODUCTIVE WRITING AND SPEAKING SKILLS

1. ***Write a paragraph of 100-120 words to describe one type of holograms at your choice. Ensure continuity within a paragraph using proper means of cohesion.***

2. ***Prepare a 5-minute talk on one of the following topics. You may choose any other topic related to holography which is not on the list.***

   1) Holography pioneers
   2) Holography in healthcare applications
   3) Interactive holograms
   4) Touchable holograms
   5) Cutting-edge technologies in holography

KEY WORDS AND WORD COMBINATIONS

Amplitude
    amplitude content
Background
Beam

incident beam, reference beam, laser beam, object beam

Coherence

high degree of coherence

Crest

Deflection

Diffraction

diffraction grating

Distortion

distortion effect

Electron microscope

Exposure

Hologram

double-exposure hologram, embossed hologram, hybrid hologram, integral hologram, multichannel hologram, reflection hologram, repeat hologram, transmission hologram; hologram negative

Holography

computer-generated holography (CGH), pulsed-laser holography

Image

mirror image, real image, reconstructed image, three-dimensional image, virtual image

Interference

interference fringes

Interferometry

holographic interferometry, optical interferometry

Laser

continuous-wave laser, pulsed laser

Lens

Light

(in)coherent light, ordinary light, white incandescent light

Pattern

diffraction pattern, fringe pattern, holographic interferometric pattern, interference pattern, wave pattern; pattern of stripes and whorls

Phase

in phase; phase content, phase relationships

Photographic plate

Reconstruction

Recording
    photographic recording
Reflection
Resolving power
Three-dimensional
    three-dimensional character, three-dimensional characteristics, three-dimensional realism, three-dimensional representation
Transparency
Trough
Wave
    wave front, wavelength

UNIT 2. LASER

TEXT 1

1. Check the pronunciation of these words in a dictionary. If necessary, specify their meaning.

alignment, atom, atomic, audio, automated, bomb, broad, chromium, debate, designator, diverse, envision, excess, frequency, guide, helium, litigation, neon, patent, profile, project, retina, royalty, ruby, spontaneously, surgeon, target, tiny

2. Read the text about the history of the laser and answer the questions below.

1) What is Einstein's contribution to the laser?
2) Who developed the idea of a maser? What does the acronym 'maser' stand for?
3) Who coined the word laser and what does it stand for?
4) When were the first ruby, gas and semiconductor lasers built and by whom?
5) What made helium-neon lasers commercially successful?
6) What application did ruby lasers find?
7) What other applications of lasers followed?

History

1. The laser is an outgrowth of a suggestion made by Albert Einstein in 1916 that under the proper circumstances atoms could release excess energy as light – either spontaneously or when stimulated by light. German physicist Rudolf Walther Ladenburg first observed stimulated emission in 1928, although at the time it seemed to have no practical use.

2. In 1951 Charles H. Townes, then at Columbia University in New York City, thought of a way to generate stimulated emission at microwave frequencies. At the end of 1953, he demonstrated a working device that focused “excited” ammonia molecules in a resonant microwave cavity, where they emitted a pure microwave frequency. Townes named the device a maser, for “microwave amplification by the stimulated emission

of radiation." Aleksandr Mikhaylovich Prokhorov and Nikolay Gennadiyevich Basov of the P.N. Lebedev Physical Institute in Moscow independently described the theory of maser operation. For their work all three shared the 1964 Nobel Prize for Physics.

3. An intense burst of maser research followed in the mid-1950s, but masers found only a limited range of applications as low-noise microwave amplifiers and atomic clocks. In 1957 Townes proposed to his brother-in-law and former postdoctoral student at Columbia University, Arthur L. Schawlow (then at Bell Laboratories), that they try to extend maser action to the much shorter wavelengths of infrared or visible light. Townes also had discussions with a graduate student at Columbia University, Gordon Gould, who quickly developed his own laser ideas. Townes and Schawlow published their ideas for an "optical maser" in a seminal paper in the December 15, 1958, issue of Physical Review. Meanwhile, Gould coined the word laser and wrote a patent application. Whether Townes or Gould should be credited as the "inventor" of the laser thus became a matter of intense debate and led to years of litigation. Eventually, Gould received a series of four patents starting in 1977 that earned him millions of dollars in royalties.

4. The Townes-Schawlow proposal led several groups to try building a laser. The Gould proposal became the basis of a classified military contract. Success came first to Theodore H. Maiman, who took a different approach at Hughes Research Laboratories in Malibu, California. He fired bright pulses from a photographer's flash lamp to excite chromium atoms in a crystal of synthetic ruby, a material he chose because he had studied carefully how it absorbed and emitted light and calculated that it should work as a laser. On May 16, 1960, he produced red pulses from a ruby rod about the size of a fingertip. In December 1960 Ali Javan, William Bennett, Jr., and Donald Herriott at Bell Labs built the first gas laser, which generated a continuous infrared beam from a mixture of helium and neon. In 1962 Robert N. Hall and coworkers at the General Electric Research and Development Center in Schenectady, New York, made the first semiconductor laser.

5. While lasers quickly caught the public imagination, perhaps for their similarity to the "heat rays" of science fiction, practical applications took years to develop. A young physicist named Irnee D'Haenens, while working with Maiman on the ruby laser, joked that the device was "a solution looking for a problem," and the line lingered in the laser community for many years. Townes and Schawlow had expected laser beams to be used in basic research and to send signals through air or

space. Gould envisioned more powerful beams capable of cutting and drilling many materials. A key early success came in late 1963 when two researchers at the University of Michigan, Emmett Leith and Juris Upatnieks, used lasers to make the first three-dimensional holograms.

6. Helium-neon lasers were the first lasers with broad commercial applications. Because they could be adjusted to generate a visible red beam instead of an infrared beam, they found immediate use projecting straight lines for alignment, surveying, construction, and irrigation. Soon eye surgeons were using pulses from ruby lasers to weld detached retinas back in place without cutting into the eye. The first large-scale application for lasers was the laser scanner for automated checkout in supermarkets, which was developed in the mid-1970s and became common a few years later. Compact disc audio players and laser printers for personal computers soon followed.

7. Lasers have become standard tools in diverse applications. Laser pointers highlight presentation points in lecture halls, and laser target designators guide smart bombs to their targets. Lasers weld razor blades, write patterns on objects on production lines without touching them, remove unwanted hair, and bleach tattoos. Laser rangefinders in space probes profiled the surfaces of Mars and the asteroid Eros in unprecedented detail. In the laboratory, lasers have helped physicists to cool atoms to within a tiny fraction of a degree of absolute zero.

LANGUAGE REVIEW

Focus on word formation

1. ***Form nouns from the following verbs.***

   absorb, align, amplify, construct, discuss, emit, excite, invent, irrigate, propose, research, solve, suggest, vision

2. ***Identify what part of speech these words represent in the text.***

   approach (par.4), cool (par.7), credit, debate (par.3), fire (par.4), focus (par.2), guide, probe, profile (par.7), range (par.3), release (par.1), share (par.2), target (par.7)

3. ***Comment on the stress in the words 'projecting' and 'surveying' in paragraph 6.***

Focus on grammar

1. Answer the questions.

1) What are the main functions of the Infinitive in the sentence?
2) What Infinitive constructions are often used in scientific texts?
3) What types of Complex Sentences can you name?

2. Do the following tasks.

1) Identify the Complex Subject in paragraph 1 and translate the sentence it is used in.
2) State the function of infinitives 'to generate' (par.2), 'to excite' (par.4), 'to weld' (par. 6)
3) Find the Complex Object in paragraph 5 and translate the sentence it is used in.
4) Trace gerunds in paragraphs 5, 6 and 7 and state their functions.
5) Identify the Subject Clause in paragraph 3 and translate the sentence it occurs in.
6) State the difference in meaning of the word 'while' in the first and second sentences in paragraph 5.
7) Indicate the asyndetically joined clause in paragraph 4.

Focus on paragraph structure and content

1. Answer the questions.

1) What key terms and phrases provide an effective means of connecting the sentences in all the paragraphs of Text 1?
2) What parallel structures are used in paragraph 7?
3) What connecting words occur in Text 1? What do they express?

2. Do the following tasks.

1) Indicate the topic sentence in each paragraph of Text 1.
2) Develop the idea of each topic sentence.
3) Sum up the main points of Text 1.

Focus on vocabulary

1. Define or explain these terms.

laser, maser, resonant microwave cavity, low-noise microwave amplifier, atomic clock, ruby laser, gas laser, semiconductor laser, laser target designator, laser rangefinder

2. ***Give English equivalents for the following word combinations.***

вынужденное излучение, микроволновые частоты, микроволновый резонатор, малошумящий микроволновый усилитель, гелий-неоновый лазер, лазерный сканер для автоматической проверки, лазерный целеуказатель, лазерный дальномер

3. ***Give Russian equivalents for the following word combinations. Make up sentences with some of them.***

to release excess energy, to have no practical use, to generate stimulated emission, to find a limited range of application, a seminal paper, to write a patent application, to become a matter of intense debate, to lead to years of litigation, a classified military contract, to take a different approach, to fire bright pulses from a photographer's flash lamp, to excite chromium atoms, a crystal of synthetic ruby, to absorb and emit light, to generate a continuous infrared beam, a mixture of helium and neon, to catch the public imagination, a solution looking for a problem, lasers with broad commercial applications, to find immediate use, to weld detached retinas back in place, to cool atoms to within a tiny fraction of a degree of absolute zero

TEXT 2

1. ***Read the text and explain the following terms.***

ground state, excited state, population inversion, three-level laser, four-level laser, metastable state, extra transition state

2. ***State the advantages of the four-level laser over the three-level one.***

Fundamental Principles
Energy levels and stimulated emissions

Laser emission is shaped by the rules of quantum mechanics, which limit atoms and molecules to having discrete amounts of stored energy that depend on the nature of the atom or molecule. The lowest energy level for an individual atom occurs when its electrons are all in the nearest possible orbits to its nucleus. This condition is called the ground state. When one or more of an atom’s electrons have absorbed energy, they can move to outer orbits, and the atom is then referred to as being “excited.”

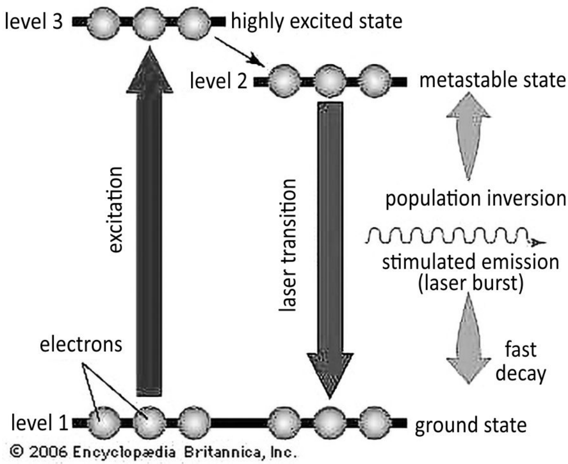
Excited states are generally not stable; as electrons drop from higher-energy to lower-energy levels, they emit the extra energy as light.

Einstein recognized that this emission could be produced in two ways. Usually, discrete packets of light known as photons are emitted spontaneously, without outside intervention. Alternatively, a passing photon could stimulate an atom or molecule to emit light – if the passing photon's energy exactly matched the energy that an electron would release spontaneously when dropping to a lower-energy configuration. Which process dominates depends on the ratio of lower-energy to higher-energy configurations. Ordinarily, lower-energy configurations predominate. This means that a spontaneously emitted photon is more likely to be absorbed and raise an electron from a lower-energy configuration to a higher-energy configuration than to stimulate a higher-energy configuration to drop to a lower-energy configuration by emitting a second photon. As long as lower-energy states are more common, stimulated emission will die out.

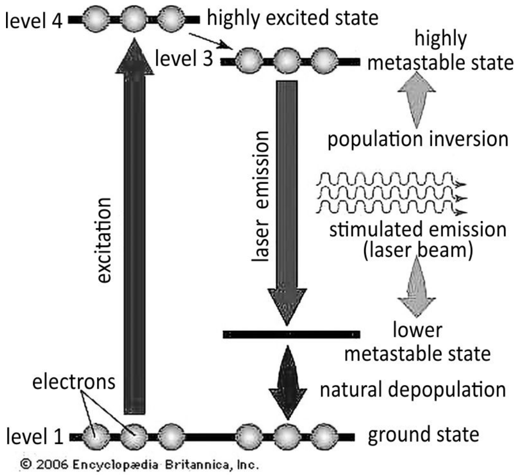
However, if higher-energy configurations predominate (a condition known as population inversion), spontaneously emitted photons are more likely to stimulate further emissions, generating a cascade of photons. Heat alone does not produce a population inversion; some process must selectively excite the atoms or molecules. Typically, this is done by illuminating the laser material with bright light or by passing an electric current through it.

The simplest conceivable system, such as the ammonia maser built by Townes, has only two energy levels. More useful laser systems involve three or four energy levels. In a three-level laser, the material is first excited to a short-lived high-energy state that spontaneously drops to a somewhat lower-energy state with an unusually long lifetime, called a metastable state. The metastable state is important because it traps and holds the excitation energy, building up a population inversion that can be further stimulated to emit radiation, dropping the species back to the ground state. The ruby laser developed by Theodore Maiman is an example of a three-level laser.

Unfortunately, the three-level laser works only if the ground state is depopulated. As atoms or molecules emit light, they accumulate in the ground state, where they can absorb the stimulated emission and shut down laser action, so most three-level lasers can only generate pulses. This difficulty is overcome in the four-level laser, where an extra transition state is located between metastable and ground states. This allows many four-level lasers to emit a steady beam for days on end.



Three-level laser. *A burst of energy excites electrons in more than half of the atoms from their ground state to a higher state, creating a population inversion. The electrons then drop into a long-lived state with slightly less energy, where they can be stimulated to quickly shed excess energy as a laser burst, returning the electrons to a stable ground state. Encyclopædia Britannica, Inc.*



Four-level laser. *A sustained laser beam can be achieved by using atoms that have two relatively stable levels between their ground state and a higher-energy excited state. As in a three-level laser, the atoms first drop to a long-lived metastable state where they can be stimulated to emit excess energy. However, instead of dropping to the ground state, they stop at another state above the ground state from which they can more easily be excited back up to the higher metastable state, thereby maintaining the population inversion needed for continuous laser operation. Encyclopædia Britannica, Inc.*

3. ***Fill in the gaps with appropriate adverbs as they occur in the text from memory: alternatively, ordinarily, typically, unfortunately, usually. If necessary, check their meaning in a dictionary.***

   1) ..., discrete packets of light known as photons are emitted spontaneously, without outside intervention.
   2) ..., a passing photon could stimulate an atom or molecule to emit light [...].
   3) ..., lower-energy configurations predominate.
   4) ..., this is done by illuminating the laser material with bright light or by passing an electric current through it.
   5) ..., the three-level laser works only if the ground state is depopulated.

4. ***Translate the following sentences into Russian. If necessary, refer to the text to clarify the context.***

   1) When one or more of an atom's electrons have absorbed energy, they can move to outer orbits, and the atom is then referred to as being "excited".
   2) Which process dominates depends on the ratio of lower-energy to higher-energy configurations.
   3) This means that a spontaneously emitted photon is more likely to be absorbed and raise an electron from a lower-energy configuration to a higher-energy configuration than to stimulate a higher-energy configuration to drop to a lower-energy configuration by emitting a second photon.
   4) However, if higher-energy configurations predominate (a condition known as population inversion), spontaneously emitted photons are more likely to stimulate further emissions, generating a cascade of photons.
   5) The metastable state is important because it traps and holds the excitation energy, building up a population inversion that can be further stimulated to emit radiation, dropping the species back to the ground state.

TEXT 3

1. ***Check the pronunciation of the following words in a dictionary.***

gelatin, neodymium (Nd), erbium (Er), ytterbium (Yb), titanium (Ti), sapphire, argon (Ar), krypton (Kr), watt, ion, carbon (C), dioxide, diode, dye, ultraviolet, VCSEL, yttrium (Y)

2. Read the text and identify the topic of each paragraph.

Types of lasers

1. Crystals, glasses, semiconductors, gases, liquids, beams of high-energy electrons, and even gelatin doped with suitable materials can generate laser beams. In nature, hot gases near bright stars can generate strong stimulated emission at microwave frequencies, although these gas clouds lack resonant cavities, so they do not produce beams.

2. In crystal and glass lasers, such as Maiman's first ruby laser, light from an external source excites atoms, known as dopants, that have been added to a host material at low concentrations. Important examples include glasses and crystals doped with the rare-earth element neodymium and glasses doped with erbium or ytterbium, which can be drawn into fibres for use as fibre-optic lasers or amplifiers. Titanium atoms doped into synthetic sapphire can generate stimulated emission across an exceptionally broad range and are used in wavelength-tunable lasers.

3. Many different gases can function as laser media. The common helium-neon laser contains a small amount of neon and a much larger amount of helium. The helium atoms capture energy from electrons passing through the gas and transfer it to the neon atoms, which emit light. The best-known helium-neon lasers emit red light, but they also can be made to emit yellow, orange, green, or infrared light; typical powers are in the milliwatt range. Argon and krypton atoms that have been stripped of one or two electrons can generate milliwatts to watts of laser light at visible and ultraviolet wavelengths. The most powerful commercial gas laser is the carbon-dioxide laser, which can generate kilowatts of continuous power.

4. The most widely used lasers today are semiconductor diode lasers, which emit visible or infrared light when an electric current passes through them. The emission occurs at the interface between two regions doped with different materials. The p-n junction can act as a laser medium, generating stimulated emission and providing lasing action if it is inside a suitable cavity. Conventional edge-emitting semiconductor lasers[1]) have mirrors on opposite edges of the p-n junction, so light oscillates in the junction plane. Vertical-cavity surface-emitting lasers (VCSELs)[2]) have mirrors above and below the p-n junction, so light

---

[1]) обычный полупроводниковый лазер с торцевым излучением

[2]) поверхностно-излучающий лазер с вертикальным резонатором (вертикально-излучающий лазер)

resonates perpendicular to the junction. The wavelength depends on the semiconductor compound.

5. A few other types of lasers are used in research. In dye lasers the laser medium is a liquid containing organic dye molecules that can emit light over a range of wavelengths; adjusting the laser cavity changes, or tunes, the output wavelength. Chemical lasers are gas lasers in which a chemical reaction generates the excited molecules that produce stimulated emission. In free-electron lasers stimulated emission comes from electrons passing through a magnetic field that periodically varies in direction and intensity, causing the electrons to accelerate and release light energy. Because the electrons do not transition between well-defined energy levels, some specialists question whether a free-electron laser should be called a laser, but the label has stuck. Depending on the energy of the electron beam and variations in the magnetic field, free-electron lasers can be tuned across a wide range of wavelengths. Both free-electron and chemical lasers can emit high powers.

3. ***Write an outline of the text in the form of questions. Discuss characteristics of different types of lasers in pairs.***

4. ***As is known, lasers can be classified according to several criteria: the state of matter of the active (gain) medium (solid, liquid, gas, or plasma), the mode of operation (CW or pulsed), pumping (electrical or optical) and laser levels (3-level laser and 4-level laser), etc. Making use of the information both from the text and the Internet, divide these lasers into groups:***

   He-Ne laser, Nd:glass laser, HF laser, CO_2 laser, Argon:ion laser, GaAs laser, Nd:YAG laser, InP laser, Rhodamine laser, Ti:sapphire laser, Coumarin laser, fiber laser, diode laser, VCSEL.

5. ***On the Internet, look for information about the excimer laser and speak about it at some length.***

6. ***Draw a chart describing characteristics of different types of lasers. Comment on the most significant items.***

TEXT 4

1. ***Read the text, then draw a mind-map to help you sum up applications for lasers in medicine.***

Medical applications

Surgical removal of tissue with a laser is a physical process similar to industrial laser drilling. Carbon-dioxide lasers burn away tissue because their infrared beams are strongly absorbed by the water that makes up the bulk of living cells. A laser beam cauterizes the cuts, stopping bleeding in blood-rich tissues. Laser wavelengths near one micrometre can penetrate the eye, welding a detached retina back into place, or cutting internal membranes that often grow cloudy after cataract surgery. Less-intense laser pulses can destroy abnormal blood vessels that spread across the retina in patients suffering from diabetes, delaying the blindness often associated with the disease. Ophthalmologists surgically correct visual defects by removing tissue from the cornea, reshaping the transparent outer layer of the eye with intense ultraviolet pulses.

Through the use of optical fibres similar to the tiny strands of glass that carry information in telephone systems, laser light can be delivered to places within the body that the beams could not otherwise reach. One important example involves threading a fibre through the urethra and into the kidney so that the end of the fibre can deliver intense laser pulses to kidney stones. The laser energy splits the stones into fragments small enough to pass through the urethra without requiring surgical incisions. Fibres also can be inserted through small incisions to deliver laser energy to precise spots in the knee joint during arthroscopic surgery.

Another medical application for lasers is in the treatment of skin conditions. Pulsed lasers can bleach certain types of tattoos as well as dark-red birthmarks called portwine stains. Cosmetic laser treatments include removing unwanted body hair and wrinkles.

2. ***Look for more information on the use of lasers in medicine and share it with other students.***

TEXT 5

1. ***Read excerpts from Tedd Adams' article, in which he presents his view of the inventions in laser physics highly recognised by the***

Nobel Committee in 2018. Dwell on the applications of optical tweezers and the importance of the technique called chirped pulsed amplification.

Our world is full of light, and we depend upon it to power life on our planet. So it is appropriate to honor three scientists who invented new ways of using light rays to explore our world.

The 2018 Nobel Prize in physics was awarded to Arthur Ashkin, Gérard Mourou and Donna Strickland for developing tools made from light beams. Ashkin won half of the prize for his work on optical tweezers, which are beams of light that can actually manipulate tiny objects like cells or atoms, while Mourou and Strickland won the other half for creating technology that generates high-intensity, ultra-short laser pulses, which are used for eye surgeries, material sciences, studies of very fast processes and plasma physics, among others.

What are optical tweezers?

Using light to manipulate our world has become very important in science and medicine over the past several decades. This year's physics Nobel recognizes the invention of tools that have facilitated advances in many fields. Optical tweezers use light to hold tiny objects in place or measure their movement. It may seem odd that light can actually hold something in place, but it has been well-known for more than a century that light can apply a force on physical objects through what is known as radiation pressure. In 1969, Arthur Ashkin used lasers to trap and accelerate micron sized objects such as tiny spheres and water droplets. This led to the invention of optical tweezers that use two or more focused laser beams aimed in opposite directions to attract a target particle or cell toward the center of the beams and hold it in place. Each time the particle moves away from the center, it encounters a force pushing it back toward the center.

Steven Chu, Claude Cohen-Tannoudji and William D. Phillips won the 1997 Nobel Prize in physics for development of laser cooling traps, known as optical traps, that hold atoms within a confined space. Askhin and Chu worked together at Bell Laboratories in the 1980s laying the foundation for work on optical traps. While Chu continued work with neutral atoms, Ashkin pursued larger, biological targets. In 1987, Ashkin used optical tweezers to examine an individual bacterium – without harming the microbe. Now optical tweezers are routinely used in studies of molecules and cells.

Why are fast laser pulses important?

Gerard Mourou and Donna Strickland worked together at the University of Rochester, where they developed the technique called chirped pulse amplification for laser light. Strickland was a graduate student and Mourou was her thesis advisor in the mid-1980s. At the time, progress on creating brighter lasers had slowed. Stronger lasers tended to damage themselves. Strickland and Mourou invented a way to create more intense light, but in short pulses.

You are probably most familiar with laser pointers or barcode scanners, which are just some of the ways we use lasers in everyday life. But these are relatively low-intensity lasers. Many scientific applications need much stronger ones.

To solve this problem, Mourou and Strickland used lasers with very short (ultrashort) pulses – quick bursts of light separated in time. With chirped pulse amplification, the pulses are stretched in time, making them longer and less intense, and then the pulses are amplified up to a million times. When these pulses are compressed again (through reversing the process used to stretch), the pulses are much more intense than can be created without the chirped pulse amplification technique. As an analogy, consider a thick rubber band. When the band is stretched, the rubber becomes thinner. When it is released, it returns to its original thickness. Now imagine that there is a way to make the stretched rubber band thicker. When the band is released, it will end up thicker than the original band. This is essentially what happens with the laser pulse.

There are a variety of ways the stretching and amplification can be done, but nearly all of the highest-power lasers in the world use some variation of this technique. Since the invention of chirped pulse amplification, the maximum intensity of new lasers has continued a dramatic rise.

In my own field of particle physics, chirped pulse amplification-based lasers are used to accelerate beams of particles, possibly providing a path to greater acceleration in a shorter distance. This could lead to lower-cost, high-energy accelerators that can push the bounds of particle physics – enabling us to detect evermore elusive particles and gain a better understanding of the universe.

But not all particle accelerators are behemoths like the Large Hadron Collider, which has a circumference of 17 miles. There are some 30,000 industrial particle accelerators worldwide that are used closer to home for material preparation, cancer treatment and medical research. Mourou and

Strickland's work may be used to shrink the size of these accelerators making them smaller and cheaper.

Ultrafast, high-intensity lasers are also now being used in eye surgery. They can be used to treat the cornea (surface of the eye) to improve vision in some patients. The chirped pulse amplification invention is also used in attosecond science for studying ultrafast processes. An attosecond is one million trillionth of a second. By having lasers that produce pulses every attosecond, we can get snapshots of extremely fast processes such as atoms losing an electron (ionizing) and then recapturing it.

The 2018 Nobel Prize in physics shines a light on the pioneering work of these three scientists. Over the past three decades, their inventions have created avenues of science and medical treatments that were previously unattainable. It is certain that we will continue to benefit from their work for a long time.

2. Find more facts about the 2018 Nobel Prize laureates in physics. Sum up the information in 10-12 sentences.

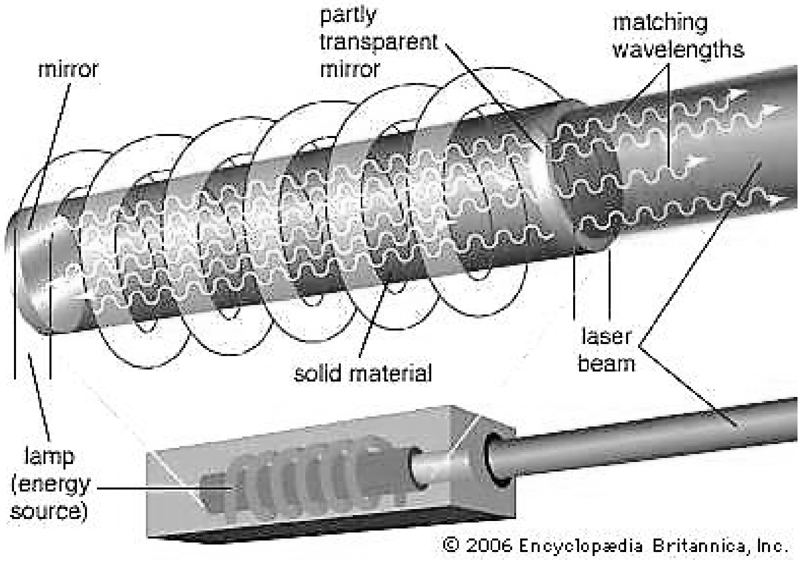
CHECK YOURSELF

1. Translate the text in writing. Time limit: 40 min.

Laser elements

Population inversions can be produced in a gas, liquid, or solid, but most laser media are gases or solids. Typically, laser gases are contained in cylindrical tubes and excited by an electric current or external light source, which is said to "pump" the laser. Similarly, solid-state lasers may use semiconductors or transparent crystals with small concentrations of light-emitting atoms.

An optical resonator is needed to build up the light energy in the beam. The resonator is formed by placing a pair of mirrors facing each other so that light emitted along the line between the mirrors is reflected back and forth. When a population inversion is created in the medium, light reflected back and forth increases in intensity with each pass through the laser medium. Other light leaks around the mirrors without being amplified. In an actual laser cavity, one or both mirrors transmit a fraction of the incident light. The fraction of light transmitted – that is, the laser beam – depends on the type of laser. If the laser generates a continuous beam, the amount of light added by stimulated emission on each round trip between the mirrors equals the light emerging in the beam plus losses within the optical resonator.



Laser producing a beam. Encyclopædia Britannica, Inc.

The combination of laser medium and resonant cavity forms what often is called simply a laser but technically is a laser oscillator. Oscillation determines many laser properties, and it means that the device generates light internally. Without mirrors and a resonant cavity, a laser would just be an optical amplifier, which can amplify light from an external source but not generate a beam internally. Elias Snitzer, a researcher at American Optical, demonstrated the first optical amplifier in 1961, but such devices were little used until the spread of communications based on fibre optics.

2. *Translate the sentences into English. Make good use of the key words from Unit II.*

1) Лазер – это устройство, создающее пучок интенсивного света. В работе лазера используется свойство электронов атома занимать только определенные орбиты вокруг своего ядра.

2) Еще в 1916 году Эйнштейн предсказал существование явления вынужденного излучения – физической основы работы любого лазера.
3) Первыми, как известно, были созданы импульсные лазеры с выращенным кристаллом рубина в качестве активного элемента.
4) Гелий-неоновый лазер – наряду с диодным и полупроводниковым – относится к числу наиболее часто используемых и самых приемлемых по цене для видимой области спектра.
5) Лазеры на свободных электронах (free-electron lasers) считаются наиболее перспективными из всех источников когерентного излучения.
6) Теодор Мейман первым реализовал условия для возникновения вынужденного излучения 16 мая 1960 года. Это было днем рождения лазера.
7) Для создания лазерного рентгеновского излучения необходим пучок электронов, разогнанный в синхротроне до скорости, близкой к скорости света.
8) Вертикально-излучающие лазеры – разновидность диодного лазера, излучающего свет в направлении, перпендикулярном поверхности кристалла, в отличие от обычных лазерных диодов, излучающих в плоскости, параллельной поверхности.
9) В лазерах с торцевым излучением полупроводниковая усиливающая среда расположена на поверхности полупроводниковой подложки. Лазеры этого типа широко используются в качестве источника излучения для оптической накачки твердотельных лазеров.

3. Translate the sentences into Russian. Identify the non-finite forms of the verb and state their function.

1) Albert Einstein may inadvertently have taken the initial step in laser development by realizing that two types of emission are possible. In an article published in 1917, he was the first to suggest the existence of stimulated emission.
2) For many years physicists thought that the spontaneous emission of light was the most likely and dominant form, and that any stimulated emission would always be much weaker. It was not until after World War II that the search began for conditions that

were necessary for stimulated emission to dominate, and to make one atom or molecule stimulate many others to produce the effect of amplifying emitted light.

3) A laser requires a mechanism to populate an excited state at a sufficiently fast rate such that at some time point there are more molecules in an upper (higher energy) state than in a lower one. Under these conditions the number of photons produced by stimulated emission can exceed those absorbed, and optical amplification or gain will result.
4) In all lasers, it is necessary for energy transitions to occur among electrons in the lasing medium, and some of these must involve the emission of photons (chategorized as optical transitions). In order for these transitions to result in emission of amplified light, the process of stimulated emission must predominate over either spontaneous emission or absorption.
5) Two soviet scientists, Nikolai Basov and Aleksander Prokhorov, shared the 1964 Nobel Prize in physics with Townes for pioneering work on the principles underlying masers and lasers.
6) Optical fiber communication, extensively used particularly for long-distance optical data transmission, mostly relies on laser light in optical glass fibers.
7) Laser ablation bears similarities to laser engraving and laser marking in the way that the process is complete, but the primary aim here is not to leave an engraving or a mark. Instead, the aim is to melt off the top surface layer of material, to reveal the surface layer below.
8) Fiber lasers, being such flexible, adaptable and versatile pieces of machinery, can be used for a multitude of fiber laser applications. The way in which they work means that they offer a huge level of control to their users over beam intensity, duration, length and heat output.
9) Lasers used to be considered too highly specialized and costly to be useful anywhere other than in the laboratory. However, the devices have since become smaller, more reliable, and less expensive, which has led to lasers being broadly adopted in applications ranging from surgery to welding, as well as in industries like the military and aerospace.

4. Translate at sight.

Solid state lasers

Solid state lasers are either semiconductor (or diode) lasers pumped electrically or those with crystalline or glass matrix pumped optically.

Diode lasers use the recombinations between the "electron-hole" pairs found in the superconductors to emit light in the form of stimulated emission. The pump source is electrical with an efficiency that can reach 60%. The wavelength can cover from the near UV to the near infrared depending on the materials chosen (GaN, GaAlInP, AlGaAs).

These are the most compact and the most efficient lasers available. The power can now reach several kilowatts by putting together hundreds of diode lasers and combining them in the same optic fibre. The only disadvantages of these diode lasers are the poor spatial quality of the emitted beam and that they cannot operate at a pulsed rate.

Other solid state lasers can compensate for the disadvantages of diode lasers. They use matrices that cannot conduct current so cannot be pumped electrically. They are pumped optically by either diode lasers or arc lamps (flash lamps). The matrices are doped with ions whose transitions provide the laser effect (Nd^{3+}, Yb^{3+}, Er^{3+}, Ti^{3+}). In general, solid state lasers emit in the red and near infrared. Of particular interest is the wavelength of Nd^{3+}:YAG($Y_3Al_5O_{12}$) with an emission at 1064 nm.

Solid state lasers differ in the geometry of their amplifying media: some are large (generally crystals) of millimetric dimensions and there are optic fibers that can be several meters long. The diode pumped solid state lasers, and particularly the fiber lasers, are extremely robust and have a lifetime longer than 10,000 hours. They are highly valued for their industrial applications (welding, marking). Their compactness is an added advantage.

5. Render the text into English.

Европейский рентгеновский лазер на свободных электронах

В сентябре 2017 года в Германии состоялась церемония открытия европейского рентгеновского лазера на свободных электронах XFEL (X-Ray Free Electron Laser). В проекте участвовали 12 стран.

По объему делового участия Россия занимает второе место после Германии. Российские специалисты представлены во всех управляющих органах XFEL и формируют программу его научных экспериментов.

Установку XFEL сравнивают с тоннелем протяженностью 3,4 км. Ученые сообщают, что сверхпроводящий линейный ускоритель частиц длиной 1,7 км в составе XFEL способен разгонять электроны до энергии в 17,5 ГэВ. После разгона до таких высоких энергий электроны направляются через специальные магнитные системы – ондуляторы (undulator). При этом частицы испускают излучение, которое постепенно усиливается до очень коротких и интенсивных рентгеновских вспышек.

XFEL позволяет производить рекордные 27 тысяч вспышек в секунду, каждая длительностью менее 100 фемтосекунд (фемтосекунда – одна квадриллионная доля секунды). Благодаря своим параметрам установка является уникальным инструментом для исследования сверхмалых структур, очень быстрых процессов и экстремальных состояний. С помощью этого лазера ученые, в частности, получили возможность проводить научные исследования в области физики твердого тела, геофизики, химии, материаловедения, медицины, структурной микробиологии.

6. Study the milestones in the history of the laser. Give details about some of the topics on the list.

History of the Laser

1950s

1951

Maser conceived

1954

Maser demonstrated

1955

Pumping method proposed

1956

Microwave solid-state maser developed

1957

Optical maser conceived

1957

Laser conceived

1958
Optical maser theory discussed

1959
Laser patent application

1960s

1960
Laser patent granted

1960
First laser constructed

1960
Laser announced

1960
Second laser demonstrated

1960
First continuous-beam (He-Ne) laser

1961
Commercial market appearance

1961
Ruby laser improved

1961
First Neodymium glass (Nd: glass) laser

1961
First medical use

1962
Q-switching invented

1962
Gallium-arsenide laser developed

1962
First yttrium aluminum garnet (YAG) laser

1962
First red-light semiconductor lasers

1963
Laser sales hit $1 million

1963
Mode-locked laser demo'd

1963
Semiconductor lasers from heterostructure devices proposed
1964
Nd:YAG (neodymium-doped YAG) laser invented
1964
First laser-related Nobel Prize awarded
1964
CO_2 laser invented
1964
Pulsed argon-ion laser discovered
1965
Two lasers are phase-locked
1965
First chemical laser
1966
Breakthrough in fiber optics
1966
Optical pumping work garners Nobel
1966
Dye laser discovered
1967
Tunable dye laser invented
1968
Laser Industry Association founded

1970s
1970
Patent rights bought
1970
Excimer laser developed
1970
Fiber optics advancement
1970
Optical trapping invented
1970
First continuous-wave room-temp. semiconductor lasers
1972
Quantum well laser invented

1972
Laser forms electronic circuit patterns
1974
Barcode scanners used in stores
1975
Continuous-wave semiconductor laser commercialized
1975
First quantum-well laser operation
1976
Semiconductor laser demonstrated beyond 1 µm
1976
First free-electron laser (FEL)
1977
Fiber optics installed under Chicago
1977
Gould awarded optical pumping patent
1978
Laser disc hits the home video market
1978
Compact disc (CD) project announced

1980s
1981
Schawlow, Bloembergen win Nobel
1982
Titanium-sapphire laser developed
1982
The audio CD debuts
1985
Lasers used to manipulate atoms
1987
Erbium-doped fiber amplifiers introduced

1990s
1994
Quantum cascade laser invented
1994
Quantum dot laser demonstrated
1994
Single atom laser demonstrated

1996
First pulsed atom laser
1997
Gallium-nitride (GaN) laser developed

2000s
2003
First laser-powered aircraft flown
2004
Electronic switching in a Raman laser demonstrated
2004
First electrically powered hybrid silicon laser
2007
First mode-locked silicon evanescent laser
2009
Fast laser pulses improve light bulbs
2009
National Ignition Facility dedicated
2009
NASA launches the LRO (Lunar Reconnaissance Orbiter)
2009
Intel announces Light Peak
2009
Multibeam IR-emitting lasers appear
2009
Laser market to hit nearly $6 billion in 2010

2010s
2010
NIF delivers 1 MJ of laser energy
2010
Short-pulse lasers announced
2010
Single-atom laser demonstrated
2012
NIF's 500-TW Laser Shot Sets Record
2018
NIF delivers 2.5 MJ of laser energy

(https://www.photonics.com)

FOCUS ON PRODUCTIVE WRITING AND SPEAKING SKILLS

1. Compare advantages and disadvantages of different types of lasers and write a paragraph of 120-150 words describing the most commercially promising laser.

2. Prepare a 5-minute talk on one of the following topics. You may choose any other topic related to lasers which is not on the list.

1) Laser pioneers
2) The history of the laser
3) Types of the laser
4) High-power laser systems
5) Laser microscopy
6) Laser spectroscopy
7) Scientific applications (laser cooling, optical tweezers, laser guide stars, etc.)
8) Emerging laser technologies
9) European XFEL

KEY WORDS AND WORD COMBINATIONS

Amplification
 chirped pulse amplification, microwave amplification, optical amplification
Amplifier
 low-noise microwave amplifier, optical amplifier
Atomic clocks
Beam
 continuous infrared beam, steady beam, sustained laser beam
Cavity
 laser cavity, resonant (microwave) cavity
Compound
 semiconductor compound
Configuration
 higher-energy configuration, lower-energy configuration
Crystal
 ruby crystal, transparent crystal
Discharge

Dopant
Emission
 coherent emission, laser emission, random emission, stimulated emission, spontaneous emission of light
Energy
 excess energy, excitation energy; energy transition
Fibre (fiber)
 optic fibre; fibre optics, optical fiber communication
Flash lamp
Flashlight
Frequency
 microwave frequency
Gain
Host material
Interface
Junction
 p-n junction; junction plane
Laser
 carbon-dioxide laser, chemical laser, chirped pulse amplification-based laser, conventional edge-emitting semiconductor laser, diode laser, dye laser, fibre laser, four-level laser, free-electron laser, gas laser, helium-neon laser, low-intensity laser, pulsed laser, ruby laser, semiconductor laser, solid state laser, three-level laser, ultrafast high-intensity laser, vertical-cavity surface-emitting laser, wavelength-tunable laser; laser ablation, laser cooling trap (optical trap), laser drilling, laser medium, laser pointer, laser printer, laser rangefinder, laser scanner, laser target designator, laser welding, laser wavelength
Light
 amplified light, incident light, infrared light, laser light, visible light
Maser
 ammonia maser; theory of maser operation
Matrix
 crystalline matrix, glass matrix
Medium (media)
 active medium, amplifying medium, gain medium, oscillating medium
Molecule
 organic dye molecule

Optical tweezers
Oscillation
Population inversion
Pump source
Pumping
    optical pumping
Radiation
    monochromatic coherent radiation
Resonator
    optical resonator
Spectrum (spectra)
    electromagnetic spectrum
State
    excited state, ground state, high-energy state, low-energy state, metastable state, transition state
Transmission
    optical data transmission
Undulator
Wavelength
    ultraviolet wavelength, visible wavelength

UNIT 3. PARTICLE PHYSICS

TEXT 1

1. ***Check the pronunciation of these terms in a dictionary.***

   beta decay, boson, electron, gauge symmetry, gluon, hyperon, integer value, lepton, meson, muon, neutrino, neutron, nucleus, photon, positron, proton, quark

2. ***Before reading the text, answer the following questions.***

   1) What is understood by subatomic particles?
   2) What are the basic atomic components?
   3) What elementary particles are protons and neutrons made up of?
   4) How would you define a positron?
   5) What are the fundamental interactions of matter?
   6) What does the unified field theory attempt to do?
   7) Why do you think research in particle physics is important?

3. ***Read the text and highlight the main points.***

Basic concepts of particle physics (I)

Subatomic particles

1. Particle physics is the study of subatomic particles and their fundamental interactions. A subatomic particle is any of various self-contained units of matter or energy that are the fundamental constituents of all matter. They may be elementary or composite. Subatomic particles include electrons, the negatively charged, almost massless particles that nevertheless account for most of the size of the atom, and they include the heavier building blocks of the small but very dense nucleus of the atom, the positively charged protons and the electrically neutral neutrons. But these basic atomic components are by no means the only known subatomic particles. Protons and neutrons, for instance, are themselves made up of elementary particles called quarks, and the electron is only one member of a class of elementary particles that also includes the muon and the neutrino. More-unusual subatomic particles – such as the positron,

the antimatter counterpart of the electron – have been detected and characterized in cosmic ray interactions in Earth's atmosphere. The field of subatomic particles has expanded dramatically with the construction of powerful particle accelerators to study high-energy collisions of electrons, protons, and other particles with matter. As particles collide at high energy, the collision energy becomes available for the creation of subatomic particles such as mesons and hyperons. Finally, completing the revolution that began in the early 20th century with theories of the equivalence of matter and energy, the study of subatomic particles has been transformed by the discovery that the actions of forces are due to the exchange of "force" particles such as photons and gluons. More than 200 subatomic particles have been detected – most of them highly unstable, existing for less than a millionth of a second – as a result of collisions produced in cosmic ray reactions or particle accelerator experiments. Theoretical and experimental research in particle physics, the study of subatomic particles and their properties, has given scientists a clearer understanding of the nature of matter and energy and of the origin of the universe.

Four basic forces

2. Quarks and leptons are the building blocks of matter, but they require some sort of mortar to bind themselves together into more-complex forms, whether on a nuclear or a universal scale. The particles that provide this mortar are associated with four basic forces that are collectively referred to as the fundamental interactions of matter. These four basic forces are gravity (or the gravitational force), the electromagnetic force, and two forces more familiar to physicists than to laypeople: the strong force and the weak force.

3. On the largest scales the dominant force is gravity. Gravity governs the aggregation of matter into stars and galaxies and influences the way that the universe has evolved since its origin in the big bang. The best-understood force, however, is the electromagnetic force, which underlies the related phenomena of electricity and magnetism. The electromagnetic force binds negatively charged electrons to positively charged atomic nuclei and gives rise to the bonding between atoms to form matter in bulk.

4. Gravity and electromagnetism are well known at the macroscopic level. The other two forces act only on subatomic scales, indeed on subnuclear scales. The strong force binds quarks together within protons, neutrons, and other subatomic particles. Rather as the electromagnetic force is ultimately responsible for holding bulk matter together, so the

strong force also keeps protons and neutrons together within atomic nuclei. Unlike the strong force, which acts only between quarks, the weak force acts on both quarks and leptons. This force is responsible for the beta decay of a neutron into a proton and for the nuclear reactions that fuel the Sun and other stars.

Field theory

5. Since the 1930s physicists have recognized that they can use field theory to describe the interactions of all four basic forces with matter. In mathematical terms a field describes something that varies continuously through space and time. A familiar example is the field that surrounds a piece of magnetized iron. The magnetic field maps the way that the force varies in strength and direction around the magnet. The appropriate fields for the four basic forces appear to have an important property in common: they all exhibit what is known as gauge symmetry. Put simply, this means that certain changes can be made that do not affect the basic structure of the field. It also implies that the relevant physical laws are the same in different regions of space and time.

6. At a subatomic, quantum level these field theories display a significant feature. They describe each basic force as being in a sense carried by its own subatomic particles. These “force” particles are now called gauge bosons, and they differ from the “matter” particles – the quarks and leptons discussed earlier – in a fundamental way. Bosons are characterized by integer values of their spin quantum number, whereas quarks and leptons have half-integer values of spin.

7. The most familiar gauge boson is the photon, which transmits the electromagnetic force between electrically charged objects such as electrons and protons. The photon acts as a private, invisible messenger between these particles, influencing their behaviour with the information it conveys, rather as a ball influences the actions of children playing catch. Other gauge bosons, with varying properties, are involved with the other basic forces.

8. In developing a gauge theory for the weak force in the 1960s, physicists discovered that the best theory, which would always yield sensible answers, must also incorporate the electromagnetic force. The result was what is now called electroweak theory. It was the first workable example of a unified field theory linking forces that manifest themselves differently in the everyday world. Unified theory reveals that the basic forces, though outwardly diverse, are in fact separate facets of a single underlying force. The search for a unified theory of everything, which

incorporates all four fundamental forces, is one of the major goals of particle physics. It is leading theorists to an exciting area of study that involves not only subatomic particle physics but also cosmology and astrophysics.

LANGUAGE REVIEW

Focus on word formation

1. Find all adverbs in -ly in Text 1. Pay attention to their position in a sentence.

2. Identify what part of speech the word 'map' represents in paragraph 5. Translate the sentence in which it occurs. Find other words in the text which can be both verbs and nouns.

3. Form other parts of speech from the following verbs.
aggregate, collide, compose, constitute, construct, create, describe, direct, discover, inform, interact, revolve, react

Focus on grammar

1. Answer the questions.

1) In what ways can the word 'only' be used in a sentence? Can you give examples of its different uses?
2) What are parentheses? How are they marked off in speech and in writing?

2. Do the following tasks.

1) Trace the Passive Voice forms in Text 1 and translate the sentences in which they occur.
2) Find the Complex Subject in paragraph 5. Translate the sentence in which it occurs.
3) Indicate the asyndetically joined clause in paragraph 7. Translate the sentence in which it is used.
4) Identify the function of the Gerund in the first sentence of paragraph 8. Translate the sentence.

5) State the function of the elliptical Participial construction 'put simply' at the beginning of sentence 6 in paragraph 5. Translate the sentence.
6) Indicate parentheses in paragraphs 1, 2, 6 and 8. Name the type of punctuation used in the sentences (commas, brackets, dashes) to separate parenthetical expressions. Read the sentences aloud with correct intonation.
7) Find the referents of the pronoun 'it' in paragraph 8. Translate the sentences in which this word occurs.

Focus on paragraph structure and content

1. ***Answer the questions.***

1) What key terms are used within each paragraph of Text 1?
2) What parallel structures are used in paragraphs 1 and 4?
3) What connecting words occur in Text 1? Does the author make good use of them?

2. ***Do the following tasks.***

1) Paragraph 1 gives a brief introduction to the subfield of physics dealing with subatomic particles. Point out the properties and characteristics of different types of particles mentioned in the text.
2) Focus on paragraph 6 and explain the difference between the 'matter' particles and the 'field' particles.
3) Look through paragraph 8 and comment on the aspiration of particle physicists to create a unified theory of everything.

Focus on vocabulary

1. ***Define or explain these terms.***

accelerator, atom, boson, electromagnetic force, electron, field theory, gauge symmetry, gauge theory, gravity, lepton, meson, neutrino, neutron, photon, positron, proton, strong force, weak force

2. ***Give English equivalents for the following word combinations.***

составляющие атома, составная частица, бета распад, вещество в объеме, полуцелый спин, калибровочный бозон, спиновое квантовое число, эксперимент на ускорителе частиц, столкновения при высоких энергиях, происхождение вселенной, целое значение, полуцелое значение, фундаментальные взаимодействия, единая теория поля

3. ***Give Russian equivalents for the following word combinations. Make up sentences with some of them.***

fundamental constituents of matter, to account for most of the charge of the atom, building blocks of the nucleus, the antimatter counterpart of the electron, cosmic ray interactions, on a nuclear scale, to be familiar to physicists, the dominant force, to govern the aggregation of matter into stars and galaxies, to underlie the related phenomena of electricity and magnetism, at the macroscopic level, to be responsible for the beta decay, to exhibit gauge symmetry, to affect the basic structure of the field, to be the same in different regions of space and time, at a subatomic level, to display a significant feature, to transmit the electromagnetic force, to convey information, to incorporate the electromagnetic force, to manifest oneself differently, separate facets of a single underlying force, the search for a unified theory of everything, major goals, an exciting area of study

TEXT 2

1. ***Read the text and answer the questions. Work in pairs.***

1) In what respects do electrons and quarks differ?
2) What role do neutrinos play in beta decays?
3) What did the quantum mechanical treatment of the atomic structure reveal?
4) What does the concept of spin imply?
5) What two classes of particles exist according to the Standard Model?
6) In what way did Dirac's relativistic theory contribute to the study of subatomic particles?
7) How was the existence of positrons discovered?
8) Under what circumstances were the first antiprotons and antineutrons found?
9) What distinguishes the so-called "extra" particles, which emerge only at very high energies in cosmic rays or particle accelerators, from such particles as the proton, neutron, and electron?

Basic concepts of particle physics (2)

Elementary particles

1. Electrons and quarks contain no discernible structure; they cannot be reduced or separated into smaller components. It is therefore reasonable to call them "elementary" particles, a name that in the past was mistakenly given to particles such as the proton, which is in fact a complex particle that contains quarks. The term subatomic particle refers both to the true elementary particles, such as quarks and electrons, and to the larger particles that quarks form.

2. Although both are elementary particles, electrons and quarks differ in several respects. Whereas quarks together form nucleons within the atomic nucleus, the electrons generally circulate toward the periphery of atoms. Indeed, electrons are regarded as distinct from quarks and are classified in a separate group of elementary particles called leptons. There are several types of lepton, just as there are several types of quark. Only two types of quark are needed to form protons and neutrons, however, and these, together with the electron and one other elementary particle, are all the building blocks that are necessary to build the everyday world. The last particle required is an electrically neutral particle called the neutrino.

3. Neutrinos do not exist within atoms in the sense that electrons do, but they play a crucial role in certain types of radioactive decay. In a basic process of one type of radioactivity, known as beta decay, a neutron changes into a proton. In making this change, the neutron acquires one unit of positive charge. To keep the overall charge in the beta-decay process constant and thereby conform to the fundamental physical law of charge conservation, the neutron must emit a negatively charged electron. In addition, the neutron also emits a neutrino (strictly speaking, an antineutrino), which has little or no mass and no electric charge. Beta decays are important in the transitions that occur when unstable atomic nuclei change to become more stable, and for this reason neutrinos are a necessary component in establishing the nature of matter.

4. The neutrino, like the electron, is classified as a lepton. Thus, it seems at first sight that only four kinds of elementary particles – two quarks and two leptons – should exist. In the 1930s, however, long before the concept of quarks was established, it became clear that matter is more complicated.

Spin

5. The concept of quantization led during the 1920s to the development of quantum mechanics, which appeared to provide physicists

with the correct method of calculating the structure of the atom. In his model Niels Bohr had postulated that the electrons in the atom move only in orbits in which the angular momentum (angular velocity multiplied by mass) has certain fixed values. Each of these allowed values is characterized by a quantum number that can have only integer values. In the full quantum mechanical treatment of the structure of the atom, developed in the 1920s, three quantum numbers relating to angular momentum arise because there are three independent variable parameters in the equation describing the motion of atomic electrons.

6. In 1925, however, two Dutch physicists, Samuel Goudsmit and George Uhlenbeck, realized that, in order to explain fully the spectra of light emitted by the atoms of alkali metals, such as sodium, which have one outer valence electron beyond the main core, there must be a fourth quantum number that can take only two values, −1/2 and +1/2. Goudsmit and Uhlenbeck proposed that this quantum number refers to an internal angular momentum, or spin, that the electrons possess. This implies that the electrons, in effect, behave like spinning electric charges. Each therefore creates a magnetic field and has its own magnetic moment. The internal magnet of an atomic electron orients itself in one of two directions with respect to the magnetic field created by the rest of the atom. It is either parallel or antiparallel; hence, there are two quantized states – and two possible values of the associated spin quantum number.

7. The concept of spin is now recognized as an intrinsic property of all subatomic particles. Indeed, spin is one of the key criteria used to classify particles into two main groups: fermions, with half-integer values of spin (1/2, 3/2,…), and bosons, with integer values of spin (0, 1, 2,…). In the Standard Model all of the "matter" particles (quarks and leptons) are fermions, whereas "force" particles such as photons are bosons. These two classes of particles have different symmetry properties that affect their behaviour.

Antiparticles

8. Two years after the work of Goudsmit and Uhlenbeck, the English theorist P.A.M. Dirac provided a sound theoretical background for the concept of electron spin. In order to describe the behaviour of an electron in an electromagnetic field, Dirac introduced the German-born physicist Albert Einstein's theory of special relativity into quantum mechanics. Dirac's relativistic theory showed that the electron must have spin and a magnetic moment, but it also made what seemed a strange prediction. The basic equation describing the allowed energies for an electron would

admit two solutions, one positive and one negative. The positive solution apparently described normal electrons. The negative solution was more of a mystery; it seemed to describe electrons with positive rather than negative charge.

9. The mystery was resolved in 1932, when Carl Anderson, an American physicist, discovered the particle called the positron. Positrons are very much like electrons: they have the same mass and the same spin, but they have opposite electric charge. Positrons, then, are the particles predicted by Dirac's theory, and they were the first of the so-called antiparticles to be discovered. Dirac's theory, in fact, applies to any subatomic particle with spin 1/2; therefore, all spin-1/2 particles should have corresponding antiparticles. Matter cannot be built from both particles and antiparticles, however. When a particle meets its appropriate antiparticle, the two disappear in an act of mutual destruction known as annihilation. Atoms can exist only because there is an excess of electrons, protons, and neutrons in the everyday world, with no corresponding positrons, antiprotons, and antineutrons.

10. Positrons do occur naturally, however, which is how Anderson discovered their existence. High-energy subatomic particles in the form of cosmic rays continually rain down on Earth's atmosphere from outer space, colliding with atomic nuclei and generating showers of particles that cascade toward the ground. In these showers the enormous energy of the incoming cosmic ray is converted to matter, in accordance with Einstein's theory of special relativity, which states that $E = mc^2$, where E is energy, m is mass, and c is the velocity of light. Among the particles created are pairs of electrons and positrons. The positrons survive for a tiny fraction of a second until they come close enough to electrons to annihilate. The total mass of each electron-positron pair is then converted to energy in the form of gamma-ray photons.

11. Using particle accelerators, physicists can mimic the action of cosmic rays and create collisions at high energy. In 1955 a team led by the Italian-born scientist Emilio Segrè and the American Owen Chamberlain found the first evidence for the existence of antiprotons in collisions of high-energy protons produced by the Bevatron, an accelerator at what is now the Lawrence Berkeley National Laboratory in California. Shortly afterward, a different team working on the same accelerator discovered the antineutron.

12. Since the 1960s physicists have discovered that protons and neutrons consist of quarks with spin 1/2 and that antiprotons and antineutrons consist of antiquarks. Neutrinos too have spin 1/2 and

therefore have corresponding antiparticles known as antineutrinos. Indeed, it is an antineutrino, rather than a neutrino, that emerges when a neutron changes by beta decay into a proton. This reflects an empirical law regarding the production and decay of quarks and leptons: in any interaction the total numbers of quarks and leptons seem always to remain constant. Thus, the appearance of a lepton – the electron – in the decay of a neutron must be balanced by the simultaneous appearance of an antilepton, in this case the antineutrino.

13. In addition to such familiar particles as the proton, neutron, and electron, studies have slowly revealed the existence of more than 200 other subatomic particles. These "extra" particles do not appear in the low-energy environment of everyday human experience; they emerge only at the higher energies found in cosmic rays or particle accelerators. Moreover, they immediately decay to the more-familiar particles after brief lifetimes of only fractions of a second. The variety and behaviour of these extra particles initially bewildered scientists but have since come to be understood in terms of the quarks and leptons. In fact, only six quarks, six leptons, and their corresponding antiparticles are necessary to explain the variety and behaviour of all the subatomic particles, including those that form normal atomic matter.

2. ***Develop the main points of the text into a summary, either oral or written.***

3. ***Translate the following sentences. Identify the Passive Voice forms, the non-finite forms of the verb, the multifunctional words. If necessary, refer to the text to clarify the context.***

   1) It is therefore reasonable to call them "elementary" particles, a name that in the past was mistakenly given to particles such as the proton, which is in fact a complex particle that contains quarks.
   2) Only two types of quark are needed to form protons and neutrons, however, and these, together with the electron and one other elementary particle, are all the building blocks that are necessary to build the everyday world.
   3) Neutrinos do not exist within atoms in the sense that electrons do, but they play a crucial role in certain types of radioactive decay.
   4) To keep the overall charge in the beta-decay process constant and thereby conform to the fundamental physical law of charge conservation, the neutron must emit a negatively charged electron.

5) Beta decays are important in the transitions that occur when unstable atomic nuclei change to become more stable, and for this reason neutrinos are a necessary component in establishing the nature of matter.
6) The concept of quantization led during the 1920s to the development of quantum mechanics, which appeared to provide physicists with the correct method of calculating the structure of the atom.
7) In the full quantum mechanical treatment of the structure of the atom, developed in the 1920s, three quantum numbers relating to angular momentum arise because there are three independent variable parameters in the equation describing the motion of atomic electrons.
8) The negative solution was more of a mystery; it seemed to describe electrons with positive rather than negative charge.
9) Positrons, then, are the particles predicted by Dirac's theory, and they were the first of the so-called antiparticles to be discovered.
10) This reflects an empirical law regarding the production and decay of quarks and leptons: in any interaction the total numbers of quarks and leptons seem always to remain constant.

4. Review the Emphatic structures and Inversion. Find emphatic sentences in paragraphs 10 and 12 and translate them.

5. Analyse the structure of paragraphs 2, 3 and 4. Indicate connecting words used to provide cohesion between the sentences. What do these words mean?

TEXT 3

1. Read the text and explain why, despite its many triumphs, the Standard Model is believed to have limitations.

Standard Model

The Standard Model is the combination of two theories of particle physics into a single framework to describe all interactions of subatomic particles, except those due to gravity. The two components of the

Standard Model are electroweak theory, which describes interactions via the electromagnetic and weak forces, and quantum chromodynamics, the theory of the strong nuclear force. Both these theories are gauge field theories, which describe the interactions between particles in terms of the exchange of intermediary "messenger" particles that have one unit of intrinsic angular momentum, or spin.

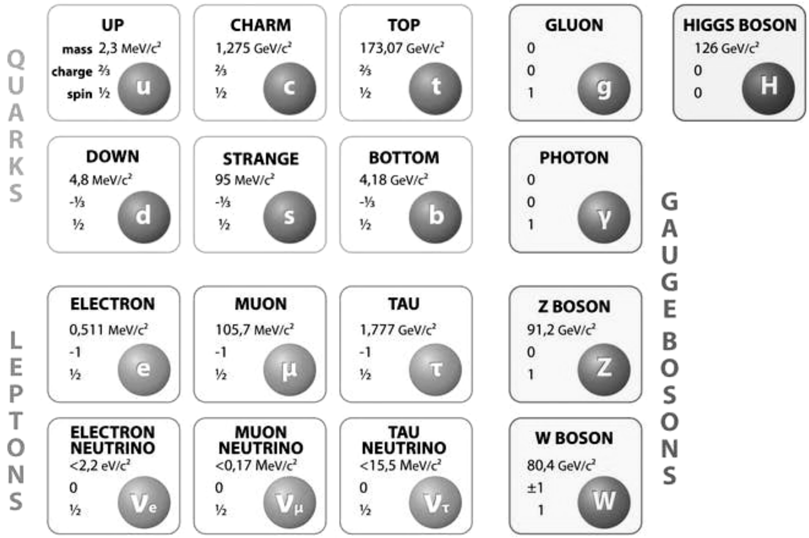
In addition to these force-carrying particles, the Standard Model encompasses two families of subatomic particles that build up matter and that have spins of one-half unit. These particles are the quarks and the leptons, and there are six varieties, or "flavours", of each, related in pairs in three "generations" of increasing mass. Everyday matter is built from the members of the lightest generation: the "up" and "down" quarks that make up the protons and neutrons of atomic nuclei; the electron that orbits within atoms and participates in binding atoms together to make molecules and more complex structures; and the electron-neutrino that plays a role in radioactivity and so influences the stability of matter. Heavier types of quark and lepton have been discovered in studies of high-energy particle interactions, both at scientific laboratories with particle accelerators and in the natural reactions of high-energy cosmic-ray particles in the atmosphere.

The Standard Model has proved a highly successful framework for predicting the interactions of quarks and leptons with great accuracy. Yet it has a number of weaknesses that lead physicists to search for a more complete theory of subatomic particles and their interactions. The present Standard Model, for example, cannot explain why there are three generations of quarks and leptons. It makes no predictions of the masses of the quarks and the leptons nor of the strengths of the various interactions. Physicists hope that, by probing the Standard Model in detail and making highly accurate measurements, they will discover some way in which the model begins to break down and thereby find a more complete theory. This may prove to be what is known as a grand unified theory, which uses a single theoretical structure to describe the strong, weak, and electromagnetic forces.

As of 2018, there are seventeen named particles in the Standard Model, organised into the chart shown below. The last particles discovered were the W and Z bosons in 1983, the top quark in 1995, the tau neutrino in 2000, and the Higgs boson in 2012.

2. ***Describe the diagram of the Standard Model, giving characteristics of the fundamental particles and their interactions.***

STANDARD MODEL OF ELEMENTARY PARTICLES



TEXT 4

1. ***Read the text and answer the questions.***
   1) What properties and characteristics make the LHC a unique instrument?
   2) What operational problem did the LHC confront?
   3) What are the goals of the LHC project?

Large Hadron Collider

The Large Hadron Collider (LHC) is world's most powerful particle accelerator. The LHC was constructed by the European Organization for Nuclear Research (CERN) in the same 27-km (17-mile) tunnel that housed its Large Electron-Positron Collider (LEP). The tunnel is circular and is located 50–175 metres (165–575 feet) below ground, on the border between France and Switzerland. The LHC ran its first test operation on September 10, 2008. An electrical problem in a cooling system on

September 18 resulted in a temperature increase of about 100 °C (180 °F) in the magnets, which are meant to operate at temperatures near absolute zero (−273.15 °C, or −459.67 °F). Early estimates that the LHC would be quickly fixed soon turned out to be overly optimistic. It restarted on November 20, 2009. Shortly thereafter, on November 30, it supplanted the Fermi National Accelerator Laboratory's Tevatron as the most powerful particle accelerator when it boosted protons to energies of 1.18 teraelectron volts (TeV; 1×10^{12} electron volts). In March 2010 scientists at CERN announced that a problem with the design of superconducting wire in the LHC required that the collider run only at half-energy (7 TeV). The LHC was shut down in February 2013 to fix the problem and was expected to run at its full energy of 14 TeV in early 2015.

The heart of the LHC is a ring that runs through the circumference of the LEP tunnel; the ring is only a few centimetres in diameter, evacuated to a higher degree than deep space and cooled to within two degrees of absolute zero. In this ring, two counterrotating beams of heavy ions or protons are accelerated to speeds within one-millionth of a percent of the speed of light. (Protons belong to a category of heavy subatomic particles known as hadrons, which accounts for the name of this particle accelerator.) At four points on the ring, the beams can intersect and a small proportion of particles crash into each other. At maximum power, collisions between protons will take place at a combined energy of up to 14 TeV, about seven times greater than has been achieved previously. At each collision point are huge magnets weighing tens of thousands of tons and banks of detectors to collect the particles produced by the collisions.

The project took a quarter of a century to realize; planning began in 1984, and the final go-ahead was granted in 1994. Thousands of scientists and engineers from dozens of countries were involved in designing, planning, and building the LHC, and the cost for materials and manpower was nearly $5 billion; this does not include the cost of running experiments and computers.

One goal of the LHC project is to understand the fundamental structure of matter by re-creating the extreme conditions that occurred in the first few moments of the universe according to the big-bang model. For decades physicists have used the so-called standard model for fundamental particles, which has worked well but has weaknesses. First, and most important, it does not explain why some particles have mass. In the 1960s British physicist Peter Higgs postulated a particle that had interacted with other particles at the beginning of time to provide them with their mass. The Higgs boson had never been observed – it should be produced only by collisions in an energy range not available for experiments before the LHC. After a year of observing collisions at the LHC, scientists there announced in 2012 that they had detected an interesting signal that was likely from a Higgs boson with a mass of about 126 gigaelectron volts (billion electron volts). Second, the standard model requires some arbitrary assumptions, which some physicists have suggested may be resolved by postulating a further class of supersymmetric particles; these might be produced by the extreme energies of the LHC. Finally, examination of asymmetries between particles and their antiparticles may provide a clue to another mystery: the imbalance between matter and antimatter in the universe.

2. *Write out the most important facts about the LHC and sum them up in 5-7 sentences orally.*

TEXT 5

1. *Read the text and answer the questions:*

1) Why is the Higgs boson so difficult to detect?
2) What indirect means of detecting the Higgs boson were used?
3) What advanced facilities were needed to find the Higgs boson?

Search for the Higgs boson

To produce Higgs bosons, two beams of particles are accelerated to very high energies and allowed to collide within a particle detector. Occasionally, although rarely, a Higgs boson will be created fleetingly as part of the collision byproducts. Because the Higgs boson decays very quickly, particle detectors cannot detect it directly. Instead the detectors register all the decay products (the decay signature) and from the data the decay process is reconstructed. If the observed decay products match a possible decay process (known as a decay channel) of a Higgs boson, this indicates that a Higgs boson may have been created. In practice, many processes may produce similar decay signatures. Fortunately, the Standard Model precisely predicts the likelihood of each of these, and each known process, occurring. So, if the detector detects more decay signatures consistently matching a Higgs boson than would otherwise be expected if Higgs bosons did not exist, then this would be strong evidence that the Higgs boson exists.

Because Higgs boson production in a particle collision is likely to be very rare (1 in 10 billion at the LHC), and many other possible collision events can have similar decay signatures, the data of hundreds of trillions of collisions needs to be analysed and must "show the same picture" before a conclusion about the existence of the Higgs boson can be reached. To conclude that a new particle has been found, particle physicists require that the statistical analysis of two independent particle detectors each indicate that there is lesser than a one-in-a-million chance that the observed decay signatures are due to just background random Standard Model events – i.e., that the observed number of events is more than 5 standard deviations (sigma) different from that expected if there was no new particle. More collision data allows better confirmation of the physical properties of any new particle observed, and allows physicists to decide whether it is indeed a Higgs boson as described by the Standard Model or some other hypothetical new particle.

To find the Higgs boson, a powerful particle accelerator was needed, because Higgs bosons might not be seen in lower-energy experiments. The collider needed to have a high luminosity in order to ensure enough collisions were seen for conclusions to be drawn. Finally, advanced computing facilities were needed to process the vast amount of data (25 petabytes per year as of 2012) produced by the collisions. For the announcement of 4 July 2012, a new collider known as the Large Hadron Collider was constructed at CERN with a planned eventual collision energy of 14 TeV – over seven times any previous collider – and over 300 trillion (3×10^{14}) LHC proton-proton collisions were analysed by the LHC Computing Grid, the world's largest computing grid (as of 2012), comprising over 170 computing facilities in a worldwide network across 36 countries.

2. ***Look for more information about the discovery of the Higgs boson and find out why it took scientists another year to definitively confirm its existence and status.***

CHECK YOURSELF

1. ***Translate the text in writing. Time limit: 60 min.***

The strong force

During the 1970s physicists developed a theory for the strong force that is similar in structure to quantum electrodynamics. In this theory quarks are bound together within protons and neutrons by exchanging gauge bosons called gluons. The quarks carry a property called “colour” that is analogous to electric charge. Just as electrically charged particles experience the electromagnetic force and exchange photons, so colour-charged, or coloured, particles feel the strong force and exchange gluons. This property of colour gives rise in part to the name of the theory of the strong force: quantum chromodynamics.

Gluons are massless and have a spin quantum number of 1. In this respect they are much like photons, but they differ from photons in one crucial way. Whereas photons do not interact among themselves – because they are not electrically charged – gluons do carry colour charge. This means that gluons can interact together, which has an important effect in limiting the range of gluons and in confining quarks within protons and other particles.

There are three types of colour charge, called red, green, and blue, although there is no connection between the colour charge of quarks and gluons and colour in the usual sense. Quarks each carry a single colour charge, while gluons carry both a colour and an anticolour charge.

The strong force acts in such a way that quarks of different colour are attracted to one another; thus, red attracts green, blue attracts red, and so on. Quarks of the same colour, on the other hand, repel each other. The quarks can combine only in ways that give a net colour charge of zero. In particles that contain three quarks, such as protons, this is achieved by adding red, blue, and green. An alternative, observed in particles called mesons, is for a quark to couple with an antiquark of the same basic colour. In this case the colour of the quark and the anticolour of the antiquark cancel each other out. These combinations of three quarks (or three antiquarks) or of quark-antiquark pairs are the only combinations that the strong force seems to allow.

The constraint that only colourless objects can appear in nature seems to limit attempts to observe single quarks and free gluons. Although a quark can radiate a real gluon just as an electron can radiate a real photon, the gluon never emerges on its own into the surrounding environment. Instead, it somehow creates additional gluons, quarks, and antiquarks from its own energy and materializes as normal particles built from quarks. Similarly, it appears that the strong force keeps quarks permanently confined within larger particles. Attempts to knock quarks out of protons by, for example, knocking protons together at high energies succeed only in creating more particles – that is, in releasing new quarks and antiquarks that are bound together and are themselves confined by the strong force.

2. Translate the text at sight.

Gravity

The weakest, and yet the most pervasive, of the four basic forces is gravity. It acts on all forms of mass and energy and thus acts on all subatomic particles, including the gauge bosons that carry the forces. The 17th-century English scientist Isaac Newton was the first to develop a quantitative description of the force of gravity. He argued that the force that binds the Moon in orbit around Earth is the same force that makes apples and other objects fall to the ground, and he proposed a universal law of gravitation.

According to Newton's law, all bodies are attracted to each other by a force that depends directly on the mass of each body and inversely on the square of the distance between them. For a pair of masses, m_1 and m_2, a distance r apart, the strength of the force F is given by $F = Gm_1m_2/r^2$. G is called the constant of gravitation and is equal to 6.67×10^{-11} newton-metre^2-kilogram^{-2}.

The constant G gives a measure of the strength of the gravitational force, and its smallness indicates that gravity is weak. Indeed, on the scale of atoms the effects of gravity are negligible compared with the other forces at work. Although the gravitational force is weak, its effects can be extremely long-ranging. Newton's law shows that at some distance the gravitational force between two bodies becomes negligible but that this distance depends on the masses involved. Thus, the gravitational effects of large, massive objects can be considerable, even at distances far outside the range of the other forces. The gravitational force of Earth, for example, keeps the Moon in orbit some 384,400 km (238,900 miles) distant.

Newton's theory of gravity proves adequate for many applications. In 1915, however, the German-born physicist Albert Einstein developed the theory of general relativity, which incorporates the concept of gauge symmetry and yields subtle corrections to Newtonian gravity. Despite its importance, Einstein's general relativity remains a classical theory in the sense that it does not incorporate the ideas of quantum mechanics. In a quantum theory of gravity, the gravitational force must be carried by a suitable messenger particle, or gauge boson. No workable quantum theory of gravity has yet been developed, but general relativity determines some of the properties of the hypothesized "force" particle of gravity, the so-called graviton. In particular, the graviton must have a spin quantum number of 2 and no mass, only energy.

3. ***Translate these excerpts from the feature article on elementary particles in the Oxford Dictionary of Physics. Pay attention to the correct translation of grammatical forms and structures.***

1) Non-relativistic quantum theory was completed in an astonishingly brief period (1923-26), but it was the relativistic version that made the greatest impact on our understanding of elementary particles. Dirac's discovery in 1928 of the equation that bears his name led to the discovery of the positive electron or positron. The mass of the positron is equal to that of the negative electron while its charge is equal in magnitude but opposite in sign. Positrons and electrons are produced simultaneously in high-energy collisions of charged particles or gamma rays with matter in the process called pair production.

2) A theory of the weak interaction was in its infancy in the 1930's. The weak interaction is responsible for beta decay, in which a radioactive nucleus is transformed into a slightly lighter nucleus with the emission of an electron. However, beta decays posed a problem because they appeared not to conserve energy and momentum. In 1931 Pauli proposed the existence of a neutral particle that might be able to carry off the missing energy and momentum in a beta decay and escape undetected. Three years later, Fermi included Pauli's principle in a comprehensive theory of beta decay, which seemed to explain many experimentally observed results. Fermi called this new particle the neutrino, the existence of which was finally established in the 1950's.

3) A plethora of experiments involving the neutrino revealed some remarkable properties for this new particle. The neutrino was found to have an intimate connection with the electron and the muon, and indeed never appeared without the simultaneous appearance of one or other of the particles. A conservation law was postulated to explain this observation. Numbers were assigned to the electron, muon, and neutrino, so that during interactions these numbers were conserved; i.e. their algebraic sums before and after these interactions were equal. Since these particles were among the lightest known at the time, these assigned numbers became known as lepton numbers (lepton: 'light ones').

4) Neutrinos have zero charge and were originally thought to have zero rest mass, but there has been some indirect experimental evidence to the contrary, beginning in the last twenty years of the 20th century. In 1985 a Soviet team reported a measurement, for the first time, of a non-zero neutrino mass. The mass measured was extremely small (10000 times less than the mass of the electron), but subsequent attempts independently to produce these results did not succeed. Later (1998-99), Japanese and US groups put forward theories and corroborating evidence to suggest, indirectly, that neutrinos do have mass.

5) Murray Gell-Mann and his collaborators proposed the particle-physics equivalent of the periodic table between 1961 and 1964. In this structure, leptons were indeed regarded as fundamental particles, but the short-lived particles discovered in the 1960's were not. These particles were found to undergo strong interactions, which did not seem to affect the leptons. Gell-Mann called these strongly interacting particles the hadrons and proposed that they occurred in two different types: baryons and mesons. These two different types correspond to two different ways of constructing hadrons from constituent particles, which Gell-Mann called quarks.

4. Translate the following mini-texts into English.

1) Стандартная модель утверждает, что существует два семейства частиц: лептоны и кварки. Они в корне отличаются друг от друга зарядом и квантовыми числами, но обладают одинаковым числом поколений. Однако, есть теории, выходящие за рамки Стандартной модели, которые предсказывают, что на высоких энергиях лептоны и кварки сливаются воедино, формируя лептокварки. Если лептокварки реальны, то они очень тяжелые и быстро распадаются на более стабильные частицы, лептоны и кварки. Лептокварки предлагаются в теориях, стремящихся объединить сильное, слабое и электромагнитное взаимодействия. Сейчас исследователи на Большом адронном коллайдере (БАК) прикладывают все усилия, чтобы либо доказать, либо опровергнуть существование этих гипотетических частиц.

2) Как известно, субатомные частицы крайне сложно наблюдать из-за их размера. Они меньше атома и длины волны видимого света. Единственный доступный способ их зарегистрировать и наблюдать их поведение – столкнуть атомные ядра, состоящие из частиц, друг с другом на невероятно высоких скоростях (близких к скорости света). В результате производится большое количество экзотических частиц. Физики считают, что эти столкновения напоминают условия, при

которых развивалась Вселенная сразу после Большого взрыва. Благодаря таким ускорителям частиц, как БАК, Релятивистский коллайдер тяжелых ионов (RHIC) и уже нефункционирующий Тэватрон, ученые достигли немалого прогресса в понимании того, как работают все субатомные частицы во Вселенной и как именно они взаимодействуют.

3) В 1960-х годах Питер Хиггс разработал теорию, объясняющую, как частицы, переносящие электромагнитное или слабое взаимодействие, могли получить разные массы в процессе постепенного остывания Вселенной. Его предположение заключалось в том, что частицы вроде протонов, нейтронов и кварков получают массу через взаимодействие с невидимым электромагнитным полем, известным как поле Хиггса (или хиггсовское поле). Некоторые частицы способны проходить через это поле, не получая массы, в то время как другие "вязнут" в нем и накапливают её. Если это так, то "невидимое" поле должно иметь связанную с ним частицу – бозон Хиггса, – которая контролирует взаимодействия с другими частицами и хиггсовским полем.

4) Событие, зарегистрированное в 2012 году Компактным мюонным соленоидом (CMS) на Большом адронном коллайдере в протон-протонных столкновениях на 8 ТэВ энергии центра масс, признается триумфом в развитии физики. Ученые, наконец, разрешили проблему, над которой работали более 40 лет: предсказание новой фундаментальной частицы – бозона Хиггса – подтвердилось. Сообщалось, что в этом событии образовалась пара Z-бозонов, один из которых распался на пару электронов, тогда как второй Z-бозон распался на пару мюонов, при этом их совместная масса была близка к 126 ГэВ. Это означает, что была получена частица массой 126 ГэВ, распавшаяся на два Z-бозона в точности с ожиданиями в случае, если наблюдаемая частица является бозоном Хиггса. Сделанное открытие положило начало новым исследованиям. Ученые работают над достижением все больших энергий на ускорителях частиц и даже добились создания капель кварк-глюонной плазмы, которая сегодня считается первичным веществом, заполнявшим все пространство сразу после большого взрыва.

5) Проблема иерархии (именно под таким названием известна несогласованность масс) проявляется в большом разрыве между экспериментально наблюдаемыми массами элементарных частиц и масштабами энергий ранней Вселенной. Масса самой тяжелой частицы Стандартной модели, топ-кварка, равна примерно 173,1 гига-

электронвольта, тогда как планковская масса, являющаяся верхним пределом для масс частиц и характерным масштабом квантовой гравитации и теории струн, – на 16 порядков выше.

В настоящее время существуют три варианта объяснения проблемы иерархии частиц. Первый связан с существованием других, еще не открытых экспериментально тяжелых частиц. На их роль претендуют, в частности, суперсимметричные частицы и темная материя. Второе объяснение не предполагает новых частиц и сводится к так называемому антропному принципу: Вселенная такая, какая есть, с заданным набором описывающих её природу параметров, поскольку иначе не существовало бы самого человека, интересующегося, среди прочего, проблемами иерархии масс. Третий вариант предполагает существование мультивселенной – множества параллельных миров, характеризуемых уникальными наборами фундаментальных констант, масс частиц и взаимодействий между ними. Набирающие популярность теории естественности, вероятно, можно считать четвертым возможным решением проблемы иерархии частиц.

6) Коллаборация физиков EXO-200 (Enriched Xenon Observatory – Обсерватория с обогащенным ксеноном), в которую входят ученые из США, Канады, России, Китая, Южной Кореи и Германии, сообщила об отрицательном результате поиска майорановских нейтрино. Обнаружение таких частиц позволило бы ученым выйти за пределы Стандартной модели, поскольку само существование гипотетических частиц нарушает законы сохранения для некоторых квантовых чисел (в данном случае – лептонного заряда). Физики искали следы майорановских нейтрино в лаборатории, расположенной в Нью-Мехико в США на глубине 650 метров под землей, что позволило уменьшить влияние фонового космического излучения и естественной радиации земли.

Сегодня существует много установок, пытающихся обнаружить нейтрино и связанные с ними осцилляции и безнейтринные ядерные реакции. Например, в России на озере Байкал с 1993 года на глубине более километра функционирует нейтринный телескоп НТ200, который предназначен для поиска нейтрино высоких энергий и некоторых гипотетических объектов, таких, например, как магнитные монополи. Однако, нейтрино чрезвычайно мало взаимодействует с веществом, что делает его наблюдение труднодоступным: длина свободного пробега в воде такой частицы может достигать порядка ста световых лет.

5. Render the text into English in writing and entitle it.

Международная группа физиков, работающая на Большом адронном коллайдере в составе коллабораций ATLAS и CMS (ЦЕРН), впервые наблюдала распад бозона Хиггса на два b-кварка (боттом-кварка). Это открытие вновь подтверждает Стандартную модель, описывающую свойства элементарных частиц. Ученые также не нашли свидетельств возможного существования Новой физики, которая могла бы объяснить возможные недостатки существующей теории.

В ускорителях частиц бозон Хиггса возникает при лобовом столкновении двух протонов, когда происходит слияние глюонов – разновидностей бозонов, отвечающих за взаимодействие между кварками и их удержание внутри протона. В результате из глюонов возникает u-кварк и анти u-кварк, из которых в свою очередь возникает короткоживущий бозон Хиггса. После этого он почти сразу же распадается, при этом возможно образование электрон-позитронных пар, фотонов, мюона и антимюона.

Согласно предсказанию Стандартной модели, распад на b-кварки происходит в 60 процентах случаев. Другие типы распада бозона Хиггса хорошо различимы на фоне «шума», в то время как возникновение b-кварка и b-антикварка маскируется другими процессами, которые приводят к появлению боттом-кварков. Например, само столкновение протонов создает ливень из субатомных частиц, включая искомые. Поэтому для выявления предсказанного события физикам необходимо было накопить статистику на пять стандартных отклонений (равносильно вероятности неслучайного результата в 99,97 процента), проанализировав сотни тысяч распадов частиц при протон-протонных столкновениях.

Новые данные были получены при двух прогонах пучков заряженных частиц по 27-километровому кольцу Большого адронного коллайдера. Столкновения протонов происходили при энергиях 7, 8 и 13 тераэлектронвольт. Затем ученые проанализировали информацию, учитывая побочные продукты при взаимодействии частиц. Это позволило обнаружить не только распад бозона Хиггса на боттом-кварки, но и подтвердить, что его скорость соответствует предсказанному Стандартной моделью значению.

Бозон Хиггса участвует в механизме (механизм Хиггса) возникновения масс таких фундаментальных частиц, как переносчиков слабого взаимодействия (W- и Z-бозоны), а также определяет отсутствие массы покоя у глюона и фотона. Несмотря на то, что открытие этой частицы подтверждает Стандартную модель, существуют проблемы (например, ассимметрия материи и антиматерии во Вселенной или несовместимость с теорией относительности), которые с ее позиции объяснить не удается. В то же время на ускорителях частиц до сих пор не было получено намеков на существование Новой физики. Некоторые ученые считают, что Новой физики вообще не существует (или она в принципе не наблюдаема), и на данный момент о Вселенной известно почти все, что только можно знать.

6. Study the timeline of discoveries of subatomic particles. Describe some of the discoveries in greater depth.

1801: Johann Wilhelm Ritter observed that silver chloride transformed faster from white to black when it was placed in a dark region of the Sun's spectrum, close to its violet end. The "chemical rays" that he discovered were later called ultraviolet radiation.

1895: German physicist Victor Schumann discovered ultraviolet radiation below 200 nm, which was later identified as photons.

1895: German physicist Wilhelm Conrad Röntgen produced electromagnetic radiation in a wavelength called X-ray.

1897: J.J. Thomson while studying properties of cathode rays discovered electrons.

1899: Ernest Rutherford in his gold foil experiment discovered the alpha particle.

1900: Paul Villard's experiments in radioactivity led to the discovery of gamma rays.

1911: The Rutherford experiment by Hans Geiger and Ernest Marsden resulted in the discovery of atomic nucleus.

1919: Ernest Rutherford discovered protons.

1932: James Chadwick discovered the unknown atomic particle which later came to be known as the neutron.

1932: Carl D. Anderson's detailed study of energy distribution of cosmic-ray particles led to the discovery of positrons.

1936: Seth Neddermeyer, with Carl Anderson, discovered the muon, a negatively charged subatomic particle.

1946: C. F. Powell discovered the pion (pi-meson), a heavy subatomic particle.

1947: George Dixon Rochester and Clifford Charles Butler discovered the kaon, the first "strange" particle.

1955: Owen Chamberlain, Emilio Segrè, Clyde Wiegand and Thomas Ypsilantis conducted an experiment which resulted in the discovery of the antiproton.
1956: Team of Frederick Reines and Clyde Cowan discovered the electron neutrino, a subatomic particle with no electric charge.
1962: Leon Lederman, Melvin Schwartz and Jack Steinberger discovered what is identified as the muon neutrino.
1964: The xi or cascade baryon was first observed at Brookhaven National Laboratory in New York.
1974: Two research groups, one at Stanford Linear Accelerator Center under Burton Richter and another at Brookhaven National Laboratory under Samuel Ting discovered J/ψ, a flavor-neutral meson.
1975: American physicist Martin Perl discovered the tau lepton.
1977: Upsilon meson was discovered by Fermilab, under Leon Lederman.
1979: The gluon was observed for the first time at DESY, the German Electron Synchrotron.
1983: Carlo Rubbia, Simon van der Meer and the CERN UA1 discovered W and Z bosons.
1995: Physicists at Fermilab's Department of Energy announced the discovery of a subatomic particle called the top quark.
1995: Antihydrogen, antimatter counterpart of hydrogen, was artificially produced for the first time at CERN.
2000: Fermilab confirmed the discovery of the tau neutrino.
2011: Members of the international STAR collaboration detected the antimatter partner of the helium nucleus, antihelium-4.
2012: Higgs boson was claimed to be discovered at ATLAS and CMS experiments at CERN's Large Hadron Collider (LHC).

FOCUS ON PRODUCTIVE WRITING AND SPEAKING SKILLS

1. ***Write 3 paragraphs of 250 words describing any of the milestones in the history of particle physics.***

2. ***Prepare a round-table talk on one of the following topics. You may choose any other topic related to problems of particle physics to discuss.***

1) Is there any physics beyond the Standard Model?
2) Unsolved mysteries of physics: the dark energy and the dark matter
3) The Grand Unified Theory – physicists' Holy Grail
4) Can the Higgs destroy the Universe?
5) Findings and discoveries of the LHC

KEY WORDS AND WORD COMBINATIONS

Accelerator
particle accelerator
Angular momentum
Angular velocity
Annihilation
Antiparticles: antilepton, antineutrino, antineutron, antiproton, antiquark
Atom
Boson
gauge boson, Higgs boson
Charge
colour charge, electric charge,
Collider
Large Hadron Collider
Collision
high-energy collisions
Cosmic ray
Coupling
Decay
beta decay; decay channel, decay product
Detector
Electron
Electron-positron pair
Energy
collision energy, dark energy
Event
Experiment
Atlas experiment, high-energy experiment, LHC experiment, particle accelerator experiment, scattering experiment
Fermion
Field

electric field, Higgs field, magnetic field
Force
electromagnetic force, gravitational force, strong force, weak force; force-carrier
Gauge symmetry
Gluon
Graviton
Gravity
Hadron
Interaction
cosmic ray interactions, fundamental interactions of matter
Law
law of charge conjugation
Lepton
Mass
Matter
antimatter, bulk matter, dark matter
Meson
Muon
Neutrino
Neutron
Nucleon
Nucleus
Pair production
Parameter
Particle
composite particle, elementary particle, exotic particle, force particle, fundamental particle, massless particle, matter particle, short-lived particle, subatomic particle; shower of particles
Photon
Positron
Property
Proton
Quantized state
Quantum
quantum mechanics, quantum number
Quark
Scale
subatomic scale, subnuclear scale
Scattering

Spin

half-integer spin, integer spin; spin quantum number

Standard Model

Supersymmetry

Theory

Einstein's theory of special relativity, Dirac's relativistic theory, guage theory, quantum field theory, quantum theory of gravity, theory of the strong nuclear force (quantum chromodynamics)

Vacuum

UNIT 4. STARS

TEXT 1

1. ***Check the pronunciation of these words in a dictionary. If necessary, specify their meaning.***

   basic, constituent, cause, gaseous, giant, gradually, hydrogen, individual, ionize, iron, measure, molecular, multiply, negligible, obey, occur, ratio, supply, surface, total

2. ***Read the text and answer the questions below.***

   1) What mathematical relations can be derived from basic physical laws?
   2) What common assumptions concerning the internal structure of a star are mentioned in the text?
   3) Under which conditions are atoms ionized within stars?
   4) What is the mean density of the Sun?
   5) Which stars do not obey the perfect gas law? Why?
   6) How do white dwarf stars differ from normal stars?
   7) How does the flow of radiation work its way to the surface of a star?
   8) What does the opacity of a star depend on?
   9) What does the molecular weight of a star depend on?

Stellar interiors

Models of the internal structure of stars – particularly their temperature, density, and pressure gradients below the surface – depend on basic principles explained in this section. It is especially important that model calculations take account of the change in the star's structure with time as its hydrogen supply is gradually converted into helium. Fortunately, given that most stars can be said to be examples of an "ideal gas," the relations between temperature, density, and pressure have a basic simplicity.

Distribution of matter

1. Several mathematical relations can be derived from basic physical laws, assuming that the gas is “ideal” and that a star has spherical symmetry; both these assumptions are met with a high degree of validity. Another common assumption is that the interior of a star is in hydrostatic equilibrium. This balance is often expressed as a simple relation between pressure gradient and density. A second relation expresses the continuity of mass; i.e., if M is the mass of matter within a sphere of radius r, the mass added, ΔM, when encountering an increase in distance Δr through a shell of volume $4\pi r^2\Delta r$, equals the volume of the shell multiplied by the density, ρ. In symbols, $\Delta M = 4\pi r^2\rho\Delta r$.

2. A third relation, termed the equation of state, expresses an explicit relation between the temperature, density, and pressure of a star’s internal matter. Throughout the star the matter is entirely gaseous, and, except in certain highly evolved objects, it obeys closely the perfect gas law. In such neutral gases the molecular weight is 2 for molecular hydrogen, 4 for helium, 56 for iron, and so on. In the interior of a typical star, however, the high temperatures and densities virtually guarantee that nearly all the matter is completely ionized; the gas is said to be a plasma, the fourth state of matter. Under these conditions not only are the hydrogen molecules dissociated into individual atoms, but also the atoms themselves are broken apart (ionized) into their constituent protons and electrons. Hence, the molecular weight of ionized hydrogen is the average mass of a proton and an electron – namely, 1/2 on the atom-mass scale noted above. By contrast, a completely ionized helium atom contributes a mass of 4 with a helium nucleus (alpha particle) plus two electrons of negligible mass; hence, its average molecular weight is 4/3. As another example, a totally ionized nickel atom contributes a nucleus of mass 58.7 plus 28 electrons; its molecular weight is then 58.7/29 = 2.02. Since stars contain a preponderance of hydrogen and helium that are completely ionized throughout the interior, the average particle mass, μ, is the (unit) mass of a proton, divided by a factor taking into account the concentrations by weight of hydrogen, helium, and heavier ions. Accordingly, the molecular weight depends critically on the star’s chemical composition, particularly on the ratio of helium to hydrogen as well as on the total content of heavier matter.

3. If the temperature is sufficiently high, the radiation pressure, P_r, must be taken into account in addition to the perfect gas pressure, P_g. The total equation of state then becomes $P = P_g + P_r$. Here P_g depends on

temperature, density, and molecular weight, whereas P_r depends on temperature and on the radiation density constant, $a = 7.5 \times 10^{-15}$ ergs per cubic cm per degree to the fourth power. With $\mu = 2$ (as an upper limit) and $\rho = 1.4$ grams per cubic cm (the mean density of the Sun), the temperature at which the radiation pressure would equal the gas pressure can be calculated. The answer is 28 million K, much hotter than the core of the Sun. Consequently, radiation pressure may be neglected for the Sun, but it cannot be ignored for hotter, more massive stars. Radiation pressure may then set an upper limit to stellar luminosity.

4. Certain stars, notably white dwarfs, do not obey the perfect gas law. Instead, the pressure is almost entirely contributed by the electrons, which are said to be particulate members of a degenerate gas. If μ' is the average mass per free electron of the totally ionized gas, the pressure, P, and density, ρ, are such that P is proportional to a 5/3 power of the density divided by the average mass per free electron; i.e., $P = 10^{13}(\rho / \mu')^{5/3}$. The temperature does not enter at all. At still higher densities the equation of state becomes more intricate, but it can be shown that even this complicated equation of state is adequate to calculate the internal structure of the white dwarf stars. As a result, white dwarfs are probably better understood than most other celestial objects.

5. For normal stars such as the Sun, the energy-transport method for the interior must be known. Except in white dwarfs or in the dense cores of evolved stars, thermal conduction is unimportant because the heat conductivity is very low. One significant mode of transport is an actual flow of radiation outward through the star. Starting as gamma rays near the core, the radiation is gradually "softened" (becomes longer in wavelength) as it works its way to the surface (typically, in the Sun, over the course of about a million years) to emerge as ordinary light and heat. The rate of flow of radiation is proportional to the thermal gradient – namely, the rate of change of temperature with interior distance. Providing yet another relation of stellar structure, this equation uses the following important quantities: a, the radiation constant noted above; c, the velocity of light; ρ, the density; and κ, a measure of the opacity of the matter. The larger the value of κ, the lower the transparency of the material and the steeper the temperature fall required to push the energy outward at the required rate. The opacity, κ, can be calculated for any temperature, density, and chemical composition and is found to depend in a complex manner largely on the two former quantities.

6. In the Sun's outermost (though still interior) layers and especially in certain giant stars, energy transport takes place by quite another mechanism: large-scale mass motions of gases – namely, convection. Huge volumes of gas deep within the star become heated, rise to higher layers, and mix with their surroundings, thus releasing great quantities of energy. The extraordinarily complex flow patterns cannot be followed in detail, but when convection occurs, a relatively simple mathematical relation connects density and pressure. Wherever convection does occur, it moves energy much more efficiently than radiative transport.

LANGUAGE REVIEW

Focus on word formation

1. ***Review adjective-forming suffixes and match the verbs and nouns with appropriate adjectives.***

   verbs: constitute, neglect, signify, act, follow, radiate
   nouns: base, gas, molecule, type, mass, proportion

2. ***Form nouns from the following verbs.***
   add, assume, compose, conduct, equate, press, radiate, relate, surround

3. ***Review negative prefixes of adjectives. Add these prefixes to the words below: dis-, il-, im-, in-, ir-, non-, un-.***

   …absorbable, …accurate, …adequate, …believable, …capable, …certain, …complete, …conceivable, …continuous, …conventional, …correct, …different, …efficient, …even, …excited, …functional, …important …known, …limited, …linear, …logical, …mobile, …organized, …perfect, …permeable, …personal, …possible, …practical, …proper, …pure, …qualified, …rational, …regular, …relevant, …replaceable, …resistible, …resolute, …responsible, …similar, …stable, …steady, …suitable, …visible

4. ***Identify what part of speech the words 'increase', 'degenerate' and 'measure' represent in paragraphs 1, 4 and 5 respectively. What other parts of speech can they belong to? Check how they should be pronounced in each case.***

Focus on grammar

1. Answer the questions.

1) How are the Degrees of Comparison of adjectives and adverbs formed?
2) What are the features of the Inversion and Emphasis?
3) What are the primary and secondary functions of modal verbs *can*, *may*, *must*?
4) What distinguishes the Absolute Participial Construction (see Text 2) from other constructions with the Participle? How is it rendered into Russian?

2. Do the following tasks.

1) Analyse the use of the Modal verbs in the text.
2) State the functions of participles throughout the text.
3) Find the sentences with the Inversion and Emphasis in the text and translate them.
4) Trace the instances of the Degrees of Comparison of adjectives and adverbs in the text.
5) Identify Comparative constructions in paragraphs 3, 4, 5 and 6 and translate them.
6) Comment on the use of the Complex Subject in the text and translate the sentences it is used in.

Focus on paragraph structure and content

1. Answer the questions.

1) What key terms and phrases provide an effective means of connecting the sentences in all the paragraphs of Text 1?
2) What parallel grammatical and structural forms (words, phrases, clauses) are used in paragraphs 1, 2 and 3?
3) What does the pronoun 'it' in paragraphs 2 and 5 refer to?
4) What connecting words and phrases are used in all the paragraphs of Text 1 to improve coherence?

2. Do the following tasks.

1) Indicate the topic sentence in each paragraph of Text 1.
2) Develop the idea of each topic sentence.
3) Sum up the main points of Text 1.

Focus on vocabulary

1. ***Define or explain these terms.***

temperature/pressure/density gradient, ideal gas, molecular weight, radiation pressure, degenerate gas, convection, luminosity, opacity

2. ***Give English equivalents for the following word combinations.***

внутреннее строение звезды, давление идеального газа, под поверхностью, гидростатическое давление, ядро солнца, точное соотношение, четко соблюдать закон идеального газа, пренебрежимо малая масса, полностью ионизированный газ, небесные тела, в недрах звезды, вырожденный газ, давление радиации, яркость/светимость звезды

3. ***Give Russian equivalents for the following word combinations. Make up sentences with some of them.***

to be gradually converted into; the change in the star's structure; to be met with a high degree of validity; to be in hydrostatic equilibrium; an explicit relation between temperature, density and pressure; the interior of a typical star; to dissociate into individual atoms; to contain a preponderance of hydrogen; throughout the interior; to set an upper limit; the energy-transport method; an actual flow of radiation outward through the star; the rate of change of temperature; a measure of the opacity of the matter; the star's chemical composition; the ratio of helium to hydrogen; large-scale mass motion of gases; to release great quantities of energy

4. ***Fill in the gaps using these lexical units: important, as well as, gradually, preponderance, critically, interior, be derived from, be divided by, common, accordingly, average, take account of, particularly, spherical. Consult the text if necessary.***

1) It is especially … that model calculations … the change in the star's structure with time as its hydrogen supply is … converted into helium.
2) Several mathematical relations can … basic physical laws, assuming that the gas is "ideal" and that a star has … symmetry.
3) Another … assumption is that the … of a star is in hydrostatic equilibrium.

4) Since stars contain a … of hydrogen and helium that are completely ionized throughout the interior, the … particle mass, μ, is the (unit) mass of a proton, … a factor taking into account the concentrations by weight of hydrogen, helium, and heavier ions.
5) …, the molecular weight depends … on the star's chemical composition, … on the ratio of helium to hydrogen … on the total content of heavier matter.

5. ***Translate the sentences from Russian into English. Pay attention to the connecting words.***

1) Поскольку характерным признаком звезды служат протекающие в ее недрах термоядерные реакции, именно их отсутствие положено в основу определения планеты.
2) Однако последние годы показали, что развитие спектральной классификации не прекратилось: появление инфракрасных приемников и обнаружение с их помощью коричневых карликов привело в конце 1990-х к введению новых спектральных классов L и T для тел с эффективной температурой менее 2000 K.
3) К тому же, кроме гравитации и давления самого газа, на него оказывают влияние гравитация звезд, давление межзвездного магнитного поля, давление излучения и космических лучей, вращение Галактики.
4) Согласно простейшему варианту этой теории, форму сжимающейся протозвезды описывает последовательность фигур равновесия самогравитирующих вращающихся однородных («жидких») тел.
5) Поскольку объекты с массами ниже этого предела уже обнаружены в немалом количестве – это коричневые карлики, то можно сказать, что последовательность наблюдаемых маломассивных звезд достигает своего физического предела, обусловленного прекращением ядерного синтеза и наступлением вырождения при низкой температуре и высокой плотности.
6) Судя по расчетам, эффективная температура коричневых карликов никогда не достигает 2800 K.
7) Впрочем, по мере роста длинноволновых возмущений может происходить агломерация малых уплотнений в более массивные.

8) При этом, как легко понять, наибольшую массу приобретают самые медленно движущиеся звезды.
9) В результате за короткое время была создана теория ядерного горения в вырожденном веществе, развиты схемы быстрого и медленного захвата нейтронов, позволившие объяснить происхождение химических элементов; было рассчитано взаимодействие оболочек сверхновых с межзвездной средой.
10) Впрочем, одиночные белые карлики и одиночные нейтронные звезды (обнаруженные в самом конце XX в.) выглядят довольно спокойными.
11) Однако за последние годы найдены сравнительно небольшие тела, заполняющие по массе промежуток между звездами и планетами.

TEXT 2

1. ***Check the pronunciation of these words in a dictionary. If necessary, specify their meaning.***

   annihilate, deuteron, effect, encounter, endure, event, finite, inevitable, roughly, source, x-ray

2. ***Read the text and describe the processes happening in the interiors of stars.***

Source of stellar energy

The most basic property of stars is that their radiant energy must derive from internal sources. Given the great length of time that stars endure (some 10 billion years in the case of the Sun), it can be shown that neither chemical nor gravitational effects could possibly yield the required energies. Instead, the cause must be nuclear events wherein lighter nuclei are fused to create heavier nuclei, an inevitable by-product being energy.

In the interior of a star, the particles move rapidly in every direction because of the high temperatures present. Every so often a proton moves close enough to a nucleus to be captured, and a nuclear reaction takes place. Only protons of extremely high energy (many times the average energy in a star such as the Sun) are capable of producing nuclear events of this kind. A minimum temperature required for fusion is roughly 10 million K. Since the energies of protons are proportional to temperature, the rate of energy production rises steeply as temperature increases.

For the Sun and other normal main-sequence stars, the source of energy lies in the conversion of hydrogen to helium. The nuclear reaction thought to occur in the Sun is called the proton-proton cycle. In this fusion reaction, two protons (^1H) collide to form a deuteron (a nucleus of deuterium, ^2H), with the liberation of a positron (the electron's positively charged antimatter counterpart, denoted e^+). Also emitted is a neutral particle of very small mass called a neutrino, ν. While the helium "ash" remains in the core where it was produced, the neutrino escapes from the solar interior within seconds. The positron encounters an ordinary negatively charged electron, and the two annihilate each other, with much energy being released. This annihilation energy amounts to 1.02 megaelectron volts (MeV), which accords well with Einstein's equation $E = mc^2$ (where m is the mass of the two particles, c the velocity of light, and E the liberated energy).

Next, a proton collides with the deuteron to form the nucleus of a light helium atom of atomic weight 3, ^3He. A "hard" X-ray (one of higher energy) or gamma-ray (γ) photon also is emitted. The most likely event to follow in the chain is a collision of this ^3He nucleus with a normal ^4He nucleus to form the nucleus of a beryllium atom of weight 7, ^7Be, with the emission of another gamma-ray photon. The ^7Be nucleus in turn captures a proton to form a boron nucleus of atomic weight 8, ^8B, with the liberation of yet another gamma ray.

The ^8B nucleus, however, is very unstable. It decays almost immediately into beryllium of atomic weight 8, ^8Be, with the emission of another positron and a neutrino. The nucleus itself thereafter decays into two helium nuclei, ^4He. These nuclear events can be represented by the following equations:

$$^3He + {}^4He \rightarrow {}^7Be + \gamma \quad \text{(rather slow reaction)}$$

$$^7Be + {}^1H \rightarrow {}^8B + \gamma \quad \text{(rapid reaction)}$$

$$\left.\begin{array}{l} ^8B \rightarrow {}^8Be + e^+ + \nu \\ ^8Be \rightarrow 2\,{}^4He \end{array}\right\} \quad \text{(instantaneous reactions)}$$

In the course of these reactions, four protons are consumed to form one helium nucleus, while two electrons perish.

The mass of four hydrogen atoms is 4 × 1.00797, or 4.03188, atomic mass units; that of a helium atom is 4.0026. Hence, 0.02928 atomic mass unit, or 0.7 percent of the original mass, has disappeared. Some of this has been carried away by the elusive neutrinos, but most of it has been converted to radiant energy. In order to keep shining at its present rate, a typical star (e.g., the Sun) needs to convert 674 million tons of hydrogen to 670 million tons of helium every second. According to the formula $E = mc^2$, more than four million tons of matter literally disappear into radiation each second. […]

The main source of energy in hotter stars is the carbon cycle (also called the CNO cycle for carbon, nitrogen, and oxygen), in which hydrogen is transformed into helium, with carbon serving as a catalyst. The reactions proceed as follows: first, a carbon nucleus, ^{12}C, captures a proton (hydrogen nucleus), ^{1}H, to form a nucleus of nitrogen, ^{13}N, a gamma-ray photon being emitted in the process; thus, $^{12}C + {}^{1}H \rightarrow {}^{13}N + \gamma$. The light ^{13}N nucleus is unstable, however. It emits a positron, e^+, which encounters an ordinary electron, e^-, and the two annihilate one another. A neutrino also is released, and the resulting ^{13}C nucleus is stable. Eventually the ^{13}C nucleus captures another proton, forms ^{14}N, and emits another gamma-ray photon. In symbols the reaction is represented by the equations $^{13}N \rightarrow {}^{13}C + e^+ + \nu$; then $^{13}C + {}^{1}H \rightarrow {}^{14}N + \gamma$. Ordinary nitrogen, ^{14}N, is stable, but when it captures a proton to form a nucleus of light oxygen-15, ^{15}O, the resulting nucleus is unstable against beta decay. It therefore emits a positron and a neutrino, a sequence of events expressed by the equations $^{14}N + {}^{1}H \rightarrow {}^{15}O + \gamma$; then $^{15}O \rightarrow {}^{15}N + e^+ + \nu$. Again, the positron meets an electron, and the two annihilate each other while the neutrino escapes. Eventually the ^{15}N nucleus encounters a fast-moving proton, 1H, and captures it, but the formation of an ordinary ^{16}O nucleus by this process occurs only rarely. The most likely effect of this proton capture is a breakdown of ^{15}N and a return to the ^{12}C nucleus − that is, $^{15}N + {}^{1}H \rightarrow {}^{12}C + {}^{4}He + \gamma$. Thus, the original ^{12}C nucleus reappears, and the four protons that have been added permit the formation of a helium nucleus. The same amount of mass has disappeared, though a different fraction of it may have been carried off by the neutrinos.

Only the hottest stars that lie on the main sequence shine with energy produced by the carbon cycle. The faint red dwarfs use the proton-proton cycle exclusively, whereas stars such as the Sun shine mostly by the proton-proton reaction but derive some contribution from the carbon cycle as well.

The aforementioned mathematical relationships permit the problem of stellar structure to be addressed notwithstanding the complexity of the problem. An early assumption that stars have a uniform chemical composition throughout their interiors simplified the calculations considerably, but it had to be abandoned when studies in stellar evolution proved that the compositions of stars change with age. Computations need to be carried out by a step-by-step process known as numerical integration. They must take into account that the density and pressure of a star vanish at the surface, whereas these quantities and the temperature remain finite at the core.

3. ***Translate the following sentences. Pay attention to the Absolute Participial Construction and other grammar forms and structures.***
   1) Instead, the cause must be nuclear events wherein lighter nuclei are fused to create heavier nuclei, an inevitable by-product being energy.
   2) Every so often a proton moves close enough to a nucleus to be captured, and a nuclear reaction takes place.
   3) The nuclear reaction thought to occur in the Sun is called the proton-proton cycle.
   4) Also emitted is a neutral particle of very small mass called a neutrino, ν.
   5) The positron encounters an ordinary negatively charged electron, and the two annihilate each other, with much energy being released.
   6) In the course of these reactions, four protons are consumed to form one helium nucleus, while two electrons perish.
   7) The main source of energy in hotter stars is the carbon cycle (also called the CNO cycle for carbon, nitrogen, and oxygen), in which hydrogen is transformed into helium, with carbon serving as a catalyst.
   8) Only the hottest stars that lie on the main sequence shine with energy produced by the carbon cycle.
   9) The same amount of mass has disappeared, though a different fraction of it may have been carried off by the neutrinos.
   10) The aforementioned mathematical relationships permit the problem of stellar structure to be addressed notwithstanding the complexity of the problem.

4. ***Read the text again and trace connecting words and phrases. If necessary, check their meaning.***

TEXT 3

1. Read the text and identify the topic of each paragraph.

Star Formation and Evolution

1. Throughout the Milky Way Galaxy (and even near the Sun itself), astronomers have discovered stars that are well evolved or even approaching extinction, or both, as well as occasional stars that must be very young or still in the process of formation. Evolutionary effects on these stars are not negligible, even for a middle-aged star such as the Sun. More massive stars must display more spectacular effects because the rate of conversion of mass into energy is higher. While the Sun produces energy at the rate of about two ergs per gram per second, a more luminous main-sequence star can release energy at a rate some 1,000 times greater. Consequently, effects that require billions of years to be easily recognized in the Sun might occur within a few million years in highly luminous and massive stars. A supergiant star such as Antares, a bright main-sequence star such as Rigel, or even a more modest star such as Sirius cannot have endured as long as the Sun has endured. These stars must have been formed relatively recently.

Birth of stars and evolution to the main sequence

2. Detailed radio maps of nearby molecular clouds reveal that they are clumpy, with regions containing a wide range of densities − from a few tens of molecules (mostly hydrogen) per cubic centimetre to more than one million. Stars form only from the densest regions, termed cloud cores, though they need not lie at the geometric centre of the cloud. Large cores (which probably contain subcondensations) up to a few light-years in size seem to give rise to unbound associations of very massive stars (called OB associations after the spectral type of their most prominent members, O and B stars) or to bound clusters of less massive stars. Whether a stellar group materializes as an association or a cluster seems to depend on the efficiency of star formation. If only a small fraction of the matter goes into making stars, the rest being blown away in winds or expanding H II regions, then the remaining stars end up in a gravitationally unbound association, dispersed in a single crossing time (diameter divided by velocity) by the random motions of the formed stars. On the other hand, if 30 percent or more of the mass of the cloud core goes into making stars, then the formed stars will remain bound to one

another, and the ejection of stars by random gravitational encounters between cluster members will take many crossing times.

3. In the centre of the Orion Nebula (M42) astronomers have identified some 700 young stars in this 2.5-light-year-wide area. They have also detected over 150 protoplanetary disks, or proplyds, which are believed to be embryonic solar systems that will eventually form planets. These stars and proplyds generate most of the nebula's light.

4. Low-mass stars also are formed in associations called T associations after the prototypical stars found in such groups, T Tauri stars. The stars of a T association form from loose aggregates of small molecular cloud cores a few tenths of a light-year in size that are randomly distributed through a larger region of lower average density. The formation of stars in associations is the most common outcome; bound clusters account for only about 1 to 10 percent of all star births. The overall efficiency of star formation in associations is quite small. Typically less than 1 percent of the mass of a molecular cloud becomes stars in one crossing time of the molecular cloud (about 5×10^{6} years). Low efficiency of star formation presumably explains why any interstellar gas remains in the Galaxy after 10^{10} years of evolution. Star formation at the present time must be a mere trickle of the torrent that occurred when the Galaxy was young.

5. A typical cloud core rotates fairly slowly, and its distribution of mass is strongly concentrated toward the centre. The slow rotation rate is probably attributable to the braking action of magnetic fields that thread through the core and its envelope. This magnetic braking forces the core to rotate at nearly the same angular speed as the envelope as long as the core does not go into dynamic collapse. Such braking is an important process because it assures a source of matter of relatively low angular momentum (by the standards of the interstellar medium) for the formation of stars and planetary systems. It also has been proposed that magnetic fields play an important role in the very separation of the cores from their envelopes. The proposal involves the slippage of the neutral component of a lightly ionized gas under the action of the self-gravity of the matter past the charged particles suspended in a background magnetic field. This slow slippage would provide the theoretical explanation for the observed low overall efficiency of star formation in molecular clouds.

6. At some point in the course of the evolution of a molecular cloud, one or more of its cores become unstable and subject to gravitational collapse. Good arguments exist that the central regions should collapse first, producing a condensed protostar whose contraction is halted by the

large buildup of thermal pressure when radiation can no longer escape from the interior to keep the (now opaque) body relatively cool. The protostar, which initially has a mass not much larger than Jupiter, continues to grow by accretion as more and more overlying material falls on top of it. The infall shock, at the surfaces of the protostar and the swirling nebular disk surrounding it, arrests the inflow, creating an intense radiation field that tries to work its way out of the infalling envelope of gas and dust. The photons, having optical wavelengths, are degraded into longer wavelengths by dust absorption and reemission, so that the protostar is apparent to a distant observer only as an infrared object. Provided that proper account is taken of the effects of rotation and magnetic field, this theoretical picture correlates with the radiative spectra emitted by many candidate protostars discovered near the centres of molecular cloud cores.

7. An interesting speculation concerning the mechanism that ends the infall phase exists: it notes that the inflow process cannot run to completion. Since molecular clouds as a whole contain much more mass than what goes into each generation of stars, the depletion of the available raw material is not what stops the accretion flow. A rather different picture is revealed by observations at radio, optical, and X-ray wavelengths. All newly born stars are highly active, blowing powerful winds that clear the surrounding regions of the infalling gas and dust. It is apparently this wind that reverses the accretion flow.

8. The geometric form taken by the outflow is intriguing. Jets of matter seem to squirt in opposite directions along the rotational poles of the star (or disk) and sweep up the ambient matter in two lobes of outwardly moving molecular gas – the so-called bipolar outflows. Such jets and bipolar outflows are doubly interesting because their counterparts were discovered sometime earlier on a fantastically larger scale in the double-lobed forms of extragalactic radio sources, such as quasars.

9. The underlying energy source that drives the outflow is unknown. Promising mechanisms invoke tapping the rotational energy stored in either the newly formed star or the inner parts of its nebular disk. There exist theories suggesting that strong magnetic fields coupled with rapid rotation act as whirling rotary blades to fling out the nearby gas. Eventual collimation of the outflow toward the rotation axes appears to be a generic feature of many proposed models.

10. Pre-main-sequence stars of low mass first appear as visible objects, T Tauri stars, with sizes that are several times their ultimate main-sequence sizes. They subsequently contract on a time scale of tens of

millions of years, the main source of radiant energy in this phase being the release of gravitational energy. As the internal temperature rises to a few million kelvins, deuterium (heavy hydrogen) is first destroyed. Then lithium, beryllium, and boron are broken down into helium as their nuclei are bombarded by protons moving at increasingly high speeds. When their central temperatures reach values comparable to 10^7 K, hydrogen fusion ignites in their cores, and they settle down to long stable lives on the main sequence. The early evolution of high-mass stars is similar; the only difference is that their faster overall evolution may allow them to reach the main sequence while they are still enshrouded in the cocoon of gas and dust from which they formed.

11. Detailed calculations show that a protostar first appears on the Hertzsprung-Russell diagram well above the main sequence because it is too bright for its colour. As it continues to contract, it moves downward and to the left toward the main sequence.

2. *Read the text again and describe the main stages of star formation and evolution.*

3. *Fill in the gaps with appropriate prepositions from memory. Translate the sentences.*

1) Evolutionary effects ... these stars are not negligible, even … a middle-aged star such as the Sun.
2) More massive stars must display more spectacular effects because the rate … conversion … mass … energy is higher.
3) While the Sun produces energy … the rate of about two ergs … gram … second, a more luminous main-sequence star can release energy … a rate some 1,000 times greater.
4) Detailed radio maps … nearby molecular clouds reveal that they are clumpy, with regions containing a wide range … densities − … a few tens … molecules (mostly hydrogen) … cubic centimetre … more than one million.
5) Stars form only … the densest regions, termed cloud cores, though they need not lie … the geometric centre … the cloud.
6) If only a small fraction … the matter goes … making stars, the rest being blown away in winds or expanding H II regions, then the remaining stars end up in a gravitationally unbound association, dispersed … a single crossing time (diameter divided … velocity) by the random motions … the formed stars.

7) The stars … a T association form from loose aggregates … small molecular cloud cores a few tenths … a light-year … size that are randomly distributed through a larger region … lower average density.
8) The proposal involves the slippage … the neutral component … a lightly ionized gas … the action … the self-gravity … the matter past the charged particles suspended in a background magnetic field.
9) Jets … matter seem to squirt … opposite directions along the rotational poles … the star (or disk) and sweep up the ambient matter in two lobes … outwardly moving molecular gas – the so-called bipolar outflows.

TEXT 4

1. Read the text and answer the following questions:

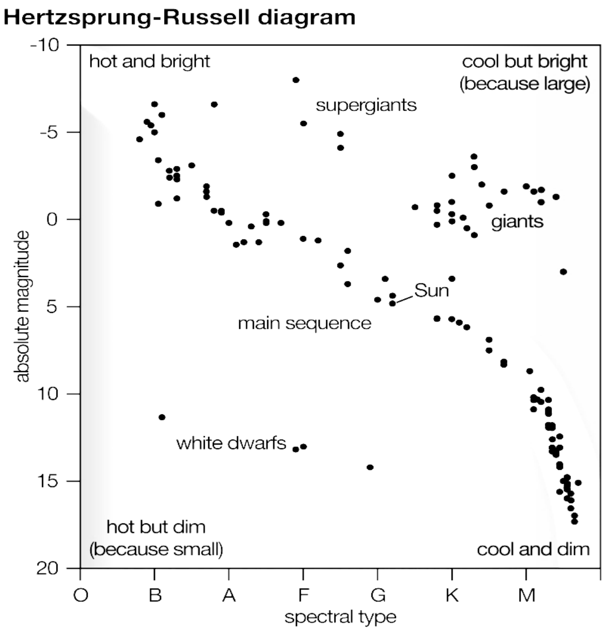
1) What is usually called a Hertzsprung-Russell diagram?
2) Which stars lie closely around a diagonal line called the main sequence?
3) What group of stars lies above the main sequence in the upper right portion of the diagram?
4) What other types of stars are mentioned in the text? What are their main features?
5) Where does the white dwarf domain lie?
6) What are the main gaps in the Hertzsprung-Russell diagram?

Hertzsprung-Russell diagram

When the absolute magnitudes of stars, or their intrinsic luminosities on a logarithmic scale, are plotted in a diagram against temperature or, equivalently, against the spectral types, the stars do not fall at random on the diagram but tend to congregate in certain restricted domains. Such a plot is usually called a Hertzsprung-Russell diagram, named for the early 20th-century astronomers Ejnar Hertzsprung of Denmark and Henry Norris Russell of the United States, who independently discovered the relations shown in it. As is seen in the diagram, most of the congregated stars are dwarfs lying closely around a diagonal line called the main sequence. These stars range from hot, O- and B-type, blue objects at least 10,000 times brighter than the Sun down through white A-type stars such as Sirius to orange K-type stars such as Epsilon Eridani and finally to M-type red dwarfs thousands of times fainter than the Sun. The sequence is continuous; the luminosities fall off smoothly with decreasing surface temperature; the masses and radii decrease but at a much slower rate; and the stellar densities gradually increase.

The second group of stars to be recognized was a group of giants − such objects as Capella, Arcturus, and Aldebaran − which are yellow, orange, or red stars about 100 times as bright as the Sun and have radii on the order of 10−30 million km (about 6−20 million miles, or 15−40 times as large as the Sun). The giants lie above the main sequence in the upper right portion of the diagram. The category of supergiants includes stars of all spectral types; these stars show a large spread in intrinsic brightness, and some even approach absolute magnitudes of −7 or −8. A few red supergiants, such as the variable star VV Cephei, exceed in size the orbit of Jupiter or even that of Saturn, although most of them are smaller. Supergiants are short-lived and rare objects, but they can be seen at great distances because of their tremendous luminosity.

Subgiants are stars that are redder and larger than main-sequence stars of the same luminosity. Many of the best-known examples are found in close binary systems where conditions favour their detection.



The white dwarf domain lies about 10 magnitudes below the main sequence. These stars are in the last stages of their evolution.

The spectrum-luminosity diagram has numerous gaps. Few stars exist above the white dwarfs and to the left of the main sequence. The giants are separated from the main sequence by a gap named for Hertzsprung, who in 1911 became the first to recognize the difference between main-sequence and giant stars. The actual concentration of stars differs considerably in different parts of the diagram. Highly luminous stars are rare, whereas those of low luminosity are very numerous.

The spectrum-luminosity diagram applies to the stars in the galactic spiral arm in the neighbourhood of the Sun and represents what would be obtained if a composite Hertzsprung-Russell diagram were constructed combining data for a large number of the star groups called open (or galactic) star clusters, as, for example, the double cluster *h* and χ Persei, the Pleiades, the Coma cluster, and the Hyades. It includes very young stars, a few million years old, as well as ancient stars perhaps as old as 10 billion years.

2. ***Describe the Hertzsprung-Russell diagram (HRD) taking account of stars' luminosity, spectral type, colour, temperature and evolutionary stage.***

TEXT 5

1. ***Read the article from Encyclopaedia Britannica devoted to stellar classification and identify the most important facts.***

Stellar classification is a scheme for assigning stars to types according to their temperatures as estimated from their spectra. The generally accepted system of stellar classification is a combination of two classification schemes: the Harvard system, which is based on the star's surface temperature, and the MK system, which is based on the star's luminosity.

In the 1860s the Italian astronomer Angelo Secchi distinguished four main spectral types of stars. At the Harvard College Observatory in the 1880s, during the compilation of the *Henry Draper Catalogue* of stars, more types were distinguished and were designated by letter in alphabetic sequence according to the strength of their hydrogen spectral lines. Most of this work was done by three assistants, Williamina P. Fleming, Antonia

C. Maury, and Annie Jump Cannon. As the work progressed, the types were rearranged in a nonalphabetic sequence to put them in order by surface temperature. From hot stars to cool, the order of stellar types is: O, B, A, F, G, K, M. (A traditional mnemonic for this sequence is "Oh Be A Fine Girl [or Guy], Kiss Me.") Additional letters have been used to designate novas and less common types of stars. Numbers from 0 to 9 are used to subdivide the types, the higher numbers applying to cooler stars. The hotter stars are sometimes referred to as early and the cooler as late. With the discovery of brown dwarfs, objects that form like stars but do not shine through thermonuclear fusion, the system of stellar classification has been expanded to include spectral types L, T, and Y.

Class O includes bluish white stars with surface temperatures typically of 25,000–50,000 K (although a few O-type stars with vastly greater temperatures have been described); lines of ionized helium appear in the spectra. Class B stars typically range from 10,000 K to 25,000 K and are also bluish white but show neutral helium lines. The surface temperatures of A-type stars range from 7,400 K to about 10,000 K; lines of hydrogen are prominent, and these stars are white. F-type stars are yellow-white, reach 6,000–7,400 K, and display many spectral lines caused by metals. The Sun is a class G star; these are yellow, with surface temperatures of 5,000–6,000 K. Class K stars are yellow to orange, at about 3,500–5,000 K, and M stars are red, at about 3,000 K, with titanium oxide prominent in their spectra. L brown dwarfs have temperatures between about 1,500 and 2,500 K and have spectral lines caused by alkali metals such as rubidium and sodium and metallic compounds like iron hydride. T brown dwarfs have prominent methane absorption in their spectra and temperatures between about 800 and 1,500 K. Class Y brown dwarfs are cooler than 800 K and have spectral lines from ammonia and water.

The MK, or Yerkes, system is the work of the American astronomers W.W. Morgan, P.C. Keenan, and others. It is based on two sets of parameters: a refined version of the Harvard O-M scale, and a luminosity scale of grades I (for supergiants), II (bright giants), III (normal giants), IV (subgiants), and V (main sequence, or dwarf, stars); further specifications may be used, such as a grade Ia for bright supergiants and grades VI and VII for subdwarfs and white dwarfs, respectively. Thus the Sun, a yellow dwarf star of some 5,800 K, is designated G2 V; while Barnard's star, a red dwarf of some 3,100 K, is classified M5 V; and the bright supergiant Rigel is classified B8 Ia.

2. ***Transform the information about stellar classification into graphic form and then summarise it by selecting and reporting the main features.***

CHECK YOURSELF

1. ***Translate the text at sight.***

Subsequent development on the main sequence

As the central temperature and density continue to rise, the proton-proton and carbon cycles become active, and the development of the (now genuine) star is stabilized. The star then reaches the main sequence, where it remains for most of its active life. The time required for the contraction phase depends on the mass of the star. A star of the Sun's mass generally requires tens of millions of years to reach the main sequence, whereas one of much greater mass might take a few hundred thousand years.

By the time the star reaches the main sequence, it is still chemically homogeneous. With additional time, the hydrogen fuel in the core is converted to helium, and the temperature slowly rises. If the star is sufficiently massive to have a convective core, the matter in this region has a chance to be thoroughly mixed, but the outer region does not mix with the core. The Sun, by contrast, has no convective core, and the helium-to-hydrogen ratio is maximum at the centre and decreases outward. Throughout the life of the Sun, there has been a steady depletion of hydrogen, so that the concentration of hydrogen at the centre today is probably only about one-third of the original amount. The rest has been transformed into helium. Like the rate of formation of a star, the subsequent rate of evolution on the main sequence is proportional to the mass of the star; the greater the mass, the more rapid the evolution. Whereas the Sun is destined to endure for some 10 billion years, a star of twice the Sun's mass burns its fuel at such a rate that it lasts about 3 billion years, and a star of 10 times the Sun's mass has a lifetime measured in tens of millions of years. By contrast, stars having a fraction of the mass of the Sun seem able to endure for trillions of years, which is much greater than the current age of the universe.

2. Translate the text in writing. Time limit: 60 min.

Evolution of low-mass stars

Theoretical calculations suggest that, as the star evolves from the main sequence, the hydrogen-helium core gradually increases in mass but shrinks in size as more and more helium ash is fed in through the outer hydrogen-burning shell. Energy is carried outward from the shell by rapid convection currents. The temperature of the shell rises; the star becomes more luminous; and it finally approaches the top of the giant domain on the Hertzsprung-Russell diagram. By contrast, the core shrinks by gravitational contraction, becoming hotter and denser until it reaches a central temperature of about 120 million K. At that temperature the previously inert helium is consumed in the production of heavier elements.

When two helium nuclei each of mass 4 atomic units (^{4}He) are jammed together, it might be expected that they would form a nucleus of beryllium of mass 8 atomic units (^{8}Be). In symbols, $^{4}He + {}^{4}He \rightarrow {}^{8}Be$. Actually, however, ^{8}Be is unstable and breaks down into two helium nuclei. If the temperature and density are high enough, though, the short-lived beryllium nucleus can (before it decays) capture another helium nucleus in what is essentially a three-body collision to form a nucleus of carbon-12 − namely, $^{8}Be + {}^{4}He \rightarrow {}^{12}C$.

This fusion of helium in the core, called the triple alpha process, can begin gradually in some stars, but in stars with masses between about half of and three times the Sun’s mass, it switches on with dramatic suddenness, a process known as the “helium flash.” Outwardly the star shows no discernible effect, but the course of its evolution is changed with this new source of energy. Having only recently become a red giant, it now evolves somewhat down and then to the left in the Hertzsprung-Russell diagram, becoming smaller and hotter. This stage of core helium burning, however, lasts only about a hundredth of the time taken for core hydrogen burning. It continues until the core helium supply is exhausted, after which helium fusion is limited to a shell around the core, just as was the case for hydrogen in an earlier stage. This again sets the star evolving toward the red giant stage along what is called the asymptotic giant branch, located slightly above the main region of giants in the Hertzsprung-Russell diagram.

In more massive stars, this cycle of events can continue, with the stellar core reaching ever-higher temperatures and fusing increasingly heavy nuclei, until the star eventually experiences a supernova explosion. In lower-mass stars like the Sun, however, there is insufficient mass to squeeze the core to the temperatures needed for this chain of fusion processes to proceed, and eventually the outermost layers extend so far from the source of nuclear burning that they cool to a few thousand kelvins. The result is an object having two distinct parts: a well-defined core of mostly carbon ash and a swollen spherical shell of cooler and thinner matter spread over a volume roughly the size of the solar system. Such shells of matter, called planetary nebulas, are actually observed in large numbers in the sky. Of the roughly 3,500 examples known in the Milky Way Galaxy alone, NGC 7027 is the most intensively studied.

3. Translate the sentences into English.

1) Гравитационное сжатие протозвезд малой массы останавливается раньше, чем температура в их центре достигает значения, необходимого для реакций синтеза H→He.
2) При массе менее $0{,}07M_{\odot}$ (точное значение зависит от химического состава) звезда не способна сжигать легкий изотоп водорода, а значит, в ее жизни нет фазы главной последовательности – самого длительного этапа в жизни нормальных звезд.
3) Карл Вейцзеккер предположил, что из переобогащенного пылью вещества формируются лишь ядра звезд, а затем на них происходит аккреция чистого газа, содержащего мало пыли.
4) Для наиболее холодных инфракрасных объектов в спектральную классификацию звезд потребовалось ввести новые классы.
5) При случайном сближении достаточно массивных облаков их взаимное гравитационное притяжение должно облегчать слияние, увеличивая эффективное сечение взаимодействия и энергию связи конгломерата.
6) Как известно, с ростом массы звезды быстро возрастает ее температура и давление излучения на внешние слои.
7) Уже первые измерения лучевых скоростей и фотометрия переменных звезд позволили многое узнать о движении их наружных слоев и создать теорию их радиальных пульсаций.
8) Именно тогда Фред Хойл заложил основы теории аккреции, которая потребовалась не только для объяснения химического состава звездных атмосфер, но и для оправдания концен-

трации наиболее молодых и массивных звезд вблизи межзвездных облаков в виде OB-ассоциаций.

4. Render the text into English, either orally or in writing.

Возраст звезд

Наблюдения позволяют надежно определять только «наружные» параметры звезды: массу, радиус, температуру поверхности и химический состав атмосферы. Распределение физических параметров и химического состава внутри звезды, в основном, выясняется путем численного моделирования. Если несколько огрубить действительность, т. е. не принимать во внимание магнитное поле и предположить, что начальное распределение химических элементов в звезде было однородным, то независимых параметров у звезды остается только три, – масса, начальный химсостав и возраст, а все прочие однозначно связаны с ними, во всяком случае, у одиночных звезд. Значит теория звездообразования, исходя из данных о межзвездной среде, должна объяснить наблюдаемое распределение звезд по массе и предложить разумный сценарий эволюции Галактики, в рамках которого можно объяснить распределение долгоживущих звезд по массе и химсоставу.

То, что звезды должны рождаться в современную эпоху, было понято в 1940-е гг., после открытия термоядерных реакций. Тогда подсчитали, что массивные O-звезды, светимость которых почти в миллион раз превосходит солнечную, исчерпывают свой ядерный источник энергии менее чем за 10 лет, а значит сформировались совсем недавно. Правда, Вейцзеккер предположил, что OB-звезды – это старые звезды, захватившие путем аккреции межзвездное вещество при пролете сквозь плотное облако и таким образом «омолодившиеся». Эта остроумная идея могла объяснить пространственную связь OB-звезд с облаками газа. Однако частое присутствие этих звезд в рассеянных скоплениях и в очень короткоживущих кратных системах типа Трапеции Ориона она объяснить не могла.

Теоретический анализ динамики OB- и T-ассоциаций позволил В. А. Амбарцумяну заключить, что эти звездные группировки не могут существовать более 10^7 лет. А поскольку в них присутствуют не только быстро эволюционирующие O- и B-звезды, но и долгоживущие G- и M-карлики, стало очевидным, что звезды всевозможных масс рождаются в Галактике в нашу эпоху.

(Сурдин В.Г. Рождение звезд)

5. ***Read an excerpt from the article "How Herschel unlocked the secrets of star formation". Draw a mind-map to help you retell the text. Time limit: 20 min.***

How Herschel unlocked the secrets of star formation

Surveying the sky for almost four years to observe the glow of cold cosmic dust embedded in interstellar clouds of gas, the Herschel Space Observatory has provided astronomers with an unprecedented glimpse into the stellar cradles of our Galaxy. As a result, giant strides have been taken in our understanding of the physical processes that lead to the birth of stars and their planetary systems. […]

Boasting a telescope with a 3.5-metre primary mirror – the largest ever to observe at far-infrared wavelengths – and detectors cooled to just above absolute zero, Herschel could perform observations with unprecedented sensitivity and spatial resolution at the wavelengths that are crucial to delve into the tangle of star-forming clouds.

This made Herschel much more capable of mapping the direct emission from cold dust than its predecessors, which include the US-Dutch-British Infrared Astronomical Satellite (IRAS), ESA's Infrared Space Observatory (ISO), NASA's Spitzer Space Telescope, and JAXA's Akari satellite.

Dust is a minor but crucial component of the interstellar medium that obscures observations at optical and near-infrared wavelengths. As such, it had long stood in the way of astronomers getting to the bottom of star formation, in our Milky Way as well as in other, more distant galaxies.

Herschel turned the situation around completely. Rather than being a problem, the dust became a crucial asset for astronomers: shining brightly at the long wavelengths probed by the observatory, dust could be used as a tracer of interstellar gas across the Galaxy and, most importantly, of its densest regions – the molecular clouds – where star formation unfolds.

In addition, Herschel provided the unique possibility to observe, with unprecedented spectral coverage and resolution, a vast number of lines in the spectra of gas clouds produced by atoms and molecules that are present, albeit in small amounts, in the gas. Together with the observation of dust, these atomic and molecular lines were instrumental in tracking down the properties of gas in a vast number of star-forming clouds.

Several of Herschel's Key Programmes were dedicated to studying the birth of stars in molecular clouds, near and far, in our Galaxy.

Prominently among them, the Herschel Gould Belt Survey concentrated on areas close to home, gathering exceptionally detailed observations of the nearest star-forming regions, which are located in clouds collectively forming a giant ring out to 1500 light-years from the Sun. Another project, the Herschel imaging survey of OB Young Stellar objects, looked specifically at how massive stars are born. And finally, the Herschel infrared Galactic Plane Survey performed a complete census of stellar nurseries across the Milky Way by collecting a 360-degree view of the Galactic Plane.

These three observing programmes alone spent over 1500 hours of observations to investigate star formation.

FOCUS ON PRODUCTIVE WRITING AND SPEAKING SKILLS

1. ***Write a paragraph of 100-120 words to describe one type of star at your choice. Ensure continuity within a paragraph using proper means of cohesion.***

2. ***Prepare a 5-minute talk on one of the following topics. You may choose any other topic related to stars which is not on the list.***

   1) Stellar interiors and fusion processes
   2) Star formation in our galaxy
   3) Evolution from main-sequence stars to red giants
   4) Sources of sunshine: thermal and gravitational energy
   5) Groundbreaking scientific discoveries in astrophysics

KEY WORDS AND WORD COMBINATIONS

Accretion
    accretion flow
Arm
    galactic spiral arm
Association
    T association, OB association, gravitationally unbound association
Binary system
    close binary system

Brightness
intrinsic brightness
Celestial
celestial object
Cluster
bound cluster, double cluster, open star cluster, star cluster; cluster member
Composition
chemical composition
Core
cloud core, convective core, dense core, hydrogen-helium core, molecular cloud core, typical cloud core, well-defined core; core helium burning, core helium supply, core hydrogen burning
Crossing time
Depletion
depletion of hydrogen
Disk
nebular disk, protoplanetary disk (proplyd)
Dwarf
red dwarf, white dwarf
Envelope
envelope of gas and dust, infalling envelope
Galaxy
the Milky Way galaxy
Gas
degenerate gas, ideal gas, infalling gas, ionized gas, lightly ionized gas, molecular gas, nearby gas, neutral gas, perfect gas
Giant
supergiant, subgiant; giant domain
Gradient
density gradient, temperature gradient, pressure gradient
Infrared object
Internal
internal matter, internal structure
Interstellar
interstellar gas, interstellar medium
Jet
jets of matter
Luminosity
intrinsic luminosity, tremendous luminosity

Molecular cloud
Nebula (nebulae)
the Orion nebula, planetary nebula
Opacity
Outflow
Protostar
candidate protostar, condensed protostar
Quasar
Shell
Solar
solar interior, solar system
Star
ancient star, A-type star, bright star, B-type star, congregated stars, evolved star, formed star, giant star, high luminosity star, highly luminous star, high-mass star, hot star, low luminosity star, low-mass star, luminous star, main-sequence star, massive star, middle-aged star, modest star, M-type star, newly formed star, normal star, O-type star, occasional star, orange star, pre-main-sequence star, prototypical stars, red star, remaining stars, supergiant star, T Tauri stars, typical star, yellow star, young star; star formation, star group, star-forming regions
Stellar
stellar core, stellar density, stellar evolution, stellar group, stellar interior, stellar structure
Temperature
central temperature, surface temperature

UNIT 5. NUCLEAR PHYSICS

FISSION

TEXT 1

1. ***Check the pronunciation of these words in a dictionary. If necessary, specify their meaning.***

   analogous, chemical, constitute, Coulomb, develop, dilute, equation, fission, nuclei, nucleon, oscillate, pursue, scission

2. ***Read the text and answer the questions below.***
   1. How may the fission process be best understood?
   2. When is the binding energy of a nucleus released?
   3. When does the largest binding energy occur?
   4. How do the nuclei lighter than mass number 56 gain in stability?
   5. What process prevents all matter to convert into nuclei of mass number 56?
   6. What is called the 'saddle point' and why?
   7. Why is it necessary to construct simplified models of the process of fission?
   8. What is the driving force for physical and chemical reactions?

Fundamentals of the Fission Process. Structure and stability of nuclear matter

1. The fission process may be best understood through a consideration of the structure and stability of nuclear matter. Nuclei consist of nucleons (neutrons and protons), the total number of which is equal to the mass number of the nucleus. The actual mass of a nucleus is always less than the sum of the masses of the free neutrons and protons that constitute it, the difference being the mass equivalent of the energy of formation of the nucleus from its constituents. The conversion of mass to energy follows Einstein's equation, $E = mc^2$, where E is the energy equivalent of a mass, m, and c is the velocity of light. This difference is

known as the mass defect and is a measure of the total binding energy (and, hence, the stability) of the nucleus. This binding energy is released during the formation of a nucleus from its constituent nucleons and would have to be supplied to the nucleus to decompose it into its individual nucleon components.

2. A curve illustrating the average binding energy per nucleon as a function of the nuclear mass number is shown in Figure 1. The largest binding energy (highest stability) occurs near mass number 56 – the mass region of the element iron. Figure 1 indicates that any nucleus heavier than mass number 56 would become a more stable system by breaking into lighter nuclei of higher binding energy, the difference in binding energy being released in the process. (It should be noted that nuclei lighter than mass number 56 can gain in stability by fusing to produce a heavier nucleus of greater mass defect – again, with the release of the energy equivalent of the mass difference. It is the fusion of the lightest nuclei that provides the energy released by the Sun and constitutes the basis of the hydrogen, or fusion, bomb. Efforts to harness fusion reaction for power production have been actively pursued.)

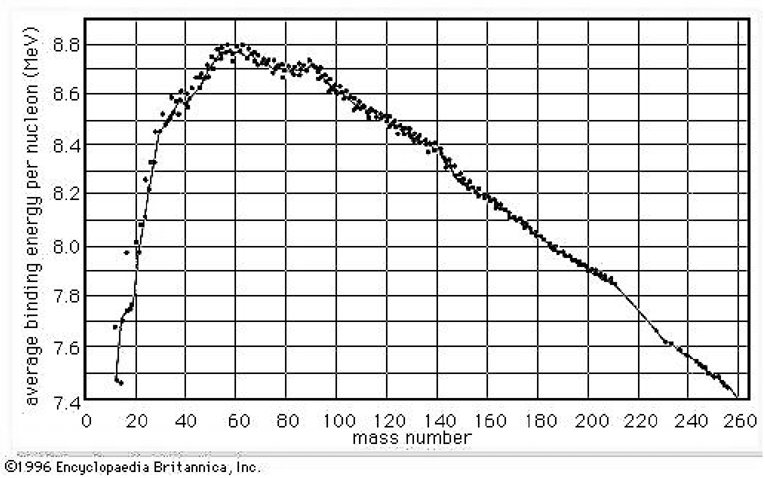


Figure 1. The average binding energy per nucleon as a function of the mass number, A(see text). The line connects the odd-A points. Encyclopædia Britannica, Inc.

3. On the basis of energy considerations alone, Figure 1 would indicate that all matter should seek its most stable configuration, becoming nuclei of mass number near 56. However, this does not happen, because barriers to such a spontaneous conversion are provided by other

factors. A good qualitative understanding of the nucleus is achieved by treating it as analogous to a uniformly charged liquid drop. The strong attractive nuclear force between pairs of nucleons is of short range and acts only between the closest neighbours. Since nucleons near the surface of the drop have fewer close neighbours than those in the interior, a surface tension is developed, and the nuclear drop assumes a spherical shape in order to minimize this surface energy. (The smallest surface area enclosing a given volume is provided by a sphere.) The protons in the nucleus exert a long-range repulsive (Coulomb) force on each other because of their positive charge. As the number of nucleons in a nucleus increases beyond about 40, the number of protons must be diluted with an excess of neutrons to maintain relative stability.

4. If the nucleus is excited by some stimulus and begins to oscillate (i.e., deform from its spherical shape), the surface forces will increase and tend to restore it to a sphere, where the surface tension is at a minimum. On the other hand, the Coulomb repulsion decreases as the drop deforms and the protons are positioned farther apart. These opposing tendencies set up a barrier in the potential energy of the system, as indicated in Figure 2.

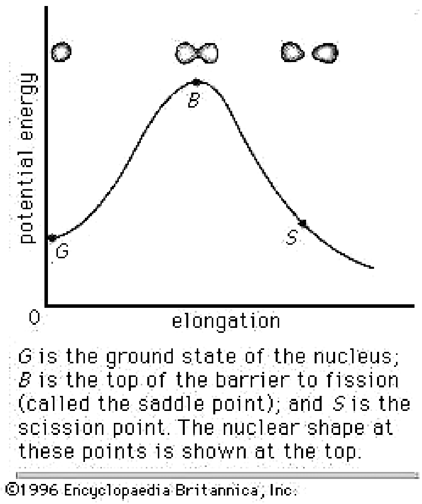


Figure 2. The potential energy as a function of elongation of a fissioning nucleus. G is the ground state of the nucleus; B is the top of the barrier to fission (called the saddle point); and S is the scission point. The nuclear shape at these points is shown at the top. Encyclopædia Britannica, Inc.

5. The curve in Figure 2 rises initially with elongation, since the strong, short-range nuclear force that gives rise to the surface tension

increases. The Coulomb repulsion between protons decreases faster with elongation than the surface tension increases, and the two are in balance at point B, which represents the height of the barrier to fission. (This point is called the “saddle point” because, in a three-dimensional view of the potential energy surface, the shape of the pass over the barrier resembles a saddle.) Beyond point B, the Coulomb repulsion between the protons drives the nucleus into further elongation until at some point, S (the scission point), the nucleus breaks in two. Qualitatively, at least, the fission process is thus seen to be a consequence of the Coulomb repulsion between protons. […]

Fission Theory

6. Nuclear fission is a complex process that involves the rearrangement of hundreds of nucleons in a single nucleus to produce two separate nuclei. A complete theoretical understanding of this reaction would require a detailed knowledge of the forces involved in the motion of each of the nucleons through the process. Since such knowledge is still not available, it is necessary to construct simplified models of the actual system to simulate its behaviour and gain as accurate a description as possible of the steps in the process. The successes and failures of the models in accounting for the various observations of the fission process can provide new insights into the fundamental physics governing the behaviour of real nuclei, particularly at the large nuclear deformations encountered in a nucleus undergoing fission.

7. The framework for understanding nuclear reactions is analogous to that for chemical reactions and involves the concept of a potential-energy surface on which the reaction occurs. The driving force for physical or chemical reactions is the tendency to lower the potential energy and increase the stability of the system. Thus, for example, a stone at the top of a hill will roll down the hill, converting its potential energy at the top to kinetic energy of motion, and will come to rest at the bottom in a more stable state of lower potential energy. The potential energy is calculated as a function of various parameters of the system being studied. In the case of fission, the potential energy may be calculated as a function of the shape of the system as it proceeds over the barrier to the scission point, and the path of lowest potential energy may be determined.

8. As has been pointed out, an exact calculation of the nuclear potential energy is not yet possible, and it is to approximate this calculation that various models have been constructed to simulate the real system. Some of the models were developed to address aspects of nuclear

structure and spectroscopy as well as features of nuclear reactions, and they also have been employed in attempts to understand the complexity of nuclear fission. The models are based on different assumptions and approximations of the nature of the nuclear forces and the dynamics of the path to scission. No one model can account for all of the extensive phenomenology of fission, but each addresses different aspects of the process and provides a foundation for further development toward a complete theory.

3. ***Study the graphs in Text 1 and describe them from memory.***

LANGUAGE REVIEW

Focus on word formation

1. ***Review noun-forming suffixes and form nouns from the verbs below.***
   behave, configure, consider, converse, deform, describe, develop, elongate, equate, fail, form, found, know, observe, produce, react, repulse, tend, understand

2. ***Identify what part of speech the words 'equivalent' (par. 1 and 2), 'lower' (par.7), 'function' (par. 2), and 'process' (par. 2 and 6) represent. Translate the sentences in which they occur.***

3. ***Comment on the stress in the words 'increase' (par.3, 5 and 7), 'decrease' (par. 5),'separate' (par.6), and 'approximate' (par. 8). Identify what part of speech they represent and then check how they should be pronounced.***

Focus on grammar

1. ***Answer the questions.***
   1) What does the grammatical category of Mood express? Can you name the English Moods?
   2) What are the main uses of the Subjunctive forms of the verb? In what formal constructions is the Subjunctive typically found?
   3) What is the Conditional Mood made from and when is it used?
   4) How many types of Conditional sentences do you know?

5) What distinguishes Type 1 Conditional sentences from Type 2 and 3 ones?
6) How is Type 1 Conditional formed?
7) How are Type 2 and 3 Conditionals formed and what is the difference between them?

2. *Do the following tasks.*

1) Translate the sentences with the Absolute Participial Construction in paragraphs 1 and 2.
2) Find the sentences with the Emphasis in the text and translate them.
3) Trace the instances of the Degrees of Comparison of adjectives and adverbs in the text. Identify Comparative constructions and translate them.
4) Indicate the Complex Subject in paragraph 5 and translate the sentence it is used in.
5) Analyse the use of the Oblique Moods in the text.

Focus on paragraph structure and content

1. *Answer the questions.*

1) What key terms and phrases provide an effective means of connecting the sentences in all the paragraphs of Text 1?
2) What does the pronoun 'it' in paragraphs 1, 3, 4, and 7 refer to?
3) What connecting words occur in Text 1? What do they express?

2. *Do the following tasks.*

1) Indicate the topic sentence in each paragraph of Text 1.
2) Develop the idea of each topic sentence.
3) Sum up the main points of Text 1.

Focus on vocabulary

1. *Define or explain these terms.*

binding energy, mass defect, mass number, mass region, saddle point, scission point, surface tension

2. *Give English equivalents for the following word combinations.*

превращение массы в энергию, область массовых чисел, усиление стабильности, составлять основу водородной бомбы, выработка энергии, самопроизвольная конверсия, сильное ядерное взаимодействие, вблизи поверхности капли, поверхностное натяжение, приобретать сферическую форму, число протонов, быть разбавленным чем-то, избыток нейтронов, поддерживать относительную стабильность, находиться на минимальном уровне, вызывать поверхностное натяжение, создавать упрощенные модели, повысить стабильность системы, прийти в равновесие, находиться в более стабильном состоянии, реакция деления ядра, быть основанным на различных предположениях и приближениях, природа ядерных взаимодействий

3. ***Give Russian equivalents for the following word combinations. Make up sentences with some of them.***

the structure and stability of nuclear matter, the binding energy of the nucleus, to be released during the formation of a nucleus, the formation of a nucleus from its constituent nucleons, to decompose a nucleus into its individual nucleon components, the average binding energy per nucleon, to become a more stable system, to break into lighter nuclei of higher binding energy, to produce a heavier nucleus of greater mass defect, the fusion of the lightest nuclei, to provide the energy released by the Sun, efforts to harness fusion reaction, a uniformly charged liquid drop, to minimize the surface energy, to exert a long-range repulsive (Coulomb) force, to be excited by some stimulus, the process of the rearrangement of hundreds of nucleons, simplified models of the actual system, the tendency to lower the potential energy, the concept of potential-surface energy, to convert the potential energy to kinetic energy of motion, an exact calculation of the nuclear potential energy, to approximate the calculation, to address aspects of nuclear structure and spectroscopy, the dynamics of the path of scission, to account for all the extensive phenomenology of fission, to provide a foundation for further development

TEXT 2

1. ***Check the pronunciation of these words in a dictionary. If necessary, specify their meaning.***

absorption, actinide, asymmetric, closure, cohesive, compound, disruptive, evaporation, excitation, exhibit, incompressible, lanthanide, measurable, qualitative, quantitative, spherical, threshold, vibration, yield

2. ***Write an outline of the text in the form of questions and discuss the basic principles of the liquid-drop model. Work in pairs.***

Nuclear Models and Nuclear Fission

The nucleus exhibits some properties that reflect the collective motion of all its constituent nucleons as a unit, as well as other properties that are dependent on the motion and state of the individual nucleons.

The analogy of the nucleus to a drop of an incompressible liquid was first suggested by George Gamow in 1935 and later adapted to a description of nuclear reactions (by Niels Bohr [1936]; and Bohr and Fritz Kalckar [1937]) and to fission (Bohr and John A. Wheeler [1939]; and Yakov Frenkel [1939]). Bohr proposed the so-called compound nucleus description of nuclear reactions, in which the excitation energy of the system formed by the absorption of a neutron or photon, for example, is distributed among a large number of degrees of freedom of the system. This excited state persists for a long time relative to the periods of motion of nucleons across the nucleus and then decays by emission of radiation, the evaporation of neutrons or other particles, or by fission. The liquid-drop model of the nucleus accounts quite well for the general collective behaviour of nuclei and provides an understanding of the fission process on the basis of the competition between the cohesive nuclear force and the disruptive Coulomb repulsion between protons. It predicts, however, a symmetric division of mass in fission, whereas an asymmetric mass division is observed. Moreover, it does not provide an accurate description of fission barrier systematics or of the ground-state masses of nuclei. The liquid-drop model is particularly useful in describing the behaviour of highly excited nuclei, but it does not provide an accurate description for nuclei in their ground or low-lying excited states. Many versions of the liquid-drop model employing improved sets of parameters have been developed. However, investigators have found that mass asymmetry and certain other features in fission cannot be adequately described on the basis of the collective behaviour posited by such models alone.

A preference for the formation of unequal masses (i.e., an asymmetric division) was observed early in fission research, and it has remained the most puzzling feature of the process to account for. Investigators have invoked various models other than that of the liquid drop in an attempt to address this question. Dealing with the mutual interaction of all the nucleons in a nucleus has been simplified by treating it as if it were equivalent to the interaction of one particle with an average spherical static potential field that is generated by all the other nucleons. The methods of quantum mechanics provide the solution for the motion of a nucleon in such a potential. A characteristic set of energy levels for neutrons and protons is obtained, and, analogous to the set of levels of the electrons in an atom, the levels group themselves into shells at certain so-called magic numbers of nucleons. (For both neutrons and protons, these numbers are 2, 8, 20, 28, 50, 82, and 126.) Shell closures at these nuclear numbers are marked by especially strong binding, or extra stability. This constitutes the essence of the spherical-shell model (sometimes called the independent-particle, or single-particle, model), as developed by Maria Goeppert Mayer and J. Hans D. Jensen and their colleagues (1949). It accounts well for ground-state masses and spins and for the existence of isomeric nuclear states (excited states having measurable half-lives) that occur when nuclear levels of widely differing spins lie relatively close to each other. The agreement with observations is excellent for spherical nuclei with nucleon numbers near the magic shell numbers. The spherical-shell model, however, does not agree well with the properties of nuclei that have other nucleon numbers – e.g., the nuclei of the lanthanide and actinide elements, with nucleon numbers between the magic numbers.

In the lanthanide and actinide nuclei, the ground state is not spherical but rather deformed into a prolate spheroidal shape – that of a football or watermelon. For such nuclei, the allowed states of motion of a nucleon must be calculated in a potential having a symmetry corresponding to a spheroid rather than a sphere. This was first done by Aage Bohr[1], Ben R. Mottelson, and Sven G. Nilsson in 1955, and the level structure was calculated as a function of the deformation of the nucleus. A spheroid has three axes of symmetry, and it can rotate in space as a unit about any one of them. The rotation can occur independent of the internal state of excitation of the individual nucleons. Various modes of vibration of the spheroid also may take place. Since this deformed shell model has components of both the independent-particle motion and the collective motion of the nucleus as a whole (i.e., rotations and vibrations), it is sometimes referred to as the unified model.

In Aage Bohr's application of the unified model to the fission process, the sequence of potential-energy surfaces for the excited states of the system are considered to be functions of a deformation parameter (i.e.,

[1] Aage Niels Bohr [ˈɔːɡə ˌniːls ˈbɔː] – Оге Нильс Бор.

elongation) characterizing the motion toward fission and evaluated at the saddle point. As the system passes over the saddle point, most of its excitation energy is used up in deforming the nucleus, and the system remains "cold"; i.e., it manifests little excitation, or heat, energy. Thus, only the low-lying excited states are available to the system. The spin and parity of the particular state (or channel) in which the system exists as it passes over the saddle point are then expected to determine the fission properties. In this channel (or transition-state) analysis of fission, a number of characteristics of the process are qualitatively accounted for. Hence, fission thresholds would depend on the spin and parity of the compound nuclear state, the fission fragment angular distribution would be governed by the collective rotational angular momentum of the state, and asymmetry in the mass distribution would result from passage over the barrier in a state of negative parity (which does not possess reflection symmetry). This model gives a good qualitative interpretation of many fission phenomena, but it must assume that at least some of the properties of the transition state at the saddle point are not altered by dynamical considerations in the descent of the system to the scission point. It is the only model that provides a satisfactory interpretation of the angular distributions of fission fragments, and it has attractive features that must be included in any complete theory of fission.

The first application of the spherical-shell model to fission was the recognition that the positions of the peaks in the fission mass distribution correlated fairly well with the magic numbers and suggested a qualitative interpretation of the asymmetric mass division. Thus, a preference for the formation of nuclei with neutron numbers close to 82 would favour the formation of nuclides near the peak in the heavy group and would thus determine the mass split for the fissioning system. Some extra stability for nuclear configurations of 50 protons would also be expected, but this is not particularly evident. In fact, the so-called doubly magic nucleus tin-132, with 50 protons and 82 neutrons, has a rather low yield in low-energy fission.

A more quantitative application of the spherical-shell model to fission was undertaken by Peter Fong in the United States in 1956. He related the probability of formation of a given pair of fragments to the available density of states for that pair of fragments at the scission point in a statistical-model approach. A model of this sort predicts that the system, in its random motions, will experience all possible configurations and so will have a greater probability of being in the region where the greatest number of such configurations (or states) is concentrated. The model assumes that the potential energy at the saddle point is essentially all converted to excitation energy and that a statistical equilibrium among all possible states is established at the scission point. The extra binding energy for closed-shell nuclei leads to a higher density of states at a given excitation energy than is present for other nuclei and, hence, leads to a higher probability of formation. An asymmetric mass distribution in good agreement with that observed for the neutron-induced fission of uranium-235 is obtained. Moreover, the changes in the mass distribution with an increased excitation energy of fission (e.g., an increase in the probability of symmetric fission relative to asymmetric fission) are accounted for by the decrease in importance of the shell effects as the excitation energy increases. Other features of the fission process also are qualitatively explained; however, extensive changes in the parameters of the model are required to obtain agreement with experiments for other fissionable nuclides. Then, too, there are fundamental problems concerning the validity of some of the basic assumptions of the model.

3. *Fill in the gaps with appropriate prepositions from memory.*

1) The analogy of the nucleus … a drop … an incompressible liquid was first suggested … George Gamow in 1935 and later adapted … a description … nuclear reactions (by Niels Bohr [1936]; and Bohr and Fritz Kalckar [1937]) and … fission (Bohr and John A. Wheeler [1939]; and Yakov Frenkel [1939]).
2) Bohr proposed the so-called compound nucleus description … nuclear reactions, in which the excitation energy … the system formed by the absorption … a neutron or photon, for example, is distributed among a large number … degrees … freedom … the system.
3) This excited state persists for a long time relative … the periods … motion … nucleons across the nucleus and then decays by emission … radiation, the evaporation … neutrons or other particles, or by fission.
4) The liquid-drop model … the nucleus accounts quite well … the general collective behaviour … nuclei and provides an understanding … the fission process … the basis … the competition between the cohesive nuclear force and the disruptive Coulomb repulsion between protons.
5) A preference … the formation … unequal masses (i.e., an asymmetric division) was observed early in fission research, and it

has remained the most puzzling feature … the process to account ….

6) The methods … quantum mechanics provide the solution … the motion … a nucleon in such a potential.
7) The agreement … observations is excellent … spherical nuclei with nucleon numbers near the magic shell numbers.
8) A more quantitative application … the spherical-shell model … fission was undertaken … Peter Fong in the United States in 1956.
9) He related the probability … formation of a given pair … fragments … the available density of states for that pair of fragments … the scission point in a statistical-model approach.
10) The model assumes that the potential energy … the saddle point is essentially all converted … excitation energy and that a statistical equilibrium among all possible states is established … the scission point.
11) The extra binding energy for closed-shell nuclei leads … a higher density … states … a given excitation energy than is present for other nuclei and, hence, leads … a higher probability … formation.

4. *Translate the following sentences into Russian. If necessary, refer to the text to clarify the context.*

1) The liquid-drop model is particularly useful in describing the behaviour of highly excited nuclei, but it does not provide an accurate description for nuclei in their ground or low-lying excited states.
2) Many versions of the liquid-drop model employing improved sets of parameters have been developed.
3) However, investigators have found that mass asymmetry and certain other features in fission cannot be adequately described on the basis of the collective behaviour posited by such models alone.
4) Investigators have invoked various models other than that of the liquid drop in an attempt to address this question.
5) Dealing with the mutual interaction of all the nucleons in a nucleus has been simplified by treating it as if it were equivalent to the interaction of one particle with an average spherical static potential field that is generated by all the other nucleons.
6) A characteristic set of energy levels for neutrons and protons is obtained, and, analogous to the set of levels of the electrons in an

atom, the levels group themselves into shells at certain so-called magic numbers of nucleons.

7) In the lanthanide and actinide nuclei, the ground state is not spherical but rather deformed into a prolate spheroidal shape – that of a football or watermelon.
8) For such nuclei, the allowed states of motion of a nucleon must be calculated in a potential having a symmetry corresponding to a spheroid rather than a sphere.
9) In Aage Bohr's application of the unified model to the fission process, the sequence of potential-energy surfaces for the excited states of the system are considered to be functions of a deformation parameter (i.e., elongation) characterizing the motion toward fission and evaluated at the saddle point.
10) The spin and parity of the particular state (or channel) in which the system exists as it passes over the saddle point are then expected to determine the fission properties. In this channel (or transition-state) analysis of fission, a number of characteristics of the process are qualitatively accounted for.
11) Hence, fission thresholds would depend on the spin and parity of the compound nuclear state, the fission fragment angular distribution would be governed by the collective rotational angular momentum of the state, and asymmetry in the mass distribution would result from passage over the barrier in a state of negative parity (which does not possess reflection symmetry).
12) Thus, a preference for the formation of nuclei with neutron numbers close to 82 would favour the formation of nuclides near the peak in the heavy group and would thus determine the mass split for the fissioning system.
13) Some extra stability for nuclear configurations of 50 protons would also be expected, but this is not particularly evident. In fact, the so-called doubly magic nucleus tin-132, with 50 protons and 82 neutrons, has a rather low yield in low-energy fission.
14) An asymmetric mass distribution in good agreement with that observed for the neutron-induced fission of uranium-235 is obtained.

5. ***Read the text again and summarise it in written form in 12-15 sentences. Make proper use of connecting words and phrases.***

TEXT 3

1. ***Write an outline of the text in the form of questions.***

History of Fission Research and Technology

The term fission was first used by the German physicists Lise Meitner and Otto Frisch in 1939 to describe the disintegration of a heavy nucleus into two lighter nuclei of approximately equal size. The conclusion that such an unusual nuclear reaction can in fact occur was the culmination of a truly dramatic episode in the history of science, and it set in motion an extremely intense and productive period of investigation.

The story of the discovery of nuclear fission actually began with the discovery of the neutron in 1932 by James Chadwick in England. Shortly thereafter Enrico Fermi and his associates in Italy undertook an extensive investigation of the nuclear reactions produced by the bombardment of various elements with this uncharged particle. In particular, these workers observed (1934) that at least four different radioactive species resulted from the bombardment of uranium with slow neutrons. These newly discovered species emitted beta particles and were thought to be isotopes of unstable "transuranium elements" of atomic numbers 93, 94, and perhaps higher. There was, of course, intense interest in examining the properties of these elements, and many radiochemists participated in the studies. The results of these investigations, however, were extremely perplexing, and confusion persisted until 1939 when Otto Hahn and Fritz Strassmann in Germany, following a clue provided by Irène Joliot-Curie and Pavle Savić in France (1938), proved definitely that the so-called transuranic elements were in fact radioisotopes of barium, lanthanum, and other elements in the middle of the periodic table.

That lighter elements could be formed by bombarding heavy nuclei with neutrons had been suggested earlier (notably by the German chemist Ida Noddack in 1934), but the idea was not given serious consideration because it entailed such a broad departure from the accepted views of nuclear physics and was unsupported by clear chemical evidence. Armed with the unequivocal results of Hahn and Strassmann, however, Meitner and Frisch invoked the recently formulated liquid-drop model of the nucleus to give a qualitative theoretical interpretation of the fission process and called attention to the large energy release that should accompany it. There was almost immediate confirmation of this reaction in dozens of laboratories throughout the world, and within a year more than 100 papers describing most of the important features of the process were published. These experiments confirmed the formation of extremely energetic heavy particles and extended the chemical identification of the products.

The chemical evidence that was so vital in leading Hahn and Strassmann to the discovery of nuclear fission was obtained by the application of carrier and tracer techniques. Since invisible amounts of the radioactive species were formed, their chemical identity had to be deduced from the manner in which they followed known carrier elements, present in macroscopic quantity, through various chemical operations. Known radioactive species were also added as tracers and their behaviour was compared with that of the unknown species to aid in the identification of the latter. Over the years, these radiochemical techniques have been used to isolate and identify some 34 elements from zinc (atomic number 30) to gadolinium (atomic number 64) that are formed as fission products. The wide range of radioactivities produced in fission makes this reaction a rich source of tracers for chemical, biologic, and industrial use.

Although the early experiments involved the fission of ordinary uranium with slow neutrons, it was rapidly established that the rare isotope uranium-235 was responsible for this phenomenon. The more abundant isotope uranium-238 could be made to undergo fission only by fast neutrons with energy exceeding 1 MeV. The nuclei of other heavy elements, such as thorium and protactinium, also were shown to be fissionable with fast neutrons; and other particles, such as fast protons, deuterons, and alphas, along with gamma rays, proved to be effective in inducing the reaction.

In 1939, Frédéric Joliot-Curie, Hans von Halban, and Lew Kowarski found that several neutrons were emitted in the fission of uranium-235, and this discovery led to the possibility of a self-sustaining chain reaction. Fermi and his coworkers recognized the enormous potential of such a reaction if it could be controlled. On Dec. 2, 1942, they succeeded in doing so, operating the world's first nuclear reactor. Known as a "pile," this device consisted of an array of uranium and graphite blocks and was built on the campus of the University of Chicago.

The secret Manhattan Project, established not long after the United States entered World War II, developed the atomic bomb. Once the war had ended, efforts were made to develop new reactor types for large-scale power generation, giving birth to the nuclear power industry.

2. Discuss the history of nuclear fission research in pairs.

FUSION

TEXT 1

1. ***Check the pronunciation of these words in a dictionary. If necessary, specify their meaning.***

   cause, consequence, crucial, determine, deuterium, exoergic, feature, fundamental, fusion, isotope, key, thermonuclear, tritium

2. ***Define or explain these terms.***

   cross section, exoergic, fusion, incident particle, isotope, nucleosynthesis, target particle, thermonuclear reaction

3. ***Read the text and answer the questions below.***

   1) Which reaction within stars leads to the formation of helium?
   2) Which elements react more efficiently, hydrogen or its isotopes? Why?
   3) What are the two basic types of fusion reaction?
   4) What reaction initiates star burning?
   5) Why does the practical fusion energy generation require the D-T reaction?
   6) What may happen if a particle of one type passes through a collection of particles of the same or different type?
   7) What does the magnitude of cross section depend on?
   8) What is called the mean free path?
   9) How is cross section measured?
   10) What role does the Coulomb barrier play in the process of fusion or fission?

The Fusion Reaction

Nuclear fusion is a process by which nuclear reactions between light elements form heavier elements (up to iron). In cases where the interacting nuclei belong to elements with low atomic numbers (e.g., hydrogen [atomic number 1] or its isotopes deuterium and tritium), substantial amounts of energy are released. The vast energy potential of nuclear fusion was first exploited in thermonuclear weapons, or hydrogen bombs, which were developed in the decade immediately following World

War II. […]Meanwhile, the potential peaceful applications of nuclear fusion, especially in view of the essentially limitless supply of fusion fuel on Earth, have encouraged an immense effort to harness this process for the production of power. […]

1. Fusion reactions constitute the fundamental energy source of stars, including the Sun. The evolution of stars can be viewed as a passage through various stages as thermonuclear reactions and nucleosynthesis cause compositional changes over long time spans. Hydrogen (H) "burning" initiates the fusion energy source of stars and leads to the formation of helium (He). Generation of fusion energy for practical use also relies on fusion reactions between the lightest elements that burn to form helium. In fact, the heavy isotopes of hydrogen – deuterium (D) and tritium (T) – react more efficiently with each other, and, when they do undergo fusion, they yield more energy per reaction than do two hydrogen nuclei. (The hydrogen nucleus consists of a single proton. The deuterium nucleus has one proton and one neutron, while tritium has one proton and two neutrons.)

2. Fusion reactions between light elements, like fission reactions that split heavy elements, release energy because of a key feature of nuclear matter called the binding energy, which can be released through fusion or fission. The binding energy of the nucleus is a measure of the efficiency with which its constituent nucleons are bound together. Take, for example, an element with Z protons and N neutrons in its nucleus. The element's atomic weight A is $Z + N$, and its atomic number is Z. The binding energy B is the energy associated with the mass difference between the Z protons and N neutrons considered separately and the nucleons bound together ($Z + N$) in a nucleus of mass M. The formula is $B = (Zmp + Nmn - M)c^2$, where mp and mn are the proton and neutron masses and c is the speed of light. It has been determined experimentally that the binding energy per nucleon is a maximum of about 1.4×10^{-12} joule at an atomic mass number of approximately 60 – that is, approximately the atomic mass number of iron. Accordingly, the fusion of elements lighter than iron or the splitting of heavier ones generally leads to a net release of energy.

Two types of fusion reactions

3. Fusion reactions are of two basic types: (1) those that preserve the number of protons and neutrons and (2) those that involve a conversion between protons and neutrons. Reactions of the first type are most

important for practical fusion energy production, whereas those of the second type are crucial to the initiation of star burning. An arbitrary element is indicated by the notation *AZX*, where *Z* is the charge of the nucleus and *A* is the atomic weight. An important fusion reaction for practical energy generation is that between deuterium and tritium (the D-T fusion reaction). It produces helium (He) and a neutron (*n*) and is written D + T → He + *n*.

4. To the left of the arrow (before the reaction) there are two protons and three neutrons. The same is true on the right.

5. The other reaction, that which initiates star burning, involves the fusion of two hydrogen nuclei to form deuterium (the H-H fusion reaction): $H + H \rightarrow D + \beta^{+} + \nu$, where β^{+} represents a positron and ν stands for a neutrino. Before the reaction there are two hydrogen nuclei (that is, two protons). Afterward there are one proton and one neutron (bound together as the nucleus of deuterium) plus a positron and a neutrino (produced as a consequence of the conversion of one proton to a neutron).

6. Both of these fusion reactions are exoergic and so yield energy. The German-born physicist Hans Bethe proposed in the 1930s that the H-H fusion reaction could occur with a net release of energy and provide, along with subsequent reactions, the fundamental energy source sustaining the stars. However, practical energy generation requires the D-T reaction for two reasons: first, the rate of reactions between deuterium and tritium is much higher than that between protons; second, the net energy release from the D-T reaction is 40 times greater than that from the H-H reaction. […]

Rate and yield of fusion reactions

7. The energy yield of a reaction between nuclei and the rate of such reactions are both important. These quantities have a profound influence in scientific areas such as nuclear astrophysics and the potential for nuclear production of electrical energy.

8. When a particle of one type passes through a collection of particles of the same or different type, there is a measurable chance that the particles will interact. The particles may interact in many ways, such as simply scattering, which means that they change direction and exchange energy, or they may undergo a nuclear fusion reaction. The measure of the likelihood that particles will interact is called the cross section, and the magnitude of the cross section depends on the type of interaction and the state and energy of the particles. The product of the cross section and the

atomic density of the target particle is called the macroscopic cross section. The inverse of the macroscopic cross section is particularly noteworthy as it gives the mean distance an incident particle will travel before interacting with a target particle; this inverse measure is called the mean free path. Cross sections are measured by producing a beam of one particle at a given energy, allowing the beam to interact with a (usually thin) target made of the same or a different material, and measuring deflections or reaction products. In this way it is possible to determine the relative likelihood of one type of fusion reaction versus another, as well as the optimal conditions for a particular reaction.

9. The cross sections of fusion reactions can be measured experimentally or calculated theoretically, and they have been determined for many reactions over a wide range of particle energies. They are well known for practical fusion energy applications and are reasonably well known, though with gaps, for stellar evolution. Fusion reactions between nuclei, each with a positive charge of one or more, are the most important for both practical applications and the nucleosynthesis of the light elements in the burning stages of stars. Yet, it is well known that two positively charged nuclei repel each other electrostatically – i.e., they experience a repulsive force inversely proportional to the square of the distance separating them. This repulsion is called the Coulomb barrier. It is highly unlikely that two positive nuclei will approach each other closely enough to undergo a fusion reaction unless they have sufficient energy to overcome the Coulomb barrier. As a result, the cross section for fusion reactions between charged particles is very small unless the energy of the particles is high, at least 10^4 electron volts (1 eV $\cong 1.602 \times 10^{-19}$joule) and often more than 10^5 or 10^6 eV. This explains why the centre of a star must be hot for the fuel to burn and why fuel for practical fusion energy systems must be heated to at least 50,000,000 kelvins (K; 90,000,000 °F). Only then will a reasonable fusion reaction rate and power output be achieved.

10. The phenomenon of the Coulomb barrier also explains a fundamental difference between energy generation by nuclear fusion and nuclear fission. While fission of heavy elements can be induced by either protons or neutrons, generation of fission energy for practical applications is dependent on neutrons to induce fission reactions in uranium or plutonium. Having no electric charge, the neutron is free to enter the nucleus even if its energy corresponds to room temperature. Fusion energy, relying as it does on the fusion reaction between light nuclei,

occurs only when the particles are sufficiently energetic to overcome the Coulomb repulsive force. This requires the production and heating of the gaseous reactants to the high temperature state known as the plasma state.

4. ***Do the following grammar tasks.***

1) Explain the difference in use between 'as' in paragraphs 1 and 8.
2) Indicate the sentence with the Inversion in paragraph 9.
3) Identify the function of constructions with Participle I in paragraph 10 and translate the sentences in which they occur.

5. ***Discuss the principles of fusion and the fundamental difference between fusion and fission using the following word combinations.***

to form heavier elements, elements with low atomic numbers, the vast energy potential of nuclear fusion, the potential peaceful application of nuclear fusion, to constitute the fundamental energy source of stars, to cause compositional changes, fusion reactions between the lightest elements, to split heavy elements, a key feature of nuclear matter, a net release of energy, a conversion between protons and neutrons, practical fusion energy production, to be crucial to initiation of star burning, the fusion of two hydrogen nuclei, the h-H fusion reaction, a consequence of the conversion, the conversion of one proton to a neutron, the potential for nuclear production of electrical energy, to interact in many ways, to undergo a nuclear fusion reaction, the atomic density of the target particle, the optimal conditions for a particular reaction, to induce fission reaction, to be sufficiently energetic to overcome the Coulomb repulsive force

TEXT 2

1. ***Read the text and answer the following questions.***

1) Why is it so important for physicists to understand how gases behave in the plasma state?
2) Why is the plasma state considered to be so dangerous to deal with?
3) Which fusion reactions are the most important for controlled power generation and why?
4) What methods are used in an attempt to harness fusion energy?

The plasma state

Typically, a plasma is a gas that has had some substantial portion of its constituent atoms or molecules ionized by the dissociation of one or more of their electrons. These free electrons enable plasmas to conduct electric charges, and a plasma is the only state of matter in which thermonuclear reactions can occur in a self-sustaining manner. Astrophysics and magnetic fusion research, among other fields, require extensive knowledge of how gases behave in the plasma state. The stars, the solar wind, and much of interstellar space are examples where the matter present is in the plasma state. Very high-temperature plasmas are fully ionized gases, which means that the ratio of neutral gas atoms to charged particles is small. For example, the ionization energy of hydrogen is 13.6 eV, while the average energy of a hydrogen ion in a plasma at 50,000,000 K is 6,462 eV. Thus, essentially all of the hydrogen in this plasma would be ionized.

A reaction-rate parameter more appropriate to the plasma state is obtained by accounting for the fact that the particles in a plasma, as in any gas, have a distribution of energies. That is to say, not all particles have the same energy. In simple plasmas this energy distribution is given by the Maxwell-Boltzmann distribution law, and the temperature of the gas or plasma is, within a proportionality constant, two-thirds of the average particle energy; i.e., the relationship between the average energy E and temperature T is $E = 3kT/2$, where k is the Boltzmann constant, 8.62×10^{-5} eV per kelvin. The intensity of nuclear fusion reactions in a plasma is derived by averaging the product of the particles' speed and their cross sections over a distribution of speeds corresponding to a Maxwell-Boltzmann distribution. The cross section for the reaction depends on the energy or speed of the particles. The averaging process yields a function for a given reaction that depends only on the temperature and can be denoted $f(T)$. The rate of energy released (i.e., the power released) in a reaction between two species, a and b, is $P_{ab} = n_a n_b f_{ab}(T) U_{ab}$, where n_a and n_b are the density of species a and b in the plasma, respectively, and U_{ab} is the energy released each time a and b undergo a fusion reaction. The parameter P_{ab} properly takes into account both the rate of a given reaction and the energy yield per reaction. […]

Fusion reactions for controlled power generation

Reactions between deuterium and tritium are the most important fusion reactions for controlled power generation because the cross sections for their occurrence are high, the practical plasma temperatures required for net energy release are moderate, and the energy yield of the reactions is high – 17.58 MeV for the basic D-T fusion reaction.

It should be noted that any plasma containing deuterium automatically produces some tritium and helium-3 from reactions of deuterium with other deuterium ions. Other fusion reactions involving elements with an atomic number above 2 can be used, but only with much greater difficulty. This is because the Coulomb barrier increases with increasing charge of the nuclei, leading to the requirement that the plasma temperature exceed 1,000,000,000 K if a significant rate is to be achieved.[…]

Methods of achieving fusion energy

Practical efforts to harness fusion energy involve two basic approaches to containing a high-temperature plasma of elements that undergo nuclear fusion reactions: magnetic confinement and inertial confinement. A much less likely but nevertheless interesting approach is based on fusion catalyzed by muons; research on this topic is of intrinsic interest in nuclear physics. […]

Magnetic confinement

In magnetic confinement the particles and energy of a hot plasma are held in place using magnetic fields. A charged particle in a magnetic field experiences a Lorentz force that is proportional to the product of the particle's velocity and the magnetic field. This force causes electrons and ions to spiral about the direction of the magnetic line of force, thereby confining the particles. When the topology of the magnetic field yields an effective magnetic well and the pressure balance between the plasma and the field is stable, the plasma can be confined away from material boundaries. Heat and particles are transported both along and across the field, but energy losses can be prevented in two ways. The first is to increase the strength of the magnetic field at two locations along the field line. Charged particles contained between these points can be made to reflect back and forth, an effect called magnetic mirroring. In a basically straight system with a region of intensified magnetic field at each end, particles can still escape through the ends due to scattering between particles as they approach the mirroring points. Such end losses can be avoided altogether by creating a magnetic field in the topology of a torus (i.e., configuration of a doughnut or inner tube).

External magnets can be arranged to create a magnetic field topology for stable plasma confinement, or they can be used in conjunction with magnetic fields generated by currents induced to flow in the plasma itself. The late 1960s witnessed a major advance by the Soviet Union in harnessing fusion reactions for practical energy production. Soviet scientists achieved a high plasma temperature (about 3,000,000 K), along with other physical parameters, in a machine referred to as a tokamak. A tokamak is a toroidal magnetic confinement system in which the plasma is kept stable both by an externally generated, doughnut-shaped magnetic field and by electric currents flowing within the plasma. Since the late 1960s the tokamak has been the major focus of magnetic fusion research worldwide, though other approaches such as the stellarator, the compact torus, and the reversed field pinch (RFP) have also been pursued. In these approaches, the magnetic field lines follow a helical, or screwlike, path as the lines of magnetic force proceed around the torus. In the tokamak the pitch of the helix is weak, so the field lines wind loosely around the poloidal direction (through the central hole) of the torus. In contrast, RFP field lines wind much tighter, wrapping many times in the poloidal direction before completing one loop in the toroidal direction (around the central hole).

Magnetically confined plasma must be heated to temperatures at which nuclear fusion is vigorous, typically greater than 75,000,000 K (equivalent to an energy of 4,400 eV). This can be achieved by coupling radio-frequency waves or microwaves to the plasma particles, by injecting energetic beams of neutral atoms that become ionized and heat the plasma, by magnetically compressing the plasma, or by the ohmic heating (also known as Joule heating) that occurs when an electric current passes through the plasma.

Employing the tokamak concept, scientists and engineers in the United States, Europe, and Japan began in the mid-1980s to use large experimental tokamak devices to attain conditions of temperature, density, and energy confinement that now match those necessary for practical fusion power generation. The machines employed to achieve these results include the Joint European Torus (JET) of the European Union, the Japanese Tokamak-60 (JT-60), and, until 1997, the Tokamak Fusion Test Reactor (TFTR) in the United States. Indeed, in both the TFTR and the JET devices, experiments using deuterium and tritium produced more than 10 megawatts of fusion power and essentially energy breakeven conditions in the plasma itself. Plasma conditions approaching those achieved in tokamaks were also achieved in large stellarator machines in Germany and Japan during the 1990s.

Inertial confinement fusion (ICF)

In this approach, a fuel mass is compressed rapidly to densities 1,000 to 10,000 times greater than normal by generating a pressure as high as 10^{17} pascals (10^{12} atmospheres) for periods as short as a nanosecond (10^{-9} second). Near the end of this time period, the implosion speed exceeds about 3×10^5 metres per second. At maximum compression of the fuel, which is now in a cool plasma state, the energy in converging shock waves is sufficient to heat the very centre of the fuel to temperatures high enough to induce fusion reactions (greater than an equivalent energy of about 4,400 eV). If the mass of this highly compressed fuel material is large enough, energy will be generated through fusion reactions before this hot plasma ball disassembles. Under proper conditions, much more energy can be released than is required to compress and shock heat the fuel to thermonuclear burning conditions.

The physical processes in ICF bear a relationship to those in thermonuclear weapons and in star formation – namely, collapse, compression heating, and the onset of nuclear fusion. The situation in star formation differs in one respect: gravity is the cause of the collapse, and a collapsed star begins to expand again due to heat from exoergic nuclear fusion reactions. The expansion is ultimately arrested by the gravitational force associated with the enormous mass of the star, at which point a state of equilibrium in both size and temperature is achieved. In contrast, the fuel in a thermonuclear weapon or ICF completely disassembles. In the ideal ICF case, however, this does not occur until about 30 percent of the fusion fuel has burned.

Over the decades, very significant progress has been made in developing the technology and systems for high-energy, short-time-pulse drivers that are necessary to implode the fusion fuel. The most common driver is a high-power laser, though particle accelerators capable of producing beams of high-energy ions are also used. Lasers that produce more than 100,000 joules in pulses of about one nanosecond are now used in experiments, and the power available in short bursts exceeds 10^{14} watts.

Two lasers capable of delivering up to 5,000,000 joules in equally short bursts, generating a power level on the fusion targets in excess of 5×10^{14} watts, are operational. One facility is the Laser MegaJoule in Bordeaux, France. The other is the National Ignition Facility at the Lawrence Livermore National Laboratory in Livermore, Calif., U.S.

Muon-catalyzed fusion

The need in traditional schemes of nuclear fusion to confine very high-temperature plasmas has led some researchers to explore alternatives that would permit fusion reactants to approach each other more closely at much lower temperatures. One method involves substituting muons (μ) for the electrons that ordinarily surround the nucleus of a fuel atom. Muons are negatively charged subatomic particles similar to electrons, except that their mass is a little more than 200 times the electron mass and they are unstable, having a half-life of about 2.2×10^{-6} second. In fact, fusion has been observed in liquid and gas mixtures of deuterium and tritium at cryogenic temperatures when muons were injected into the mixture.

Muon-catalyzed fusion is the name given to the process of achieving fusion reactions by causing a deuteron (deuterium nucleus, D^+), a triton (tritium nucleus, T^+), and a muon to form what is called a muonic molecule. Once a muonic molecule is formed, the rate of fusion reactions is approximately 3×10^{-8} second. However, the formation of a muonic molecule is complex, involving a series of atomic, molecular, and nuclear processes.

In schematic terms, when a muon enters a mixture of deuterium and tritium, the muon is first captured by one of the two hydrogen isotopes in the mixture, forming either atomic D^+-μ or T^+-μ, with the atom now in an excited state. The excited atom relaxes to the ground state through a cascade collision process, in which the muon may be transferred from a deuteron to a triton or vice versa. More important, it is also possible that a muonic molecule (D^+-μ-T^+) will be formed. Although a much rarer reaction, once a muonic molecule does form, fusion takes place almost immediately, releasing the muon in the mixture to be captured again by a deuterium or tritium nucleus and allowing the process to continue. In this sense the muon acts as a catalyst for fusion reactions within the mixture. The key to practical energy production is to generate enough fusion reactions before the muon decays.

The complexities of muon-catalyzed fusion are many and include generating the muons (at an energy expenditure of about five billion electron volts per muon) and immediately injecting them into the deuterium-tritium mixture. In order to produce more energy than what is required to initiate the process, about 300 D-T fusion reactions must take place within the half-life of a muon.

2. *Translate the following sentences into Russian. If necessary, refer to the text to clarify the context.*

1) These free electrons enable plasmas to conduct electric charges, and a plasma is the only state of matter in which thermonuclear reactions can occur in a self-sustaining manner.
2) Thus, essentially all of the hydrogen in this plasma would be ionized.
3) A reaction-rate parameter more appropriate to the plasma state is obtained by accounting for the fact that the particles in a plasma, as in any gas, have a distribution of energies.
4) The intensity of nuclear fusion reactions in a plasma is derived by averaging the product of the particles' speed and their cross sections over a distribution of speeds corresponding to a Maxwell-Boltzmann distribution.
5) Reactions between deuterium and tritium are the most important fusion reactions for controlled power generation because the cross sections for their occurrence are high, the practical plasma temperatures required for net energy release are moderate, and the energy yield of the reactions are high – 17.58 MeV for the basic D-T fusion reaction.
6) It should be noted that any plasma containing deuterium automatically produces some tritium and helium-3 from reactions of deuterium with other deuterium ions.
7) Other fusion reactions involving elements with an atomic number above 2 can be used, but only with much greater difficulty.
8) Practical efforts to harness fusion energy involve two basic approaches to containing a high-temperature plasma of elements that undergo nuclear fusion reactions: magnetic confinement and inertial confinement.
9) This force causes electrons and ions to spiral about the direction of the magnetic line of force, thereby confining the particles. When the topology of the magnetic field yields an effective magnetic well and the pressure balance between the plasma and the field is stable, the plasma can be confined away from material boundaries.
10) Charged particles contained between these points can be made to reflect back and forth, an effect called magnetic mirroring.
11) External magnets can be arranged to create a magnetic field topology for stable plasma confinement, or they can be used in conjunction with magnetic fields generated by currents induced to flow in the plasma itself.

12) Magnetically confined plasma must be heated to temperatures at which nuclear fusion is vigorous, typically greater than 75,000,000 K (equivalent to an energy of 4,400 eV).
13) This can be achieved by coupling radio-frequency waves or microwaves to the plasma particles, by injecting energetic beams of neutral atoms that become ionized and heat the plasma, by magnetically compressing the plasma, or by the ohmic heating (also known as Joule heating) that occurs when an electric current passes through the plasma.
14) Employing the tokamak concept, scientists and engineers in the United States, Europe, and Japan began in the mid-1980s to use large experimental tokamak devices to attain conditions of temperature, density, and energy confinement that now match those necessary for practical fusion power generation.
15) Plasma conditions approaching those achieved in tokamaks were also achieved in large stellarator machines in Germany and Japan during the 1990s.

3. *Fill in the gaps with appropriate prepositions from memory.*

1) Typically, a plasma is a gas that has had some substantial portion … its constituent atoms or molecules ionized by the dissociation … one or more … their electrons.
2) The cross section for the reaction depends … the energy or speed … the particles.
3) A much less likely but nevertheless interesting approach is based … fusion catalyzed by muons; research … this topic is … intrinsic interest in nuclear physics.
4) In a basically straight system with a region … intensified magnetic field … each end, particles can still escape through the ends due … scattering between particles as they approach the mirroring points.
5) A tokamak is a toroidal magnetic confinement system in which the plasma is kept stable both … an externally generated, doughnut-shaped magnetic field and … electric currents flowing within the plasma.
6) In the tokamak the pitch … the helix is weak, so the field lines wind loosely … the poloidal direction (through the central hole) … the torus.

7) … contrast, RFP field lines wind much tighter, wrapping many times … the poloidal direction before completing one loop … the toroidal direction (around the central hole).
8) Magnetically confined plasma must be heated … temperatures … which nuclear fusion is vigorous, typically greater than 75,000,000 K (equivalent … an energy of 4,400 eV).

4. ***Compare advantages and disadvantages of each method of achieving fusion energy. Work in pairs.***

TEXT 3

1. ***Write an outline of the text in the form of questions.***

History of Fusion Energy Research

The fusion process has been studied in order to understand nuclear matter and forces, to learn more about the nuclear physics of stellar objects, and to develop thermonuclear weapons. During the late 1940s and early ’50s, research programs in the United States, United Kingdom, and the Soviet Union began to yield a better understanding of nuclear fusion, and investigators embarked on ways of exploiting the process for practical energy production. Fusion reactor research focused primarily on using magnetic fields and electromagnetic forces to contain the extremely hot plasmas needed for thermonuclear fusion.

Researchers soon found, however, that it is exceedingly difficult to contain plasmas at fusion reaction temperatures because the hot gases tend to expand and escape from the enclosing magnetic structure. Plasma physics theory in the 1950s was incapable of describing the behaviour of the plasmas in many of the early magnetic confinement systems.

The undeniable potential benefits of practical fusion energy led to an increasing call for international cooperation. American, British, and Soviet fusion programs were strictly classified until 1958, when most of their research programs were made public at the Second Geneva Conference on the Peaceful Uses of Atomic Energy, sponsored by the United Nations. Since that time, fusion research has been characterized by international collaboration. In addition, scientists have also continued to study and measure fusion reactions between the lighter elements so as to arrive at a more accurate determination of reaction rates. The formulas developed by nuclear physicists for predicting the rate of fusion energy generation have been adopted by astrophysicists to derive new information about the structure and evolution of stars.

Work on the other major approach to fusion energy, inertial confinement fusion (ICF), was begun in the early 1960s. The initial idea was proposed in 1961, only a year after the reported invention of the laser, in a then-classified proposal to employ large pulses of laser energy (which no one then quite knew how to achieve) to implode and shock-heat matter to temperatures at which nuclear fusion would proceed vigorously. Aspects of inertial confinement fusion were declassified in the 1970s and, especially, in the early 1990s to reveal important aspects of the design of the targets containing fusion fuels. Very painstaking and sophisticated work to design and develop short-pulse, high-power lasers and suitable millimetre-sized targets continues, and significant progress has been made.

Although practical fusion reactors have not been built yet, the necessary conditions of plasma temperature and heat insulation have been largely achieved, suggesting that fusion energy for electric-power production is now a serious possibility. Commercial fusion reactors promise an inexhaustible source of electricity for countries worldwide. From a practical viewpoint, however, the initiation of nuclear fusion in a hot plasma is but the first step in a whole sequence of steps required to convert fusion energy to electricity. In the end, successful fusion power systems must be capable of producing electricity safely and in a cost-effective manner, with a minimum of radioactive waste and environmental impact. The quest for practical fusion energy remains one of the great scientific and engineering challenges of humankind.

2. Discuss the history of nuclear fusion research in pairs.

CHECK YOURSELF

1. Translate the text at sight.

Nuclear fission is a subdivision of a heavy atomic nucleus, such as that of uranium or plutonium, into two fragments of roughly equal mass. The process is accompanied by the release of a large amount of energy.

In nuclear fission the nucleus of an atom breaks up into two lighter nuclei. The process may take place spontaneously in some cases or may be induced by the excitation of the nucleus with a variety of particles (e.g., neutrons, protons, deuterons, or alpha particles) or with electromagnetic radiation in the form of gamma rays. In the fission process, a large quantity of energy is released, radioactive products are formed, and several neutrons are emitted. These neutrons can induce fission in a nearby nucleus of fissionable material and release more neutrons that can repeat the sequence, causing a chain reaction in which a large number of nuclei undergo fission and an enormous amount of energy is released. If controlled in a nuclear reactor, such a chain reaction can provide power for society's benefit. If uncontrolled, as in the case of the so-called atomic bomb, it can lead to an explosion of awesome destructive force.

The discovery of nuclear fission has opened a new era – the "Atomic Age." The potential of nuclear fission for good or evil and the risk/benefit ratio of its applications have not only provided the basis of many sociological, political, economic, and scientific advances but grave concerns as well. Even from a purely scientific perspective, the process of nuclear fission has given rise to many puzzles and complexities, and a complete theoretical explanation is still not at hand.

2. Translate the text in writing. Time limit: 30 min.

Cold fusion and bubble fusion

Two disputed fusion experiments merit mention. In 1989 two chemists, Martin Fleischmann of the University of Utah and Stanley Pons of the University of Southampton in England, announced that they had produced fusion reactions at essentially room temperature. Their system consisted of electrolytic cells containing heavy water (deuterium oxide, D_2O) and palladium rods that absorbed the deuterium from the heavy water. Efforts to give a theoretical explanation of the results failed, as did worldwide efforts to reproduce the claimed cold fusion.

In 2002 Rusi Taleyarkhan and colleagues at Purdue University in Lafayette, Ind., claimed to have observed a statistically significant increase in nuclear emissions of products of fusion reactions (neutrons and tritium) during acoustic cavitation experiments with chilled deuterated (bombarded with deuterium) acetone. Their experimental setup was based on the known phenomenon of sonoluminescence. In sonoluminescence a gas bubble is imploded with high-pressure sound waves. At the end of the implosion process, and for a short time afterward, conditions of high density and temperature are achieved that lead to light emission. By starting with larger, millimetre-sized cavitations (bubbles) that had been deuterated in the acetone liquid, the researchers claimed to have produced densities and temperatures sufficient to induce fusion reactions just before the bubbles broke up. As with cold fusion, most attempts to replicate their results have failed.

3. *Translate the sentences into English.*

1) Чтобы термоядерная реакция была энергетически выгодной, нужно обеспечить достаточно высокую температуру термоядерного топлива, достаточно высокую его плотность и малые потери энергии.
2) Омический нагрев плазмы – за счет протекания через нее электрического тока – наиболее эффективен на первых этапах, так как с ростом температуры у плазмы снижается электрическое сопротивление.
3) Электромагнитный нагрев плазмы использует частоту, совпадающую с частотой вращения вокруг магнитных силовых линий электронов или ионов.
4) При инжекции быстрых нейтральных атомов создается поток отрицательных ионов, которые затем нейтрализуются, превращаясь в нейтральные атомы, способные проходить через магнитное поле в центр плазмы, чтобы передать свою энергию именно там.
5) D-T-реакция рождает 14 МэВ нейтроны, которые могут делить даже обедненный уран.
6) Деление одного ядра урана сопровождается выделением примерно 200 МэВ энергии, что в десять с лишним раз превосходит энергию, выделяющуюся при синтезе.
7) Уже существующие токамаки могли бы стать энергетически выгодными, если бы их окружили урановой оболочкой.
8) Крайне интенсивные потоки нейтронов должны перерабатывать долгоживущие продукты деления урана в короткоживущие, что существенно снижает проблему захоронения отходов.

4. *Render the text into English.*

Мирный термояд – почти реальность

Одна из главных проблем, которую надо решить при создании термоядерной станции, – повышение ее КПД, т. е. отношение полученной мощности к затраченной в ходе термоядерной реакции. Этот параметр (фактор *Q*), естественно, должен быть больше единицы. Для промышленной же электростанции значение *Q* должно быть не меньше пяти: только в этом случае заряженные альфа-частицы, которые вместе с нейтронами рождаются при термоядерной реакции, но, в отличие от последних, не покидают магнитную ловушку, будут способствовать поддержанию высокой температуры. Таким образом, при *Q*, равном пяти, достаточно один раз «зажечь» плазму, а потом никаких дополнительных манипуляций с реактором проводить уже не нужно. В идеале значение *Q* должно достигать десяти.

Но создание подобной установки не под силу ни одной стране мира в одиночку. Поэтому в 1980-х гг. советские физики-ядерщики выступили с инициативой строительства международного экспериментального термоядерного реактора – с проектом ИТЭР. Тогдашний глава СССР М. С. Горбачев, президенты Р. Рейган (США) и Ф. Миттеран (Франция) поддержали эту идею. Но прошло еще два десятилетия, прежде чем мир сделал очередной шаг к термоядерному будущему: было определено место для строительства экспериментального реактора.

Выбор пал на область Прованс на юго-востоке Франции. Это место соответствовало всем требованиям, включая комфортный климат и хорошую транспортную доступность, в том числе по морю. Последнее было важно, так как планировалась транспортировка громоздких деталей, вес которых мог достигать 100 т и более. Наконец, уже в середине первого десятилетия нового века, началось строительство токамака ИТЭР.

ИТЭР – это токамак, т. е. магнитная ловушка закрытого типа, однако ИЯФ является признанным мировым лидером в создании альтернативного варианта – открытых магнитных ловушек. Сейчас в институте работают две подобные установки: ГДЛ (газодинамическая ловушка) и ГОЛ-3 (гофрированная ловушка), а недавно была запущена новая экспериментальная установка СМОЛА. На этих установках наши специалисты занимаются не только собственными исследованиями физики плазмы, но и решают нетривиальные физические задачи для проекта ИТЭР.

Как работает такой научный обмен? Возьмем физику неустойчивостей, в которой мы работаем. Явления подобной природы проявляются одинаково как в закрытых, так и в открытых системах, где есть магнитное удержание плазмы. Например, на токамаках ученые научились бороться с желобковой неустойчивостью, и эти знания мы можем использовать в открытых ловушках.

Но есть вопросы, связанные, к примеру, со взаимодействием плазмы и материала, которые нельзя решить на существующих сегодня токамаках. В частности, на них нельзя достичь параметров плазменных потоков, которые будут контактировать со стенками термоядерного реактора. А вот на открытых ловушках в силу их геометрической конфигурации такие потоки получить можно. Поэтому подобные эксперименты проводятся в ИЯФ, а полученная информация используется в проекте ИТЭР.

(*Бурдаков А.В.* О настоящем и будущем термоядерной энергетики)

5. ***Read the text about the role nuclear accelerators play in technical and industrial fields. Draw a mind-map to help you retell the text. Time limit: 15 min.***

Cosmic Rays, Electronic Devices, and Nuclear Accelerators

Cosmic rays are continuously bombarding Earth: more during active solar periods, more at the poles, and less at the equator. When cosmic rays, or radiation from their secondary products, interact with an electronic device, the function of that device can be compromised. The resulting errors in the functionality of an electronic device can have very serious consequences for technologies used by such disparate industries as aerospace and autos.

A single event upset (SEU) refers to a change in the state of the logic or support circuitry of an electronic device caused by radiation striking a sensitive location or node in the device. SEUs can range from temporary nondestructive soft errors to hard error damage in devices. The detailed physics determining the rate at which SEUs occur is both complicated and device dependent. Circuit manufacturers try to design around the risks posed by cosmic ray interactions by introducing redundancy or other protective measures to compensate for the radiation-induced errors. To do so requires detailed knowledge of the expected rates and types of SEUs that can occur. Thus, experimental testing of semiconductor device response to radiation requires beams of particles that provide realistic analogs of cosmic rays and their secondary products. The main particles responsible for SEUs are neutrons, protons, and alpha particles, as well as heavy ions. Thus, the beams needed for this large experimental program require a range of nuclear accelerator facilities to test for device vulnerabilities and to characterize the radiation-induced failure modes of the electronic chips. For this, nuclear physics accelerator facilities are a unique resource, and agencies and companies from all over the world purchase beam time at accelerator facilities to test for device vulnerabilities and to characterize the radiation-induced failure modes of the electronic chips. In the United States alone, each year national and university nuclear physics laboratories provide almost 10,000 hours of accelerator time for this important service.

FOCUS ON PRODUCTIVE WRITING AND SPEAKING SKILLS

1. ***Write 2-3 paragraphs of 200-250 words to comment on the statement that nuclear physics is cross-disciplinary in nature. Ensure continuity within and between the paragraphs using proper means of cohesion.***

2. ***Prepare a 5-minute talk on one of the following topics. You may choose any other topic related to nuclear physics which is not on the list.***

   1) Experimental progress in nuclear physics
   2) Unsolved theoretical problems in nuclear physics
   3) Advances in nuclear medicine
   4) Addressing environmental challenges with nuclear accelerators
   5) Arguments for and against cold fusion

KEY WORDS AND WORD COMBINATIONS

Atomic

atomic mass, atomic mass number, atomic number, atomic process, atomic weight

Element

heavy element, light element, transuranium element

Energy

average energy, binding energy, fission energy, kinetic energy, laser energy, nuclear energy, particle energy, potential energy;

energy equivalent, energy generation, energy potential, energy production, energy release, energy yield

Fission

asymmetric fission, low-energy fission, neutron-induced fission, nuclear fission, symmetric fission; fission barrier, fission fragments, fission phenomena, fission process, fission research, fission threshold

Fusion

fusion energy, fusion fuel, fusion power, fusion power generation, fusion power process, fusion reactant, fusion reaction, fusion reactor, fusion research; bubble fusion, cold fusion, inertial confinement fusion, muon-catalyzed fusion, nuclear fusion; undergo fusion

Mass

mass asymmetry, mass defect, mass distribution, mass division, mass equivalent, mass number, mass region, mass split; actual mass, electron mass, ground-state mass, proton mass, unequal mass

Model

deformed shell model, independent-particle model, liquid-drop model, shell model, simplified model, single-particle model, spherical-shell model, unified model

Neutron

free neutron, slow neutron; neutron mass

Nuclear

nuclear astrophysics, nuclear deformation, nuclear energy, nuclear fuel, nuclear level, nuclear matter, nuclear model, nuclear number, nuclear physics, nuclear physicists, nuclear power industry, nuclear process, nuclear reaction, nuclear reactor, nuclear spectroscopy, nuclear state, nuclear structure

Nuclear force

attractive nuclear force, cohesive nuclear force, repulsive nuclear force, short-range nuclear force, strong nuclear force, weak nuclear force

Nucleus (nuclei)

closed-shell nucleus, deuterium nucleus, fissioning nucleus, heavy nucleus, hydrogen nucleus, interacting nuclei, light nucleus, magic-number nucleus, nearby nucleus, real nucleus

Nucleon

constituent nucleon, individual nucleon; individual nucleon components; pairs of nucleons

Reaction

chemical reaction, H-H fusion reaction, D-T reaction, nuclear fusion reaction, physical reaction, self-sustained reaction; reaction rate

Surface

surface area, surface force, surface energy, surface tension; potential energy surface

Thermonuclear

thermonuclear fusion, thermonuclear reaction, thermonuclear weapon

UNIT 6. NANOTECHNOLOGY

TEXT 1

3. ***Check the pronunciation of these words in a dictionary. If necessary, specify their meaning.***

   chemistry, deoxyribonucleic acid, dwarf, effort, enzyme, exhibit, hybrid, manufacture, microscopic, opaque, oxide, ultimately, ultraviolet, vehicle, zinc

4. ***Read the text and answer the questions below.***
   1. What modern-day applications of nanotechnology are mentioned in the text?
   2. What future applications of nanotechnology will be possible? Will they have a positive effect on the environment?
   3. What does the term 'nanotechnology' refer to?
   4. How has nature been using nanotechnology for billions of years?
   5. What are the two principal reasons for qualitative differences in material behaviour at the nanoscale?
   6. What positive changes may nanotechnology bring to the basic industrial production?
   7. Where do scientists take their inspiration for nanotechnology from?

Overview of nanotechnology

1. Nanotechnology is the manipulation and manufacture of materials and devices on the scale of atoms or small groups of atoms. The "nanoscale" is typically measured in nanometres, or billionths of a metre (nanos, the Greek word for "dwarf," being the source of the prefix), and materials built at this scale often exhibit distinctive physical and chemical properties due to quantum mechanical effects. Although usable devices this small may be decades away, techniques for working at the nanoscale have become essential to electronic engineering, and nanoengineered materials have begun to appear in consumer products. For example, billions of microscopic "nanowhiskers," each about 10 nanometres in length, have been molecularly hooked onto natural and synthetic fibres to

impart stain resistance to clothing and other fabrics; zinc oxide nanocrystals have been used to create invisible sunscreens that block ultraviolet light; and silver nanocrystals have been embedded in bandages to kill bacteria and prevent infection.

2. Possibilities for the future are numerous. Nanotechnology may make it possible to manufacture lighter, stronger, and programmable materials that require less energy to produce than conventional materials, that produce less waste than with conventional manufacturing, and that promise greater fuel efficiency in land transportation, ships, aircraft, and space vehicles. Nanocoatings for both opaque and translucent surfaces may render them resistant to corrosion, scratches, and radiation. Nanoscale electronic, magnetic, and mechanical devices and systems with unprecedented levels of information processing may be fabricated, as may chemical, photochemical, and biological sensors for protection, health care, manufacturing, and the environment; new photoelectric materials that will enable the manufacture of cost-efficient solar-energy panels; and molecular-semiconductor hybrid devices that may become engines for the next revolution in the information age. The potential for improvements in health, safety, quality of life, and conservation of the environment are vast.

3. At the same time, significant challenges must be overcome for the benefits of nanotechnology to be realized. Scientists must learn how to manipulate and characterize individual atoms and small groups of atoms reliably. New and improved tools are needed to control the properties and structure of materials at the nanoscale; significant improvements in computer simulations of atomic and molecular structures are essential to the understanding of this realm. Next, new tools and approaches are needed for assembling atoms and molecules into nanoscale systems and for the further assembly of small systems into more-complex objects. Furthermore, nanotechnology products must provide not only improved performance but also lower cost. Finally, without integration of nanoscale objects with systems at the micro- and macroscale (that is, from millionths of a metre up to the millimetre scale), it will be very difficult to exploit many of the unique properties found at the nanoscale.

4. Nanotechnology is highly interdisciplinary, involving physics, chemistry, biology, materials science, and the full range of the engineering disciplines. The word nanotechnology is widely used as shorthand to refer to both the science and the technology of this emerging field. Narrowly defined, nanoscience concerns a basic understanding of physical, chemical, and biological properties on atomic and near-atomic

scales. Nanotechnology, narrowly defined, employs controlled manipulation of these properties to create materials and functional systems with unique capabilities.

5. In contrast to recent engineering efforts, nature developed "nanotechnologies" over billions of years, employing enzymes and catalysts to organize with exquisite precision different kinds of atoms and molecules into complex microscopic structures that make life possible. These natural products are built with great efficiency and have impressive capabilities, such as the power to harvest solar energy, to convert minerals and water into living cells, to store and process massive amounts of data using large arrays of nerve cells, and to replicate perfectly billions of bits of information stored in molecules of deoxyribonucleic acid (DNA).

6. There are two principal reasons for qualitative differences in material behaviour at the nanoscale (traditionally defined as less than 100 nanometres). First, quantum mechanical effects come into play at very small dimensions and lead to new physics and chemistry. Second, a defining feature at the nanoscale is the very large surface-to-volume ratio of these structures. This means that no atom is very far from a surface or interface, and the behaviour of atoms at these higher-energy sites has a significant influence on the properties of the material. For example, the reactivity of a metal catalyst particle generally increases appreciably as its size is reduced – macroscopic gold is chemically inert, whereas at nanoscales gold becomes extremely reactive and catalytic and even melts at a lower temperature. Thus, at nanoscale dimensions material properties depend on and change with size, as well as composition and structure.

7. Using the processes of nanotechnology, basic industrial production may veer dramatically from the course followed by steel plants and chemical factories of the past. Raw materials will come from the atoms of abundant elements – carbon, hydrogen, and silicon – and these will be manipulated into precise configurations to create nanostructured materials that exhibit exactly the right properties for each particular application. For example, carbon atoms can be bonded together in a number of different geometries to create variously a fibre, a tube, a molecular coating, or a wire, all with the superior strength-to-weight ratio of another carbon material – diamond. Additionally, such material processing need not require smokestacks, power-hungry industrial machinery, or intensive human labour. Instead, it may be accomplished either by "growing" new structures through some combination of chemical catalysts and synthetic enzymes or by building them through new techniques based on patterning and self-assembly of nanoscale materials into useful predetermined

designs. Nanotechnology ultimately may allow people to fabricate almost any type of material or product allowable under the laws of physics and chemistry. While such possibilities seem remote, even approaching nature's virtuosity in energy-efficient fabrication would be revolutionary.

8. Even more revolutionary would be the fabrication of nanoscale machines and devices for incorporation into micro- and macroscale systems. Once again, nature has led the way with the fabrication of both linear and rotary molecular motors. These biological machines carry out such tasks as muscle contraction (in organisms ranging from clams to humans) and shuttling little packets of material around within cells while being powered by the recyclable, energy-efficient fuel adenosine triphosphate. Scientists are only beginning to develop the tools to fabricate functioning systems at such small scales, with most advances based on electronic or magnetic information processing and storage systems. The energy-efficient, reconfigurable, and self-repairing aspects of biological systems are just becoming understood.

9. The potential impact of nanotechnology processes, machines, and products is expected to be far-reaching, affecting nearly every conceivable information technology, energy source, agricultural product, medical device, pharmaceutical, and material used in manufacturing. Meanwhile, the dimensions of electronic circuits on semiconductors continue to shrink, with minimum feature sizes now reaching the nanorealm, under 100 nanometres. Likewise, magnetic memory materials, which form the basis of hard disk drives, have achieved dramatically greater memory density as a result of nanoscale structuring to exploit new magnetic effects at nanodimensions. These latter two areas represent another major trend, the evolution of critical elements of microtechnology into the realm of nanotechnology to enhance performance. They are immense markets driven by the rapid advance of information technology.

5. ***Read the text again and write five extra questions to discuss in pairs.***

LANGUAGE REVIEW

Focus on word formation

1. ***Form adjectives from the following words. Consult the text if necessary.***

   biology, conceive, convention, function, impress, magnet, microscope, nature, programme, recycle, resist, revolution

2. ***Identify what part of speech the word 'increase' represents in paragraph 6 and check how it should be pronounced.***

Focus on grammar

1. ***Answer the questions.***
   1) How are multi-component terms formed?
   2) What models of multi-component terms do you know?
   3) What are the ways of their translation?

2. ***Do the following tasks.***
   1) Analyse the use of the Infinitive throughout the text.
   2) Comment on the use of modal verbs *may*, *would*, *need*, *must*, *can* in paragraphs 1, 2, 3, 7 and 8.
   3) Find the Absolute Participial Construction in paragraphs 8 and 9. Translate the sentences it occurs in.
   4) Identify the function of 'it' in paragraphs 2, 3 and 7 and the function of 'that' in paragraph 2.
   5) Indicate the difference between the Verbal Noun and the Gerund and decide which is which in paragraphs 1, 2, 3, 4 and 7.
   6) Identify the Complex Subject in paragraph 9 and translate the sentence it is used in.
   7) Find the sentence with the Inversion in paragraph 8 and translate it.
   8) Write out 5 multi-component terms and translate them.

Focus on paragraph structure and content

1. ***Answer the questions.***
   1) What key terms and phrases provide an effective means of connecting the sentences in all the paragraphs of Text 1?
   2) What parallel grammatical and structural forms (words, phrases, clauses) are used in paragraphs 2 and 7?

2. ***Do the following tasks.***
   1) Indicate the topic sentence in each paragraph of Text 1.
   2) Develop the idea of each topic sentence.
   3) Sum up the main points of Text 1.

Focus on vocabulary

1. ***Define or explain these terms.***

   hybrid, nanocoating, nanodimention, nanomanufacture, nanomaterial, nanotechnology, nanoscale, self-assembly

2. ***Give English equivalents for the following word combinations.***

   изготовление материалов, квантово-механический эффект, проявлять/демонстрировать характерные физические свойства, сделать поверхность устойчивой к коррозии, обычное производство, беспрецедентный уровень обработки информации, охрана окружающей среды, решить серьезные проблемы, качественные отличия, контролировать свойства и структуру материалов в нанометровом масштабе, обрабатывать огромные объёмы данных, обладать впечатляющими возможностями, большое отношение поверхности к объёму, обладать значительным влиянием на свойства материала, создать наноструктурированный материал

3. ***Give Russian equivalents for the following word combinations. Make up sentences with some of them.***

   on the scale of atoms, to be typically measured in nanometres, to be built at nanoscale, to be molecularly hooked onto natural and synthetic fibres, to manufacture programmable materials, nanoscale electronic magnetic and mechanical devices and systems, the potential for improvements in health, to manipulate and characterize atoms reliably, integration of nanoscale objects with systems at the micro- and macroscale, to create materials and functional systems with unique capabilities, to exploit many of the unique properties found at the nanoscale, to exhibit exactly the right properties, strength-to-weight ratio, self-assembly of nanoscale materials, energy-efficient fabrication, the result of nanoscale structuring, to exploit new magnetic effects at nanodimensions

TEXT 2

1. ***Write an outline of the text in the form of questions and discuss the basic changes of the properties of materials at the nanoscale. Work in pairs.***

Properties at the nanoscale

At nanoscale dimensions the properties of materials no longer depend solely on composition and structure in the usual sense. Nanomaterials display new phenomena associated with quantized effects and with the preponderance of surfaces and interfaces.

Quantized effects arise in the nanometre regime because the overall dimensions of objects are comparable to the characteristic wavelength for fundamental excitations in materials. For example, electron wave functions in semiconductors are typically on the order of 10 to 100 nanometres. Such excitations include the wavelength of electrons, photons, phonons, and magnons, to name a few. These excitations carry the quanta of energy through materials and thus determine the dynamics of their propagation and transformation from one form to another. When the size of structures is comparable to the quanta themselves, it influences how these excitations move through and interact in the material. Small structures may limit flow, create wave interference effects, and otherwise bring into play quantum mechanical selection rules not apparent at larger dimensions.

Electronic and photonic behaviour

Quantum mechanical properties for confinement of electrons in one dimension have long been exploited in solid-state electronics. Semiconductor devices are grown with thin layers of differing composition so that electrons (or "holes" in the case of missing electron charges) can be confined in specific regions of the structure (known as quantum wells). Thin layers with larger energy bandgaps can serve as barriers that restrict the flow of charges to certain conditions under which they can "tunnel" through these barriers – the basis of resonant tunneling diodes. Superlattices are periodic structures of repeating wells that set up a new set of selection rules which affect the conditions for charges to flow through the structure. Superlattices have been exploited in cascade lasers to achieve far infrared wavelengths. Modern telecommunications is based on semiconductor lasers that exploit the unique properties of quantum wells to achieve specific wavelengths and high efficiency.

The propagation of photons is altered dramatically when the size and periodicity of the transient structure approach the wavelength of visible light (400 to 800 nanometres). When photons propagate through a periodically varying dielectric constant – for example, semiconductor posts surrounded by air – quantum mechanical rules define and limit the propagation of the photons depending on their energy (wavelength). This new behaviour is analogous to the quantum mechanical rules that define the motion of electrons through crystals, giving bandgaps for semiconductors. In one dimension, compound semiconductor superlattices can be grown epitaxially with the alternating layers having different dielectric constants, thus providing highly reflective mirrors for specific wavelengths as determined by the repeat distance of layers in the superlattice. These structures are used to provide "built-in" mirrors for vertical-cavity surface-emitting lasers, which are used in communications applications. In two and three dimensions, periodic structures known as photonic crystals offer additional control over photon propagation.

Photonic crystals are being explored in a variety of materials and periodicities, such as two-dimensional hexagonal arrays of posts fabricated in compound semiconductors or stacked loglike arrays of silicon bars in three dimensions. The dimensions of these structures depend on the wavelength of light being propagated and are typically in the range of a few hundred nanometres for wavelengths in the visible and near infrared. Photonic crystal properties based on nanostructured materials offer the possibility of confining, steering, and separating light by wavelength on unprecedented small scales and of creating new devices such as lasers that require very low currents to initiate lasing (called near-thresholdless lasers). These structures are being extensively investigated as the tools for nanostructuring materials are steadily advancing. Researchers are particularly interested in the infrared wavelengths, where dimensional control is not as stringent as at the shorter visible wavelengths and where optical communications and chemical sensing provide motivation for potential new applications.

Magnetic, mechanical, and chemical behaviour

Nanoscale materials also have size-dependent magnetic behaviour, mechanical properties, and chemical reactivity. At very small sizes (a few nanometres), magnetic nanoclusters have a single magnetic domain, and the strongly coupled magnetic spins on each atom combine to produce a particle with a single "giant" spin. For example, the giant spin of a ferromagnetic iron particle rotates freely at room temperature for diameters below about 16 nanometres, an effect termed superparamagnetism. Mechanical properties of nanostructured materials can reach exceptional strengths. As a specific example, the introduction of two-nanometre aluminum oxide precipitates into thin films of pure nickel results in yield strengths increasing from 0.15 to 5 gigapascals, which is more than twice that for a hard bearing steel. Another example of exceptional mechanical properties at the nanoscale is the carbon nanotube, which exhibits great strength and stiffness along its longitudinal axis.

The preponderance of surfaces is a major reason for the change in behaviour of materials at the nanoscale. Since up to half of all the atoms in nanoparticles are surface atoms, properties such as electrical transport are no longer determined by solid-state bulk phenomena. Likewise, the atoms in nanostructures have a higher average energy than atoms in larger structures, because of the large proportion of surface atoms. For example, catalytic materials have a greater chemical activity per atom of exposed surface as the catalyst is reduced in size at the nanoscale. Defects and impurities may be attracted to surfaces and interfaces, and interactions between particles at these small dimensions can depend on the structure and nature of chemical bonding at the surface. Molecular monolayers may be used to change or control surface properties and to mediate the interaction between nanoparticles.

Surfaces and their interactions with molecular structures are basic to all biology. The intersection of nanotechnology and biotechnology offers the possibility of achieving new functions and properties with nanostructured surfaces. In this surface- and interface-dominated regime, biology does an exquisite job of selectively controlling functions through a combination of structure and chemical forces. The transcription of information stored in genes and the selectivity of biochemical reactions based on chemical recognition of complex molecules are examples where interfaces play the key role in establishing nanoscale behaviour. Atomic forces and chemical bonds dominate at these dimensions, while macroscopic effects – such as convection, turbulence, and momentum (inertial forces) – are of little consequence.

2. *Translate the following sentences into Russian. If necessary, refer to the text to clarify the context.*

1) Semiconductor devices are grown with thin layers of differing composition so that electrons (or "holes" in the case of missing electron charges) can be confined in specific regions of the structure (known as quantum wells).
2) Thin layers with larger energy bandgaps can serve as barriers that restrict the flow of charges to certain conditions under which they

can “tunnel” through these barriers – the basis of resonant tunneling diodes.

3) Modern telecommunications is based on semiconductor lasers that exploit the unique properties of quantum wells to achieve specific wavelengths and high efficiency.
4) When photons propagate through a periodically varying dielectric constant – for example, semiconductor posts surrounded by air – quantum mechanical rules define and limit the propagation of the photons depending on their energy (wavelength).
5) In one dimension, compound semiconductor superlattices can be grown epitaxially with the alternating layers having different dielectric constants, thus providing highly reflective mirrors for specific wavelengths as determined by the repeat distance of layers in the superlattice.
6) These structures are used to provide “built-in” mirrors for vertical-cavity surface-emitting lasers, which are used in communications applications.
7) Photonic crystals are being explored in a variety of materials and periodicities, such as two-dimensional hexagonal arrays of posts fabricated in compound semiconductors or stacked loglike arrays of silicon bars in three dimensions.
8) Photonic crystal properties based on nanostructured materials offer the possibility of confining, steering, and separating light by wavelength on unprecedented small scales and of creating new devices such as lasers that require very low currents to initiate lasing (called near-thresholdless lasers).
9) These structures are being extensively investigated as the tools for nanostructuring materials are steadily advancing.
10) Defects and impurities may be attracted to surfaces and interfaces, and interactions between particles at these small dimensions can depend on the structure and nature of chemical bonding at the surface.
11) Molecular monolayers may be used to change or control surface properties and to mediate the interaction between nanoparticles.
12) The intersection of nanotechnology and biotechnology offers the possibility of achieving new functions and properties with nanostructured surfaces.

13) In this surface- and interface-dominated regime, biology does an exquisite job of selectively controlling functions through a combination of structure and chemical forces.
14) The transcription of information stored in genes and the selectivity of biochemical reactions based on chemical recognition of complex molecules are examples where interfaces play the key role in establishing nanoscale behaviour.

3 Fill in the gaps with appropriate adverbs as they occur in the text from memory: extensively, freely, typically, solely, steadily, particularly, highly, dramatically. Mind that you may use some of them twice.

1) At nanoscale dimensions the properties of materials no longer depend … on composition and structure in the usual sense.
2) For example, electron wave functions in semiconductors are … on the order of 10 to 100 nanometres.
3) The propagation of photons is altered … when the size and periodicity of the transient structure approach the wavelength of visible light (400 to 800 nanometres).
4) In one dimension, compound semiconductor superlattices can be grown epitaxially with the alternating layers having different dielectric constants, thus providing … reflective mirrors for specific wavelengths as determined by the repeat distance of layers in the superlattice.
5) The dimensions of these structures depend on the wavelength of light being propagated and are … in the range of a few hundred nanometres for wavelengths in the visible and near infrared.
6) These structures are being … investigated as the tools for nanostructuring materials are … advancing.
7) Researchers are … interested in the infrared wavelengths, where dimensional control is not as stringent as at the shorter visible wavelengths and where optical communications and chemical sensing provide motivation for potential new applications.
8) For example, the giant spin of a ferromagnetic iron particle rotates … at room temperature for diameters below about 16 nanometres, an effect termed superparamagnetism.

4. Read the text again and trace connecting words and phrases. If necessary, check their meaning.

TEXT 3

1. Read the text and identify the topic of each paragraph.

Nanomaterials

1. Material properties – electrical, optical, magnetic, mechanical, and chemical – depend on their exact dimensions. This opens the way for development of new and improved materials through manipulation of their nanostructure. Hierarchical assemblies of nanoscale-engineered materials into larger structures, or their incorporation into devices, provide the basis for tailoring radically new materials and machines.

2. Nature's assemblies point the way to improving structural materials. The often-cited abalone seashell provides a beautiful example of how the combination of a hard, brittle inorganic material with nanoscale structuring and a soft, "tough" organic material can produce a strong, durable nanocomposite – basically, these nanocomposites are made of calcium carbonate "bricks" held together by a glycoprotein "glue." New engineered materials are emerging – such as polymer-clay nanocomposites – that are not only strong and tough but also lightweight and easier to recycle than conventional reinforced plastics. Such improvements in structural materials are particularly important for the transportation industry, where reduced weight directly translates into improved fuel economy. Other improvements can increase safety or decrease the impact on the environment of fabrication and recycling. Further advances, such as truly smart materials that signal their impending failure or are even able to self-repair flaws, may be possible with composites of the future.

3. Sensors are central to almost all modern control systems. For example, multiple sensors are used in automobiles for such diverse tasks as engine management, emission control, security, safety, comfort, vehicle monitoring, and diagnostics. While such traditional applications for physical sensing generally rely on microscale sensing devices, the advent of nanoscale materials and structures has led to new electronic, photonic, and magnetic nanosensors, sometimes known as "smart dust." Because of their small size, nanosensors exhibit unprecedented speed and sensitivity, extending in some cases down to the detection of single molecules. For example, nanowires made of carbon nanotubes, silicon, or other semiconductor materials exhibit exceptional sensitivity to chemical

species or biological agents. Electrical current through nanowires can be altered by having molecules attached to their surface that locally perturb their electronic band structure. By means of nanowire surfaces coated with sensor molecules that selectively attach particular species, charge-induced changes in current can be used to detect the presence of those species. This same strategy is adopted for many classes of sensing systems. New types of sensors with ultrahigh sensitivity and specificity will have many applications; for example, sensors that can detect cancerous tumours when they consist of only a few cells would be a very significant advance.

4. Nanomaterials also make excellent filters for trapping heavy metals and other pollutants from industrial wastewater. One of the greatest potential impacts of nanotechnology on the lives of the majority of people on Earth will be in the area of economical water desalination and purification. Nanomaterials will very likely find important use in fuel cells, bioconversion for energy, bioprocessing of food products, waste remediation, and pollution-control systems.

5. A recent concern regarding nanoparticles is whether their small sizes and novel properties may pose significant health or environmental risks. In general, ultrafine particles – such as the carbon in photocopier toners or in soot produced by combustion engines and factories – have adverse respiratory and cardiovascular effects on people and animals. Studies are under way to determine if specific nanoscale particles pose higher risks that may require special regulatory restrictions. Of particular concern are potential carcinogenic risks from inhaled particles and the possibility for very small nanoparticles to cross the blood-brain barrier to unknown effect. Nanomaterials currently receiving attention from health officials include carbon nanotubes, buckyballs, and cadmium selenide quantum dots. Studies of the absorption through the skin of titanium oxide nanoparticles (used in sunscreens) are also planned. More far-ranging studies of the toxicity, transport, and overall fate of nanoparticles in ecosystems and the environment have not yet been undertaken. Some early animal studies, involving the introduction of very high levels of nanoparticles which resulted in the rapid death of many of the subjects, are quite controversial.

2. Write an outline of the text in the form of questions and discuss them in pairs.

TEXT 4

1. ***Read the text, then draw a mind-map to help you sum up applications for nanotechnology in medicine.***

Biomedicine and health care

Drug delivery

Nanotechnology promises to impact medical treatment in multiple ways. First, advances in nanoscale particle design and fabrication provide new options for drug delivery and drug therapies. More than half of the new drugs developed each year are not water-soluble, which makes their delivery difficult. In the form of nanosized particles, however, these drugs are more readily transported to their destination, and they can be delivered in the conventional form of pills.

More important, nanotechnology may enable drugs to be delivered to precisely the right location in the body and to release drug doses on a predetermined schedule for optimal treatment. The general approach is to attach the drug to a nanosized carrier that will release the medicine in the body over an extended period of time or when specifically triggered to do so. In addition, the surfaces of these nanoscale carriers may be treated to seek out and become localized at a disease site—for example, attaching to cancerous tumours. One type of molecule of special interest for these applications is an organic dendrimer. A dendrimer is a special class of polymeric molecule that weaves in and out from a hollow central region. These spherical "fuzz balls" are about the size of a typical protein but cannot unfold like proteins. Interest in dendrimers derives from the ability to tailor their cavity sizes and chemical properties to hold different therapeutic agents. Researchers hope to design different dendrimers that can swell and release their drug on exposure to specifically recognized molecules that indicate a disease target. This same general approach to nanoparticle-directed drug delivery is being explored for other types of nanoparticles as well.

Another approach involves gold-coated nanoshells whose size can be adjusted to absorb light energy at different wavelengths. In particular, infrared light will pass through several centimetres of body tissue, allowing a delicate and precise heating of such capsules in order to release the therapeutic substance within. Furthermore, antibodies may be attached to the outer gold surface of the shells to cause them to bind specifically to certain tumour cells, thereby reducing the damage to surrounding healthy cells.

Bioassays

A second area of intense study in nanomedicine is that of developing new diagnostic tools. Motivation for this work ranges from fundamental biomedical research at the level of single genes or cells to point-of-care applications for health delivery services. With advances in molecular biology, much diagnostic work now focuses on detecting specific biological "signatures." These analyses are referred to as bioassays. Examples include studies to determine which genes are active in response to a particular disease or drug therapy. A general approach involves attaching fluorescing dye molecules to the target biomolecules in order to reveal their concentration.

Another approach to bioassays uses semiconductor nanoparticles, such as cadmium selenide, which emit light of a specific wavelength depending on their size. Different-size particles can be tagged to different receptors so that a wider variety of distinct colour tags are available than can be distinguished for dye molecules. The degradation in fluorescence with repeated excitation for dyes is avoided. Furthermore, various-size particles can be encapsulated in latex beads and their resulting wavelengths read like a bar code. This approach, while still in the exploratory stage, would allow for an enormous number of distinct labels for bioassays.

Another nanotechnology variation on bioassays is to attach one half of the single-stranded complementary DNA segment for the genetic sequence to be detected to one set of gold particles and the other half to a second set of gold particles. When the material of interest is present in a solution, the two attachments cause the gold balls to agglomerate, providing a large change in optical properties that can be seen in the colour of the solution. If both halves of the sequence do not match, no agglomeration will occur and no change will be observed.

Approaches that do not involve optical detection techniques are also being explored with nanoparticles. For example, magnetic nanoparticles can be attached to antibodies that in turn recognize and attach to specific biomolecules. The magnetic particles then act as tags and "handlebars" through which magnetic fields can be used for mixing, extracting, or identifying the attached biomolecules within microlitre- or nanolitre-sized samples. For example, magnetic nanoparticles stay magnetized as a single domain for a significant period, which enables them to be aligned and detected in a magnetic field. In particular, attached antibody–magnetic-nanoparticle combinations rotate slowly and give a distinctive magnetic signal. In contrast, magnetically tagged antibodies that are not attached to the biological material being detected rotate more rapidly and so do not give the same distinctive signal.

Microfluidic systems, or "labs-on-chips," have been developed for biochemical assays of minuscule samples. Typically cramming numerous electronic and mechanical components into a portable unit no larger than a credit card, they are especially useful for conducting rapid analysis in the field. While these microfluidic systems primarily operate at the microscale (that is, millionths of a metre), nanotechnology has contributed new concepts and will likely play an increasing role in the future. For example, separation of DNA is sensitive to entropic effects, such as the entropy required to unfold DNA of a given length. A new approach to separating DNA could take advantage of its passage through a nanoscale array of posts or channels such that DNA molecules of different lengths would uncoil at different rates.

Other researchers have focused on detecting signal changes as nanometre-wide DNA strands are threaded through a nanoscale pore. Early studies used pores punched in membranes by viruses; artificially fabricated nanopores are also being tested. By applying an electric potential across the membrane in a liquid cell to pull the DNA through, changes in ion current can be measured as different repeating base units of the molecule pass through the pores. Nanotechnology-enabled advances in the entire area of bioassays will clearly impact health care in many ways, from early detection, rapid clinical analysis, and home monitoring to new understanding of molecular biology and genetic-based treatments for fighting disease.

Assistive devices and tissue engineering

Another biomedical application of nanotechnology involves assistive devices for people who have lost or lack certain natural capabilities. For example, researchers hope to design retinal implants for vision-impaired individuals. The concept is to implant chips with photodetector arrays to transmit signals from the retina to the brain via the optic nerve. Meaningful spatial information, even if only at a rudimentary level, would be of great assistance to the blind. Such research illustrates the tremendous challenge of designing hybrid systems that work at the interface between inorganic devices and biological systems.

Closely related research involves implanting nanoscale neural probes in brain tissue to activate and control motor functions. This requires effective and stable "wiring" of many electrodes to neurons. It is exciting because of the possibility of recovery of control for motor-impaired individuals. Studies employing neural stimulation of damaged spinal cords by electrical signals have demonstrated the return of some locomotion. Researchers are also seeking ways to assist in the regeneration and healing of bone, skin, and cartilage – for example, developing synthetic biocompatible or biodegradable structures with nanosized voids that would serve as templates for regenerating specific tissue while delivering chemicals to assist in the repair process. At a more sophisticated level, researchers hope to someday build nanoscale or microscale machines that can repair, assist, or replace more-complex organs.

2. ***Discuss the advantages and disadvantages of nanotechnology in the field of medicine.***

3. ***Look for more information on the use of nanotechnology in medicine and share it with other students.***

CHECK YOURSELF

1. ***Translate the text in writing. Time limit: 45 min.***

Information storage

Current approaches to information storage and retrieval include high-density, high-speed, solid-state electronic memories, as well as slower (but generally more spacious) magnetic and optical discs. As the minimum feature size for electronic processing approaches 100 nanometres, nanotechnology provides ways to decrease further the bit size of the stored information, thus increasing density and reducing interconnection distances for obtaining still-higher speeds. For example, the basis of the current generation of magnetic disks is the giant magnetoresistance effect. A magnetic read/write head stores bits of information by setting the direction of the magnetic field in nanometre-thick metallic layers that alternate between ferromagnetic and nonferromagnetic. Differences in spin-dependent scattering of electrons at the interface layers lead to resistance differences that can be read by the magnetic head. Mechanical properties, particularly tribology (friction and wear of moving surfaces), also play an important role in magnetic hard disk drives, since magnetic heads float only about 10 nanometres above spinning magnetic disks.

Another approach to information storage that is dependent on designing nanometre-thick magnetic layers is under commercial development. Known as magnetic random access memory (MRAM), a line of electrically switchable magnetic material is separated from a permanently magnetized layer by a nanoscale nonmagnetic interlayer. A resistance change that depends on the relative alignment of the fields is read electrically from a large array of wires through cross lines. MRAM will require a relatively small evolution from conventional semiconductor manufacturing, and it has the added benefit of producing nonvolatile memory (no power or batteries are needed to maintain stored memory states).

Still at an exploratory stage, studies of electrical conduction through molecules have generated interest in their possible use as memory. While still very speculative, molecular and nanowire approaches to memory are intriguing because of the small volume in which the bits of memory are stored and the effectiveness with which biological systems store large amounts of information.

2. Translate the text at sight.

Communications

Nanoscale structuring of optical devices, such as vertical-cavity surface-emitting lasers (VCSELs), quantum dot lasers, and photonic crystal materials, is leading to additional advances in communications technology.

VCSELs have nanoscale layers of compound semiconductors epitaxially grown into their structure – alternating dielectric layers as mirrors and quantum wells. Quantum wells allow the charge carriers to be confined in well-defined regions and provide the energy conversion into light at desired wavelengths. They are placed in the laser's cavity to confine carriers at the nodes of a standing wave and to tailor the band structure for more efficient radiative recombination. One-dimensional nanotechnology techniques involving precise growth of very thin epitaxial semiconductor layers were developed during the 1990s. Such nanostructuring has enhanced the efficiency of VCSELs and reduced the current required for lasing to start (called the threshold current). Because of improving performance and their compatibility with planar manufacturing technology, VCSELs are fast becoming a preferred laser source in a variety of communications applications.

More recently, the introduction of quantum dots (regions so small that they can be given a single electric charge) into semiconductor lasers has been investigated and found to give additional benefits – both further reductions in threshold current and narrower line widths. Quantum dots further confine the optical emission modes within a very narrow spectrum and give the lowest threshold current densities for lasing achieved to date in VCSELs. The quantum dots are introduced into the laser during the growth of strained layers, by a process called Stransky-Krastanov growth. They arise because of the lattice mismatch stress and surface tension of the growing film. Improvements in ways to control precisely the resulting quantum dots to a more uniform single size are still being sought.

3. Translate the sentences into English.

1) Нанонаука – это исследование явлений и объектов на атомарном, молекулярном и макромолекулярном уровнях, характеристики которых существенно отличаются от свойств их макроаналогов.
2) Нанотехнологии – это конструирование, характеристика, производство и применение структур, приборов и систем, свойства которых определяются их формой и размером на нанометровом уровне.
3) Нанообъектами (наночастицами) называются объекты (частицы) с характерным размером в 1–100 нанометров хотя бы по одному измерению.
4) Именно открытие фуллеренов проложило путь в новый мир нанометровых структур из чистого углерода и привело к появлению огромного количества работ в этой области.
5) В 2004 г. группой физиков во главе с А. Геймом и К. Новосёловым были получены первые образцы графена, что произвело революцию в этой области, так как такие двумерные структуры оказались, в частности, способными проявлять поразительные электронные свойства, качественно отличающиеся от всех прежде наблюдаемых.
6) Серебро в форме наночастиц становится чрезвычайно губительным для бактерий – это его свойство успешно применяется в современных ранозаживляющих повязках, а также в антимикробных тканях.

7) Нанопорошок из отработанных шин при добавлении в сырье для асфальта делает дорожное покрытие чрезвычайно износоустойчивым.
8) Нанопорошки глины в последние годы активно используют в изолирующих покрытиях силовых кабелей – такая изоляция плохо горит, и это хорошо для безопасности зданий.
9) Наночастицы диоксида титана (основы всем известных титановых белил) являются эффективным фотокатализатором и используются как активный элемент в фильтрах бытовых воздухоочистителей.
10) Современные исследования коллоидного серебра показали, что оно обладает способностью обезвреживать некоторые штаммы вируса гриппа, а также энтеро- и аденовирусы.
11) Так как в нанообъектах число поверхностных атомов резко возрастает, то их вклад в свойства нанообъекта становится определяющим и растет с дальнейшим уменьшением размера объекта.
12) Один из важнейших вопросов, стоящих перед нанотехнологией – как заставить молекулы группироваться определённым способом, самоорганизовываться, чтобы в итоге получить новые материалы или устройства.

4. Render the text into English.

Наночастицы

Современная тенденция к миниатюризации показала, что вещество может иметь совершенно новые свойства, если взять очень маленькую частицу этого вещества. Частицы размерами от 1 до 200 нанометров обычно называют «наночастицами». Так, например, оказалось, что наночастицы некоторых материалов имеют очень хорошие каталитические и адсорбционные свойства. Другие материалы показывают удивительные оптические свойства, например, сверхтонкие пленки органических материалов применяют для производства солнечных батарей. Такие батареи, хоть и обладают сравнительно низкой квантовой эффективностью, зато более дёшевы и могут быть механически гибкими. Удается добиться взаимодействия искусственных наночастиц с природными объектами наноразмеров – белками, нуклеиновыми кислотами и др. Тщательно очищенные наночастицы могут самовыстраиваться в определённые структуры. Такая структура содержит строго упорядоченные наночастицы и также зачастую проявляет необычные свойства.

Нанообъекты делятся на 3 основных класса: трёхмерные частицы, получаемые взрывом проводников, плазменным синтезом, восстановлением тонких плёнок и т. д.; двумерные объекты – плёнки, получаемые методами молекулярного наслаивания, CVD, ALD, методом ионного наслаивания и т. д.; одномерные объекты – вискеры, эти объекты получаются методом молекулярного наслаивания, введением веществ в цилиндрические микропоры и т. д. Также существуют нанокомпозиты – материалы, полученные введением наночастиц в какие-либо матрицы. На данный момент обширное применение получил только метод микролитографии, позволяющий получать на поверхности матриц плоские островковые объекты размером от 50 нм, применяется он в электронике; метод CVD и ALD в основном применяется для создания микронных плёнок. Прочие методы в основном используются в научных целях. В особенности следует отметить методы ионного и молекулярного наслаивания, поскольку с их помощью возможно создание реальных монослоёв.

Особый класс составляют органические наночастицы как естественного, так и искусственного происхождения.

Поскольку многие физические и химические свойства наночастиц, в отличие от объемных материалов, сильно зависят от их размера, в последние годы проявляется значительный интерес к методам измерения размеров наночастиц в растворах: анализ траекторий наночастиц, динамическое светорассеяние, седиментационный анализ, ультразвуковые методы.

5. ***Read the text about a new technology in the field of computing systems. Draw a mind-map to help you retell the text. Time limit: 20 min.***

New graphene-based 'atomristors' could pave the way towards more powerful computing

Researchers at The University of Texas at Austin, in collaboration with Peking University scientists, have developed what they refer to as the thinnest memory storage device with dense memory capacity, paving the way for faster, smaller and smarter computer chips for everything from consumer electronics to big data to brain-inspired computing.

They named their creation "atomristors", and stated that before this work, it was considered impossible to make memory devices from materials that were only one atomic layer thick. The "atomristors" improve upon memristors, an emerging memory storage technology with lower memory scalability.

"Atomristors will allow for the advancement of Moore's Law at the system level by enabling the 3D integration of nanoscale memory with nanoscale transistors on the same chip for advanced computing systems," the team said.

Memory storage and transistors have traditionally been separate components on a microchip, but atomristors combine both functions on a single, more efficient computer system. By using graphene sheets as electrodes and semiconducting atomic sheets (molybdenum sulfide) as the active layer, the entire memory cell is a sandwich about 1.5 nanometers thick, which makes it possible to densely pack atomristors layer by layer in a plane. This is a substantial advantage over conventional flash memory, which occupies far larger space. In addition, the thinness allows for faster and more efficient electric current flow.

Given their size, capacity and integration flexibility, atomristors can be packed together to make advanced 3D chips that are crucial to the successful development of brain-inspired computing. One of the greatest challenges in this growing field of engineering is how to make a memory architecture with 3D connections akin to those found in the human brain. "The sheer density of memory storage that can be made possible by layering these synthetic atomic sheets onto each other, coupled with integrated transistor design, means we can potentially make computers that learn and remember the same way our brains do," the researchers said.

The research team also discovered another unique application for the technology. In existing ubiquitous devices such as smartphones and tablets, radio frequency switches are used to connect incoming signals from the antenna to one of the many wireless communication bands in order for different parts of a device to communicate and cooperate with one another. This activity can significantly affect a smartphone's battery life. The atomristors are the smallest radio frequency memory switches to be demonstrated with no DC battery consumption, which can ultimately lead to longer battery life.

FOCUS ON PRODUCTIVE WRITING AND SPEAKING SKILLS

1. Write 3 paragraphs of 250 words describing any of the modern day achievements in nanotechnology.

2. Prepare a 5-minute talk on one of the following topics. You may choose any other topic related to nanotechnology which is not on the list.

1) Major trends in nanotechnology: the current status of the developments in the field
2) Great potential for applications of nanomaterials
3) Advances and challenges in nanomedicine
4) Nanotechnology in our daily lives
5) Benefits and potential negative impact of nanotechnology

KEY WORDS AND WORD COMBINATIONS

Dimension
  exact dimension, overall dimensions, nanodimension, small dimension

Fabrication
  energy-efficient fabrication

Macroscale
  macroscale system

Manipulation

Material
  conventional material, improved material, nanoengineered material, nanoscale material, nanostructured material, programmable material, raw material, structural material; material behaviour, material processing

Microscale
  microscale machine, microscale sensing device, microscale system

Microtechnology

Nano
  nanocoating, nanocluster, nanocomposite, nanocrystal, nanodimension, nanomaterial, nanomedicine, nanometre,

nanoparticle, nanoscience, nanosensor, nanoshell, nanostructure, nanotube, nanowhiskers, nanowire

Nanometre-thick

nanometre-thick metallic layers, nanometre-thick magnetic layers

Nanoscale

nanoscale array, nanoscale behaviour, nanoscale carrier, nanoscale device, nanoscale dimension, nanoscale layer, nanoscale machine, nanoscale object, nanoscale particle, nanoscale pore, nanoscale probe, nanoscale structure, nanoscale structuring, nanoscale system, nanoscale-engineered material

Nanosized

nanosized carrier, nanosized particle, nanosized void

Nanostructured surface

Nanotechnology

nanotechnology machines, nanotechnology process, nanotechnology product, nanotechnology technique

Scale

atomic scale, near-atomic scale, small scale

Self-assembly

Quantum mechanical

quantum mechanical effects, quantum mechanical properties, quantum mechanical rules

COURSE VOCABULARY

Abandon (v)
absorb (v)
  absorption (n)
abundant (adj)
accelerate (v)
  accelerator (n)
accompany (v)
accomplish (v)
  accomplishment (n)
accord (v) with
  in accordance (n) with
  according to (prep)
  accordingly (adv)
account (n)
  on account of (prep)
  to take account of
  to take into account
  account for (phr v)
accretion (n)
accuracy (n)
  accurate (adj)
achieve (v)
  achievement (n)
acquire (v)
act (n), (v)
  action (n)
  activity (n)
  actual (adj)
  actually (adv)
add (v)
  addition (n)
  in addition (to)
  additional (adj)
  additionally (adv)
address (v)
adequate (adj)
  adequately (adj)
adjacent (adj)
adjust (v)
  adjustment (n)
admit (v)
  admittedly (adv)
adopt (v)
advance (n), (v)
  advanced (adj)
advantage (n)
advent (n)
affect (v)
afterward (adv)
aggregate (n), (v), (adj)
agree (v)
  agreement (n)
  in agreement with
aircraft (n)
align (v)
  alignment (n)
along with (adv)
alongside (adv), (prep)
alter (v)
  alteration (n)

alternate (v), (adj)
alternative (n), (adj)
alternatively (adv)
alternating (adj)
although (conj)
altogether (adv)
ambient (adj)
amenable (adj)
amount (n), (v)
amplification (n)
amplifier (n)
amplitude (n)
analogy (n)
analogous (adj)
analyse/ze (v)
analysis (n) (pl analyses)
analytical (adj)
angle (n)
angular (adj)
annihilate (v)
annihilation (n)
announce (v)
announcement (n)
apparatus (n)
apparent (adj)
apparently (adv)
appear (v)
appearance (n)
apply (v)
applicable (adj)
application (n)
applied (adj)
appreciate (v)
appreciable (adj)
appreciably (adv)
approach (n), (v)
appropriate (adj)
approximate (v), (adj)
approximately (adv)
approximation (n)
arbitrary (adj)
area (n)
argue (v)
arguably (adv)
argument (n)
arrange (v)
arrangement (n)
array (n), (v)
aspect (n)
assembly (n)
associate (v)
to be associated with
association (n)
assume (v)
assumption (n)
assure (v)
asymmetry (n)
asymmetric (adj)
atmosphere (n)
attach (v)
attain (v)
attempt (n), (v)
attract (v)
attraction (n)
attractive (adj)
attribute (n), (v)
available (adj)
availability (n)
average (adj)
avoid (v)

axis (n) (pl axes)

Background (n)
balance (n)
bandgap (n)
barrier (n)
base (n), (v)
    basic (adj)
    basically (adv)
    to be based on
beam (n)
behave (v)
    behavio(u)r (n)
bend (v)
benefit (n), (v)
binary (adj)
bind (v)
    binding (n)
bombard (v)
    bombardment (n)
bond (n), (v)
    bonding (n)
borrow (v)
bound (adj)
boundary (n)
branch (n)
break (v)
    break up (phr v)
    break into (phr v)
breakdown (n)
breakthrough (n)
bulk (n)
burst (n), (v)

Calculate (v)
    calculation (n)
cancel (v)
capable (adj)
    capability (n)
capture (n), (v)
carry (v)
    carry out (phr v)
    carrier (n)
cascade (n), (v)
catalyst (n)
cavity (n)
    cavitation (n)
celestial (adj)
certain (adj)
    certainly (adv)
chain (n)
challenge (n), (v)
    challenging (adj)
chamber (n)
chance (n), (v)
change (n), (v)
    changeable (adj)
    changeability (n)
character (n)
    characteristic (n), (adj)
    charecterise/ze (v)
charge (n), (v)
circuit (n)
circulate (v)
circumstance (n)
claim (n), (v)
classify (v)
    classification (n)
closure (n)
clue (n)

cluster (n)
coating (n)
coherence (n)
    coherent (adj)
cohesion (n)
    cohesive (adj)
collapse (n), (v)
collide (v)
    collider (n)
    collision (n)
combine (v)
    combination (n)
common (adj)
communication (n)
compare (v)
    comparison (n)
    comparable (adj)
complete (v), (adj)
    completely (adv)
    completion (n)
complex (adj)
    complexity (n)
    complicated (adj)
component (n)
composition (n)
compound (n)
compress (v)
    compressible (adj)
comprise (v)
compute (v)
    computer (n)
conceive (v)
    conceivable (adj)
concentration (n)
concern (n), (v)
    concerning (prep)
conclude (v)
    conclusive (adj)
    conclusion (n)
concept (n)
    conceptual (adj)
condition (n)
conduct (v)
    conductivity (n)
configure (v)
    configuration (n)
confine (v)
    confinement (n)
confirm (v)
    confirmation (n)
conform (v)
congregate (v)
connect (v)
    connection (n)
consequence (n)
    consequently (adv)
conserve (v)
    conservation (n)
consider (v)
    considerable (adj)
    consideration (n)
consist (v) of/in
    consistent (adj)
constant (n)
constitute (v)
    constituent (n), (adj)
constraint (n)
construct (v)
    construction (n)
    constructively (adv)

consume (v)
    consumer (n)
    consumption (n)
contain (v)
content (n)
continue (v)
    continuity (n)
    continuous (adj)
contrary (adj), (n)
    contrary to
    on the contrary
contrast (n), (v)
    by contrast
contract (v)
contribute (v)
    contribution (n)
control (n), (v)
convection (n)
conventional (adj)
convert (v)
    conversion (n)
convey (v)
core (n)
correct (adj)
    correctly (adv)
    correction (n)
correlate (v)
    correlation (n)
correspond (v)
    corresponding (adj)
    correspondingly (adv)
corrosion (n)
counterpart (n)
couple (n), (v)
    coupling (n)
cover (n), (v)
create (v)
    creation (n)
criterion (n) (pl criteria)
critical (adj)
    critically (adv)
cross-section (n)
crucial (adj)
crystal (n)
current (n), (adj)
    currently (adv)
curve (n), (v)
    curvature (n)
cycle (n), (v)
    cyclic (adj)

Damage (n), (v)
debate (n), (v)
decade (n)
decay (n), (v)
decide (v)
    decision (n)
decompose (v)
deep (adj)
    depth (n)
define (v)
    defining (adj)
    definitively (adv)
deflect (v)
    deflection (n)
degradation (n)
deform (v)
    deformation (n)
degree (n)
delay (n), (v)

deliver (v)
    delivery (n)
demand (n), (v)
demonstrate (v)
denote (v)
dense (adj)
    density (n)
deny (v)
departure (n)
depend (v) on
    dependence (n)
depletion (n)
derive (v)
descent (n)
describe (v)
    description (n)
design (n), (v)
despite (prep)
destroy (v)
    destruction (n)
    destructive (adj)
    destructively (adv)
detail (n)
    in detail
detect (v)
    detection (n)
    detector (n)
determine (v)
develop (v)
    development (n)
device (n)
    devise (v)
diagonal (n), (adj)
diameter (n)
differ (v)
    difference (n)
    different (adj)
    differentiate (v)
diffract (v)
    diffraction (n)
dilute (v), (adj)
dimension (n)
    dimensional (adj)
diminish (v)
diode (n)
direct (v), (adj)
    direction (n)
disadvantage (n)
disappear (v)
discover (v)
    discovery (n)
discrepancy (n)
discuss (v)
    discussion (n)
    under discussion
disperse (v)
displace (v)
    displacement (n)
display (n), (v)
disrupt (v)
    disruptive (adj)
distance (n)
    distant (adj)
distinct (adj)
    distinctive (adj)
distinguish (v)
distort (v)
    distortion (n)
distribute (v)
    distribution (n)

diverse (v)
    diversity (n)
divide (v)
    division (n)
domain (n)
dominate (v)
dope (v)
    dopant (n)
dramatic (adj)
    dramatically (adv)
draw (v)
drawback (n)
drastic (adj)
    drastically (adv)
drop (n), (v)
dual (adj)
due to (prep)
duration (n)
dwarf (n)
dye (n)
dynamic (adj)
    dynamical (adj)
    dynamically (adv)
    dynamics (n)

Effect (n), (v)
efficient (adj)
    efficiently (adv)
    efficiency (n)
effort (n)
eject (v)
    ejection (n)
elastic (adj)
element (n)
    elementary (adj)
eliminate (v)
elusive (adj)
embed (v)
emerge (v)
emit (v)
    emission (n)
    emitter (n)
empirical (adj)
employ (v)
enable (v)
enclose (v)
encompass (v)
encounter (n), (v)
endure (v)
energy (n)
engineering (n)
enhance (v)
enormous (adj)
ensure (v)
entail (v)
entire (adj)
    entirely (adv)
envelope (n)
    envelop (v)
environment (n)
envision (v)
enzyme (n)
equal (adj)
    equally (adv)
equation (n)
equilibrium (n)
equip (v)
    equipment (n)
equivalent (adj)
    equivalence (n)

escape (n), (v)
especial (adj)
    especially (adv)
essence (n)
    essential (adj)
    essentially (adv)
establish (v)
estimate (n), (v)
evaluate (v)
    evaluation (n)
evaporate (v)
    evaporation (n)
even (adj), (adv)
event (n)
    eventual (adj)
    eventually (adv)
evidence (n)
    evident (adj)
    evidently (adv)
evolve (v)
    evolution (n)
    evolutionary (adj)
exact (adj)
examine (v)
exceed (v)
    exceedingly (adv)
    excess (n), (adj)
except (v), (prep)
    exception (n)
exchange (n), (v)
excite (v)
    exciting (adj)
    excitation (n)
exclude (v)
exhaust (v)
exhibit (v)
exist (v)
    existence (n)
expand (v)
expect (v)
experience (n), (v)
experiment (n), (v)
explain (v)
    explanation (n)
explicit (adj)
    explicitly (adv)
explode (v)
    explosion (n)
exploit (v)
explore (v)
    exploration (n)
    exploratory (adj)
expose (v)
    exposure (n)
express (v)
    expression (n)
exquisite (adj)
extend (v)
    extension (n)
    extent (n)
    to some extent
external (adj)
extinction (n)
extract (n), (v)
extraordinary (adj)
extreme (adj)
    extremely (adv)

Fabric (n)
    fabricate (v)

fabrication (n)
face (n), (v)
to be faced with
facet (n)
facilitate (v)
facility (n)
fact (n)
in fact
factor (n)
fail (v)
failure (n)
faint (adj)
familiar (adj)
to be familiar with
far-reaching (adj)
favo(u)r (n), (v)
favo(u)rable (adj)
feature (n), (v)
fibre (n)
field (n)
finally (adv)
finite (adj)
fission (n)
fissionable (adj)
flash (n), (v)
flaw (n)
flexible (adj)
flexibility (n)
flow (n), (v)
focus (n), (v)
follow (v)
as follows
the following
force (n), (v)
form (n), (v)
formation (n)
formula (n) (pl formulae)
fortunately (adv)
found (v)
foundation (n)
fraction (n)
fragment (n)
framework (n)
freedom (n)
frequency (n)
fringe (n)
front (n)
fuel (n), (v)
fulfill (v)
function (n), (v)
fundamental (adj)
further (adj), (v), (adv)
furthermore (adv)
fuse (v)
fusion (n)

Gain (n), (v)
gas (n)
gaseous (adj)
gauge (n), (v)
general (adj)
in general
generally (adv)
generalise/ze(v)
generate (v)
generation (n)
generator (n)
giant (n), (adj)
goal (n)
govern (v)

gradient (n)
gradual (adj)
    gradually (adv)
grating (n)
gravitation (n)
    gravitational (adj)
    gravity (n)
grid (n)
ground (n), (adj)
guarantee (n), (v)
guide (n), (v)

Hard (adj), (adv)
    hardly (adv)
harness (v)
harvest (n), (v)
heat (n), (v)
hence (adv)
hierarchy (n)
hold (v)
hologram (n)
homogeneous (adj)
horizon (n)
however (adv)
huge (adj)
hybrid (n), (adj)
hypothesis (n) (pl hypotheses)
    hypothesise/ze (v)
    hypothetical (adj)

Idea (n)
ideal (n), (adj)
identify (v)
    identification (n)
    identity (n)
ignore (v)
illuminate (v)
    illumination (n)
illustrate (v)
image (n)
    imagine (v)
imbalance (n)
immediate (adj)
    immediately (adv)
impact (n), (v)
imply (v)
    implication (n)
implode (v)
    implosion (n)
impose (v)
improvement (n)
impulse (n)
impurity (n)
incandescent (adj)
incident (adj)
include (v)
incorporate (v)
    incorporation (n)
indeed (adv)
independent (adj)
    independently (adv)
indicate (v)
individual (adj)
induce (v)
    induction (n)
inert (adj)
inevitable (adj)
    inevitably (adv)
infer (v)
    inference (n)

influence (n), (v)
ineffective (adj)
initial (adj)
    initially (adv)
initiate (v)
    initiative (n)
insight (n)
instant (n), (adj)
    instantly (adv)
instead (adv)
instrument (n)
integer (n)
integrate (v)
    integration (n)
intense (adj)
    intensity (n)
interact (v)
    interaction (n)
interface (n), (v)
interfere (v)
    interference (n)
interferometer (n)
interior (n), (adj)
internal (adj)
interpret (v)
    interpretation (n)
intersection (n)
intricate (adj)
intrinsic (adj)
    intrinsically (adv)
introduce (v)
invaluable (adj)
invent (v)
    invention (n)
inverse (adj), (n)
    inversely (adv)
    inversion (n)
investigate (v)
    investigation (n)
invisible (adj)
invoke (v)
involve (v)
ion (n)
    ionise/ze (v)
isolate (v)
    isolation (n)

Judge (v)
    judg(e)ment (n)
junction (n)
justify (v)

Key (n)
knowledge (n)
knock out (phr v)

Laboratory (n)
lack (n), (v)
largely (adv)
lattice (n)
law (n)
layer (n)
lead (v) to
least (adj), (adv)
    at least
level (n)
lifetime (n)
light (n)
likewise (adv)
limit (n),(v)

limitation (n)
linear (adj)
liquid (n), (adj)
locate (v)
location (n)
longitudinal (adj)
loose (adj)
loss (n)
luminous (adj)
luminosity (n)

Machine (n)
magnet (n)
magnitude (n)
major (adj)
majority (n)
manifest (v)
manifestation (n)
manipulate (v)
manipulation (n)
manner (n)
manufacture (n), (v)
map (n), (v)
match (n), (v)
matrix (n) (pl matrices)
matter (n), (v)
mean (v), (adj)
meaning (n)
means (n)
by means of
meanwhile (adv)
measure (n), (v)
measurement (n)
measurable (adj)
mechanism (n)
mediate (v)
medium (n) (pl media)
melt (v)
mention (n), (v)
merit (n), (v)
method (n)
microscope (n)
microscopic (adj)
minimise/ze (v)
mix (n), (v)
mixture (n)
mode (n)
model (n), (v)
modeling (n)
modify (v)
molecule (n)
molecular (adj)
moment (n)
momentum (n)
motion (n)
moreover (adv)
move (v)
movement (n)
multiply (v)
multiple (n), (adj)
multitude (n)
mutual (adj)
mutually (adv)
mystery (n)
mysterious (adj)

Name (n), (v)
to name a few
namely (adv)
narrow (adj)

nature (n)
natural (adj)
naturally (adv)
nebula (n) (pl nebulae)
necessary (adj)
neglect (v)
negligible (adj)
neighbo(u)r (n), (v)
neighbo(u)rhood (n)
network (n), (v)
nevertheless (adv)
note (n), (v)
notably (adv)
noteworthy (adv)
notice (n), (v)
notion (n)
notwithstanding (prep), (adv)
number (n)
a number of
numerical (adj)
numerous (adj)

Obey (v)
object (n), (v)
objective (n)
observe (v)
observation (n)
obtain (v)
occasion (n)
occasional (adj)
occasionally (adv)
occupy (v)
occur (v)
occurrence (n)
offer (n), (v)
opaque (adj)
opacity (n)
operate (v)
operation (n)
operational (adj)
opposite (adj)
orbit (n), (v)
order (n), (v)
ordinary (adj)
ordinarily (adv)
organise/ze (v)
orient (v)
orientation (n)
origin (n)
original (adj)
originally (adv)
originate (v)
oscillate (v)
oscillator (n)
otherwise (adv)
output (n)
overall (adj)
overcome (v)
overlap (v)
owing to (prep)
oxide (n)

Pair (n), (adj)
parallel (n), (v), (adj)
parameter (n)
parity (n)
part (n), (v)
in part
partial (adj)
partially (adv)

participate (v)
particle (n)
particular (n), (adj)
    in particular
    particularly (adv)
patent (n)
path (n)
pattern (n), (v)
peak (n), (v)
penetrate (v)
percent (n)
    percentage (n)
perfect (adj)
perform (v)
    performance (n)
period (n)
perish (v)
permanently (adv)
permit (v)
    permission (n)
perspective (n)
phase (n)
phenomenon (n) (pl phenomena)
picture (n), (v)
place (n), (v)
    to take place
plane (n)
planetary (adj)
plate (n)
point (n)
    point out (phr v)
pollute (v)
    pollutant (n)
    pollution (n)
population (n)
position (n), (v)
possess (v)
possible (adj)
    possibility (n)
postulate (v)
potential (n), (adj)
power (n), (v)
    powerful (adj)
practice (n), (v)
    practically (adv)
precipitate (v)
precise (adj)
    precisely (adv)
    precision (n)
predict (v)
    prediction (n)
prefer (v)
    preference (n)
    preferable (adj)
preponderance (n)
present (v), (adj)
    presence (n)
pressure (n)
presume (v)
    presumably (adv)
prevail (v)
    prevailing (adj)
prevent (v)
previous (adj)
    previously (adv)
primary (adj)
    primarily (adv)
principal (adj)
    principally (adv)
principle (n)

probable (adj)
    probably (adv)
    probability (n)
probe (n), (v)
problem (n)
procedure (n)
proceed (v)
process (n), (v)
    processing (n)
produce (v)
    product (n)
    by-product
    production (n)
propagate (v)
    propagation (n)
proper (adj)
    properly (adv)
property (n)
proportion (n)
    proportional (adj)
    proportionality (n)
propose (v)
    proposal (n)
    proposition (n)
prove (v)
    proof (n)
provide (v)
    provided (that) (conj)
pulse (n), (v)
pure (adj)
    purely (adv)
purpose (n)
pursue (v)
push (n), (v)
put forward (phr v)

Quality (n)
    qualitative (adj)
    qualitatively (adv)
quantity (n)
    quantitative (adj)
    quantitatively (adv)
quantum (n) (pl quanta)
    quantization (n)
quest (n)
question (n)

Radiate (v)
    radiation (n)
    radiative (adj)
radius (n) (pl radii)
random (adj)
    randomly (adv)
range (n)
    range (v) from … to
rapid (adj)
    rapidly (adv)
rare (adj)
    rarely (adv)
rate (n), (v)
rather (adv)
ratio (n)
raw (adj)
ray (n)
reach (n),(v)
react (v)
    reaction (n)
    reactor (n)
realise/ze (v)
    realization (n)

realm (n)
reason (n), (v)
  reasonable (adj)
receive (v)
recognise/ze (v)
  recognition (n)
record (n), (v)
  recording (n)
reconstruct (v)
recreate (v)
reduce (v)
  reduction(n)
refer (v) to
  to be referred to as
  reference (n)
reflect (v)
  reflection (n)
regard (n), (v)
  in regard to
  regarding (prep)
region (n)
relate (v)
  relation (n)
  relationship (n)
  relative (adj)
  relatively (adv)
  relativity (n)
release (n), (v)
rely (v)
  reliable (adj)
remain (v)
  remaining (adj)
remarkable (adj)
remnant (n)
remote (adj)
remove (v)
repel (v)
  repulsion (n)
  repulsive (adj)
replace (v)
  replacement (n)
represent (v)
  representation (n)
require (v)
  requirement (n)
research (n), (v)
  researcher (n)
resemble (v)
  resemblance (n)
resist (v)
  resistance (n)
  resistant (adj)
resolve (v)
  resolution (n)
resonance (n)
  resonator (n)
respect (n)
  with respect to
  respectively (adv)
respond (v)
  response (n)
  to be responsible (adj) for
rest (n), (v)
  at rest
restrict (v)
  restriction (n)
result (n), (v)
  as a result
  to result from
  to result in

resulting (adj)
retain (v)
reveal (v)
reverse (n), (adj), (v)
reversal (n)
revolve (v)
revolution (n)
rigid (adj)
rigidity (n)
rigorous (adj)
rise (n), (v)
to give rise to
robust (adj)
rotate (v)
rotation (n)
rough (adj)
roughly (adv)
rule (n), (v)
rule out (phr v)

Satisfy (v)
scale (n)
scan (v)
scatter (v)
scattering (n)
scene (n)
scheme (n), (v)
schematic (adj)
scission (n)
search (n), (v)
select (v)
selection (n)
selective (adj)
semiconductor (n)
sense (n), (v)
sensible (adj)
sensitive (adj)
sensitivity (n)
sensor (n)
separate (adj), (v)
separately (adv)
sequence (n)
series (n)
serve (v)
service (n)
set (n), (v)
set up (phr v)
shape (n), (v)
shower (n), (v)
sign (n), (v)
signature (n)
signify (v)
significant (adj)
similar (adj)
similarly (adv)
similarity (n)
simple (adj)
simplify (v)
simplicity (n)
simplification (n)
simulate (v)
simulation (n)
simultaneous (adj)
simultaneously (adv)
single (adj)
site (n)
shell (n)
solar (adj)
solve (v)
solution (n)

sophisticated (adj)
source (n)
species (n)
specify (v)
    specific (adj)
    specifically (adv)
spectrum (n) (pl spectra)
spectacular (adj)
speculation (n)
spiral (adj)
sphere (n)
    spherical (adj)
spontaneous (adj)
stable (adj)
    stability (n)
stage (n)
standard (n)
state (n), (v)
    statement (n)
stellar (adj)
store (v)
    storage (n)
stream (n), (v)
strength (n)
strict (adj)
    strictly (adv)
strike (n), (v)
stringent (adj)
study (n), (v)
subject (n), (v)
    subject (adj) to
subsequent (adj)
    subsequently (adv)
substance (n)
subtle (adj)
succeed (v) in
    success (n)
    successful (adj)
succession (n)
sufficient (adj)
    sufficiently (adv)
suggest (v)
    suggestion (n)
suitable (adj)
superimpose (v)
supply (n), (v)
support (n), (v)
surface (n)
surround (v)
survive (v)
    survival (adj)
sustain (v)
    sustainable (adj)
symbol (n)
    symbolise/ze (v)
symmetry (n)
    symmetric (adj)
    symmetrical (adj)
synthesise/ze (v)

Target (n), (v)
technique (n)
technology (n)
tend (v)
    tendency (n)
tension (n)
term (n)
    in terms of
theorem (n)
theory (n)

thereafter (adv)
thereby (adv)
therefore (adv)
thorough (adj)
    thoroughly (adv)
through (prep)
threshold (n)
tilt (v)
tiny (adj)
tissue (n)
tool (n)
top (n)
torrent (n)
total (n), (adj)
    totally (adv)
transfer (n), (v)
transform (v)
    transformation (n)
transition (n)
transmit (v)
    transmission (n)
transparent (adj)
    transparency (n)
transport (v)
trap (n), (v)
travel (v)
treat (v)
    treatment (n)
tremendous (adj)
trend (n)
trigger (n), (v)
true (adj)
    truly (adv)
    truth (n)
turbulence (n)
turn (n), (v)
    in turn
typical (adj)
    typically (adv)

Ultimate (adj)
    ultimately (adv)
ultraviolet (adj)
uncertainty (n)
undergo (v)
underlie (v)
    underlying (adj)
undertake (v)
undulation (n)
unfortunately (adv)
unify (v)
    unified (adj)
uniform (adj)
unit (n)
universe (n)
    universal (adj)
unique (adj)
use (n), (v)
    useful (adj)
    useless (adj)
utilise/ze (v)

Vacuum (n)
valence (n)
valid (adj)
    validity (n)
value (n), (v)
    valuable (adj)
vanish (v)
vary (v)

variety (n)
various (adj)
variable (n)
variation (n)
vehicle (n)
velocity (n)
verify (v)
verification (n)
version (n)
vibration (n)
view (n), (v)
viewer (n)
violate (v)
violation (n)
virtual (adj)
virtually (adv)
visible (adj)
vital (adj)
volume (n)

Wave (n)
wavelength (n)
waste (n), (v)
way (n)
to be under way
weight (n)
whereas (conj)
whereby (adv)
width (n)

Yield (n), (v)

Zone (n)

БИБЛИОГРАФИЯ

1) Корешев С.Н. Основы голографии и голограммной оптики. – СПб: СПбГУ ИТМО, 2009. – 97 с.
2) Сурдин В.Г. Рождение звезд. 3-е изд.– М.: УРСС, 2001.–264 с.
3) Бурдаков А.В. О настоящем и будущем термоядерной энергетики. [Электронный ресурс]: «НАУКА ИЗ ПЕРВЫХ РУК» №5–6(76), 2017. Элементы. URL: http://elementy.ru/nauchnopopulyarnaya_biblioteka/433967/O_nastoyashchem_i_budushchem_termoyadernoy_energetiki
4) Десять в минус девятой: популярно о нанотехнологиях. [Электронный ресурс]: «ПОПУЛЯРНАЯ МЕХАНИКА» №4, 2009// НАНОТЕХНОЛОГИИ// Элементы. URL: https://elementy.ru/nauchnopopulyarnaya_biblioteka/430816/Desyat_v_minus_devyatoy_populyarno_o_nanotekhnologiyakh–
5) Егоров И. Звезды на земле: термояд. [Электронный ресурс]: «ПОПУЛЯРНАЯ МЕХАНИКА» №5, 2012. Элементы. URL: http://elementy.ru/nauchnopopulyarnaya_biblioteka/431618/Zvezdy_na_zemle_termoyad
6) Нанотехнология. [Электронный ресурс]: Википедия. Свобод-ная энциклопедия. URL: https://ru.wikipedia.org/wiki/Нанотехнология
7) Пиотровский Л.Б., Кац Е.А. «Нанотехнология», «нанонаука» и «нанообъекты»: что значит «нано»? [Электронный ресурс]: «ЭКОЛОГИЯ И ЖИЗНЬ» №8, 2012. Элементы. URL: http://elementy.ru/nauchnopopulyarnaya_biblioteka/431265/Nanotekhnologiya_nanonauka_i_nanoobekty_chto_znachit_nano
8) Brecher K., Chaisson E. J., Fernie J. D., Aller L. H. Stellar-structure. [Электронный ресурс]: ENCYCLOPÆDIA BRITANNICA. URL: https://www.britannica.com/science/star-astronomy/stellar-structure
9) Conn R. W. Nuclear fusion. [Электронный ресурс]: ENCYCLOPÆDIA BRITANNICA. URL: https://www.britannica.com/science/nuclear-fusion
10) Cosmic Rays, Electronic Devices, and Nuclear Accelerators. [Электронный ресурс]: The National Academies Press. URL: https://www.nap.edu/read/13438/chapter/6#178
11) Hecht J. Laser. [Электронный ресурс]: ENCYCLOPÆDIA BRITANNICA. URL: https://www.britannica.com/technology/laser

12) Holography. [Электронный ресурс]: ENCYCLOPÆDIA BRITANNICA. URL: https://www.britannica.com/technology/holography
13) How Herschel unlocked the secrets of star formation. [Электронный ресурс]: Phys Org. URL: https://phys.org/news/2017-09-herschel-secrets-starformation.html
14) New graphene-based 'atomristors' could pave the way towards more powerful computing. [Электронный ресурс]: Graphene-info. URL: https://www.graphene-info.com/new-graphene-based-atomristors-could-pave-way-towards-more-powerful-computing
15) Photonics media. [Электронный ресурс]: Photonics.com. URL: https://www.photonics.com
16) Picraux S. T. Nanotechnology. [Электронный ресурс]: ENCYCLOPÆDIA BRITANNICA. URL: https://www.britannica.com/technology/nanotechnology
17) SPIE. The International Society of Optics and Photonics. [Электронный ресурс]: SPIE.Org. URL: https://spie.org/Documents/Publications
18) Steinberg E. P. Nuclear-fission. [Электронный ресурс]: ENCYCLOPÆDIA BRITANNICA. URL: https://www.britannica.com/science/nuclear-fission
19) Stellar classification. [Электронный ресурс]: ENCYCLOPÆDIA BRITANNICA. URL: https://www.britannica.com/science/stellar-classification
20) Sutton C. Particle-accelerator [Электронный ресурс]: ENCYCLOPÆDIA BRITANNICA. URL: https://www.britannica.com/technology/particle-accelerator
21) Sutton C. Subatomic-particle. [Электронный ресурс]: ENCYCLOPÆDIA BRITANNICA. URL: https://www.britannica.com/science/subatomic-particle
22) Daintith, John. A Dictionary of Physics. [Текст]/ J. Daintith. – New York: Oxford University Press, 2009. – 616 p.

-

Учебное издание

Коваленко Ирина Юрьевна,
Плотникова Анна Вячеславовна

SCIENTIFIC ENGLISH FOR STUDENTS OF PHYSICS

Подписано в печать 03.12.2019.
Формат 60x90/16. Объем 12 п.л. Тираж 500 экз.
Заказ №

Физический факультет МГУ им. М.В. Ломоносова
119991, Москва ГСП-1, Ленинские горы, д. 1, стр. 2.