МИНИСТЕРСТВО ОБРАЗОВАНИЯ И НАУКИ РОССИЙСКОЙ ФЕДЕРАЦИИ

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«МИФИ»

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English Thesaurus of Student-Physicist

Учебное пособие
для обучения студентов-физиков англоязычной лексике
широкой специальности «Общая физика»

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Цель пособия – обучить студентов-физиков профессиональной англоязычной терминологии широкой специальности в объеме, требуемом образовательными стандартами. Для этого использованы наиболее эффективные приемы обучения лексике. Наряду с текстами по специальности пособие содержит лексические упражнения и терминологический словарь.

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Part 6. Modern Physics

ПРЕДИСЛОВИЕ

Предлагаемое учебное пособие предназначено для обучения профессиональной англоязычной терминологии студентов, широкой или узкой специальностью которых является предмет «Общая физика». В соответствии с требованиями стандартов образования и с учетом рекомендаций примерной программы дисциплины «Иностранный язык», утвержденной Министерством образования и науки РФ для обучения студентов естественных факультетов университетов и вузов естественно-научного и технического профиля, рекомендуется при обучении языку для специальных целей (language for specific purposes – LSP) использовать сборники текстов на иностранном языке по основам специальности.

Весь текстовой материал пособия аутентичный и отобран из учебника «Serway's College Physics». Уровень изложения предмета «Общая физика» в этом англоязычном учебнике вполне доступен российским учащимся, избравшим физику и технические дисциплины в качестве своей будущей профессии. Последовательность изложения предмета, порядок и названия глав в предлагаемом учебном пособии полностью соответствуют первоисточнику. Это дает возможность будущим физикам ознакомиться с особенностями изложения предмета за рубежом, так как учебник издан международным издательством, охватывающим кроме США, страны Азии, Австралии, Европы, Латинской Америки и Канаду. Кроме того, в текстах пособия сохранена история развития физики и наших знаний о существовании Вселенной. При этом в разработанное пособие не вошли сложные и многочисленные математические вычисления, и изложение материала происходит исключительно на качественном уровне, что позволяет учащимся сосредоточиться на изучении профессиональной англоязычной терминологии в ее исторической и логической последовательности. Учебное пособие состоит из 30 разделов (Units), сгруппированных в шесть частей: часть 1 – *«Механика»*; часть 2 – *«Термодинамика»*; часть 3 – *«Колебания и волны»*; часть 4 – *«Электричество и магнетизм»*; часть 5 – *«Свет и оптика»*; часть 6 – *«Современная физика»*.

Каждый урок пособия, наряду с введением лексического материала в виде текстов, содержит терминологический тезаурус, который позволяет выявить и логически упорядочить термины каждого урока в их связи с другими разделами и понятиями. Тезаурус, или тематический словарь, устанавливает предметные и логические связи базовых, основных, производных и прочих терминов, заменяя контекст и естественным образом откладываясь в памяти учащихся. Способ отбора лексического материала в пособии является методическим, что позволяет более эффективно усваивать профессиональную англоязычную лексику за счет парадигматических контекстных связей терминов, что весьма актуально в условиях ограниченных временных возможностей для изучения английского языка в техническом вузе. В каждом уроке содержатся вопросы к тексту, ответы на которые предусматривают активное использование изучаемой терминологии.

Для формирования лексических навыков в каждом уроке содержится три вида упражнений. Упражнение 1 предлагает составить термины из предлагаемого набора букв и направлено на развитие продуктивных лексических навыков. В упражнении 2 требуется составить правильные словосочетания из отдельных слов, что направлено на узнавание фразеологических единиц, являющихся самостоятельными терминами. В упражнении 3 предлагается выбрать термин среди перечисленных и вставить его в текст. Упражнение направлено на формирование знаний семантики термина и распознавание его значения по контексту.

В приложении пособия помещен терминологический словарь, состоящий как из отдельных слов, так и из словосочетаний (составляющих более 80% терминов физики). Слова, входящие в словосочетание, могут отсутствовать в терминологическом словаре приложения в виде отдельных понятий, так как предполагается формирование потенциального словаря учащегося в процессе обучения. При этом некоторые термины могут присутствовать неоднократно, так как их перевод зависит от контекста. Типичным примером является понятие «momentum», являющееся основополагающим в физике, правильный перевод которого зависит от области применения.

Настоящее учебное пособие позволяет усвоить более 1000 учебных лексических единиц и направлено на эффективное обучение профессиональной терминологии в контексте предметной области. Пособие может быть использовано как дополнение к основному курсу английского языка для специальных целей (English for specific purposes – ESP). Чтение текстов и ответы на вопросы займут лишь часть времени, отводимого на занятие, а упражнения могут быть предложены в качестве домашнего задания. Предлагаемое учебное пособие также может быть использовано для изучения профессиональной англоязычной лексики в колледжах, лицеях и гимназиях соответствующего профиля.

P A R T I

Mechanics

UNIT 1
FUNDAMENTAL CONCEPTS

Read the following texts. Study the thesaurus on fig. 1, answer the questions after the texts

The goal of physics is to provide an understanding of the physical world by developing theories based on experiments. A physical theory is essentially a guess, usually expressed mathematically, about how a given physical system works. The theory makes certain predictions about the physical system which can then be checked by observations and experiments. If the predictions turn out to correspond closely to what is actually observed, then the theory stands, although it remains provisional. No theory to date has given a complete description of all physical phenomena, even within a given subdiscipline of physics. Every theory is a work in progress.

The basic laws of physics involve such physical quantities as force, velocity, volume, and acceleration, all of which can be described in terms of more fundamental quantities. In mechanics, the three most fundamental quantities are length (**L**), mass (**M**), and time (**T**); all other physical quantities can be constructed from these three.

Standards of Length, Mass and Time

To communicate the result of a measurement of a certain physical quantity, a unit for the quantity must be defined. For example, if our fundamental unit of length is defined to be 1.0 meter, and someone familiar with our system of measurement reports that a wall is 2.0 meters high, we know that the height of the wall is twice the fundamental unit of length. Likewise, if our fundamental unit of mass is defined as 1.0 kilogram, and we are told that a person has a mass of 75 kilograms, then that person has a mass 75 times as great as the fundamental unit of mass.

In 1960, an international committee agreed on a standard system of units for the fundamental quantities of science, called SI (System International). Its units of length, mass, and time are the meter, kilogram, and second, respectively.

Length

In 1799, the legal standard of length in France became the meter, defined as one ten-millionth of the distance from the equator to the North Pole. Until 1960, the office length of the meter was the distance between two lines on a specific bar of platinum iridium alloy stored under controlled conditions. This standard was abandoned for several reasons, the principal one being that measurements of the separation between the lines are not precise enough. In 1960, the meter was denned as 1650763.73 wavelengths of orange-red light emitted from a krypton-86 lamp. In October 1983, this definition was abandoned also, and the meter was redefined as the distance traveled by light in vacuum during a time interval of 1/299792458 second. This latest definition establishes the speed of light at 299792458 meters per second.

Mass

The SI unit of mass, the kilogram, is defined as the mass of a specific platinum-iridium alloy cylinder kept at the International Bureau of Weights and Measures at Sevres, France. Mass is a quantity used to measure the resistance to a change in the motion of an object. It's more difficult to cause a change in the motion of an object with a large mass than an object with a small mass.

Time

Before 1960, the time standard was defined in terms of the average length of a solar day in the year 1900. (A solar day is the time between successive appearances of the Sun at the highest point it reaches in the sky each day.) The basic unit of time, the second, was denned to be (1/60)*(1/60)*(1/24) = 1/86400 of the average solar day. In 1967, the second was redefined to take advantage of the high precision attainable with an atomic clock, which uses the characteristic frequency of the light emitted from the cesium-133 atom as its "reference clock". The second is now defined as 9192631700 times the period of oscillation of radiation from the cesium atom.

Coordinate systems

One convenient and commonly used coordinate system is the Cartesian coordinate system, sometimes called the rectangular coordinate system. An arbitrary point in this system is labeled with the coordinates (***x, y***). Positive x is usually selected as right of the origin and positive y upward from the origin, but in two dimensions this choice is largely a matter of taste.

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<tr><td rowspan="19">Fundamental concepts</td><td rowspan="3">Fundamental quantities</td><td>Length</td><td>Standard of length</td><td></td><td></td></tr>
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</table>

Fig. 1. **Thesaurus for Unit 1**

Sometimes it's more convenient to locate a point in space by its plane polar coordinates (***r*, £**). A point is then specified by the distance r from the origin to the point and by the angle **£** between the reference line and a line drawn from the origin to the point. The standard reference line is usually selected to be the positive ***x***-axis of a Cartesian coordinate system. The angle **£** is considered positive when measured counterclockwise from the reference line and negative when measured clockwise.

Trigonometry

The basic trigonometric functions defined by such a triangle are the ratios of the lengths of the sides of the triangle. These relationships are called the sine, cosine, and tangent functions. Another important relationship, called the Pythagorean theorem, exists between the lengths of the sides of a right triangle.

1. What physical quantities do the basic laws of physics involve?
2. What are the three most fundamental quantities in mechanics?
3. What do you know about the standard system of units called SI?
4. What is the standard of length nowadays?
5. What three relationships in trigonometry could you name?

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Вычисления	*cuonlaclatis*
Секунда	*condse*
Сантиметр	*tinecmeter*
Измерения	*mentssureaem*
Метр	*terem*

2. Match the words in A with the words in B to form word combinations:

A	B
Order-of-magnitude	*values*
Fundamental	*International*
System	*theorem*
Reference	*calculations*
Pythagorean	*line*
Approximate	*quantities*

3. Fill in the gaps with the missing words from the list:

dimension, slag, coordinate system, second, SI units,, estimate, foot

1. In physics, the world _____ denotes the physical nature of quantity.
2. In U.S. customary system the units of length, mass, and time are the _____, _____, and _____.
3. _____ are almost universally accepted in science and industry.
4. Any _____ under ten thousand are small compared with Earth's total population, but a million or more would be alarming.
5. Many aspects of physics deal with location in space, which require the definition of a _____.

UNIT 2
MOTION IN ONE DIMENSION

Read the following texts. Study the thesaurus on fig. 2, answer the questions after the texts

Life is motion. Our muscles coordinate motion microscopically to enable us to walk and jog. Our hearts pump tirelessly for decades, moving blood through our bodies. Cell wall mechanisms move select atoms and molecules in and out of cells. From the prehistoric chase of antelopes across the savanna to the pursuit of satellites in space, mastery of motion has been critical to our survival and success as a species.

The study of motion and of physical concepts such as force and mass is called dynamics. The part of dynamics that describes motion without regard to its causes is called kinematics. In this Unit, the focus is on kinematics in one dimension: motion along a straight line. This kind of motion - and, indeed, any motion - involves the concepts of displacement, velocity, and acceleration. Here, we use these concepts to study the motion of objects undergoing constant acceleration.

The first recorded evidence of the study of mechanics can be traced to the people of ancient Sumeria and Egypt, who were interested primarily in understanding the motions of heavenly bodies. The most systematic and detailed early studies of the heavens were conducted by the Greeks from about 300 b.c. to a.d. 300. Ancient scientists and laypeople regarded the Earth as the center of the Universe. This geocentric model was accepted by such notables as Aristotle (384-322 b.c.) and Claudius Ptolemy (about a.d. 140). Largely because of the authority of Aristotle, the geocentric model became the accepted theory of the Universe until the 17th century.

About 250 b.c, the Greek philosopher Aristarchus worked out the details of a model of the Solar System based on a spherical Earth that rotated on its axis and revolved around the Sun. He proposed that the sky appeared to turn westward because the Earth was turning eastward. This model wasn't given much consideration, because it was believed that if the Earth turned, it would set up a great wind as it moved through the air. We know now that the Earth carries the air and everything else with it as it rotates.

The Polish astronomer Nicolaus Copernicus (1473-1543) is credited with initiating the revolution that finally replaced the geocentric model. In his system, called the heliocentric model, Earth and the other planets revolve in circular orbits around the Sun.

This early knowledge formed the foundation for the work of Galileo Galilei (1564-1642), who stands out as the dominant facilitator of the entrance of physics into the modern era. In 1609, he became one of the first to make astronomical observations with a telescope. He observed mountains on the Moon, the larger satellites of Jupiter, spots on the Sun, and the phases of Venus. Galileo's observations convinced him of the correctness of the Copernican theory. His quantitative study of motion formed the foundation of Newton's revolutionary work in the next century.

Displacement

Motion involves the displacement of an object from one place in space and time to another. Describing the motion requires some convenient coordinate system and a specified origin. A frame of reference is a choice of coordinate axes that defines the starting point for measuring any quantity, an essential first step in solving virtually any problem in mechanics.

Because displacement has both a magnitude (size) and a direction, it's a vector quantity, as are velocity and acceleration. In general, a vector quantity is characterized by having both a magnitude and a direction. By contrast, a scalar quantity has magnitude, but no direction. Scalar quantities such as mass and temperature are completely specified by a numeric value with appropriate units; no direction is involved.

Velocity

In day-to-day usage, the terms speed and velocity are interchangeable. In physics, however, there's a clear distinction between them: Speed is a scalar quantity, having only magnitude, while velocity is a vector, having both magnitude and direction.

Why must velocity be a vector? If you want to get to a town 70 km away in an hour's time, it's not enough to drive at a speed of 70 km/h; you must travel in the correct direction as well. This is obvious, but shows that velocity gives considerably more information than speed, as will be made more precise in the formal definitions.

The average speed of an object over a given time interval is defined as the total distance traveled divided by the total time elapsed.

Acceleration

Going from place to place in your car, you rarely travel long distances at constant velocity. The velocity of the car increases when you step harder on the gas pedal and decreases when you apply the brakes. The velocity also changes when you round a curve, altering your direction of motion. The changing of an object's velocity with time is called acceleration. The average acceleration during the time interval is the change in velocity divided by time (meter per second per second, m/s^2).

Acceleration is a vector quantity having dimensions of length divided by the time squared. For the case of motion in a straight line, the direction of the velocity of an object and the direction of its acceleration are related as follows: When the object's velocity and acceleration are in the same direction, the speed of the object increases with time. When the object's velocity and acceleration are in opposite directions, the speed of the object decreases with time. The minus signs indicate that the velocities of the car are in the negative direction; they do not mean that the car is slowing down! Positive and negative accelerations specify directions relative to chosen axes, not "speeding up" or "slowing down." The terms "speeding up" or "slowing down" refer to an increase and a decrease in speed, respectively.

The value of the average acceleration often differs in different time intervals, so it's useful to define the instantaneous acceleration. The instantaneous acceleration is the limit of the average acceleration as the time interval.

Motion In One dimension	*Kinematics*	*Displacement*	*Displacement in two dimensions*	*Displacement in vehicular movement*
		Speed	*Scalar quantity*	*Meter per second*
			Average speed	*Total distance*
				Total time
		Velocity	*Vector*	*Magnitude*
				Direction
			Instantaneous velocity	
			Velocity vs. Time graph	
		Acceleration	*Average acceleration*	*Meter per second per second*
				Speeding up
				Slowing down
			Instantaneous acceleration	*Instantaneous acceleration of running ball player*
			Negative acceleration	
			Deceleration	
			Motion diagram	
			Zero acceleration	
		Freely-falling-objects	*Free-fall acceleration*	

Fig. 2. **Thesaurus for Unit 2**

Negative acceleration doesn't necessarily mean an object is slowing down. If the acceleration is negative and the velocity is also negative, the object is speeding up. The word deceleration means a reduction in speed, a slowing down. Some confuse it with a negative acceleration, which can speed something up.

Velocity and acceleration are sometimes confused with each other, but they're very different concepts, as can be illustrated with the help of motion diagrams. If the car moves the same distance in each time interval, this means that the car moves with constant positive velocity and has zero acceleration.

Freely falling objects

According to legend, Galileo discovered the law of falling objects by observing that two different weights dropped simultaneously from the Leaning Tower of Pisa hit the ground at approximately the same time. Although it's unlikely that this particular experiment was carried out, we know that Galileo performed many systematic experiments with objects moving on inclined planes. In his experiments, he rolled balls down a slight incline and measured the distances they covered in successive time intervals. The purpose of the incline was to reduce the acceleration and enable Galileo to make accurate measurements of the intervals. Galileo's achievements in the science of mechanics paved the way for Newton in his development of the laws of motion.

1. What does dynamics study?
2. What is the part of dynamics that describes motion without regard to its causes?
3. What do you know about geocentric and heliocentric models?
4. What is a frame of reference?
5. What is the difference between terms speed and velocity?
6. Give the definition of the average speed.
7. Give the definition of acceleration.

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Замедление	*cedeleration*
Смещение	*placementdis*
Скорость (вектор)	*lovetyci*
Величина	*tudenigam*
Ускорение	*lerationacc*

2. Match the words in A with the words in B to form word combinations:

A	B
Instantaneous	*distance*
Freely-falling	*velocity*
Total	*acceleration*
Motion	*down*
Free-fall	*objects*
Slowing	*diagram*

3. Fill in the gaps with the missing words from the list:

average velocity, average speed, deceleration, constant positive velocity, zero acceleration, displacement, free-fall acceleration, distance

1. The ball travels a ______ equal to twice the maximum height reached, but its ______ is zero.
2. If you run from x = 0 m to x = 25 m and back to you starting point in a time interval of 5 s, the ______ is zero, while the ______ is 10 m/s.
3. The world ______ means a reduction in speed, a slowing down.
4. The car moves the same distance in each time interval, if it moves with ______ and has ______.
5. An object falling in the presence of Earth's gravity exhibits a ______ directed towards Earth's center.

UNIT 3
VECTORS AND TWO-DIMENSIONAL MOTION

Read the following texts. Study the thesaurus on fig. 3, answer the questions after the texts

In discussion of one-dimensional we used the concept of vectors only to limited extent. In our further study of motion, manipulating vector quantities will become increasingly important, so much of this Unit is devoted to vector techniques. We'll then apply these mathematical tools to two-dimensional motion, especially that of projectiles, and to the understanding of relative motion.

Vectors and their properties

Each of physical quantities can be categorized as either a vector quantity or a scalar quantity. Vector has both direction and magnitude (size). A scalar can be completely specified by its magnitude with appropriate units; it has no direction. Displacement, velocity, and acceleration are vector quantities. Temperature is an example of a scalar quantity. If the temperature of an objects is -5°C, that information completely specifies the temperature of the object; no direction is required. Masses, time intervals, and volumes are scalars as well. Scalar quantities can be manipulated with the rules of ordinary arithmetic. Vector can also be added and subtracted from each other, and multiplied, but there are a number of important differences.

Equality of Two Vectors. Two vectors are equal if they have the same magnitude and the same direction. This property allows us to translate a vector parallel to itself in a diagram without affecting the vector. In fact, for most purposes, any vector can be moved parallel to itself without being affected.

Adding Vectors. When two or more vectors are added, they must all have the same units. For example, it doesn't make sense to add a velocity vector, carrying units of meters per second, to a displacement vector, carrying units of meters. Scalars obey the same rule: It would be similarly meaningless to add temperatures to volumes or masses to time intervals.

Vectors can be added geometrically or algebraically. The resultant vector $\mathbf{R} = \mathbf{A} + \mathbf{B}$ is the vector drawn from the tail of **A** to the tip of **B**. This procedure is known as the triangle method of addition. When two vectors are added, their sum is independent of the order of the addition: $\mathbf{A} + \mathbf{B} = \mathbf{B} + \mathbf{A}$. This relationship is called the commutative law of addition.

Negative of a Vector. The negative of the vector **A** is defined as the vector that gives zero when added to **A**. This means that **A** and **-A** have the same magnitude but opposite directions.

Displacement, velocity, and acceleration in two dimensions

In one-dimensional motion the direction of a vector quantity such as a velocity or acceleration can be taken into account by specifying whether the quantity is positive or negative. The velocity of a rocket, for example, is positive if the rocket is going up and negative if it's going down. This simple solution is no longer available in two or three dimensions. Instead, we must make full use of the vector concept.

Motion in two dimensions

Anyone who has tossed any kind of object into the air has observed projectile motion. If the effects of air resistance and the rotation are neglected, the path of a projectile in Earth's gravity field is curved in the shape of a parabola. The most important experimental fact about projectile motion in two dimensions is that the horizontal and vertical motions are completely independent of each other. This means that motion in one direction has no effect on motion in the other direction.

In general, the equations of constant acceleration developed in Unit 2 follow separately for both the x-direction and the y-direction. An important difference is that the initial velocity now has two components. We assume that at $t = 0$, the projectile leaves the origin with an initial velocity. If the velocity vector makes an angle Q with the horizontal, Q is called the projection angle.

For example:

A water fountain. The individual water streams follow parabolic trajectories. The horizontal range and maximum height of a given stream of water depend on the elevation angle of that stream's initial velocity as well as its initial speed.

Acceleration at the Highest Point

The acceleration in the y-direction is not zero at the top of a projectile's trajectory. Only the y-component of the velocity is zero there. If the acceleration were zero, too, the projectile would never come down!

Relative velocity

Relative velocity is all about relating the measurements of two different observers one moving with respect to the other. The measured

Vectors and Two-Dimensional Motion	*Scalar quantity*			
	Vector quantity	*Equality of two vectors*	*Parallel to itself*	
		Adding vectors	*Same units*	
			Triangle method addition	
			Commutative law of addition	
		Negative of a vector	*Negative vector*	*Resultant vector*
		Relationship		
	Motion in two-dimensional	*Projectile motion*	*Shape of a parabola*	*Water fountain*
			Horizontal motion	
			Vertical motion	
			Initial velocity	
			Projection angle	*X-direction*
				Y-direction
			Acceleration at the Highest point	*Meter per second squared*
		Relative velocity	*Reference frame*	*Coordinate systems*
				Stationary frame of reference
				Moving frame of reference

Fig. 3. **Thesaurus for Unit 3**

velocity of an object depends on the velocity of the observer with respect to the object. On highways, for example, cars moving in the same direction are often moving at high speed relative to Earth, but relative each other they hardly move at all. To an observer at rest at the side of the road, a car might be traveling at 60 mi/h, but to an observer in a truck traveling in the same direction at 50 mi/h, the car would appear to be traveling only 10 mi/h.

So measurements of velocity depend on the reference frame of the observer. Reference frames are just coordinate systems. Most of the time, we use a stationary frame of reference relative to Earth, but occasionally we use a moving frame of reference associated with a bus, car, or plane moving with constant velocity relative to Earth.

1. A scalar has no direction. Is it right?
2. Give examples of vector quantities.
3. On what condition vectors are considered to be equal?
4. Give the definition of negative of a vector.
5. Consider motion in one direction. How do horizontal and vertical motion depend on each other?
6. What does measurement of velocity depend on?

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Скаляр	*larsca*
Вектор	*torvec*
Летящий предмет	*jectilepro*
Отношения	*shiprelation*
Треугольник	*angletri*

2. Match the words in A with the words in B to form word combinations:

A	B
Negative	*Systems*
Meter per	*At the Highest point*
Vertical	*second squared*
Acceleration	*motion*
Reference	*Of a vector*
Coordinate	*frame*

3. Fill in the gaps with the missing words from the list:

projectile, scalar quantity, vector lies, x-axis, rate of change, acceleration vector, relative velocity, y-component

1. The number of grapes in bunch is one example of a _____.
2. If the _____ in the second or third quadrant, the angle, as measured from the positive _____, will be the angle returned by your calculator plus 180º.
3. The _____ of the velocity is zero at the Highest Point of the projectile's trajectory.
4. As a _____ moves in its parabolic path, the velocity vector and _____ are perpendicular to each other at the peak of its path.
5. The _____ of the resultant vector with respect to time is the _____ equation.

UNIT 4
THE LAWS OF MOTION

Read the following texts. Study the thesaurus on fig. 4, answer the questions after the texts

Classical mechanics describes the relationship between the motion of objects found in our everyday world and the forces acting on them. As long as the system under study doesn't involve objects comparable in size to an atom or traveling close to the speed of light, classical mechanics provides an excellent description of nature.

Newton's three laws of motion are simple and sensible. The first law states that a force must be applied to an object in order to change its velocity. Changing an object's velocity means accelerating it, which implies a relationship between force and acceleration. This relationship, the second law, states that the net force on an object equals the object's mass times its acceleration. Finally, the third law says that whenever we push on something, it pushes back with equal force in the opposite direction. These are the three laws in a nutshell.

Newton's three laws, together with his invention of calculus are used routinely today in virtually all areas of mathematics, science, engineering, and technology. Newton's theory of universal gravitation had a similar impact, starting a revolution in celestial mechanics and astronomy that continues to this day. With the advent of this theory, the orbits of all the planets could be calculated to high precision and the tides understood. The theory even led to the prediction of "dark stars," now called black holes, over two centuries before any evidence for their existence was observed.

Forces

A force is commonly imagined as a push or a pull on some object, perhaps rapidly, as when we hit a tennis ball with a racket. We can hit the ball at different speeds and direct it into different parts of the opponent's court. This means that we can control the magnitude of the applied force and also its direction, so force is a vector quantity, just like velocity and acceleration.

Another class of forces doesn't involve any direct physical contact. Early scientists, including Newton, were uneasy with the concept of forces that act between two disconnected objects. Nonetheless, Newton used this 'action-at-a-distance' concept in his law of gravity, whereby a mass at one location, such as the Sun, affects the motion of a distant object such as Earth despite no evident physical connection between the two objects. To overcome the conceptual difficulty associated with action at a distance, Michael Faraday (1791-1867) introduced the concept of a field. The corresponding forces are called field forces.

The known fundamental forces in nature are all field forces: the strong nuclear force between subatomic particles; the electromagnetic forces between electric charges; the weak nuclear force, which arises in certain radioactive decay processes; and the gravitational force between objects.

Newton’s first law

Before about 1600, scientists felt that the natural state of matter was the state of rest. Galileo, however, devised thought experiments - such as an object moving on a frictionless surface, as just described - and concluded that it's not the nature of an object to stop, once set in motion, but rather to continue in its original state of motion. This approach was later formalized as Newton's first law of motion: An object moves with a velocity that is constant in magnitude and direction, unless acted on by a nonzero net force. The net force on an object is defined as the vector sum of all external forces exerted on the object. External forces come from the object's environment. If an object's velocity isn't changing in either magnitude or direction, then its acceleration and the net force acting on it must both be zero.

Mass and Inertia

Imagine hitting a golf ball off a tee with a driver. If you're a good golfer, the ball will sail over two hundred yards down the fairway. Now imagine teeing up a bowling ball and striking it with the same club. Your club would probably break, you might sprain your wrist, and the bowling ball, at best, would fall off the tee, take half a roll and come to rest.

From this thought experiment, we conclude that while both balls resist changes in their state of motion, the bowling ball offers much more effective resistance. The tendency of an object to continue in its original state of motion is called inertia. While inertia is the tendency of an object to continue its motion in the absence of a force, mass is a measure of the object's resistance to changes in its motion due to a force.

Newton’s second law

Newton's second law answers the question of what happens to an object that does have a net force acting on it. Imagine pushing a block of ice across a frictionless horizontal surface. When you exert some horizontal force on the block, it moves with an acceleration of, 2 m/s^2. If you apply a force twice as large, the acceleration doubles to 4 m/s^2. Pushing three times as hard triples the acceleration, and so on. From such observations, we conclude that the acceleration of an object is directly proportional the net force acting on it. Mass also affects acceleration. The acceleration of an object is inversely proportional to its mass. This approach was later formalized as Newton's second law of motion: The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.

The Gravitational Force

The gravitational force is the mutual force of attraction between any two objects in the Universe. Although the gravitational force can be very strong between very large objects, it's the weakest of the fundamental forces. In addition to contributing to the understanding of motion, Newton studied gravity extensively. Newton's law of universal gravitation states that every particle in the Universe attracts every other particle with a force that is directly proportional to the product of the masses of the particles and inversely proportional to the square of the distance between them. If the particles have masses m_1 and m_2 and are separated by a distance r, the magnitude of the gravitational force, F is $G * m_1 * m_2 / r^2$, where G is the universal gravitation constant.

The Laws of Motion	*Forces*	*Contact forces*		
		Field forces	*Action-at-a-distance*	*Strong nuclear force*
				Electromagnetic forces
				Weak nuclear force
				Gravitational forces
	Newton first law	*External forces*		
		Mass	*Mass number*	
		Inertia	*Inertial property of mass*	
	Newton second law	*Net force*	*Acceleration of an object*	
			Mass of an object	*Inversely proportional*
		Gravitational force	*Gravitation*	*Universal gravitation constant*
			Newton (N)	
		Gravity	*Weight*	*Acceleration of gravity*
	Newton third law	*Action force*	*Drag force*	
		Reaction force	*Opposites in direction*	
	Application of Newton's laws	*Three laws in a nutshell*	*Free-body diagram*	
			Zero net force	
	Forces of friction	*Static friction*		
		Kinetic friction	*Coefficient of kinetic friction*	

Fig. 4. **Thesaurus for Unit 4**

The magnitude of the gravitational force acting on an object of mass ***m*** near Earth's surface is called the weight, ***w***, of the object, given by ***w = mg***, where ***g*** is the acceleration of gravity. SI unit: newton (N). Unlike mass, weight is not an inherent property of an object because it can take different values, depending on the value of ***g*** in a given location.

Newton's third law

According to Newton, as the nail is driven into the block by the force exerted by the hammer, the hammer is slowed down and stopped by the force exerted by the nail. Newton described such paired forces with his third law: If object 1 and object 2 interact, the force F12 exerted by object 1 on object 2 is equal in magnitude but opposite in direction to the force F21 exerted by object 2 on object 1.

Newton's third law constantly affects our activities in everyday life. Without it, no locomotion of any kind would be possible, whether on foot, on a bicycle, or in a motorized vehicle.

Applications of Newton's laws

When we apply Newton's law to an object, we are interested only in those forces which act on the object. The most important step in solving a problem by means of Newton's second law is to draw the correct free-body diagram. Include only those forces that act directly on the object of interest.

A zero net force on a particle does not mean that the particle isn't moving. It means that the particle isn't accelerating. If the particle has a nonzero initial velocity and is acted upon by a zero net force, it continues to move with the same velocity.

Forces of friction

An object moving on a surface or through a viscous medium, such as air or water, encounters resistance as it interacts with its surroundings. This resistance is called friction. Forces of friction are essential in our everyday lives. Even standing in one spot would be impossible without friction, as the slightest shift would instantly cause you to slip and fall. The force that counteracts F and keeps is called the force of static friction. We call the friction force for an object in motion the force of kinetic friction. Friction makes it possible to grip and hold things, drive a car, walk, and run.

1. Can we control the direction of applied force? What does it mean?
2. What concept introduced Michael Faraday?

3. Formulate Newton's first law.
4. What is inertia?
5. Formulate Newton's second law.
6. Give the definition of the gravitational force.
7. Formulate Newton's third law.

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Силы	*cesfor*
Трение	*ricftion*
Вес	*ghtwei*
Действие на расстоянии	*Distance-a-at-action*
Сила тяжести	*vitygra*

2. Match the words in A with the words in B to form word combinations:

A	B
Newton	*speed*
Drag	*Second law*
Terminal	*Gravitation constant*
Universal	*friction*
Static	*of kinetic friction*
Coefficient	*force*

3. Fill in the gaps with the missing words from the list:

inertia, reaction force, gravitational force, action force, forces of friction, motion

1. _____ can be used to explain the operation of one type of seat belt mechanism.
2. Force causes changes in _____.
3. The _____ on Earth due to Moon is much weaker than the gravitational force on Earth due to the Sun.
4. In applying Newton's third law, remember that an _____ and _____ always act on different objects.
5. _____ are important in the analysis of the motion of cars and other wheeled vehicles.

UNIT 5
ENERGY

Read the following texts. Study the thesaurus on fig. 5, answer the questions after the texts

Energy is one of the most important concepts in the world of science. In everyday use, energy is associated with the fuel needed for transportation and heating, with electricity for lights and appliances, and with the foods we consume. These associations, however, don't tell us what energy is, only what it does, and that producing it requires fuel.

Energy is present in the Universe in a variety of forms, including mechanical, chemical, electromagnetic, and nuclear energy. Even the inert mass of everyday matter contains a very large amount of energy. Although energy can be transformed from one kind to another, all observations and experiments to date suggest that the total amount of energy in the Universe never changes. This is also true for an isolated system - a collection of objects that can exchange energy with each other, but not with the rest of the Universe. If one form of energy in an isolated system decreases, then another form of energy in the system must increase. For example, if the system consists of a motor connected to a battery, the battery converts chemical energy to electrical energy, and the motor converts electrical energy to mechanical energy. Understanding how energy changes from one form to another is essential in all the sciences.

Using an energy approach to solve certain problems is often much easier than using forces and Newton's three laws. These two very different approaches are linked through the concept of work.

Work

Work has a different meaning in physics than it does in everyday usage. In the physics definition, a programmer does very little work typing away at a computer. In physics, work is done only if an object is moved through some displacement while a force is applied to it. It's easy to see the difference between the physics definition and the everyday definition of work. The programmer exerts very little force on the keys of a keyboard, creating only small displacements, so relatively little physics work is done. The mason must exert much larger forces on the concrete blocks and move them significant distances, and so performs a much greater amount of work. Even very tiring tasks, however, may not constitute work according to the physics definition. A truck driver, for example, may drive for several hours, but if he doesn't exert a force, and he doesn't do any work.

Kinetic energy

Solving problems using Newton's second law can be difficult if the forces involved are complicated. An alternative is to relate the speed of an object to the net work done on it by external forces. If the net work can be calculated for a given displacement, the change in the object's speed is easy to evaluate. We can think of kinetic energy as the work a moving object can do in coming to rest. For example, suppose a hammer is on the verge of striking a nail. The moving hammer has kinetic energy and can therefore do work on the nail.

Gravitational Potential energy

An object with kinetic energy (energy of motion) can do work on another object, just like a moving hammer can drive a nail into a wall. A brick on a high shelf can also do work. It can fall off the shelf, accelerate downwards, and hit a nail squarely, driving it into the floorboards. The brick is said to have potential energy associated with it, because from its location on the shelf it can potentially do work. Potential energy is a property of a system, rather than of a single object, because it's due to a physical position in space relative a center of force.

Gravitational Work and Potential Energy

For most trajectories - say, for a ball traversing a parabolic arc - finding the gravitational work done on the ball requires sophisticated techniques from calculus. Fortunately, for conservative fields there's a simple alternative: potential energy. Gravity is a conservative force, and for every conservative force a special expression called a potential energy function can be found.

Spring Potential energy

Springs are important elements in modern technology. They are found in machines of all kinds, in watches, toys, cars, and trains. Work done by an applied force in stretching or compressing a spring can be recovered by removing the applied force, so like gravity, the spring force is conservative.

Pushing a block against the spring compresses it a distance x. While x appears to be merely a coordinate, for springs it also represents a displacement from the equilibrium position. $\boldsymbol{F_s = -kx}$, where $\boldsymbol{k}$ is a constant of proportionality, the spring constant, carrying units of newtons per meter and called Hooke's law.

Energy	Universe	Chemical energy			
		Electromagnetic energy			
		Nuclear energy			
		Environment	Inert mass		
	Mechanical energy	Kinetic energy			
		Potential energy	Property of a system		
			Gravitational potential energy	Conservative fields	
			Spring potential energy	Hooke's law	Restoring force
					Spring constant
	Work	Physics definition	Joule(J)		
			Newton per meter	Foot-pound (US)	
		Net work			
		Gravitational work			
	Energy conservation	Internal energy			
	Power	Issue	Average power	Fuel	
		Watt(W)	Kilowatt-hour	Electrical appliances	
		Horsepower			

Fig. 5. **Thesaurus for Unit 5**

The energy either leaves the system and goes into the surrounding environment, or it stays in the system and is converted into a. nonmechanical form such as thermal energy. A simple example is a block sliding along a rough surface. Friction creates thermal energy, absorbed partly by the block and partly by the surrounding environment. When the block warms up, something called internal energy increases. The internal energy of a system is related to its temperature, which in turn is a consequence of the activity of its parts, such as the moving atoms of a gas or the vibration of atoms in a solid. Energy can be transferred between a nonisolated system and its environment.

Power

The rate at which energy is transferred is important in the design and use of practical devices, such as electrical appliances and engines of all kinds. The issue is particularly interesting for living creatures, since the maximum work per second, or power output, of an animal varies greatly with output duration. Power is denned as the rate of energy transfer with time. If an external force is applied to an object, and if the work done by this force in the time interval, then the average power delivered to the object during this interval is the work done divided by the time interval.

The SI unit of power is the joule/sec, also called the watt, named after James Watt. The horsepower was first defined by Watt, who needed a large power unit to rate the power output of his new invention, the steam engine. In electric power generation, it's customary to use the kilowatt-hour as a measure of energy.

1. What forms of energy do you know?
2. Give the physics definition of work.
3. What is kinetic energy?
4. Potential energy is a property of a system, rather than of a single object. Why?
5. Gravity is a conservative force, is not it?
6. What do you know about spring constant?
7. Give the definition of power.

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Энергия	*neregy*
Работа	*rkwo*
Топливо	*elfu*
Мощность	*werpo*
Вселенная	*niuverse*

2. Match the words in A with the words in B to form word combinations:

A	B
Mechanical	*constant*
Restoring	*conservation*
Spring	*energy*
Energy	*definition*
Physics	*power*
Average	*force*

3. Fill in the gaps with the missing words from the list:

system, work, foot-pound, potential energy, center of mass, internal

1. ______ is a scalar quantity - a number rather than a vector - and consequently is easier to handle.
2. The U.S. customary unit of work is the ______, because distances are measured in feet and forces in pounds in that system.
3. ______ is a property of a system, rather than of a single object, because it's due to a physical position in space relative a center of force.
4. We define a ______ as a collection of objects interacting via forces or other processes that are ______ to the system.
5. ______ is the point in the body at which all the mass may be considered to be concentrated.

UNIT 6
MOMENTUM AND COLLISIONS

Read the following texts. Study the thesaurus on fig. 6, answer the questions after the texts

What happens when two automobiles collide? How does the impact affect the motion of each vehicle, and what basic physical principles determine the likelihood of serious injury? How do rockets work, and what mechanisms can be used to overcome the limitations imposed by exhaust speed? Why do we have to brace ourselves when firing small projectiles at high velocity? Finally, how can we use physics to improve our golf game?

To begin answering such questions, we introduce momentum. Intuitively, anyone or anything that has a lot of momentum is going to be hard to stop. In politics, the term is metaphorical. Physically, the more momentum an object has, the more force has to be applied to stop it in a given time. This concept leads to one of the most powerful principles in physics: conservation of momentum. Using this law, complex collision problems can be solved without knowing much about the forces involved during contact. We'll also be able to derive information about the average force delivered in an impact. With conservation of momentum, we'll have a better understanding of what choices to make when designing an automobile or a moon rocket, or when addressing a golf ball on a tee.

Momentum and impulse

In physics, momentum has a precise definition. A slowly moving brontosaurus has a lot of momentum, but so does a little hot lead shot from the muzzle of a gun. We therefore expect that momentum will depend on an object's mass and velocity. The linear momentum p of an object of mass m moving with velocity v is the product of its mass and velocity.

Changing the momentum of an object requires the application of a force. This is, in fact, how Newton originally stated his second law of motion. Changing an object's momentum requires the continuous application of a force over a period of time, leading to the definition of impulse. Impulse is a vector quantity with the same direction as the constant force acting on the object. The impulse of the force acting on an object equals the change in momentum of that object.

Conservation of momentum

When a collision occurs in an isolated system, the total momentum of the system doesn't change with the passage of time. Instead, it remains constant both in magnitude and in direction. The momenta of the individual objects in the system may change, but the vector sum of all the momenta will not change. Action and reaction, together with the accompanying exchange of momentum between two objects, is responsible for the phenomenon known as recoil.

<table>
<tr><td rowspan="15">Momentum and Collisions</td><td rowspan="5">Momentum</td><td>Firing small projectiles</td><td>Likelihood</td><td></td></tr>
<tr><td>Serious injury</td><td></td><td></td></tr>
<tr><td>Linear momentum</td><td>Impulse</td><td></td></tr>
<tr><td rowspan="2">Isolated system</td><td rowspan="2">Conservation of momentum</td><td>Momenta</td></tr>
<tr><td>Recoil</td></tr>
<tr><td rowspan="10">Collision</td><td>Elastic collision</td><td>Impact</td><td></td></tr>
<tr><td>Inelastic collision</td><td>Tonometer</td><td>Puff of air</td></tr>
<tr><td>Perfectly inelastic collision</td><td></td><td></td></tr>
<tr><td>Glancing collision</td><td></td><td></td></tr>
<tr><td rowspan="6">Reaction force</td><td>Friction</td><td>Vehicles</td></tr>
<tr><td rowspan="3">Rocket propulsion</td><td>Thrust</td></tr>
<tr><td>Explosion</td></tr>
<tr><td>Multistage rockets</td></tr>
<tr><td rowspan="2">Automobiles collide</td><td>Exhaust speed</td></tr>
<tr><td>Exhaust gases</td></tr>
</table>

Fig. 6. **Thesaurus for Unit 6**

We can summarize the types of collisions as follows:

In an elastic collision, both momentum and kinetic energy are conserved.

In an inelastic collision, momentum is conserved but kinetic energy is not.

In a perfectly inelastic collision, momentum is conserved, kinetic energy is not, and the two objects stick together after the collision, so their final velocities are the same.

Collision

A collision may be the result of physical contact between two objects. For any type of collision, the total momentum of the system just before the collision equals the total momentum just after the collision as long as the system may be considered isolated. An elastic collision is defined as one in which both momentum and kinetic energy are conserved. The collision of a rubber ball with a hard surface is inelastic, because some of the kinetic energy is lost when the ball is deformed during contact with the surface. Elastic and perfectly inelastic collisions are limiting cases; most actual collisions fall into a range in between them.

In application, medical professionals use a device called a tonometer to measure the pressure inside the eye. This device releases a puff of air against the outer surface of the eye and measures the speed of the air after reflection from the eye. At normal pressure, the eye is slightly spongy, and the pulse is reflected at low speed. As the pressure inside the eye increases, the outer surface becomes more rigid, and the speed of the reflected pulse increases. In this way, the speed of the reflected puff of air can measure the internal pressure of the eye.

An important subset of collisions takes place in a plane. The game of billiards is a familiar example involving multiple glancing collisions of objects moving on a two-dimensional surface.

Rocket propulsion

When ordinary vehicles such as cars and locomotives move, the driving force of the motion is friction. In the case of the car, this driving force is exerted by the road on the car, a reaction to the force exerted by the wheels against the road. Similarly, a locomotive "pushes" against the tracks; hence, the driving force is the reaction force exerted by the tracks on the locomotive.

However, a rocket moving in space has no road or tracks to push against. In fact, reaction forces also propel a rocket. When the explosion occurs, the gas presses against the chamber in all directions, but can't press against anything at the hole, where it simply escapes into space.

1. What phenomenon goes to one of the most powerful principle in physics?
2. What phenomenon the change of amount of motion goes to?
3. Describe the phenomenon known as recoil.
4. What is the result of physical contact between two objects?
5. What forces make rocket move?
6. In what case the total momentum of the system doesn't change with the passage of time?

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Соударение	*pactim*
Количество движения	*menmotum*
Вероятность	*hoodlilike*
Отдача	*coilre*
Взрыв	*losionexp*

2. Match the words in A with the words in B to form word combinations:

A	B
Conservation of	*propulsion*
Inelastic	*gases*
Rocket	*collide*
Automobiles	*force*
Exhaust	*collision*
Reaction	*momentum*

3. Fill in the gaps with the missing words from the list:

inelastic, tonometer, thrust, elastic, multistage rocket, momentum, collisions

1. Billiard ball _____ and the collisions of air molecules with the walls of a container at ordinary temperatures are highly _____.
2. In an _____ collision, _____ is conserved but kinetic energy is not.
3. A _____ to measure the pressure releases a puff of air against the outer surface of the eye and measures the speed of the air after reflection from the eye.
4. The _____ on the rocket is defined as the force exerted on the rocket by the ejected exhaust gases.
5. Space Shuttle and a number of other rockets, such as Titan4 or Russian Proton used concept of the _____.

UNIT 7
ROTATIONAL MOTION AND THE LAW OF GRAVITY

Read the following texts. Study the thesaurus on fig. 7, answer the questions after the texts

Rotational motion is an important part of everyday life. The rotation of the Earth creates the cycle of day and night, the rotation of wheels enables easy vehicular motion, and modern technology depends on circular motion in a variety of contexts, from the tiny gears in a Swiss watch to the operation of lathes and other machinery. The concepts of angular speed, angular acceleration, and centripetal acceleration are central to understanding the motions of a diverse range of phenomena, from a car moving around a circular race track to clusters of galaxies.

Rotational motion, when combined with Newton's law of universal gravitation and his laws of motion, can also explain certain facts about space travel and satellite motion, such as where to place a satellite so it will remain fixed in position over the same spot on the Earth. The generalization of gravitational potential energy and energy conservation offers an easy route to such results as planetary escape speed. Finally, we present Kepler's three laws of planetary motion, which formed the foundation of Newton's approach to gravity.

Angular speed and angular acceleration

In the study of linear motion, the important concepts are displacement, velocity, and acceleration. Each of these concepts has its analog in rotational motion: angular displacement, angular velocity and angular acceleration. The radian, a unit of angular measure, is essential to the understanding of these concepts. Generally, angular quantities in physics must be expressed in radians. Be sure to set your calculator to radian mode; neglecting to do this is a common error.

Rotation motion under constant angular acceleration

A number of parallels exist between the equations for rotational motion and those for linear motion. The procedure used to develop the kinematic equations for linear motion under constant acceleration can be used to derive a similar set of equations for rotational motion under constant angular acceleration.

Relations between angular and linear quantities

Angular variables are closely related to linear variables. The tangential speed of a point on a rotating object equals the distance of that point from the axis of rotation multiplied by the angular speed. Every point on the rotating object has the same angular speed. The tangential acceleration of a point on a rotating object equals the distance of that point from the axis of rotation multiplied by the angular acceleration.

Centripetal acceleration

For circular motion at constant speed, the acceleration vector always points toward the center of the circle. Such an acceleration is called a centripetal (center-seeking) acceleration. Geometric result relating the centripetal acceleration to the angular speed, but physically an acceleration can occur only if some force is present. For example, if a car travels in a circle on flat ground, the force of static friction between the tires and the ground provides the necessary centripetal force.

The acceleration itself is always directed towards the center of rotation. Because the tangential and centripetal components of acceleration are perpendicular to each other, we can find the magnitude of the total acceleration with the Pythagorean theorem.

Fictitious Forces

Anyone who has ridden a merry-go-round as a child (or as a fun-loving grown-up) has experienced what feels like a "center-fleeing" force. Holding onto the railing and moving toward the center feels like a walk up a steep hill.

Rotational Motion and the Law of Gravity	*Rotational motion*	*Rotation of the Earth*	*Cycle of day and night*	
		Rotation of wheels	*Vehicular motion*	
		Operation of lathes		
		Angular quantities	*Plane angle*	*Radian(rad)*
			Angular displacement	
			Angular velocity	*Angular speed*
				Tangential speed
				Instantaneous angular speed
			Angular acceleration	*Centripetal acceleration*
				Centripetal force
				Total acceleration
		Fictitious forces	*Radial displacement*	*Radial displacement*
			Merry-go-round	*Fun-loving grown-up*
			Lathes	
	Law of Gravity	*Straight-line path*		
		Circular orbit	*Circular motion*	*Satellite motion*
				Axis of rotation
		Planetary escape speed		
		Newtonian gravitation	*Gravitational constant*	*Uniform sphere*
				Entire mass

Fig. 7. **Thesaurus for Unit 7**

Actually, this so-called centrifugal force is fictitious. In reality, the rider is exerting a centripetal force on his body with his hand and arm muscles. In addition, a smaller centripetal force is exerted by the static friction between his feet and the platform. If the rider's grip slipped, he wouldn't be flung radially away; rather, he would go off on a straight line, tangent to the point in space where he let go of the railing. The rider lands at a point, that is further away from the center, but not by "fleeing the center" along a radial line. Instead, he travels perpendicular to a radial line, traversing an angular displacement while increasing his radial displacement.

Newtonian gravitation

Prior to 1686, a great deal of data had been collected on the motions of the Moon and planets, but no one had a clear understanding of the forces affecting them. In that year, Isaac Newton provided the key that unlocked the secrets of the heavens. He knew from the first law that a net force had to be acting on the Moon. If it were not, the Moon would move in a straight-line path rather than in its almost circular orbit around Earth. Newton reasoned that this force arose as a result of an attractive force between Moon and Earth, called the force of gravity, and that it was the same kind of force that attracted objects - such as apples - close to the surface of the Earth. In 1687, Newton published his work on the law of universal gravitation.

The gravitational force exerted by a uniform sphere on a particle outside the sphere is the same as the force exerted if the entire mass of the sphere were concentrated at its center. This is called Gauss's law, after the German mathematician and astronomer Karl Friedrich Gauss. The gravitational constant was first measured in an important experiment by Henry Cavendish in 1798.

1. Why does physics study the rotational motion?
2. What analogies of linear motion exist in rotational motion?
3. What is the unit of angular measure?
4. Give the definition of tangential acceleration.
5. Which acceleration is called a centripetal?
6. Give an example of fictitious force.
7. Which law is called Gauss's law?

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Радиан	*dianra*
Цикл	*lecyc*
Касательная	*genttan*
Ось	*xisa*
Спутник	*tellitesa*

2. Match the words in A with the words in B to form word combinations:

A	B
Angular	*constant*
Fictitious	*displacement*
Gravitational	*acceleration*
Circular	*escape speed*
Radial	*motion*
Planetary	*forces*

3. Fill in the gaps with the missing words from the list:

circular motion, angular displacement, centripetal acceleration, instantaneous angular speed, gravitational constant

1. Each point on the disc undergoes the same ______ in any given time interval.
2. For very short time intervals, the average angular speed approaches the ______, just as in the linear case.
3. For ______ at constant speed, the acceleration vector always points toward the center of the circle.
4. ______ itself is always directed towards the center of rotation.
5. The ______ was first measured in an important experiment by Henry Cavendish in 1798.

UNIT 8
ROTATIONAL EQUILIBRIUM AND ROTATIONAL DYNAMICS

Read the following texts. Study the thesaurus on fig. 8, answer the questions after the texts

In the study of linear motion, objects were treated as point particles without structure. It didn't matter where a force was applied, only whether it was applied or not.

The reality is that the point of application of a force does matter. In football, for example, if the ball carrier is tackled near his midriff, he might carry the tackier several yards before falling. If tackled well below the waistline, however, his center of mass rotates toward the ground, and he can be brought down immediately. Tennis provides another good example. A tennis ball is struck with a strong horizontal force acting through its center of mass, it may travel a long distance before hitting the ground, far out of bounds. Instead, the same force applied in an upward, glancing stroke will impart topspin to the ball, which can cause it to land in the opponent's court.

The concepts of rotational equilibrium and rotational dynamics are also important in other disciplines. For example, students of architecture benefit from understanding the forces that act on buildings and biology students should understand the forces at work in muscles and on bones and joints. These forces create torques, which tell us how the forces affect an object's equilibrium and rate of rotation.

Finally, torques applied to an object through a given time interval can change the object's angular momentum. In the absence of external torques, angular momentum is conserved, a property that explains some of the mysterious and formidable properties of pulsars - remnants of supernova explosions that rotate at equatorial speeds approaching that of light.

Torque

Forces cause accelerations; torques cause angular accelerations. There is a definite relationship, however, between the two concepts. If a force F is applied to the door, there are three factors that determine the effectiveness of the force in opening the door: the magnitude of the force, the position of application of the force, and the angle at which it is applied.

Under these conditions, an object can rotate around the chosen axis in one of two directions. By convention, counterclockwise is taken to be the positive direction, clockwise the negative direction. When an applied force causes an object to rotate counterclockwise, the torque on the object is positive. When the force causes the object to rotate clockwise, the torque on the object is negative. If the net torque isn't zero, the object starts rotating at an ever-increasing rate. If the net torque is zero, the object's rate of rotation doesn't change.

Torque is a vector perpendicular to the plane determined by the position and force vectors. The direction can be determined by the right-hand rule.

An object in mechanical equilibrium must satisfy the following two conditions:

1. The net external force must be zero.
2. The net external torque must be zero.

The center of gravity

The center of mass and center of gravity of an object are exactly the same when the free-fall acceleration doesn't vary significantly over the object.

The center of gravity of a homogeneous, symmetric body must lie on the axis of symmetry. For example, the center of gravity of a homogeneous rod lies midway between the ends of the rod, and the center of gravity of a homogeneous sphere or a homogeneous cube lies at the geometric center of the object. The center of gravity of an irregularly shaped object, such as a wrench, can be determined experimentally by suspending the wrench from two different arbitrary points.

A rigid object in a uniform gravitational field can be balanced by a single force equal in magnitude to the weight of the object, as long as the force is directed upward through the object's center of gravity.

Relationship between torque and angular acceleration

When a rigid object is subject to a net torque, it undergoes an angular acceleration that is directly proportional to the net torque. This result is analogous to Newton's second law. The torque on the object is proportional to the angular acceleration of the object, where the constant of proportionality is called the moment of inertia of the object.

Rotational Equilibrium and Rotational Dynamics	*Torque*	*Angular accelerations*	*Magnitude of the force*	
			Position of application	
			Angle	
		Positive torque	*Counter-clockwise*	
		Negative torque	*Clockwise*	
		Uniform rotational motion	*Rate of angular motion*	*Right-hand rule*
		Net torque		
		Newton-meter (N-m)		
		Rate of rotation	*Ever-increasing rate*	*Wrench*
	Mechanical equilibrium	*Center of gravity*	*Axis of symmetry*	
		Center of mass	*Rigid object*	
			Irregularly shaped object	
	Moment of inertia	*Angular momentum*	*Topspin*	

Fig. 8. **Thesaurus for Unit 8**

Angular momentum

The net torque acting on an object is equal to the time rate of change of the object's angular momentum. Recall that this equation also parallels the impulse-momentum theorem.

The mechanical energy, linear momentum, and angular momentum of an isolated system all remain constant. If the moment of inertia of an isolated rotating system changes, the system's angular speed will change. Note that conservation of angular momentum applies to macroscopic objects such as planets and people, as well as to atoms and molecules.

There are many examples of conservation of angular momentum; one of the most dramatic is that of a figure skater spinning in the finale of her act. Coming out of the spin, she needs to reduce her angular velocity, so she extends her arms and legs again, increasing her moment of inertia and thereby slowing her rotation.

1. The point of application of a force does matter. Give examples.
2. What do torques cause?
3. What two conditions are necessary for an object in mechanical equilibrium?
4. What can you say about center of gravity of an object?
5. What result is a like Newton's law?
6. What values of isolated system are always constant?

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Темп, скорость	*tera*
Крутящий момент	*quetor*
Угол	*anleg*
Против часовой стрелки	*wiseclockcounter*
Рывок	*rewnch*

2. Match the words in A with the words in B to form word combinations:

A	B
Rotational	*object*
Ever-increasing	*rule*
Negative	*equilibrium*
Irregularly shaped	*torque*
Angular	*momentum*
Right-hand	*rate*

3. Fill in the gaps with the missing words from the list:

tangential acceleration, net torque, center of gravity, moment of inertia, rate

1. An object remains in a state of uniform rotational motion unless acted on by a _____.
2. The _____ of rotation of an object doesn't change, unless the object is acted on by a net torque.
3. The _____ of a homogeneous rod lies midway between the ends of the rod.
4. Because there is no force to oppose this tangential force, the object undergoes a _____ in accordance with Newton's second law.
5. The torque on the object is proportional to the angular acceleration of the object, where the constant of proportionality is called the _____.

UNIT 9
SOLIDS AND FLUIDS

Read the following texts. Study the thesaurus on fig. 9, answer the questions after the texts

There are four known states of matter: solids, liquids, gases, and plasmas. In the universe at large, plasmas - systems of charged particles interacting electromagnetically - are the most common. In our environment on Earth, solids, liquids, and gases predominate.

An understanding of the fundamental properties of these different states of matter is important in all the sciences, in engineering, and in medicine.

Forces put stresses on solids, and stresses can strain, deform, and break those solids, whether they are steel beams or bones. Fluids under pressure can perform work, or they can carry nutrients and essential solutes, like the blood flowing through our arteries and veins. Flowing gases cause pressure differences that can lift a massive cargo plane or the roof off a house in a hurricane. High-temperature plasmas created in fusion reactors may someday allow humankind to harness the energy source of the sun. The study of any one of these states of matter is itself a vast discipline.

States of matter

Everyday experience tells us that a solid has a definite volume and shape. A brick, for example, maintains its familiar shape and size day in and day out. A liquid has a definite volume but no definite shape. A gas differs from solids and liquids in that it has neither definite volume nor definite shape. Because gas can flow, however, it shares many properties with liquids.

All matter consists of some distribution of atoms or molecules. The atoms in a solid, held together by forces that are mainly electrical, are located at specific positions with respect to one another and vibrate about those positions. At low temperatures, the vibrating motion is slight and the atoms can be considered essentially fixed. As energy is added to the material, the amplitude of the vibrations increases. A vibrating atom can be viewed as being bound in its equilibrium position by springs attached to neighboring atoms. Solids can be classified as either crystalline or amorphous.

For any given substance, the liquid state exists at a higher temperature than the solid state. The intermolecular forces in a liquid aren't strong enough to keep the molecules in fixed positions, and they wander through the liquid in random fashion. Solids and liquids both have the property that when an attempt is made to compress them, strong repulsive atomic forces act internally to resist the compression.

In the gaseous state, molecules are in constant random motion and exert only weak forces on each other. The average distance between the molecules of a gas is quite large compared with the size of the molecules. Occasionally the molecules collide with each other, but most of the time they move as nearly free, noninteracting particles. As a result, unlike solids and liquids, gases can be easily compressed.

When a gas is heated to high temperature, many of the electrons surrounding each atom are freed from the nucleus. The resulting system is a collection of free, electrically charged particles - negatively charged electrons and positively charged ions. Such a highly ionized state of matter containing equal amounts of positive and negative charges is called a plasma. A Unlike a neutral gas, the long-range electric and magnetic forces allow the constituents of a plasma to interact with each other. Plasmas are found inside stars and in accretion disks around black holes, for example, and are far more common than the solid, liquid, and gaseous states because there are far more stars around than any other form of celestial matter, except possibly dark matter. Dark matter, inferred by observations of the motion of stars around the galaxy, makes up about 90% of the matter in the universe and is of unknown composition.

The deformation of solids

While a solid may be thought of as having a definite shape and volume, it's possible to change its shape and volume by applying external forces. A sufficiently large force will permanently deform or break an object, but otherwise, when the external forces are removed, the object tends to return to its original shape and size. This is called elastic behavior.

The elastic properties of solids are discussed in terms of stress and strain. Stress is the force per unit area causing a deformation; strain is a measure of the amount of the deformation. For sufficiently small stresses, stress is proportional to strain, with the constant of proportionality depending on the material being deformed and on the nature of the deformation. We call this proportionality constant the elastic modulus.

We define the tensile stress as the ratio of the magnitude of the external force to the cross-sectional area. The SI unit of stress is the newton per square meter (N/m^2), called the pascal (Pa). The tensile strain is defined as the ratio of the change in length to the original length and is therefore a dimensionless quantity. We can write an equation relating tensile stress to tensile strain, where the constant of proportionality is Young's modulus.

It's possible to exceed the elastic limit of a substance by applying a sufficiently great stress. A material subjected to a stress beyond this limit ordinarily doesn't return to its original length when the external force is removed. As the stress is increased further, it surpasses the ultimate strength: the greatest stress the substance can withstand without breaking. The breaking point for brittle materials is just beyond the ultimate strength.

Solids and Fluids	States of matter	Solid	Volume	Amorphous solid
			Shape	Crystalline solid
		Liquid	Intermolecular forces	Strong repulsive
		Gas	Noninteracting particles	
		Plasma	Dark matter	
	Deformation of solids	Elastic behavior	Stress	Elastic modulus
			Strain	Young's modulus
			Tensile stress	Tensile strain
				Dimensionless
			Elastic limit	Ultimate strength
				Breaking point
			Shear stress	Shear Modulus
			Volume Elasticity	Compressibility
				Bulk modulus
				Bulk stress
	Density			
	Pressure	Pascal (Pa)		
		Archimedes's principle	Buoyant force	
	Fluids in motion	Streamline	Laminar flow	
		Irregular	Turbulent flow	
	Transport phenomena	Diffusion		
		Osmosis		

Fig. 9. **Thesaurus for Unit 9**

Another type of deformation occurs when an object is subjected to a force parallel to one of its faces while the opposite face is held fixed by a second force. This kind of stress is called a shear stress. There is no change in volume with this kind of deformation. A material having a large shear modulus is difficult to bend.

The volume stress is defined as the ratio of the magnitude of the change in the applied force to the surface area. The bulk modulus characterizes the response of a substance to uniform squeezing. The reciprocal of the bulk modulus is the compressibility of the material.

Density and pressure

Equal masses of aluminum and gold have an important physical difference: The aluminum takes up over seven times as much space as the gold. While the reasons for the difference lie at the atomic and nuclear levels, a simple measure of this difference is the concept of density.

Fluids don't sustain shearing stresses, so the only stress that a fluid can exert on a submerged object is one that tends to compress it, which is bulk stress. The force exerted by the fluid on the object is always perpendicular to the surfaces of the object. The pressure at a specific point in a fluid can be measured. As the device is submerged in a fluid, the fluid presses down on the top of the piston and compresses the spring until the inward force exerted by the fluid is balanced by the outward force exerted by the spring. Notice that the force that compresses the spring is spread out over the entire area, motivating our formal definition of pressure.

Buoyant forces and Archimedes's principle

A fundamental principle affecting objects submerged in fluids was discovered by the Greek mathematician and natural philosopher Archimedes. Archimedes's principle can be stated as follows: Any object completely or partially submerged in a fluid is buoyed up by a force with magnitude equal to the weight of the fluid displaced by the object.

Fluids in motion

When a fluid is in motion, its flow can be characterized in one of two ways. The flow is said to be streamline, or laminar, if every particle that passes a particular point moves along exactly the same smooth path followed by previous particles passing that point. This path is called a streamline. The flow of a fluid becomes irregular, or turbulent, above a certain velocity or under any conditions that can cause abrupt changes in velocity.

Surface tension

If you look closely at a dewdrop sparkling in the morning sunlight, you will find that the drop is spherical. The drop takes this shape because of a property of liquid surfaces called surface tension.

Transport phenomena

When a fluid flows through a tube, the basic mechanism that produces the flow is a difference in pressure across the ends of the tube. This pressure difference is responsible for the transport of a mass of fluid from one location to another. The two fundamental processes involved in fluid transport resulting from concentration differences are called diffusion and osmosis.

1. What four states of matter do you know?
2. How solids can be classified?
3. How does gas turn to plasma?
4. What is elastic modulus?
5. What concept does explain difference in volume within the same mass?
6. Give the definition of Archimedes's principle.
7. What property makes drop spherical?

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Твердое тело	*lidso*
Жидкость	*iqulid*
Деформация	*ssstre*
Относительная деформация	*instra*
Плотность	*sityden*

2. Match the words in A with the words in B to form word combinations:

A	B
Noninteracting	*phenomena*
Breaking	*modulus*
Shear	*particles*
Bulk	*strain*
Transport	*stress*
Tensile	*point*

3. Fill in the gaps with the missing words from the list:

amorphous solid, crystalline solid, pressure, elastic modulus, shear stress, tensile stress,

1. In a ______ the atoms have an ordered structure.
2. In an ______, such as glass, the atoms are arranged almost randomly.
3. A material having a large ______ is very stiff and difficult to deform.
4. It's important to remember that in ______, the applied force is parallel to the cross-sectional area, whereas in ______ the force is perpendicular to the cross-sectional area.
5. If the person is wearing snowshoes, that force is distributed over the very large area of each snowshoe, so that the ______ at any given point is relatively low and the person doesn't penetrate very deeply into the snow.

PART II

Thermodynamics

UNIT 10
THERMAL PHYSICS

Read the following texts. Study the thesaurus on fig. 10, answer the questions after the texts

How can trapped water blow off the top of a volcano in a giant explosion? What causes a sidewalk or road to fracture and buckle spontaneously when the temperature changes? How can thermal energy be harnessed to do work, running the engines that make everything in modern living possible?

Answering these and related questions is the domain of thermal physics, the study of temperature, heat, and how they affect matter. Quantitative descriptions of thermal phenomena require careful definitions of the concepts of temperature, heat, and internal energy. Heat leads to changes in internal energy and thus to changes in temperature, which cause the expansion or contraction of matter. Such changes can damage roadways and buildings, create stress fractures in metal, and render flexible materials stiff and brittle, the latter resulting in compromised O-rings and the Challenger disaster. Changes in internal energy can also be harnessed for transportation, construction, and food preservation.

Gases are critical in the harnessing of thermal energy to do work. Within normal temperature ranges, a gas acts like a large collection of non-interacting point particles, called an ideal gas. Such gases can be studied on either a macroscopic or microscopic scale. On the macroscopic scale, the pressure, volume, temperature, and number of particles associated with a gas can be related in a single equation known as the ideal gas law. On the microscopic scale, a model called the kinetic theory of gases pictures the components of a gas as small particles. This model will enable us to understand how processes on the atomic scale affect macroscopic properties like pressure, temperature, and internal energy.

Temperature and the Zeroth law of thermodynamics

Temperature is commonly associated with how hot or cold an object feels when we touch it. While our senses provide us with qualitative indications of temperature, they are unreliable and often misleading. A metal ice tray feels colder to the hand, for example, than a package of frozen vegetables at the same temperature, due to the fact metals conduct thermal energy more rapidly than a cardboard package. What we need is a reliable and reproducible method of making quantitative measurements that establish the relative "hotness" or "coldness" of objects - a method related solely to temperature. Scientists have developed a variety of thermometers for making such measurements.

When placed in contact with each other, two objects at different initial temperatures will eventually reach a common intermediate temperature. If a cup of hot coffee is cooled with an ice cube, for example, the ice rises in temperature and eventually melts while the temperature of the coffee decreases. Understanding the concept of temperature requires understanding thermal contact and thermal equilibrium. The exchange of energy between two objects because of differences in their temperatures is called heat.

We can summarize these results in a statement known as the zeroth law of thermodynamics (the law of equilibrium): If objects A and B are separately in thermal equilibrium with a third object C, then A and B are in thermal equilibrium with each other.

Thermometers and temperature scales

Thermometers are devices used to measure the temperature of an object or a system. When a thermometer is in thermal contact with a system, energy is exchanged until the thermometer and the system are in thermal equilibrium with each other. For accurate readings, the thermometer must be much smaller than the system, so that the energy the thermometer gains or loses doesn't significantly alter the energy content of the system. All thermometers make use of some physical property that changes with temperature and can be calibrated to make the temperature measurable.

One common thermometer in everyday use consists of a mass of liquid - usually mercury or alcohol - that expands into a glass capillary tube when its temperature rises. In this case the physical property that changes is the volume of a liquid. To serve as an effective thermometer, the change in volume of the liquid with change in temperature must be very nearly constant over the temperature ranges of interest. When the cross-sectional area of the capillary tube is constant as well, the change in volume of the liquid varies linearly with its length along the tube. The most common temperature scale in use in the United States is the Fahrenheit scale.

The Constant-Volume Gas Thermometer and the Kelvin Scale

We can construct practical thermometers such as the mercury thermometer, but these types of thermometers don't define temperature in a fundamental way. One thermometer, however, is more fundamental, and offers a way to define temperature and relate it directly to internal energy: the gas thermometer. In a gas thermometer, the temperature readings are nearly independent of the substance used in the thermometer. The behavior observed in this device is the variation of pressure with temperature of a fixed volume of gas.

Absolute zero is used as the basis for the Kelvin temperature scale. The second point is the triple point of water, which is the single temperature and pressure at which water, water vapor, and ice can coexist in equilibrium.

Thermal expansion of solids and liquids

The discussion of the liquid thermometer made use of one of the best-known changes that occur in most substances: As temperature of the substance increases, its volume increases. This phenomenon, known as thermal expansion**,** plays an important role in numerous applications. Thermal expansion joints, for example, must be included in buildings, concrete highways, and bridges to compensate for changes in dimensions with variations in temperature.

The overall thermal expansion of an object is a consequence of the change in the average separation between its constituent atoms or molecules. To understand this idea, consider how the atoms in a solid substance behave.

Macroscopic description of an ideal gas

The properties of gases are important in a number of thermodynamic processes. Our weather is a good example of the types of processes that depend on the behavior of gases. If we introduce a gas into a container, it expands to fill the container uniformly, with its pressure depending on the size of the container, the temperature, and the amount of gas.

Thermal Physics	*Temperature*	*Thermal contact*		
		Thermal equilibrium		
		Heat		
		Zeroth law of thermodynamics		
	Thermometer	*Temperature scales*	*Celsius temperature scale*	*Degree Celsius(°C)*
				Ice point
				Freezing point
				Steam point
				Boiling point
			Kelvin temperature scale	*Kelvin(K)*
				Gas thermometer
				Absolute temperature
				Absolute zero
				Triple point
	Thermal expansion	*Coefficient of linear expansion*	*Zero-point energy*	
	Ideal gas	*Equation of state*		
		Amount of substance	*Mole(mol)*	
	Kinetic theory of gases	*Molecular Model*	*Randomly*	
			Translational kinetic energy	

Fig. 10. **Thesaurus for Unit 10**

An ideal gas is a collection of atoms or molecules that move randomly and exert no long-range forces on each other. Each particle of the ideal gas is individually point-like, occupying a negligible volume. A gas usually consists of a very large number of particles, so it's convenient to express the amount of gas in a given volume in terms of the number of moles.

1. Why do we need the concepts of temperature, heat and internal energy?
2. What is called heat?
3. Formulate the zeroth law of thermodynamics.
4. What physical property do thermometers use?
5. What is the most common temperature scale in use in the United States?
6. Give examples of thermal expansion playing an important role in multiple applications.
7. Give the definition of an ideal gas.

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Температура	*Temturepera*
Теплота	*athe*
Термометр	*hertmometer*
Расширение	*pansionex*
Моль	*lemo*

2. Match the words in A with the words in B to form word combinations:

A	B
Thermal	*point*
Temperature	*zero*
Boiling	*equilibrium*
Absolute	*state*
Equation of	*point*
Triple	*scales*

3. Fill in the gaps with the missing words from the list:

thermal expansion, thermal contact, freezing point, thermal equilibrium, thermometer

1. Two objects are in _____ if energy can be exchanged between them.
2. Two objects are in _____ if they are in thermal contact and there is no net exchange of energy.
3. On the Celsius scale, the temperature of the ice-water mixture is defined to be zero degrees Celsius, written 0°C and called the ice point or _____ of water.
4. Experiments show that the _____ readings are nearly independent of the type of gas used, as long as the gas pressure is low and the temperature is well above the point at which the gas liquifies.
5. If the _____ of an object is sufficiently small compared with the object's initial dimensions, then the change in any dimension is, to a good approximation, proportional to the first power of the temperature change.

UNIT 11
ENERGY IN THERMAL PROCESSES

Read the following texts. Study the thesaurus on fig. 11, answer the questions after the texts

When two objects with different temperatures are placed in thermal contact, the temperature of the warmer object decreases while the temperature of the cooler object increases. With time, they reach a common equilibrium temperature somewhere in between their initial temperatures. During this process, we say that energy is transferred from the warmer object to the cooler one.

Until about 1850, the subjects of thermodynamics and mechanics were considered two distinct branches of science, and the principle of conservation of energy seemed to describe only certain kinds of mechanical systems. Experiments performed by the English physicist James Joule (1818-1889) and others showed that the decrease in mechanical energy (kinetic plus potential) of an isolated system was equal to the increase in internal energy of the system. Today, internal energy is treated as a form of energy that can be transformed into mechanical energy and vice versa. Once the concept of energy was broadened to include internal energy, the law of conservation of energy emerged as a universal law of nature.

Heat and internal energy

A major distinction must be made between internal energy and heat. These terms are not interchangeable - heat involves a transfer of internal energy from one location to another. The following formal definitions will make the distinction precise.

Internal energy is the energy associated with the microscopic components of a system - the atoms and molecules of the system. The internal energy includes kinetic and potential energy associated with the random translational, rotational, and vibrational motion of the particles that make up the system, and any potential energy bonding the particles together. Heat is the transfer of energy between a system and its environment due to a temperature difference between them.

Early in the development of thermodynamics, before scientists realized the connection between thermodynamics and mechanics, heat was defined in terms of the temperature changes it produced in an object, and a separate unit of energy, the calorie, was used for heat.

Specific heat

The historical definition of the calorie is the amount of energy necessary to raise the temperature of one gram of a specific substance - water - by one degree. The amount of energy required to raise the temperature of one kilogram of an arbitrary substance by 1° varies with the substance. Every substance requires a unique amount of energy per unit mass to change the temperature of that substance by 1.0°C.

High specific heat is responsible for the moderate temperatures found in regions near large bodies of water. As the temperature of a body of water decreases during winter, the water transfers energy to the air, which carries the energy landward when prevailing winds are toward the land. Off the western coast of the United States, the energy liberated by the Pacific Ocean is carried to the east, keeping coastal areas much warmer than they would otherwise be. Winters are generally colder in the eastern coastal states, because the prevailing winds tend to carry the energy away from land.

Energy in Thermal Processes	*Internal energy*	*Kinetic energy*		
		Potential energy		
		Translational motion		
		Rotational motion		
		Vibrational motion		
	Heat	*Calorie*		
		British thermal unit (Btu)		
		Mechanical equivalent of heat		
		Specific heat	*Thermals effect*	*Archimedes's principle*
	Phase change	*Melting*		
		Boiling		
		Latent heat	*Latent heat of fusion*	*Heat of solidification*
			Latent heat of vaporization	*Heat of condensation*
			Joule per kilogram	
	Energy transfer	*Thermal conduction*	*Global warming*	*Greenhouse gases*
				Greenhouse effect
		Convection		
		Radiation		

Fig. 11. **Thesaurus for Unit 11**

During the day, the Sun adds roughly equal amounts of energy to the beach and the water, but the lower specific heat of sand causes the beach to reach a higher temperature than the water. As a result, the air above the land reaches a higher temperature than the air above the water. The denser cold air pushes the less dense hot air upward (due to Archimedes's principle), resulting in a breeze from ocean to land during the day.

Calorimetry

One technique for measuring the specific heat of a solid or liquid is to raise the temperature of the substance to some value, place it into a vessel containing cold water of known mass and temperature, and measure the temperature of the combination after equilibrium is reached. Define the system as the substance and the water. If the vessel is assumed to be a good insulator, so that energy doesn't leave the system, then we can assume the system is isolated. Vessels having this property are called calorimeters, and analysis performed using such vessels is called calorimetry.

The principle of conservation of energy for this isolated system requires that the net result of all energy transfers is zero. If one part of the system loses energy, another part has to gain the energy, because the system is isolated and the energy has nowhere else to go. When a warm object is placed in the cooler water of a calorimeter, the warm object becomes cooler while the water becomes warmer.

Latent heat and phase change

A substance usually undergoes a change in temperature when energy is transferred between the substance and its environment. In some cases, however, the transfer of energy doesn't result in a change in temperature. This can occur when the physical characteristics of the substance change from one form to another, commonly referred to as a phase change. Some common phase changes are solid to liquid (melting), liquid to gas (boiling), and a change in the crystalline structure of a solid. Any such phase change involves a change in the internal energy, but no change in the temperature.

Latent heat of the substance, depends on the nature of the phase change. The unit of latent heat is the joule per kilogram (J/kg). The latent heat of fusion is used when a phase change occurs during melting or freezing, while the latent heat of vaporization is used when a phase change occurs during boiling or condensing. When a gas cools, it eventually returns to the liquid phase, or condenses. The energy per unit mass given up during the process is called the heat of condensation, and it equals the heat of vaporization. When a liquid cools, it eventually solidifies, and the heat of solidification equals the heat of fusion.

Global warming and greenhouse gases

Many of the principles of energy transfer, and opposition to it, can be understood by studying the operation of a glass greenhouse. During the day, sunlight passes into the greenhouse and is absorbed by the walls, soil, plants, and so on. This absorbed visible light is subsequently reradiated as infrared radiation, causing the temperature of the interior to rise.

In addition, convection currents are inhibited in a greenhouse. As a result, warmed air can't rapidly pass over the surfaces of the greenhouse that are exposed to the outside air and thereby cause an energy loss by conduction through those surfaces.

A phenomenon commonly known as the greenhouse effect can also play a major role in determining the Earth's temperature. First, note that the Earth's atmosphere is a good transmitter (and hence a poor absorber) of visible radiation and a good absorber of infrared radiation. The visible light that reaches the Earth's surface is absorbed and reradiated as infrared light, which in turn is absorbed (trapped) by the Earth's atmosphere. An extreme case is the warmest planet, Venus, which has a carbon dioxide (CO2) atmosphere and temperatures approaching 850°F.

1. What happens when two objects with different temperatures are placed in thermal contact?
2. What kinds of energy does internal energy include?
3. Give the definition of calorie.
4. What vessels are called calorimeters?
5. What kinds of phase changes do you know?
6. What do you know about global warming?

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Калория	*lorieca*
Таяние	*ingmelt*
Кипение	*ingboil*
Калориметрия	*metrycalori*
Конвекция	*concvection*

2. Match the words in A with the words in B to form word combinations:

A	B
Internal	*change*
Specific	*warming*
Phase	*energy*
Global	*motion*
Greenhouse	*effect*
Vibrational	*heat*

3. Fill in the gaps with the missing words from the list:

British thermal unit (Btu), internal energy, greenhouse gases, heat, specific heat

1. The _____ of a monatomic ideal gas is associated with the translational motion of its atoms.
2. _____ is the transfer of thermal energy, just as work is the transfer of mechanical energy.
3. The unit of heat in the U.S. customary system, the _____, was defined as the energy required to raise the temperature of 1 lb of water from 63°F to 64°F.
4. The fact that the _____ of water is higher than the specific heat of sand is responsible for the pattern of airflow at a beach.
5. Whether the increasing _____ are responsible or not, there is convincing evidence that global warming is underway.

UNIT 12
THE LAWS OF THERMODINAMICS

Read the following texts. Study the thesaurus on fig. 12, answer the questions after the texts

According to the first law of thermodynamics, the internal energy of a system can be increased either by adding energy to the system or by doing work on it. This means the internal energy of a system, which is just the sum of the molecular kinetic and potential energies, can change as a result of two separate types of energy transfer across the boundary of the system. Although the first law imposes conservation of energy for both energy added by heat and work done on a system, it doesn't predict which of several possible energy-conserving processes actually occur in nature.

The second law of thermodynamics constrains the first law by establishing which processes allowed by the first law actually occur. For example, the second law tells us that energy never flows by heat spontaneously from a cold object to a hot object. One important application this law is in the study of heat engines (such as the internal combustion engine) and the principles that limit their efficiency.

Work in thermodynamic processes

Energy can be transferred to a system by heat and by work done on the system. In most cases of interest treated here, the system is a volume of gas, which is important in understanding engines. All such systems of gas will be assumed to be in thermodynamic equilibrium, so that every part of the gas is at the same temperature and pressure. If that were not the case, the ideal gas law wouldn't apply and most of the results presented here wouldn't be valid.

The first law of thermodynamics

The first law of thermodynamics is another energy conservation law that relates changes in internal energy - the energy associated with the position and jiggling of all the molecules of a system - to energy transfers due to heat and work. The first law is universally valid, applicable to all kinds of processes, providing a connection between the microscopic and macroscopic worlds.

There are two ways energy can be transferred between a system and its surroundings: by doing work, which requires a macroscopic displacement of an object through the application of a force; and by heat, which occurs through random molecular collisions. Both mechanisms result in a change in internal energy, of the system and therefore in measurable changes in the macroscopic variables of the system, such as the pressure, temperature, and volume. The energy transferred to the system is positive when energy is transferred into the system by heat and negative when energy is transferred out of the system by heat.

A gas with a larger molar specific heat requires more energy to realize a given temperature change. The size of the molar specific heat depends on the structure of the gas molecule and how many different ways it can store energy. A monatomic gas such as helium can store energy as motion in three different directions. A gas such as hydrogen, on the other hand, is diatomic in normal temperature ranges, and aside from moving in three directions, it can also tumble, rotating in two different directions. So hydrogen molecules can store energy in the form of translational motion, and in addition can store energy through tumbling. Molecules can also store energy in the vibrations of their constituent atoms. A gas composed of molecules with more ways to store energy will have a larger molar specific heat.

There are four basic types of thermal processes. In an isobaric process the pressure remains constant as the gas expands or is compressed. Expanding volume and decreasing temperature means the pressure must also decrease, in conformity with the ideal gas law. In the adiabatic process, no energy enters or leaves the system by heat. Such a system is insulated - thermally isolated from its environment. An adiabatic expansion is of practical importance and is nearly realized in an internal combustion engine. An isovolumetric process, sometimes called an isochoric process, proceeds at constant volume. In an isochoric process, the change in internal energy of a system equals the energy transferred to the system by heat. During an isothermal process the temperature of a system doesn't change. If the system is an ideal gas undergoing an isothermal process, the work done on the system is equal to the negative of the thermal energy transferred to the system.

Heat engines and the second law of thermodynamics

A heat engine takes in energy by heat and partially converts it to other forms, such as electrical and mechanical energy. In a typical process for producing electricity in a power plant, for instance, coal or some other fuel is burned, and the resulting internal energy is used to convert water to steam. The steam is then directed at the blades of a turbine, setting it rotating. Finally, the mechanical energy associated with this rotation is used to drive an electric generator. In another heat engine - the internal combustion engine in an automobile - energy enters the engine as fuel is injected into the cylinder and combusted, and a fraction of this energy is converted to mechanical energy.

In general, a heat engine carries some working substance through a cyclic process during which (1) energy is transferred by heat from a source at a high temperature, (2) work is done by the engine, and (3) energy is expelled by the engine by heat to a source at lower temperature. As an example, consider the operation of a steam engine in which the working substance is water. The water in the engine is carried through a cycle in which it first evaporates into steam in a boiler and then expands against a piston. After the steam is condensed with cooling water, it returns to the boiler, and the process is repeated.

The thermal efficiency of a heat engine is defined as the work done by the engine, divided by the energy absorbed during one cycle. We can think of thermal efficiency as the ratio of the benefit received (work) to the cost incurred. Heat engines can operate in reverse. The work is done in the compressor unit of the refrigerator, compressing a refrigerant such as freon, causing its temperature to increase. A household air conditioner is another example of a heat pump. Some homes are both heated and cooled by heat pumps.

There are limits to the efficiency of heat engines. The ideal engine would convert all input energy into useful work, but it turns out that such an engine is impossible to construct. The Kelvin-Planck formulation of the second law of thermodynamics can be stated as follows: No heat engine operating in a cycle can absorb energy from a reservoir and use it entirely for the performance of an equal amount of work.

To summarize, the first law says we can't get a greater amount of energy out of a cyclic process than we put in, and the second law says we can't break even. No engine can operate with 100% efficiency, but different designs yield different efficiencies, and it turns out one design in particular delivers the maximum possible efficiency. This design is the Carnot cycle. Understanding it requires the concepts of reversible and irreversible processes. In a reversible process, every state along the path is an equilibrium state, so the system can return to its initial conditions by going along the same path in the reverse direction. A process that doesn't satisfy this requirement is irreversible.

<table>
<tr><td rowspan="17">The Laws of Thermodynamics</td><td>Thermodynamic processes</td><td>Work done on the system</td><td></td><td></td></tr>
<tr><td rowspan="6">First law of thermodynamics</td><td rowspan="6">Isolated system</td><td>Surroundings</td><td>Jiggling</td></tr>
<tr><td>Molar specific heat</td><td></td></tr>
<tr><td>Isobaric process</td><td></td></tr>
<tr><td>Adiabatic process</td><td></td></tr>
<tr><td>Isovolumetric process</td><td></td></tr>
<tr><td>Isothermal processes</td><td></td></tr>
<tr><td rowspan="9">Second law of thermodynamics</td><td rowspan="8">Heat engine</td><td rowspan="3">Cyclic process</td><td>Internal combustion engine</td></tr>
<tr><td>Power plant</td></tr>
<tr><td>Movable piston</td></tr>
<tr><td rowspan="4">Thermal efficiency</td><td>Reversible processes</td></tr>
<tr><td>Irreversible processes</td></tr>
<tr><td>Refrigerators</td></tr>
<tr><td>Heat pumps</td></tr>
<tr><td>Carnot cycle</td><td>Carnot engine</td></tr>
<tr><td>Entropy</td><td>Disorder</td><td>Boltzman’s constant</td></tr>
<tr><td>Third law of thermodynamics</td><td>Friction</td><td>Brevity of cycles</td><td>Maximum efficiency</td></tr>
</table>

Fig. 12. **Thesaurus for Unit 12**

The Carnot Engine

In 1824, in an effort to understand the efficiency of real engines, a French engineer named Sadi Carnot (1796-1832) described a theoretical engine now called a Carnot engine that is of great importance from both a practical and a theoretical viewpoint. He showed that a heat engine operating in an ideal, reversible cycle-now called a Carnot cycle - between two energy reservoirs is the most efficient engine possible. Such an engine establishes an upper limit on the efficiencies of all real engines. Carnot's theorem can be stated as follows: No real engine operating between two energy reservoirs can be more efficient than a Carnot engine operating between the same two reservoirs.

According to the third law of thermodynamics, it's impossible to lower the temperature of a system to absolute zero in a finite number of steps, so such reservoirs are not available, and the maximum efficiency is always less than one. In most practical cases, the cold reservoir is near room temperature, about 300 K, so increasing the efficiency requires raising the temperature of the hot reservoir. All real engines operate irreversibly, due to friction and the brevity of their cycles, and are therefore less efficient than the Carnot engine.

A state variable called the entropy is related to the second law of thermodynamics. We define entropy on a macroscopic scale as the German physicist Rudolf Clausius (1822-1888) first expressed it in 1865. The concept of entropy gained wide acceptance in part because it provided another variable to describe the state of a system, along with pressure, volume, and temperature. Its significance was enhanced when it was found that the entropy of the Universe increases in all natural processes. This is yet another way of stating the second law of thermodynamics.

Entropy originally found its place in thermodynamics, but its importance grew tremendously as the field of statistical mechanics developed. One of the main conclusions of the statistical mechanical approach is that isolated systems tend toward greater disorder, and entropy is a measure of that disorder.

1. What laws of thermodynamics do you know?
2. How many ways of transferring energy between a system and its surroundings do you know?
3. Name four types of thermal processes.
4. Give the Kelvin-Planck formulation of the second law of thermodynamics.

5. Why law is the concept of entropy connected with?
6. What is the principle of work of Carnot engine?

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Окружающая среда	*Surdingsround*
Холодильник	*friregerator*
Двигатель	*gineen*
Энтропия	*troepyn*
Неупорядоченность	*sorderdi*

2. Match the words in A with the words in B to form word combinations:

A	B
Movable	*pumps*
Thermodynamic	*piston*
Isovolumetric	*engine*
Heat	*process*
Carnot	*plant*
Power	*variable*

3. Fill in the gaps with the missing words from the list:

internal energy, adiabatic process, entropy, thermodynamic variables, degree of freedom

1. The _____ of any isolated system must remain constant.
2. When a system isn't isolated, the change in internal energy will be zero if the system goes through a cyclic process in which all the _____ - pressure, volume, temperature, and moles of gas - return to their original values.
3. Each different way a gas molecule can store energy is called a _____.
4. A sufficiently rapid process may be considered approximately _____ because there isn't time for any significant transfer of energy by heat.
5. The concept of _____ is satisfying because it enables us to present the second law of thermodynamics in the form of a mathematical statement.

PART III

Vibrations and Waves

UNIT 13
VIBRATION AND WAVES

Read the following texts. Study the thesaurus on fig. 13, answer the questions after the texts

Periodic motion, from masses on springs to vibrations of atoms, is one of the most important kinds of physical behavior. In this Unit we take a more detailed look at Hooke's law, where the force is proportional to the displacement, tending to restore objects to some equilibrium position. A large number of physical systems can be successfully modeled with this simple idea, including the vibrations of strings, the swinging of a pendulum, and the propagation of waves of all kinds. All these physical phenomena involve periodic motion.

Periodic vibrations can cause disturbances that move through a medium in the form of waves. Many kinds of waves occur in nature, such as sound waves, water waves, seismic waves, and electromagnetic waves. These very different physical phenomena are described by common terms and concepts introduced here.

Hooke's law

One of the simplest types of vibrational motion is that of an object attached to a spring, previously discussed in the context of energy in Unit 5. We assume that the object moves on a frictionless horizontal surface. If the spring is stretched or compressed a small distance x from its unstretched or equilibrium position and then released, it exerts a force on the object. The value of the spring constant k is a measure of the stiffness of the spring. Stiff springs have large k values, and soft springs have small the spring constant values. A restoring force always pushes or pulls the object toward the equilibrium position.

Simple harmonic motion occurs when the net force along the direction of motion obeys Hooke's law - when the net force is proportional to the displacement from the equilibrium point and is always directed toward the equilibrium point. Not all periodic motions over the same path can be classified as simple harmonic motion. A ball being tossed back and forth between a parent and a child moves repetitively, but the motion isn't simple harmonic motion, because the force acting on the ball doesn't take the form of Hooke's law.

The following three concepts are important in discussing any kind of periodic motion. The amplitude is the maximum distance of the object from its equilibrium position. The period is the time it takes the object to move through one complete cycle of motion. The frequency is the number of complete cycles or vibrations per unit of time.

Elastic potential energy

A system of interacting objects has potential energy associated with the configuration of the system. A compressed spring has potential energy that, when allowed to expand, can do work on an object, transforming spring potential energy into the object's kinetic energy. The energy stored in a stretched or compressed spring or some other elastic material is called elastic potential energy.

A valuable example of the relationship between simple harmonic motion and circular motion can be seen in vehicles and machines that use the back-and-forth motion of a piston to create rotational motion in a wheel.

The period T represents the time required for one complete trip back and forth, is also the time it takes the ball to make one complete circular trip on the turntable. The inverse of period is frequency. The units of frequency are cycles per second, or hertz(Hz).

Motion of a pendulum

A simple pendulum is mechanical system that exhibits periodic motion. It consists of a small bob of mass m suspended by a light string of length L fixed at its upper end. (By a light string, we mean that the string's mass is assumed to be very small compared with the mass of the bob and hence can be ignored.) When released, the bob swings to and fro over the same path; but is its motion simple harmonic?

Answering this question requires examining the restoring force - the force of gravity - that acts on the pendulum. The pendulum bob moves along a circular arc, rather than back and forth in a straight line. When the oscillations are small, however, the motion of the bob is nearly straight, so Hooke's law may apply approximately.

Vibrations and Waves	*Periodic motion*	*Vibrations of strings*		
	Hooke's law	*Spring force*	*Spring*	*Spring constant*
				Stiff springs
				Soft springs
			Restoring force	*Unstreched*
				Released
		Simple harmonic motion	*Equilibrium position*	
			Amplitude	
			Period	
			Frequency	*Hertz(Hz)*
	Elastic potential energy	*Compressed spring*		
	Damped oscillation	*Shock absorbers*		
		Under-damped oscillation		
		Over-damped oscillation		
	Waves	*Traveling wave*	*Wavelength*	*Up-and-down motion*
			Wave speed	*Transverse wave*
		Interference of waves		
		Reflection of waves		

Fig. 13. **Thesaurus for Unit 13**

Damped oscillation

The vibrating motions we have discussed so far have taken place in ideal systems that oscillate indefinitely under the action of a linear restoring force. In all real mechanical systems, forces of friction retard the motion, so the systems don't oscillate indefinitely. The friction reduces the mechanical energy of the system as time passes, and the motion is said to be damped.

Shock absorbers in automobiles are one practical application of damped motion. A shock absorber consists of a piston moving through a liquid such as oil. The upper part of the shock absorber is firmly attached to the body of the car. When the car travels over a bump in the road, holes in the piston allow it to move up and down in the fluid in a damped fashion.

Damped motion varies with the fluid used. For example, if the fluid has a relatively low viscosity, the vibrating motion is preserved but the amplitude of vibration decreases in time and the motion ultimately ceases. This is known as underdamped oscillation. If the fluid viscosity is increased, the object returns rapidly to equilibrium after it's released and doesn't oscillate. In this case, the system is said to be critically damped. If the viscosity is made greater still, the system is said to be overdamped.

Waves

The world is full of waves: sound waves, waves on a string, seismic waves, and electromagnetic waves, such as visible light, radio waves, television signals, and x-rays. All of these waves have as their source a vibrating object, so we can apply the concepts of simple harmonic motion in describing them.

In the case of sound waves, the vibrations that produce waves arise from sources such as a person's vocal chords or a plucked guitar string. The vibrations of electrons in an antenna produce radio or television waves, and the simple up-and-down motion.

Interference of waves

Many interesting wave phenomena in nature require two or more waves passing through the same region of space at the same time. Two traveling waves can meet and pass through each other without being destroyed or even altered. For instance, when two pebbles are thrown into a pond, the expanding circular waves don't destroy each other. In fact, the ripples pass through each other. Likewise, when sound waves from two sources move through air, they pass through each other. In the region of overlap, the resultant wave is found by adding the displacements of the individual waves.

Reflection of waves

Whenever a traveling wave reaches a boundary, part or all of the waves is reflected. Note that the reflected pulse is inverted. This can be explained as follows: When the pulse meets the wall, the string exerts an upward force on the wall.

1. Give examples of physical phenomena containing periodic motion.
2. On what condition does the spring exert a force on the object?
3. What do you know about a restoring force?
4. What do you understand under the term simple harmonic motion?
5. Explain the term a simple pendulum.
6. What can you say about the vibrations in the case of sound waves?
7. Explain the phenomena of reflection of waves.

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Частота	*qufreency*
Упругость, пружина	*ringsp*
Распространение	*pagationpro*
Маятник	*dulumpen*
Струна	*trings*

2. Match the words in A with the words in B to form word combinations:

A	B
Equilibrium	*oscillation*
Shock	*motion*
Stiff	*wave*
Over-damped	*absorbers*
Transverse	*position*
Up-and-down	*spring*

3. Fill in the gaps with the missing words from the list:

frequency, simple harmonic motion, amplitude, simple pendulum, period

1. _____ occurs when the net force along the direction of motion obeys Hooke's law.
2. The _____ is the maximum distance of the object from its equilibrium position.
3. The _____ is the time it takes the object to move through one complete cycle of motion.
4. The _____ is the number of complete cycles or vibrations per unit of time.
5. The period of a _____ doesn't depend on the mass, but only on the pendulum's length and on the free-fall acceleration.

UNIT 14
SOUND

Read the following texts. Study the thesaurus on fig. 14, answer the questions after the texts

Sound waves are the most important example of longitudinal waves. In this Unit we discuss the characteristics of sound waves: how they are produced, what they are, and how they travel through matter. We then investigate what happens when sound waves interfere with each other. The insights gained in this Unit will help you understand how we hear.

Producing a sound wave

Whether it conveys the shrill whine of a jet engine or the soft melodies of a crooner, any sound wave has its source in a vibrating object. Musical instruments produce sounds in a variety of ways. The sound of a clarinet is produced by a vibrating reed, the sound of a drum by the vibration of the taut drumhead, the sound of a piano by vibrating strings, and the sound from a singer by vibrating vocal cords.

Sound waves are longitudinal waves traveling through a medium, such as air. In order to investigate how sound waves are produced, we focus our attention on the tuning fork, a common device for producing pure musical notes. A tuning fork consists of two metal prongs, or tines, that vibrate when struck. Their vibration disturbs the air near them.

Characteristics of sound wave

The general motion of elements of air near a vibrating object is back and forth between regions of compression and rarefaction. This back-and-forth motion of elements of the medium in the direction of the disturbance is characteristic of a longitudinal wave. By contrast, in a transverse wave, the vibrations of the elements of the medium are at right angles to the direction of travel of the wave.

Categories of Sound Waves

Sound waves fall into three categories covering different ranges of frequencies. Audible waves are longitudinal waves that lie within the range of sensitivity of the human ear, approximately 20 to 20 000 Hz. Infrasonic waves are longitudinal waves with frequencies below the audible range. Earthquake waves are an example. Ultrasonic waves are longitudinal waves with frequencies above the audible range for humans and are produced by certain types of whistles. Animals such as dogs can hear the waves emitted by these whistles.

Applications of Ultrasound

Ultrasonic waves are sound waves with frequencies greater than 20 kHz. Because of their high frequency and corresponding short wavelengths, ultrasonic waves can be used to produce images of small objects and are currently in wide use in medical applications, both as a diagnostic tool and in certain treatments. Internal organs can be examined via the images produced by the reflection and absorption of ultrasonic waves. Although ultrasonic waves are far safer than x-rays, their images don't always have as much detail. Certain organs, however, such as the liver and the spleen, are invisible to x-rays but can be imaged with ultrasonic waves.

The speed of sound

The speed of a sound wave in a fluid depends on the fluid's compressibility and inertia. The speed of sound is much higher in solids than in gases, because the molecules in a solid interact more strongly with each other than do molecules in a gas. In general, sound travels faster through solids than liquids and faster through liquids than gases, although there are exceptions. The speed of sound also depends on the temperature of the medium.

Sound	*Sound wave*	*Longitudinal wave*	*Tuning fork*	*Metal prong*
				Compression
				Rarefaction
			Audible wave	
			Infrasonic wave	
			Ultrasonic wave	
		Speed of sound	*Compressibility*	*Bulk modulus*
		Intensity of a wave	*Threshold of hearing*	
			Threshold of pain	
			Intensity level	*Decibel(dB) level*
		Spherical wave	*Point source*	*Wavelength*
			Wave front	
		Plane wave	*Doppler effect*	
		Standing wave	*Traveling wave*	*Incident wave*
				Reflected wave
		Forced vibration	*Resonant frequency*	*Resonance*

Fig. 14. **Thesaurus for Unit 14**

Energy and intensity of sound waves

As the tines of a tuning fork move back and forth through the air, they exert a force on a layer of air and cause it to move. In other words, the tines do work on the layer of air. The fact that the fork pours sound energy into the air is one of the reasons the vibration of the fork slowly dies out. Intensity of a wave on a given surface is defined as the rate at which energy flows through the surface. The average intensity of a wave on a given surface is defined as the rate at which energy flows through the surface, divided by the surface area.

The faintest sounds the human ear can detect at a frequency of 1 000 Hz have an intensity of about $10^{-12} W/m^2$. This intensity is called the threshold of hearing. The loudest sounds the ear can tolerate have an intensity of about 1 W/m^2 (the threshold of pain). The relative intensity of a sound is called the intensity level or decibel level.

Spherical and plane waves

If a small spherical object oscillates so that its radius changes periodically with time, a spherical sound wave is produced. The wave moves outward from the source at a constant speed. Because all points on the vibrating sphere behave in the same way, we conclude that the energy in a spherical wave propagates equally in all directions. This means that no one direction is preferred over any other.

The distance between adjacent wave fronts equals the wavelength. The radial lines pointing outward from the source and perpendicular to the arcs are called rays.

Now consider a small portion of a wave front that is at a great distance from the source. In this case, the rays are nearly parallel to each other and the wave fronts are very close to being planes. At distances from the source that are great relative to the wavelength, therefore, we can approximate the wave front with parallel planes, called plane waves. Any small portion of a spherical wave that is far from the source can be considered a plane wave.

The Doppler effect

If a car or truck is moving while its horn is blowing, the frequency of the sound you hear is higher as the vehicle approaches you and lower as it moves away from you. This is one example of the Doppler effect, named for the Austrian physicist Christian Doppler (1803-1853), who discovered it. The same effect is heard if you're on a motorcycle and the horn is stationary: the frequency is higher as you approach the source and lower as you move away.

Standing wave

Standing waves can be set up in a stretched string by connecting one end of the string to a stationary clamp and connecting the other end to a vibrating object, such as the end of a tuning fork, or by shaking the hand holding the string up and down at a steady rate. Traveling waves then reflect from the ends and move in both directions on the string. The incident and reflected waves combine according to the superposition principle. If the string vibrates at exactly the right frequency, the wave appears to stand still - hence its name, standing wave.

Forced vibrations and resonance

In Unit 13 we learned that the energy of a damped oscillator decreases over time because of friction. It's possible to compensate for this energy loss by applying an external force that does positive work on the system.

For example, suppose an object-spring system having some natural frequency of vibration is pushed back and forth by a periodic force with frequency. The system vibrates at the frequency of the driving force. This type of motion is referred to as a forced vibration. Its amplitude reaches a maximum when the frequency of the driving force equals the natural frequency of the system called the resonant frequency of the system. Under this condition, the system is said to be in resonance.

1. Explain the process of producing a sound wave.
2. What characteristics of a sound wave do you know?
3. What are the three categories of a sound wave?
4. Give the definition of ultrasonic wave.
5. What do you know about Doppler effect?
6. In what conditions do we observe a standing wave?

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Звук	*undso*
Сжатие	*prescomsion*
Разрежение	*factionrare*
Длина волны	*lengthwave*
Резонанс	*sonancere*

2. Match the words in A with the words in B to form word combinations:

A	B
Longitudinal	*wave*
Tuning	*source*
Doppler	*vibration*
Point	*wave*
Forced	*effect*
Incident	*fork*

3. Fill in the gaps with the missing words from the list:

sound wave, longitudinal sound wave, intensities, standing longitudinal waves, wave speed

1. We can use a sinusoidal curve to represent a ______.
2. The motion of the elements of the medium in a ______ is back and forth along the direction in which the wave travels.
3. The ______ depends on an elastic property of the medium and on an inertial property of the medium.
4. The loudest tolerable sounds have ______ about 1.0 X 10^{12} times greater than the faintest detectable sounds.
5. ______ can be set up in a tube of air, such as an organ pipe, the result of interference between sound waves traveling in opposite directions.

PART IV

Electricity and Magnetism

UNIT 15
ELECTRIC FORCES AND ELECTRIC FIELDS

Read the following texts. Study the thesaurus on fig. 15, answer the questions after the texts

Electricity is the lifeblood of technological civilization and modern society. Without it, we revert to the mid-nineteenth century: no telephones, no television, none of the household appliances that we take for granted. Modern medicine would be a fantasy, and due to the lack of sophisticated experimental equipment and fast computers - and especially the slow dissemination of information - science and technology would grow at a glacial pace.

Instead, with the discovery and harnessing of electric forces and fields, we can view arrangements of atoms, probe the inner workings of the cell, and send spacecraft beyond the limits of the solar system. All this has become possible in just the last few generations of human life, a blink of the eye compared to the million years our kind spent foraging the savannahs of Africa.

Around 700 B.C. the ancient Greeks conducted the earliest known study of electricity. It all began when someone noticed that a fossil material called amber would attract small objects after being rubbed with wool. Since then we have learned that this phenomenon is not restricted to amber and wool, but occurs (to some degree) when almost any two nonconducting substances are rubbed together.

We use the effect of charging by friction to begin an investigation of electric forces. Coulomb's law is the fundamental law of force between any two stationary charged particles. The concept of an electric field associated with charges is introduced and its effects on other charged particles described.

Properties of electric charges

After running a plastic comb through your hair, you will find that the comb attracts bits of paper. The attractive force is often strong enough to suspend the paper from the comb, defying the gravitational pull of the entire Earth. The same effect occurs with other rubbed materials, such as glass and hard rubber.

Another simple experiment is to rub an inflated balloon against wool (or across your hair). On a dry day, the rubbed balloon will then stick to the wall of a room often for hours. These materials have become electrically charged. Experiments also demonstrate that there are two kinds of electric charge, which Benjamin Franklin (1706-1790) named positive and negative.

Objects usually contain equal amounts of positive and negative charge - electrical forces between objects arise when those objects have net negative or positive charges. Charge transfers readily from one type of material to another. Rubbing the two materials together serves to increase the area of contact, facilitating the transfer process.

An important characteristic of charge is that electric charge is always conserved. Charge isn't created when two neutral objects are rubbed together; rather, the objects become charged because negative charge is transferred from one object to the other. One object gains a negative charge while the other loses an equal amount of negative charge and hence is left with a net positive charge.

Insulators and conductors

Substances can be classified in terms of their ability to conduct electric charge. In conductors, electric charges move freely in response to an electric force. All other materials are called insulators.

Glass and rubber are insulators. When such materials are charged by rubbing, only the rubbed area becomes charged, and there is no tendency for the charge to move into other regions of the material. In contrast, materials such as copper, aluminum, and silver are good conductors. When such materials are charged in some small region, the charge readily distributes itself over the entire surface of the material. If you hold a copper rod in your hand and rub the rod with wool or fur, it will not attract a piece of paper. This might suggest that a metal can't be charged. However, if you hold the copper rod with an insulator and then rub it with wool or fur, the rod remains charged and attracts the paper. In the first case, the electric charges produced by rubbing readily move from the copper through your body and finally to ground. In the second case, the insulating handle prevents the flow of charge to ground.

Semiconductors are a third class of materials, and their electrical properties are somewhere between those of insulators and those of conductors. Silicon and germanium are well-known semiconductors that are widely used in the fabrication of a variety of electronic devices.

Electric Forces and Electric Fields	*Electric charge*	*Charging by friction*	*Amber*	
			Hard rubber	*Plastic comb*
		Nonconducting substances		
		Coulomb(C)	*Positive charge*	
			Negative charge	
		Coulomb's law	*Coulomb constant*	
		Insulators	*Glass*	
			Rubber	
		Conductors	*Copper rod*	
			Aluminum	
			Silver	
		Semiconduc-tors	*Silicon*	
			Germanium	
		Conduction		
	Electric field	*Electrostatic forces*		
		Electrostatic equilibrium		
		Conductors in electrostatic equilibrium		
		Van de Graaff generator		
	Gauss's law	*Electric flux*	*Gaussian surface*	*Permittivity of free space*

Fig. 15. **Thesaurus for Unit 15**

Coulomb's law

In 1785 Charles Coulomb (1736-1806) experimentally established the fundamental law of electric force between two stationary charged particles. An electric force has the following properties:

1. It is directed along a line joining the two particles and is inversely proportional to the square of the separation distance between them.

2. It is proportional to the product of the magnitudes of the charges of the two particles.

3. It is attractive if the charges are of opposite sign and repulsive if the charges have the same sign.

The electric field

The gravitational force and the electrostatic force are both capable of acting through space, producing an effect even when there isn't any physical contact between the objects involved. Field forces can be discussed in a variety of ways, but an approach developed by Michael Faraday (1791-1867) is the most practical. In this approach, an electric field is said to exist in the region of space around a charged object. The electric field exerts an electric force on any other charged object within the field. This differs from the Coulomb's law concept of a force exerted at a distance, in that the force is now exerted by something - the field - that is in the same location as the charged object.

Conductors in electrostatic equilibrium

A good electric conductor like copper, though electrically neutral, contains charges (electrons) that aren't bound to any atom and are free to move about within the material. When no net motion of charge occurs within a conductor, the conductor is said to be in electrostatic equilibrium.

In 1929 Robert J.Van de Graaff (1901-1967) designed and built an electrostatic generator that has been used extensively in nuclear physics research. The principles of its operation can be understood with knowledge of the properties of electric fields and charges already presented in this Unit.

Electric flux and Gauss's law

Gauss's law is essentially a technique for calculating the average electric field on a closed surface, developed by Karl Friedrich Gauss (1777-1855). When the electric field, because of its symmetry, is constant everywhere on that surface and perpendicular to it, the exact electric field can be found. In such special cases, Gauss's law is far easier to apply than Coulomb's law.

Gauss's law relates the electric flux through a closed surface and the total charge inside that surface. A closed surface has an inside and an outside: an example is a sphere. Electric flux is a measure of how much the electric field vectors penetrate through a given surface. If the electric field vectors are tangent to the surface at all points, for example, then they don't penetrate the surface and the electric flux through the surface is zero.

1. Why electricity is the lifeblood of technological civilization and modern society?
2. What law is the fundamental law of force between any two stationary charged particles?
3. What properties of electric charges do you know?
4. What's the difference between insulators and conductors?
5. What does the Coulomb's law state?
6. For what purpose do we use Gauss's law?

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Кулон	*lombcou*
Диэлектрическая постоянная	*tivitypermit*
Изолятор	*sulatorin*
Полупроводник	*conductorsemi*
Кремний	*liconsi*

2. Match the words in A with the words in B to form word combinations:

A	B
Electric	*equilibrium*
Coulomb	*surface*
Electrostatic	*charge*
Van de Graaf	*generator*
Gaussian	*by friction*
Charging	*constant*

3. Fill in the gaps with the missing words from the list:

Gauss's law, coulomb constant, electric force, gaussian surface, charge

1. In modern terms, the _____ is said to be quantized, meaning that charge occurs in discrete chunks that can't be further subdivided.
2. The value of the _____ depends on the choice of units.
3. When a positive test charge is used, the electric field always has the same direction as the _____ on the test charge.
4. Though it's not obvious, _____ describes how charges create electric fields.
5. A _____ is an imaginary surface, created solely to facilitate a mathematical calculation.

UNIT 16
ELECTRICAL ENERGY AND CAPACITANCE

Read the following texts. Study the thesaurus on fig. 16, answer the questions after the texts

By using the principle of conservation of energy, we are often able to avoid working directly with forces when solving problems. The potential energy concept is also useful in the study of electricity. Because the Coulomb force is conservative, we can define an electric potential energy corresponding to that force. In addition, we define an electric potential - the potential energy per unit charge - corresponding to the electric field.

With the concept of electric potential in hand, we can begin to understand electric circuits, starting with an investigation of a common circuit element called a capacitor. These simple devices store electrical energy and have found uses virtually everywhere, from etched circuits on a microchip to the creation of enormous bursts of power in fusion experiments.

Potential difference and electric potential

Electric potential energy and electric potential are closely related concepts. The electric potential turns out to be just the electric potential energy per unit charge. This is similar to the relationship between electric force and the electric field, which is the electric force per unit charge.

The electric force is conservative, so the electric work depends only on the endpoints of the path. Because the electric field is conservative, the change in potential energy doesn't depend on the path. Because electric potential energy is a scalar quantity, electric potential is also a scalar quantity.

The electric potential difference is a measure of the change in electric potential energy per unit charge. Alternately, the electric potential difference is the work per unit charge that would have to be done by some force to move a charge from point ***A*** to point ***B*** in the electric field.

Released from rest, positive charges accelerate spontaneously from regions of high potential to low potential. If a positive charge is given some initial velocity in the direction of high potential, it can move in that direction, but will slow and finally turn around, just like a ball tossed upwards in a gravity field. Negative charges do exactly the opposite: Released from rest, they accelerate from regions of low potential toward regions of high potential. Work must be done on negative charges to make them go in the direction of lower electric potential.

Electric potential and potential energy due to point charges

In electric circuits, a point of zero electric potential is often defined by grounding (connecting to Earth) some point in the circuit. For example, if the negative terminal of a 12-V battery were connected to ground, it would be considered have a potential of zero, while the positive terminal would have a potential of + 12 V. The potential difference created by the battery, however, is only locally defined. In this Unit we describe the electric potential of a point charge which is defined throughout space.

The electric field of a point charge extends throughout space, so its electric potential does, also. The zero point of electric potential could be taken anywhere but is usually taken to be an infinite distance from the charge, far from its influence and the influence of any other charges.

The electric potential of two or more charges is obtained by applying the superposition principle: the total electric potential at some point due to several point charges is the algebraic sum of the electric potentials due to the individual charges.

<table>
<tr><td rowspan="17">Electrical Energy and Capacitance</td><td rowspan="6">Electric potential energy</td><td rowspan="6">Electric potential</td><td>Potential difference</td><td></td></tr>
<tr><td>Potential energy</td><td></td></tr>
<tr><td>Low potential</td><td></td></tr>
<tr><td>High potential</td><td></td></tr>
<tr><td>Point charge</td><td>Superposition principle</td></tr>
<tr><td>Charged conductor</td><td></td></tr>
<tr><td>Equipotential surfaces</td><td>Equipotentials</td><td></td><td></td></tr>
<tr><td rowspan="10">Capacitance</td><td>Farad (F)</td><td></td><td></td></tr>
<tr><td rowspan="7">Capacitor</td><td>The parallel-plate capacitor</td><td>Tune the frequency</td></tr>
<tr><td>Ignition system</td><td>Eliminate sparking</td></tr>
<tr><td>Positive terminals</td><td>Negative terminals</td></tr>
<tr><td>Capacitors in parallel</td><td></td></tr>
<tr><td>Capacitors in series</td><td></td></tr>
<tr><td rowspan="2">Capacitors with dielectrics</td><td>Dielectric constant</td></tr>
<tr><td>Dielectric strength</td></tr>
<tr><td rowspan="2">Charged capacitor</td><td>Wire</td><td>Energy stored</td></tr>
<tr><td></td><td>Degree of shock</td></tr>
</table>

Fig. 16. **Thesaurus for Unit 16**

Equipotential surfaces

A surface on which all points are at the same potential is called an equipotential surface. The potential difference between any two points on an equipotential surface is zero. Hence, no work is required to move a charge at constant speed on an equipotential surface.

Equipotential surfaces have a simple relationship to the electric field: The electric field at every point of an equipotential surface is perpendicular to the surface. If the electric field ***E*** had a component parallel to the surface, that component would produce an electric force on a charge placed on the surface. This force would do work on the charge as it moved from one point to another, in contradiction to the definition of an equipotential surface.

Capacitance

A capacitor is a device used in a variety of electric circuits - for example, to tune the frequency of radio receivers, eliminate sparking in automobile ignition systems, or store short-term energy for rapid release in electronic flash units. A capacitor consists of two parallel metal plates separated by a distance **d**. Used in an electric circuit, the plates are connected to the positive and negative terminals of a battery or some other voltage source. When this connection is made, electrons are pulled off one of the plates, leaving it with a charge of **+ Q**, and are transferred through the battery to the other plate, leaving it with a charge of **– Q**. The transfer of charge stops when the potential difference across the plates equals the potential difference of the battery. A charged capacitor is a device that stores energy that can be reclaimed when needed for a specific application.

The capacitance of a capacitor is the ratio of the magnitude of the charge on either conductor (plate) to the magnitude of the potential difference between the conductors (plates). SI Unit: farad (F) = coulomb per volt (C/V).

Energy stored in a charged capacitor

Almost everyone who works with electronic equipment has at some time verified that a capacitor can store energy. If the plates of a charged capacitor are connected by a conductor such as a wire, charge transfers from one plate to the other until the two are uncharged. The discharge can often be observed as a visible spark. If you accidentally touched the opposite plates of a charged capacitor, your fingers would act as a pathway by which the capacitor could discharge, inflicting an electric shock. The degree of shock would depend on the capacitance and voltage applied to the capacitor. Where high voltages and large quantities of charge are present, as in the power supply of a television set, such a shock can be fatal.

Capacitors with dielectrics

A dielectric is an insulating material, such as rubber, plastic, or waxed paper. When a dielectric is inserted between the plates of a capacitor, the capacitance increases. If the dielectric completely fills the space between the plates, the capacitance is multiplied by the factor κ, called the dielectric constant.

1. What's the difference between potential difference and electric potential?
2. The electric field of a point charge extends throughout space. What about its electric potential?
3. Formulate the superposition principle.
4. What's the potential difference between any two points on equipotential surface?
5. Where do we use a capacitor?
6. Why dielectric is used in capacitor?

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Эквипотенциалы	*potentialsequi*
Емкость	*citancecapa*
Конденсатор	*citorcapa*
Электропровод	*rewi*
Зажим, клемма	*minalter*

2. Match the words in A with the words in B to form word combinations:

A	B
Potential	*charge*
Point	*surfaces*
Equipotential	*difference*
Superposition	*potential*
Dielectric	*principle*
Low	*strength*

3. Fill in the gaps with the missing words from the list:

capacitance ,electric potential energy, charged conductor, equipotentials, electric potential

1. _____ differs significantly from gravitational potential energy, however, in that there are two kinds of electrical charge - positive and negative - whereas gravity has only positive "gravitational charge" (i.e. mass).
2. _____ is characteristic the field only, independent of a test charge that may be placed in that field.
3. All points on the surface of a _____ in electrostatic equilibrium are at the same potential.
4. The _____ of a point charge are a family of spheres centre on the point charge.
5. The equivalent _____ of a parallel combination of capacitors is greater than any of the individual capacitances.

UNIT 17
CURRENT AND RESISTANCE

Read the following texts. Study the thesaurus on fig. 17, answer the questions after the texts

Many practical applications and devices are based on the principles of static electricity, but electricity was destined to become an inseparable part of our daily lives when scientists learned how to produce a continuous flow of charge for relatively long periods of time using batteries. The battery or voltaic cell was invented in 1800 by the Italian physicist Alessandro Volta. Batteries supplied a continuous flow of charge at low potential, in contrast to earlier electrostatic devices that produced a tiny flow of charge at high potential for brief periods. This steady source of electric current allowed scientists to perform experiments to learn how to control the flow of electric charges in circuits. Today, electric currents power our lights, radios, television sets, air conditioners, computers, and refrigerators. They ignite the gasoline in automobile engines, travel through miniature components making up the chips of microcomputers, and provide the power for countless other invaluable tasks.

Electric current

If charges move in a direction perpendicular to a surface, the current is the rate at which charge flows through this surface. One ampere of current is equivalent to one coulomb of charge passing through the cross-sectional area in a time interval of 1 s. The direction of conventional current used in this book is the direction positive charges flow. (This historical convention originated about 200 years ago, when the ideas of positive and negative charges were introduced.) In a common conductor such as copper, the current is due to the motion of negatively charged electrons, so the direction of the current is opposite the direction of motion of the electrons. On the other hand, for a beam of positively-charged protons in an accelerator, the current is in the same direction as the motion of the protons. In some cases - gases and electrolytes, for example - the current is the result of the flows of both positive and negative charges. Moving charges, whether positive or negative, are referred to as charge carriers. In a metal, for example, the charge carriers are electrons.

In electrostatics, where charges are stationary, the electric potential is the same everywhere in a conductor. This is no longer true for conductors carrying current: as charges move along a wire, the electric potential is continually decreasing (except in the special case of superconductors). The phrases flow of current and current flow are commonly used, but here the word flow is redundant because current is already defined as a flow (of charge). Avoid this construction!

Current and drift speed

Macroscopic currents can be related to the motion of the microscopic charge carriers making up the current. It turns out that current depends on the average speed of the charge carriers in the direction of the current, the number of charge carriers per unit volume, and the size of the charge carried by each.

If the carriers move with a constant average speed, it called the drift speed. To understand the meaning of drift speed, consider a conductor in which the charge carriers are free electrons. If the conductor is isolated, these electrons undergo random motion similar to the motion of the molecules of a gas. The drift speed is normally much smaller than the free electrons' average speed between collisions with the fixed atoms of the conductor. When a potential difference is applied between the ends of the conductor (say, with a battery), an electric field is set up in the conductor, creating an electric force on the electrons and hence a current. In reality, the electrons don't simply move in straight lines along the conductor. Instead, they undergo repeated collisions with the atoms of the metal, and the result is a complicated zigzag motion with only a small average drift speed along the wire. The energy transferred from the electrons to the metal atoms during a collision increases the vibrational energy of the atoms and causes a corresponding increase in the temperature of the conductor.

Current and voltage measurements in circuits

To study electric current in circuits, we need to understand how to measure currents and voltages. The circuit consists of only a battery and a light-bulb. The word "circuit" means "a closed loop" of some sort around which current circulates. The battery pumps charge through the bulb and around the loop. No charge would flow without a complete conducting path from the positive terminal of the battery into one side of the bulb, out the other side, and through the copper conducting wires back to the negative terminal of the battery. To measure the current in the bulb, we place an ammeter, the device for measuring current, in line with the bulb so there is no path for the current to bypass the meter; all of the charge passing through the bulb must also pass through the ammeter. The voltmeter measures the potential difference, or voltage, between the two ends of the bulb's filament.

Resistance and Ohm's law

When a voltage (potential difference) is applied across the ends of a metallic conductor the current in the conductor is found to be proportional to the applied voltage. The proportionality constant R is called the resistance of the conductor. Resistance has SI units of volts per ampere, called ohms.

Current and Resistance	*Electric current*	*Voltaic cell*	*Electric potential*	*Volt(V)*
			Steady source	*Ampere(A)*
		Charge carriers	*Direction of conventional current*	*Direction positive charges*
			Average speed of the charge carriers	*Drift speed*
		Circuit	*Potential difference*	*Voltage*
			Closed loop	
			Light-bulb	*Bulb*
				Filament
			Battery	
			Ammeter	
			Voltmeter	
	Resistance	*Ohm's law*	*Resistor*	*Ohm(Ω,omega)*
				Ohmic
				Nonohmic
			Resistivity	*Critical temperature*
				Superconductors
	Electrical energy	*Power*	*Kilowatt-hour(kWh)*	

Fig. 17. **Thesaurus for Unit 17**

The concepts of electric current, voltage, and resistance can be compared with the flow of water in a river. As water flows downhill in a river of constant width and depth, the flow rate (water current) depends on the steepness of descent of the river and the effects of rocks, the riverbank, and other obstructions. The voltage difference is analogous to the steepness, and the resistance to the obstructions. Based on this analogy, it seems reasonable that increasing the voltage applied to a circuit should increase the current in the circuit, just as increasing the steepness of descent increases the water current. Also, increasing the obstructions in the river's path will reduce the water current, just as increasing the resistance in a circuit will lower the electric current. Resistance in a circuit arises due to collisions between the electrons carrying the current with fixed atoms inside the conductor. For many materials, including most metals, experiments show that the resistance remains constant over a wide range of applied voltages or currents. This statement is known as Ohm's law.

Ohm's law is an empirical relationship valid only for certain materials. Materials that obey Ohm's law, and hence have a constant resistance over a wide range of voltages, are said to be ohmic. Materials having resistance that changes with voltage or current are nonohmic.

Electrons don't move in straight-line paths through a conductor. Instead, they undergo repeated collisions with the metal atoms. The resistance of an ohmic conductor increases with length, which makes sense because the electrons going through it must undergo more collisions in a longer conductor. A smaller cross-sectional area also increases the resistance of a conductor, just as a smaller pipe slows the fluid moving through it. The resistance is proportional to the conductor's length and inversely proportional to its cross-sectional area, the constant of proportionality is called the resistivity. The resistivity $\boldsymbol{\rho}$, and hence the resistance, of a conductor depends on a number of factors. One of the most important is the temperature of the metal. For most metals, resistivity increases with increasing temperature.

There is a class of metals and compounds with resistances that fall virtually to zero below a certain temperature called the critical temperature. These materials are known as superconductors.

Electrical energy and power

If a battery is used to establish an electric current in a conductor, chemical energy stored in the battery is continuously transformed into kinetic energy of the charge carriers. This kinetic energy is quickly lost as a result of collisions between the charge carriers and fixed atoms in the conductor, causing an increase in the temperature of the conductor. In this way, the chemical energy stored in the battery is continuously transformed into thermal energy.

Regardless of the ways in which you use electrical energy in your home, you ultimately must pay for it or risk having your power turned off. The unit of energy used by electric companies to calculate consumption, the kilowatt-hour, is denned in terms of the unit of power and the amount of time it's supplied.

1. What did the Italian physicist Alessandro Volta invent?
2. Why do we need electric currents ?
3. How do electrons move in conductor?
4. What do we need to measure the current in the bulb?
5. What materials do we call ohmic and nonohmic?
6. For what purpose do we use kilowatt-hour?

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Цепь	*cuitcir*
Амперметр	*meteram*
Сопротивление	*sistancere*
Удельное сопротивление	*retivitysis*
Нить накаливания	*mentfila*

2. Match the words in A with the words in B to form word combinations:

A	B
Steady	*loop*
Drift	*energy*
Ohm’s	*temperature*
Critical	*source*
Electrical	*speed*
Closed	*law*

3. Fill in the gaps with the missing words from the list:
resistor, drift velocity, resistance, superconductors, battery

1. Despite the collisions the electrons move slowly along the conductor with the ______.
2. The ______ does not provide electrons to the circuit; it provides energy to the existing electrons.
3. After Georg Simon Ohm (1789-1854) was the first to conduct a systematic study of electrical ______.
4. A ______ is a conductor that provides a specified resistance in an electric circuit.
5. Today thousands of ______ are known, including such common metals as aluminum, tin, lead, zinc, and indium.

UNIT 18
DIRECT-CURRENT CIRCUITS

Read the following texts. Study the thesaurus on fig. 18, answer the questions after the texts

Batteries, resistors, and capacitors can be used in various combinations to construct electric circuits, which direct and control the flow of electricity and the energy it conveys. Such circuits make possible all the modern conveniences in a home - electric lights, electric stove tops and ovens, washing machines, and a host of other appliances and tools. Electric circuits are also found in our cars, in tractors that increase farming productivity, and in all types of medical equipment that saves so many lives every day.

The analysis of the number of simple direct-current circuits is simplified by the use of two rules known as Kirchhoff's rules, which follow from the principle of conservation of energy and the law of conservation of charge. Most of the circuits are assumed to be in steady state, which means that the currents are constant in magnitude and direction.

Sources of emf

A current is maintained in a closed circuit by a source of emf. Among such sources are any devices (for example, batteries and generators) that increase the potential energy of the circulating charges. A source of emf can be thought of as a "charge pump" that forces electrons to move in a direction opposite the electrostatic field inside the source. The emf в of a source is the work done per unit charge; hence the SI unit of emf is the volt.

The terminal voltage when the current is zero, called the open-circuit voltage. Terminal voltage also equal the potential difference across the external resistance, often called the load resistance. The current in simple circuit depends on both the resistance external to the battery and the internal resistance of the battery. We will assume in our examples and problems that the internal resistance of a battery in a circuit is negligible.

Resistors in series

When two or more resistors are connected end to end, they are said to be in series. The resistors could be simple devices, such as light-bulbs or heating elements. Regardless of how many resistors we have in series, the sum of the potential differences across the resistors is equal to the total potential difference across the combination. The equivalent resistance of a series combination of resistors is the algebraic sum of the individual resistances and is always greater than any individual resistance.

Resistors in parallel

Now consider two resistors connected in parallel. In this case, the potential differences across the resistors are the same because each is connected directly across the battery terminals. The potential drop must be the same for the two resistors and must also equal the potential drop across the battery.

Kirchhoff's rules

We can analyze simple circuits using Ohm's law and the rules for series and parallel combinations of resistors. However, there are many ways in which resistors can be connected so that the circuits formed can't be reduced to a single equivalent resistor. The procedure for analyzing more complex circuits can be facilitated by the use of two simple rules called Kirchhoff's rules.

RC-circuits

So far, we have been concerned with circuits with constant currents. We now consider direct-current circuits containing capacitors, in which the currents vary with time. We assume that the capacitor is initially uncharged with the switch opened. After the switch is closed, the battery begins to charge the plates of the capacitor and the charge passes through the resistor. As the capacitor is being charged, the circuit carries a changing current. The charging process continues until the capacitor is charged to its maximum equilibrium value. Once the capacitor is fully charged, the current in the circuit is zero. If we assume that the capacitor is uncharged before the switch is closed, and if the switch is closed at t = 0, we find that the charge on the capacitor varies with time.

Household circuits are a practical application of some of the ideas presented in this Unit. In a typical installation, the utility company distributes electric power to individual houses with a pair of wires, or power lines. Electrical devices in a house are then connected in parallel to these lines. The potential difference between the two wires is about 120V. (These currents and voltages are actually alternating currents and voltages, but for the present discussion we will assume that they are direct currents and voltages.) One of the wires is connected to ground, and the other wire, sometimes called the "hot" wire, is at a potential of 120V. A meter and a circuit breaker (or a fuse) are connected in series with the wire entering the house. In modern homes, circuit breakers are used in place of fuses.

Many heavy-duty appliances, such as electric ranges and clothes dryers, require 240V to operate. The power company supplies this voltage by providing, in addition to a live wire that is 120 V above ground potential, another wire, also considered live, that is 120V below ground potential . Therefore, the potential drop across the two live wires is 240V. An appliance operating from a 240V line requires half the current of one operating from a 120-V line; consequently, smaller wires can be used in the higher-voltage circuit without becoming overheated.

Electrical safety

A person can be electrocuted by touching a live wire (which commonly is live because of a frayed cord and exposed conductors) while in contact with ground. The ground contact might be made by touching a water pipe (which is normally at ground potential) or by standing on the ground with wet feet, because impure water is a good conductor. Obviously, such situations should be avoided at all costs. Electric shock can result in fatal burns, or it can cause the muscles of vital organs, such as the heart, to malfunction. As an additional safety feature for consumers, electrical equipment manufacturers now use electrical cords that have a third wire, called a case ground.

Special power outlets called ground-fault interrupters (GFIs) are now being used in kitchens, bathrooms, basements, and other hazardous areas of new homes. They are designed to protect people from electrical shock by sensing small currents - approximately 5 mA and greater - leaking to ground.

Direct-Current Circuits	*Flow of electricity*	*Electric lights*		
		Household circuits	*Electric stove tops*	*Electric stove ovens*
		Heavy-duty appliances	*Electric ranges*	*Electric clothes dryers*
	Emf(electromotive force)	*Batteries*		
		Generators		
		Terminal voltage	*Open-circuit voltage*	
			Load resistance	
	Ohm's law	*Resistors in series*	*Equivalent resistance*	
		Resistors in parallel	*Potential drop*	
	Kirchhoffs	*Complex DC circuits*		
	RC-circuits	*Switch*	*Charging process*	*Maximum equilibrium value*
		Electrical safety	*Live wire*	*Exposed conductor*
				Hot wire
				Case ground
				Circuit breaker(Fuse)
				Ground-fault interrupters
			Neurons	*Action potentials*
				Firing threshold

Fig. 18. **Thesaurus for Unit 18**

Conduction of electrical signals by neurons

The most remarkable use of electrical phenomena in living organisms is found in the nervous system of animals. Specialized cells in the body called neurons forma complex network that receives, processes, and transmits information from one part of the body to another. The center of this network is located in the brain, which has the ability to store and analyze information. On the basis of this information, the nervous system controls parts of the body.

The nervous system is highly complex and consists of about 10^{10} interconnected neurons. Some aspects of the nervous system are well known. Over the p 45 years, the method of signal propagation through the nervous system has been established. The messages transmitted by neurons are voltage pulses called action potentials. When a neuron receives a strong enough stimulus, it produces identical voltage pulses that are actively propagated along its structure. The strength of the stimulus is conveyed by the number of pulses produced. When the pulses reach the end of the neuron, they activate either muscle cells or other neurons. There is a "firing threshold" for neurons: action potentials propagate along a neuron only if the stimulus is sufficiently strong.

1. Where do we use electric circuits?
2. What is emf?
3. Resistors in series or in parallel. What does it mean?
4. What rules are called Kirchhoff's rules?
5. What elements do RC-circuits contain?
6. What devices are used for electrical safety?
7. What is the most remarkable use of electrical phenomena in living organisms?

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Электродвижущая сила	*fmE*
RC-цепи	*CRcuit-scir*
Плавкий предохранитель	*sefu*
Безопасность	*satyfe*
Переключатель	*tchswi*

2. Match the words in A with the words in B to form word combinations:

A	B
Open-circuit	*rules*
Kirchhoff's	*wire*
Live	*breaker*
Case	*voltage*
Circuit	*conductor*
Exposed	*ground*

3. Fill in the gaps with the missing words from the list:

equivalent resistor, neurons, time constant, circuit breaker, emf

1. If we neglect the internal resistance of the battery, the potential drop across the battery (the terminal voltage) equals the _____ of the battery.
2. The _____ has the same effect on the circuit because it results in the same current in the circuit as the two resistors.
3. It's important to note that a capacitor charges very slowly in a circuit with a long _____, whereas it charges very rapidly in a circuit with a short time constant.
4. The wire and _____ are carefully selected to meet the current demands of a circuit.
5. _____ can be divided into three classes: sensory neurons, motor neurons, and interneurons.

UNIT 19
MAGNETISM

Read the following texts. Study the thesaurus on fig. 19, answer the questions after the texts

In terms of applications, magnetism is one of the most important fields in physics. Large electromagnets are used to pick up heavy loads. Magnets are used in such devices as meters, and loudspeakers. Magnetic tapes and disks are used routinely in sound- and video-recording equipment and to store computer data. Intense magnetic fields are used in magnetic resonance imaging (MRI) devices to explore the human body with better resolution and greater safety than x-rays can provide. Giant superconducting magnets are used in the cyclotrons that guide particles into targets at nearly the speed of light, and magnetic bottles hold anti-matter, possibly the key to future space propulsion systems.

Magnetism is closely linked with electricity. Magnetic fields affect moving charges, and moving charges produce magnetic fields. Changing magnetic fields can even create electric fields. These phenomena signify an underlying unity of electricity and magnetism, which James Clerk Maxwell first described in the 19th century. The ultimate source of any magnetic field is electric current.

Magnets

Most people have had experience with some form of magnet. You are most likely familiar with the common iron horseshoe magnet that can pick up iron-containing objects such as paper clips and nails. In the discussion that follows, we assume the magnet has the shape of a bar. Iron objects are most strongly attracted to either end of such a bar magnet, called its poles. One end is called the north pole and the other the south pole. The names come from the behavior of a magnet in the presence of Earth's magnetic field. If a bar magnet is suspended from its midpoint by a piece of string so that it can swing freely in a horizontal plane, it will rotate until its north pole points to the north and its south pole points to the south. The same idea is used to construct a simple compass. Magnetic poles also exert attractive or repulsive forces on each other similar to the electrical forces between charged objects. In fact, simple experiments with two bar magnets show that like poles repel each other and unlike poles attract each other.

Although the force between opposite magnetic poles is similar to the force between positive and negative electric charges, there is an important difference: positive and negative electric charges can exist in isolation of each other; north and south poles don't. No matter how many times a permanent magnet is cut, each piece always has a north pole and a south pole. There is some theoretical basis for the speculation that magnetic monopoles (isolated north or south poles) exist in nature, and the attempt to detect them is currently an active experimental field of investigation.

An unmagnetized piece of iron can be magnetized by stroking it with a magnet. Magnetism can also be induced in iron (and other materials) by other means. For example, if a piece of unmagnetized iron is placed near a strong permanent magnet, the piece of iron eventually becomes magnetized. The process can be accelerated by heating and then cooling the iron.

Naturally occurring magnetic materials such as magnetite are magnetized in this way because they have been subjected to Earth's magnetic field for long periods of time. The extent to which a piece of material retains its magnetism depends on whether it is classified as magnetically hard or soft. Soft magnetic materials, such as iron, are easily magnetized, but also tend to lose their magnetism easily. In contrast, hard magnetic materials, such as cobalt and nickel, are difficult to magnetize, but tend to retain their magnetism.

Forensic scientists use a technique similar to find fingerprints at a crime scene. One way to find latent, or invisible, prints is by sprinkling a powder of iron dust on a surface. The iron adheres to any perspiration or body oils that are present and can be spread around on the surface with a magnetic brush that never comes into contact with the powder or the surface.

Earth’s magnetic field

A small bar magnet is said to have north and south poles, but it's more accurate to say it has a "north-seeking" pole and a "south-seeking" pole. By these expressions, we mean that if such a magnet is used as a compass, one end will "seek," or point to, the geographic North Pole of Earth and the other end will "seek," or point to, the geographic South Pole of Earth. We conclude that the geographic North Pole of Earth corresponds to a magnetic south pole, and the geographic South Pole of Earth corresponds to a magnetic north pole.

If a compass needle is suspended in bearings that allow it to rotate in the vertical plane as well as in the horizontal plane, the needle is horizontal with respect to Earth's surface only near the equator. As the device is moved northward, the needle rotates so that it points more and more toward the surface of Earth. The angle between the direction of the magnetic field and the horizontal is called the dip angle.

There is some evidence that the strength of a planet's magnetic field is related to the planet's rate of rotation. For example, Jupiter rotates faster than Earth, and recent space probes indicate that Jupiter's magnetic field is stronger than Earth's, even though Jupiter lacks an iron core. Venus, on the other hand, rotates more slowly than Earth, and its magnetic field is weaker. Investigation into the cause of Earth's magnetism continues.

Magnetic fields

Experiments show, that a stationary charged particle doesn't interact with a static magnetic field. When a charged particle is moving through a magnetic field, however, a magnetic force acts on it. This force has its maximum value when the charge moves in a direction perpendicular to the magnetic field lines, decreases in value at other angles, and becomes zero when the particle moves along the field lines. This is quite different from the electric force, which exerts a force on a charged particle whether it's moving or at rest. Further, the electric force is directed parallel to the electric field while the magnetic force on a moving charge is directed perpendicular to the magnetic field.

The SI unit of magnetic field is the tesla (T), also called the weber (Wb) per square meter. To determine the direction of the magnetic force, we employ the right-hand rule.

If a magnetic field exerts a force on a single charged particle when it moves through a magnetic field, it should be no surprise that magnetic forces are exerted on a current-carrying wire. This follows from the fact that the current is a collection of many charged particles in motion; hence, the resultant force on the wire is due to the sum of the individual forces on the charged particles. The force on the particles is transmitted to the "bulk" of the wire through collisions with the atoms making up the wire.

During a lecture demonstration in 1819, the Danish scientist Hans Oersted (1777-1851) found that an electric current in a wire deflected a nearby compass needle. This momentous discovery, linking a magnetic field with an electric current for the first time, was the beginning of our understanding of the origin of magnetism.

A simple experiment first carried out by Oersted in 1820 clearly demonstrates that a current-carrying conductor produces a magnetic field. In this experiment, several compass needles are placed in a horizontal plane near a long vertical wire. When there is no current in the wire, all needles point in the same direction (that of Earth's field), as one would expect. However, when the wire carries a strong, steady current, the needles all deflect in directions tangent to the circle. These observations show that the direction of magnetic field **B** is consistent with the following convenient rule, right-hand rule number: Point the thumb of your right hand along a wire in the direction of positive current. Your fingers then naturally curl in the direction of the magnetic field **B**.

Magnetism	*Magnets*	*Large electro-magnets*	*Giant superconducting magnets*	*Propulsion*
		Magnetic devices	*Meters*	
			Loudspeakers	
			Magnetic resonance imaging	*Magnetic tapes*
				Magnetic disks
		Bar magnet	*Permanent magnet*	*North pole*
				South pole
		Like poles	*Unlike poles*	
		Magnetized magnetic material	*Soft magnetic materials*	
			Hard magnetic materials	
			Forensic scientists	*Crime scene*
		Right-hand rule	*Dip angle*	*Weber*
		Magnetic force	*Current-carrying conductor*	*Magnetic field of a long*
				Electrics motor
			Straight wire	*Ampere's law*
			Current loop	*Ampere's circuital law*
				Solenoid
			Magnetic field line	*Tesla (T)*
		Magnetic properties	*Spin magnetic moment*	
			Ferromagnetic	*Magnetic domains*

Fig. 19. **Thesaurus for Unit 19**

A general procedure for deriving equations to calculate the magnetic field due to a long, straight wire carrying a current was proposed by the French scientist Andre-Marie Ampere (1775-1836); it provides a relation between the current in an arbitrarily shaped wire and the magnetic field produced by the wire.

Magnetic force between two parallel conductors

A magnetic force acts on a current-carrying conductor when the conductor is placed in an external magnetic field. Because a conductor carrying a current creates a magnetic field around itself, it is easy to understand that two current-carrying wires placed close together exert magnetic forces on each other. Parallel conductors carrying currents in the same direction attract each other parallel conductors carrying currents in opposite directions repel each other.

Magnetic fields of current loops and solenoids

The strength of the magnetic field set up by a piece of wire carrying a current can be enhanced at a specific location if the wire is formed into a loop. If a long, straight wire is bent into a coil of several closely spaced loops, the resulting device is a solenoid, often called an electromagnet. This device is important in many applications because it acts as a magnet only when it carries a current.

Magnetic domains

The magnetic field produced by a current in a coil of wire gives us a hint as to what might cause certain materials to exhibit strong magnetic properties. The magnetic properties of many materials can be explained by the fact that an electron not only circles in an orbit, but also spins on its axis like a top, with spin magnetic moment. In atoms containing many electrons, the electrons usually pair up with their spins opposite each other, so that their fields cancel each other. That is why most substances are not magnets. However, in certain strongly magnetic materials, such as iron, cobalt, and nickel, the magnetic fields produced by the electron spins don't cancel completely. Such materials are said to be ferromagnetic. In ferromagnetic materials, strong coupling occurs between neighboring atoms, forming large groups of atoms with spins that are aligned. Called domains, the sizes of these groups typically range from about $10\sim^{4}$ cm to 0.1 cm.

1. Where do we use magnets?
2. How can you describe magnets?

3. What do we mean by saying a "north-seeking" pole and a "south-seeking" pole?
4. What do we need to determine the direction of the magnetic force?
5. What magnetic field affects charged particle?
6. What do you know about the experiment carried out by Oersted in 1820?

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Измерительные приборы	*Metres*
Магнит	*netmag*
Соленоид	*idnosole*
Ферромагнетик	*magneticferro*
Домены	*mainsdo*

2. Match the words in A with the words in B to form word combinations:

A	B
Magnetic	*conductor*
North	*wire*
Straight	*magnet*
Like	*field line*
Permanent	*pole*
Current-carrying	*poles*

3. Fill in the gaps with the missing words from the list:

magnetized magnetic material, magnetic field line, magnetic force, magnetic south pole, right-hand rule

1. A magnetic field also surrounds a properly _____.
2. The magnetic field of a bar magnet can be traced with the aid of a compass, defining a _____.
3. The north pole of a magnet in a compass points north because it's attracted to the Earth's _____ - located near the Earth's geographic north pole.

4. The total _____ on the wire is the sum of all the magnetic forces on the individual charges producing the current.

5. Application of the _____ at any point shows that the magnetic force is always directed toward the center of the circular path.

UNIT 20
INDUCED VOLTAGES AND INDUCTANCE

Read the following texts. Study the thesaurus on fig. 20, answer the questions after the texts

In 1819, Hans Christian Oersted discovered that an electric current exerted a force on a magnetic compass. Although there had long been speculation that such a relationship existed, Oersted's finding was the first evidence of a link between electricity and magnetism. Because nature is often symmetric, the discovery that electric currents produce magnetic fields led scientists to suspect that magnetic fields could produce electric currents. Indeed, experiments conducted by Michael Faraday in England and independently by Joseph Henry in the United States in 1831 showed that a changing magnetic field could induce an electric current in a circuit. The results of these experiments led to a basic and important law known as Faraday's law.

Induced emf and magnetic flux

An experiment first conducted by Faraday demonstrated that a current can be produced by a changing magnetic field. The apparatus consists of a coil connected to a switch and a battery. We will refer to this coil as the primary coil and to the corresponding circuit as the primary circuit. The coil is wrapped around an iron ring to intensify the magnetic field produced by the current in the coil. A second coil, at the right, is wrapped around the iron ring and is connected to an ammeter. This is called the secondary coil, and the corresponding circuit is called the secondary circuit. It's important to notice that there is no battery in the secondary circuit.

At first glance, you might guess that no current would ever be detected in the secondary circuit. However, when the switch in the primary circuit is suddenly closed, something amazing happens: the ammeter measures a current in the secondary circuit and then returns to zero! When the switch is opened again, the ammeter reads a current in the opposite direction an again returns to zero. Finally, whenever there is a steady current in the primal circuit, the ammeter reads zero. From observations such as these, Faraday concluded that an electric current could be produced by a changing magnetic field.

In order to evaluate induced emfs quantitatively, we need to understand what factors affect the phenomenon. While changing magnetic fields always induce electric fields, there are also situations in which the magnetic field remains constant, yet an induced electric field is still produced. The best example of this is an electric generator: A loop of conductor rotating in a constant magnetic field creates an electric current.

The physical quantity associated with magnetism that creates an electric field is a changing magnetic flux. SI unit: weber (Wb).

Faraday's law of induction

The usefulness of the concept of magnetic flux can be made obvious by another simple experiment that demonstrates the basic idea of electromagnetic induction. If a magnet is moved toward the loop, the ammeter reads a current in one direction. If the magnet is moved away from the loop, the ammeter reads a current in the opposite direction. If the magnet is held stationary and the loop is moved either toward or away from the magnet, the ammeter also reads a current. From these observations, it can be concluded that a current is set up in the circuit as long as there is relative motion between the magnet and the loop. The same experimental results are found whether the loop moves or the magnet moves. We call such a current an induced current, because it is produced by an induced emf.

In each case, an emf is induced in a circuit when the magnetic flux through the circuit changes with time. It turns out that the instantaneous emf induced in a circuit equals the negative of the rate of change of magnetic flux with respect to time through the circuit. This is Faraday's law of magnetic induction.

The polarity determines which of two different directions current will flow in a loop, a direction given by Lenz's law**:** The current caused by the induced emf travels in the direction that creates a magnetic field with flux opposing the change in the original flux through the circuit.

<table>
<tr><td rowspan="14">Induced Voltages and Inductance</td><td rowspan="2">Changing magnetic field</td><td rowspan="2">Induced current</td><td rowspan="2">Induced emf</td><td>Primary coil</td><td></td></tr>
<tr><td>Secondary coil</td><td></td></tr>
<tr><td rowspan="8">Faraday's law</td><td rowspan="3">Magnetic flux</td><td>Weber(Wb)</td><td></td><td></td></tr>
<tr><td>Electromagnetic induction</td><td>Lenz's law</td><td></td></tr>
<tr><td>Motional emf</td><td>Commercial generators</td><td></td></tr>
<tr><td rowspan="5">Electric generator</td><td rowspan="3">Alternating-current (AC) generator</td><td>Wire loop</td><td></td></tr>
<tr><td>Hydroelectric plant</td><td>Blades of a turbine</td></tr>
<tr><td>Coal-fired plant</td><td>Slip rings</td></tr>
<tr><td rowspan="2">Direct current (DC) generator</td><td>Split- ring</td><td></td></tr>
<tr><td>Commutator</td><td></td></tr>
<tr><td rowspan="4">Self-induction</td><td>Inductance</td><td>Henry (H)</td><td></td><td></td></tr>
<tr><td rowspan="3">Opposing induced emf</td><td rowspan="3">Self-induced emf</td><td rowspan="2">Inductance of a coil</td><td>Inductor</td></tr>
<tr><td>RL-circuits</td></tr>
<tr><td>Energy stored by an inductor</td><td></td></tr>
</table>

Fig. 20. **Thesaurus for Unit 20**

Generators

Generators and motors are important practical devices that operate on the principle of electromagnetic induction. The alternating-current (AC) generator is a device that converts mechanical energy to electrical energy. In its simplest form, the AC generator consists of a wire loop rotated in a magnetic field by some external means. In commercial power plants, the energy required to rotate the loop can be derived from a variety of sources. For example, in a hydroelectric plant, falling water directed against the blades of a turbine produces the rotary motion; in a coal-fired plant, heat produced by burning coal is used to convert water to steam, and this steam is directed against the turbine blades. As the loop rotates, the magnetic flux through it changes with time, inducing an emf and a current in an external circuit. The ends of the loop are connected to slip rings that rotate with the loop.

The components of the direct current (DC) generator are essentially the same as those of the AC generator, except that the contacts to the rotating loop are made by a split ring, or commutator. A pulsating DC current is not suitable for most applications. To produce a steady DC current, commercial DC generators use many loops and commutators distributed around the axis of rotation so that the sinusoidal pulses from the loops overlap in phase. When these pulses are superimposed, the DC output is almost free of fluctuations.

Self-induction

When the switch is closed, the current doesn't immediately change from zero to its maximum value. The law of electromagnetic induction - Faraday's law - prevents this. What happens instead is the following: as the current increases with time, the magnetic flux through the loop due to this current also increases. The increasing flux induces an emf in the circuit that opposes the change in magnetic flux. The net potential difference across the resistor is the emf of the battery minus the opposing induced emf As the magnitude of the current increases, the rate of increase lessens and hence the induced emf decreases. This opposing emf results in a gradual increase in the current. For the same reason, when the switch is opened, the current doesn't immediately fall to zero. This effect is called self-induction because the changing flux through the circuit arises from the circuit itself. The emf that is set up in the circuit is called a self-induced emf.

The inductance of a coil depends on the cross-sectional area of the coil and other quantities, all of which can be grouped under the general heading of geometric factors. The SI unit of inductance is the henry (H).

A circuit element that has a large inductance, such as a closely wrapped coil of many turns, is called an inductor. The circuit symbol for an inductor is RL. The emf induced by an inductor prevents a battery from establishing an instantaneous current in a circuit. The battery has to do work to produce a current. We can think of this needed work as energy stored in the inductor in its magnetic field.

1. What did Hans Christian Oersted discovered in 1819?
2. What did Faraday concluded from his obswervations?
3. Describe the experiment demonstrating the main idea of electromagnetic induction.
4. What components is alternating-current generator consist of?
5. Could you explain the phenomenon of self-induction?

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Индуктивность	*ducintance*
Самоиндукция	*inductionself*
RL-цепи	*cuCirits-LR*
Коммутатор	*torcommuta*
Индуктор	*ductorin*

2. Match the words in A with the words in B to form word combinations:

A	B
Magnetic	*plant*
Coal-fired	*emf*
Alternating-current	*flux*
Self-induced	*coil*
Induced	*generator*
Secondary	*current*

3. Fill in the gaps with the missing words from the list:

commercial generators, induced emf, magnetic flux, self-induced emf, Lenz's law

1. An _____ is produced in the secondary circuit by the changing magnetic field.
2. The value of the _____ is proportional to the total number of lines passing through the loop.
3. _____ says that if the magnetic flux through a loop is becoming more positive, say, then the induced emf creates a current and associated magnetic field that produces negative magnetic flux.
4. In the United States and Canada the frequency of rotation for _____ is 60 Hz, whereas in some European countries 50 Hz is used.
5. The _____ must be proportional to the rate of change of the current with time.

UNIT 21
ALTERNATING CURRENT CIRCUITS AND ELECTROMAGNETIC WAVES

Read the following texts. Study the thesaurus on fig. 21, answer the questions after the texts

Every time we turn on a television set, a stereo system, or any of a multitude of other electric appliances, we call on alternating currents (AC) to provide the power to operate them. We begin our study of AC circuits by examining the characteristics of a circuit containing a source of emf and one other circuit element: a resistor, a capacitor, or an inductor. Then we examine what happens when these elements are connected in combination with each other. Our discussion is limited to simple series configurations of the three kinds of elements.

We conclude this Unit with a discussion of electromagnetic waves, which are composed of fluctuating electric and magnetic fields. Electromagnetic waves in the form of visible light enable us to view the world around us; infrared waves warm our environment; radio-frequency waves carry our television and radio programs, as well as information about processes in the core of our galaxy. X-rays allow us to perceive structures hidden inside our bodies, and study properties of distant, collapsed stars. Light is key to our understanding of the universe.

Resistors in an AC circuit

An AC circuit consists of combinations of circuit elements and an AC generator or an AC source, which provides the alternating current. To explain the concept of alternating current, we begin by discussing the current-versus-time curve. The current and voltage are in step with each other because they vary identically with time. Because the current and the voltage reach their maximum values at the same time, they are said to be in phase. Notice that the average value of the current over one cycle is zero. This is because the current is maintained in one direction (the positive direction) for the same amount of time and at the same magnitude as it is in the opposite direction (the negative direction). However, the direction of the current has no effect on the behavior of the resistor in the circuit: the collisions between electrons and the fixed atoms of the resistor result in an increase in the resistor's temperature regardless of the direction of the current.

The important quantity in an AC circuit is a special kind of average value of current, called the rms current - the direct current that dissipates the same amount of energy in a resistor that is dissipated by the actual alternating current. To find the rms current, we first square the current, then find its average value, and finally take the square root of this average value. Hence, the rms current is the square root of the average (mean) of the square of the current. In this Unit we use rms values when discussing alternating currents and voltages. One reason is that AC ammeters and voltmeters are designed to read rms values. Further, if we use rms values, many of the equations for alternating current will have the same form as those used in the study of direct-current (DC) circuits.

Capacitors in an AC circuit

To understand the effect of a capacitor on the behavior of a circuit containing an AC voltage source, we first review what happens when a capacitor is placed in a circuit containing a DC source, such as a battery. When the switch is closed in a series circuit containing a battery, a resistor, and a capacitor, the initial charge on the plates of the capacitor is zero. The motion of charge through the circuit is therefore relatively free, and there is a large current in the circuit. As more charge accumulates on the capacitor, the voltage across it increases, opposing the current. After some time interval, which depends on the time constant RC, the current approaches zero. Consequently, a capacitor in a DC circuit limits or impedes the current so that it approaches zero after a brief time.

At high frequency, there is less time available to charge the capacitor, so less charge and voltage accumulate on the capacitor, which translates into less opposition to the flow of charge and, consequently, a higher current. The analogy between capacitive reactance and resistance means that we can write an equation of the same form as Ohm's law to describe AC circuits containing capacitors.

Inductors in an AC circuit

Now consider an AC circuit consisting only of an inductor connected to the terminals of an AC source. The changing current output of the generator produces a back emf that impedes the current in the circuit. The effective resistance of the coil in an AC circuit is measured by a quantity called the inductive reactance. This occurs because back emfs always oppose the change in the current.

The RLC series circuit

We now consider when an inductor, a capacitor, and a resistor are combined. To account for the different phases of the voltage drops, we use a technique involving vectors. We represent the voltage across each element with a rotating vector. It's convenient to define a parameter called the impedance **Z** of the circuit. Both the impedance and, therefore, the current in an AC circuit depend on the resistance, the inductance, the capacitance, and the frequency (because the reactances are frequency dependent).

Power in an AC circuit

No power losses are associated with pure capacitors and pure inductors in an AC circuit. A pure capacitor, by definition, has no resistance or inductance, while a pure inductor has no resistance or capacitance. These are idealizations: in a real capacitor, for example, inductive effects could become important at high frequencies.

The power delivered by an AC source to any circuit depends on the phase difference between the source voltage and the resulting current. This fact has many interesting applications. For example, factories often use devices such as large motors in machines, generators, and transformers that have a large inductive load due to all the windings. To deliver greater power to such devices without using excessively high voltages, factory technicians introduce capacitance in the circuits to shift the phase.

Resonance in a series RLC circuit

The rms current in a series RLC has its maximum value when the impedance has its minimum value. In such a circumstance, the impedance of the circuit reduces to **Z = R**. The frequency at which this happens is called the resonance frequency of the circuit.

The tuning circuit of a radio is an important application of a series resonance circuit. The radio is tuned to a particular station (which transmits a specific radio-frequency signal) by varying a capacitor, which changes the resonance frequency of the tuning circuit. When this resonance frequency matches that of the incoming radio wave, the current in the tuning circuit increases.

The transformer

It's often necessary to change a small AC voltage to a larger one or vice versa. Such changes are effected with a device called a transformer. In its simplest form, the AC transformer consists of two coils of wire wound around a core of soft iron. The purpose of the common iron core is to increase the magnetic flux and to provide a medium in which nearly all the flux through one coil passes through the other.

Maxwell's predictions

During the early stages of their study and development, electric and magnetic phenomena were thought to be unrelated. In 1865, however, James Clerk Maxwell (1831-1879) provided a mathematical theory that showed a close relationship between all electric and magnetic phenomena. In addition to unifying the formerly separate fields of electricity and magnetism, his brilliant theory predicted that electric and magnetic fields can move through space as waves.

From Faraday's law and from Maxwell's own generalization of Ampere's law, Maxwell calculated the speed of the waves to be equal to the speed of light. He concluded that visible light and other electromagnetic waves consist of fluctuating electric and magnetic fields traveling through empty space, with each varying field inducing the other! This was truly one of the greatest discoveries of science, on a par with Newton's discovery of the laws of motion. Like Newton's laws, it had a profound influence on later scientific developments.

In 1887, after Maxwell's death, Heinrich Hertz (1857-1894) was the first to generate and detect electromagnetic waves in a laboratory setting, using LC circuits.

Alternating Current Circuits and Electromagnetic Waves	*AC circuits*	*AC generator*	*AC source*	
		Rms (root mean square) values	*Rms current*	*Average of the square of the current*
				Square root
			Rms voltage	
		Resistors in an AC circuit		
		Capacitors in an AC circuit	*Initial charge*	*Time constant RC*
		Inductors in an AC circuit	*Inductive coil*	*Inductor*
			Back emf	
			Inductive reactance	
		The RLC series circuit	*Impedance*	*Reactance*
	Power in an AC circuit	*Pure capacitor*		
		Pure inductor	*Windings*	
		Phase difference		
	Resonance	*Resonance circuit*		
	Transformer	*Iron core*		
	Electromagnetic wave	*Electromagnetic spectrum*	*Radio waves*	*Antenna*
			Infrared waves	
			Visible light	
			Ultraviolet (UV) light	
			X-rays	
			Gamma rays	

Fig. 21. **Thesaurus for Unit 21**

The spectrum of electromagnetic waves

It is now known that other forms of electromagnetic waves exist that are distinguished by their frequencies and wavelengths. Brief descriptions of the wave types follow, in order of decreasing wavelength. There is no sharp division between one kind of electromagnetic wave and the next. All forms of electromagnetic radiation are produced by accelerating charges.

Radio waves are the result of charges accelerating through conducting wires. They are, of course, used in radio and television communication systems.

Microwaves (short-wavelength radio waves) are generated by electronic devices. Their short wavelengths make them well suited for the radar systems used in aircraft navigation and for the study of atomic and molecular properties of matter.

Infrared waves produced by hot objects and molecules. They are readily absorbed by most materials. Infrared radiation has many practical and scientific applications, including physical therapy, infrared photography, and the study of the vibrations of atoms.

Visible light, the most familiar form of electromagnetic waves, may be defined as the part of the spectrum that is detected by the human eye. Light is produced by the rearrangement of electrons in atoms and molecules.

Ultraviolet (UV) light covers wavelengths ranging from about 400 nm down 0.6 nm. The Sun is an important source of ultraviolet light. Most of the ultraviolet light from the Sun is absorbed by atoms in the upper atmosphere, or stratosphere. This is fortunate, because UV light in large quantities has harmful effects on humans.

X-rays are electromagnetic waves with wavelengths from about 10 nm down to $10{\sim}^{4}$nm. The most common source of x-rays is the acceleration of high-energy electrons bombarding a metal target. X-rays are used as a diagnostic tool in medicine and as a treatment for certain forms of cancer.

Gamma rays – electromagnetic waves emitted by radioactive nuclei – have wavelengths ranging from about $10{\sim}^{10}$m to less than $10{\sim}^{14}$m. They are highly penetrating and cause serious damage when absorbed by living tissues. Accordingly, those working near such radiation must be protected by garments.

1. Would an inductor and a capacitor used together in an AC circuit dissipate any energy?
2. What is the important quantity in an AC circuit?
3. Describe the role of capacitor in AC circuit.

4. How a transformer is constructed?
5. What do you know about Maxwell's predictions?
6. Who was the first to generate and detect electromagnetic waves in a laboratory setting, using LC circuits?

Exercises

3. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Резонанс	*nancereso*
Трансформатор	*formertrans*
Обмотки	*dingswin*
Микроволны	*wavesmicro*
Сердечник (железный)	*reco*

2. Match the words in A with the words in B to form word combinations:

A	B
Rms	*spectrum*
Inductive	*waves*
Electromagnetic	*current*
Infrared	*light*
Visible	*capacitor*
Pure	*reactance*

3. Fill in the gaps with the missing words from the list:

electromagnetic wave, inductive coil, transformer, rms current, antenna

1. The ______ is the square root of the average (mean) of the square of the current.
2. In any real circuit, there is some resistance in the wire forming the ______.
3. It may seem that a ______ is a device in which it is possible to get something for nothing.
4. An alternating voltage applied to the wires of an ______ forces electric charges in the antenna to oscillate.
5. A detailed analysis would show that the energy carried by an ______ is shared equally by the electric and magnetic fields.

PART V

Light and Optics

UNIT 22
REFLECTION AND REFRACTION OF LIGHT

Read the following texts. Study the thesaurus on fig. 22, answer the questions after the texts

Light has a dual nature. In some experiments it acts like a particle, while in others it acts like a wave. In this part of the book, we concentrate on the aspects of light that are best understood through the wave model. First we discuss the reflection of light at the boundary between two media and the refraction (bending) of light as it travels from one medium into another. We use these ideas to study the refraction of light as it passes through lenses and the reflection of light from mirrored surfaces. Finally, we describe how lenses and mirrors can be used to view objects with telescopes and microscopes and how lenses are used in photography. The ability to manipulate light has greatly enhanced our capacity to investigate and understand the nature of the universe.

The nature of light

Until the beginning of the 19th century, light was modeled as a stream of particles emitted by a source that stimulated the sense of sight on entering the eye. The chief architect of the particle theory of light was Newton. With this theory, he provided simple explanations of some known experimental facts concerning the nature of light-namely, the laws of reflection and refraction.

Most scientists accepted Newton's particle theory of light. During Newton's lifetime, however, another theory was proposed. In 1678, the Dutch physicist and astronomer Christian Huygens (1629-1695) showed that a wave theory of light could also explain the laws of reflection and refraction. The wave theory didn't receive immediate acceptance, for several reasons. First, all the waves known at the time (sound, water, and so on) traveled through some sort of medium, but light from the Sun could travel to Earth through empty space. Further, it was argued that if light were some form of wave, it would bend around obstacles; hence, we should be able to see around corners. It is now known that light does indeed bend around the edges of objects. This phenomenon, known as diffraction, is difficult to observe because light waves have such short wavelengths. Even though experimental evidence for the diffraction of light was discovered by Francesco Grimaldi (1618-1663) around 1660, for more than a century most scientists rejected the wave theory and adhered to Newton's particle theory, probably due to Newton's great reputation as a scientist.

The first clear demonstration of the wave nature of light was provided in 1801 by Thomas Young (1773-1829), who showed that under appropriate conditions, light exhibits interference behavior. Light waves emitted by a single source and traveling along two different paths can arrive at some point and combine and cancel each other by destructive interference. Such behavior couldn't be explained at that time by a particle model, because scientists couldn't imagine how two or more particles could come together and cancel each other. The most important development in the theory of light was the work of Maxwell, who predicted in 1865, that light was a form of high-frequency electromagnetic wave.

Although the classical theory of electricity and magnetism explained most known properties of light, some subsequent experiments couldn't be explained by the assumption that light was a wave. The most striking of these was the photoelectric effect, discovered by Hertz. Hertz found that clean metal surfaces emit charges when exposed to ultraviolet light.

In 1905, Einstein published a paper that formulated the theory of light quanta ("particles") and explained the photoelectric effect. He reached the conclusion that light was composed of corpuscles, or discontinuous quanta of energy. These corpuscles or quanta are now called photons to emphasize their particle-like nature. According to Einstein's theory, the energy of a photon is proportional to the frequency of the electromagnetic wave associated with it, or: $E=hf$, where h - is Planck's constant.

Reflection and refraction

An important property of light that can be understood based on common experience is the following: light travels in a straight-line path in a homogeneous medium, until it encounters a boundary between two different materials. When light strikes a boundary, it is either reflected from that boundary, passes into the material on the other side of the boundary, or partially does both.

The preceding observation leads us to use what is called the ray approximation to represent beams of light. For example, a beam of sunlight passing through a darkened room traces out the path of a light ray. We will also make use of the concept of wave fronts of light. A wave front is a surface passing through the points of a wave that have the same phase and amplitude. The rays, corresponding to the direction of wave motion, are straight lines perpendicular to the wave fronts. When light rays travel in parallel paths, the wave fronts are planes perpendicular to the rays.

When a light ray traveling in a transparent medium encounters a boundary leading into a second medium, part of the incident ray is reflected back into the first medium. The reflected rays are parallel to each other. The reflection of light from such a smooth surface is called specular reflection. Reflection from any rough surface is known as diffuse reflection.

You may have noticed a common occurrence in photographs of individuals: their eyes appear to be glowing red. This occurs when a photographic flash device is used and the flash unit is close to the camera lens. Light from the flash unit enters the eye and is reflected back along its original path from the retina. This type of reflection back along the original direction is called retroreflection.

When light passes from one transparent medium to another, it's refracted because the speed of light is different in the two media. The index of refraction, $\boldsymbol{n}$, of a medium is defined as the ratio $\boldsymbol{c/v}$, where $\boldsymbol{c}$ – is speed of light in vacuum, $\boldsymbol{v}$ – is speed of light in a medium. If we make careful measurements, however, we find that the index of refraction in anything but vacuum depends on the wavelength of light. The dependence of the index of refraction on wavelength is called dispersion.

When light strikes a prism, a ray of light of a single wavelength emerges bent away from its original direction of travel by an angle, called the angle of deviation. Prisms are often used in an instrument known as a prism spectrometer. The dispersion of light into a spectrum is demonstrated most vividly in nature through the formation of a rainbow, often seen by an observer positioned between the Sun and a rain shower.

Reflection and Refraction of Light	*Dual nature*	*Particle-like nature*		
		Wave nature	*Diffraction*	
			Interference	
		Theory of light quanta	*Photoelectric effect*	
			Photons	*Planck's constant*
	Reflection	*Medium*	*Ray approximation*	
			Wave front	*Phase*
				Amplitude
		Specular reflection	*Angle of incidence*	
		Diffuse reflection		
		Retroreflection	*Flash device*	
	Refraction	*Index of refraction*		
		Dispersion	*Angle of deviation*	*Prism spectrometer*
				Rainbow
	Huygens' principle	*Wavelets*		
	Total internal reflection	*Higher index of refraction*		
		Lower index of refraction		
		Light pipe		

Fig. 22. **Thesaurus for Unit 22**

Huygens' principle

The laws of reflection and refraction can be deduced using a geometric method proposed by Huygens in 1678. Huygens assumed that light is a form of wave motion rather than a stream of particles. He had no knowledge of the nature of light or of its electromagnetic character. Nevertheless, his simplified wave model is adequate for understanding many practical aspects of the propagation of light.

In Huygens' construction, all points on a given wave front are taken as point sources for the production of spherical secondary waves, called wavelets, which propagate in the forward direction with speeds characteristic of waves in that medium. After some time has elapsed, the new position of the wave front is the surface tangent to the wavelets.

Total internal reflection

An interesting effect called total internal reflection can occur when light encounters the boundary between a medium with a higher index of refraction and one with a lower index of refraction. Total internal reflection occurs only when light attempts to move from a medium of higher index of refraction to a medium of lower index of refraction.

Interesting application of total internal reflection is the use of solid glass or transparent plastic rods to "pipe" light from one place to another. Such a light pipe can be quite flexible if thin fibers are used rather than thick rods. If a bundle of parallel fibers is used to construct an optical transmission line, images can be transferred from one point to another. Very little light intensity is lost in these fibers as a result of reflections on the sides. Any loss of intensity is due essentially to reflections from the two ends and absorption by the fiber material. Fiber-optic devices are particularly useful for viewing images produced at inaccessible locations. Physicians often use fiber-optic cables to aid in the diagnosis and correction of certain medical problems without the intrusion of major surgery.

1. Why does light have a dual nature?
2. What was the contribution of the Dutch physicist and astronomer Christian Huygens into the theory of light?
3. Describe the first clear demonstration of the wave nature of light provided in 1801 by Thomas Young.
4. What is the energy of a photon according to Einstein's theory?
5. What is retroreflection?
6. Where the effect of total internal reflection is used?

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Отражение	*lectionref*
Преломление	*fractionre*
Дифракция	*fractiondif*
Интерференция	*ferenceinter*
Дисперсия	*persiondis*

2. Match the words in A with the words in B to form word combinations:

A	B
Particle-like	*reflection*
Specular	*refraction*
Wave	*nature*
Index of	*pipe*
Light	*devices*
Fiber-optic	*front*

3. Fill in the gaps with the missing words from the list:
reflection, dual nature, refraction, index of refraction, angle of incidence

1. Light must be regarded as having a _____: in some experiments light acts as a wave and in others it acts as a particle.
2. In _____, part of the light encountering the second medium bounces off that medium.
3. In _____, the light passing into the second medium bends through an angle with respect to the normal to the boundary.
4. Experiments show that the angle of reflection equals the _____.
5. The _____ is inversely proportional to the wave speed.

UNIT 23
MIRRORS AND LENSES

Read the following texts. Study the thesaurus on fig. 23, answer the questions after the texts

The development of the technology of mirrors and lenses led to a revolution in the progress of science. These devices, relatively simple to construct from cheap materials, led to microscopes and telescopes, extending human sight and opening up new pathways to knowledge, from microbes to distant planets.

This Unit covers the formation of images when plane and spherical light waves fall on plane and spherical surfaces. Images can be formed by reflection from mirrors or by refraction through lenses. In our study of mirrors and lenses, we continue to assume that light travels in straight lines (the ray approximation), ignoring diffraction.

Flat mirrors

Consider the flat mirror. Light rays leave the source and are reflected from the mirror. Regardless of the system under study, images are formed at the point where rays of light actually intersect or where they appear to originate. Images are classified as real or virtual. In the formation of a real image, light actually passes through the image point. For a virtual image, the light doesn't pass through the image point, but appears to come (diverge) from there. In fact, the images seen in flat mirrors are always virtual (for real objects). Real images can be displayed on a screen (as at a movie), but virtual images cannot.

Finally, note that a flat mirror produces an image having an apparent left-right reversal. You can see this reversal standing in front of a mirror and raising your right hand. Your image in the mirror raises his left hand. Likewise, your hair appears to be parted on the opposite side, and a mole on your right cheek appears to be on your image's left cheek..

Images formed by spherical mirrors

A spherical mirror, as its name implies, has the shape of a segment of a sphere. A spherical mirror with a silvered inner, concave surface, is called a concave mirror. After reflecting from the mirror, rays converge to meet at point, called the image point. The rays then continue and diverge from this point as if there were an object there. As a result, a real image is formed. Whenever reflected light actually passes through a point, the image formed there is real.

Mirrors and Lenses	*Flat mirrors*	*Object distance*		
		Image of the object	*Image distance*	
		Real image	*Virtual image*	*Magnification*
				Enlargement
				Lateral magnification
			Left-right reversal	
	Spherical mirrors	*Concave mirror*	*Principal axis*	*Image point*
			Mirror equation	*Halfway*
		Focal point	*Focal length*	
		Convex mirror	*Front side*	
			Back side	
		Ray diagrams		
		Atmospheric refraction	*Mirage*	
	Thin lens	*Converging lenses*	*Positive lens*	
		Diverging lenses	*Negative lens*	
		Thin-lens equation		
	Imperfect images	*Spherical aberration*		
		Chromatic aberration		

Fig. 23. **Thesaurus for Unit 23**

We often assume that all rays that diverge from the object make small angles with the principal axis. Rays that make a large angle with the principal axis converge to other points on the principal axis, producing a blurred image. This effect, called spherical aberration, is present to some extent with any spherical mirror.

A convex mirror is silvered so that light is reflected from the outer, convex surface. This is sometimes called a diverging mirror because the rays from any point on the object diverge after reflection, as though they were coming from some point behind the mirror.

We won't derive any equations for convex spherical mirrors. If we did, we would find that the equations developed for concave mirrors can be used with convex mirrors if particular sign conventions are used. We call the region in which light rays move the front side of the mirror, and the other side, where virtual images are formed, the back side.

We can conveniently determine the positions and sizes of images formed by mirrors by constructing ray diagrams. This kind of graphical construction tells us the overall nature of the image and can be used to check parameters calculated from the mirror and magnification equations. Making a ray diagram requires knowing the position of the object and the location of the center of curvature.

Thin lens

A typical thin lens consists of a piece of glass or plastic, ground so that each of its two refracting surfaces is a segment of either a sphere or a plane. Lenses are commonly used to form images by refraction in optical instruments, such as cameras, telescopes, and microscopes. The equation that relates object and image distances for a lens is virtually identical to the mirror equation, and the method used to derive it is also similar.

The distance from the focal point to the lens is called the focal length. The focal length is the image distance that corresponds to an infinite object distance. Recall that we are considering the lens to be very thin. As a result, it makes no difference whether we take the focal length to be the distance from the focal point to the surface of the lens or the distance from the focal point to the center of the lens, because the difference between these two lengths is negligible. A thin lens has two focal points, one on each side of the lens. One focal point corresponds to parallel rays traveling from the left and the other corresponds to parallel rays traveling from the right.

Note that a converging lens has a positive focal length under this convention and a diverging lens has a negative focal length. Hence the names positive and negative are often given to these lenses.

Lens and mirror aberrations

One of the basic problems of systems containing mirrors and lenses is the imperfect quality of the images, which is largely the result of defects in shape and form. The simple theory of mirrors and lenses assumes that rays make small angles with the principal axis and that all rays reaching the lens or mirror from a point source are focused at a single point, producing a sharp image. This is not always true in the real world. Where the approximations used in this theory do not hold, imperfect images are formed.

The departures of real (imperfect) images from the ideal predicted by the simple theory are called aberrations. Two common types of aberrations are spherical aberration and chromatic aberration. Spherical aberration results from the fact that the focal points of light rays passing far from the principal axis of a spherical lens (or mirror) are different from the focal points of rays with the same wavelength passing near the axis. Chromatic aberration for a diverging lens is opposite that for a converging lens. Chromatic aberration can be greatly reduced by a combination of converging and diverging lenses.

1. What devices do mirrors use?
2. Explain how does a flat mirror produce an image?
3. What kinds of spherical mirrors do you know?
4. What equations developed for concave mirrors can be used for convex ones?
5. In what devices thin lenses are used?
6. Why one of the basic problems of systems containing mirrors and lenses is the imperfect quality of the images?
7. What are the two common types of aberrations?

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Зеркала	*rorsmir*
Линзы	*seslen*
Усиление	*ficationmagni*
Увеличение	*largementen*
Фокус	*Calfo ntipo*

2. Match the words in A with the words in B to form word combinations:

A	B
Real	*reversal*
Concave	*lenses*
Convex	*image*
Chromatic	*mirror*
Diverging	*aberration*
Left-right	*mirror*

3. Fill in the gaps with the missing words from the list:

ray diagrams, magnification, thin-lens equation, image, focal point

1. The _____ formed by an object placed in front of a flat mirror is as far behind the mirror as the object is in front of the mirror.
2. Note that the word _____, as used in optics, doesn't always mean enlargement, because the image could be smaller than the object.
3. The _____ is not the point at which light rays focus to form an image, the focal point of a mirror is determined solely by its curvature - it doesn't depend on the location of any object.
4. The equation, called the _____, can be used with both converging and diverging lenses if we adhere to a set of sign conventions.
5. _____ are essential for understanding the overall image formation by a thin lens or a system of lenses.

UNIT 24
WAVE OPTICS

Read the following texts. Study the thesaurus on fig. 24, answer the questions after the texts

Colors swirl on a soap bubble as it drifts through the air on a summer day, and vivid rainbows reflect from the filth of oil films in the puddles of a dirty city street. Beachgoers, covered with thin layers of oil, wear their coated sunglasses that absorb half the incoming light. In laboratories, scientists determine the precise composition of materials by analyzing the light they give off when hot, and in observatories around the world, telescopes gather light from distant galaxies, filtering out individual wavelengths in bands and thereby determining the speed of expansion of the universe.

Understanding how these rainbows are made and how certain scientific instruments can determine wavelengths is the domain of wave optics. Light can be viewed as either a particle or a wave. Geometric optics, the subject of the previous Unit, depends on the particle nature of light. Wave optics depends on the wave nature of light. The three primary topics we examine in this Unit are interference, diffraction, and polarization. These phenomena can't be adequately explained with ray optics, but can be understood if light is viewed as a wave.

Conditions for interference

In our discussion of interference of mechanical waves in Unit 13, we found that two waves could add together either constructively or destructively. In constructive interference, the amplitude of the resultant wave is greater than that of either of the individual waves, whereas in destructive interference, the resultant amplitude is less than that of either individual wave. Light waves also interfere with each other. Fundamentally, all interference associated with light waves arises when the electromagnetic fields that constitute the individual waves combine.

Two sources (producing two traveling waves) are needed to create interference. To produce a stable interference pattern, the individual waves must maintain a constant phase with one another. When this situation prevails, the sources are said to be coherent. The sound waves emitted by two side-by-side loudspeakers driven by a single amplifier can produce interference because the two speakers respond to the amplifier in the same way at the same time - they are in phase.

If two light sources are placed side by side, however, no interference effects are observed, because the light waves from one source are emitted independently of the waves from the other source; hence, the emissions from the two sources don't maintain a constant phase relationship with each other during the time of observation. The result is that no interference effects are observed, because the eye can't follow such short-term changes. Ordinary light sources are said to be incoherent.

Currently it's much more common to use a laser as a coherent source to demonstrate interference. A laser produces an intense, coherent, monochromatic beam over a width of several millimeters. This means that the laser may be used to illuminate multiple slits directly and that interference effects can be easily observed in a fully lighted room.

Thomas Young first demonstrated interference in light waves from two sources in 1801. Light is incident on a screen containing a narrow slit. The light waves emerging from this slit arrive at a second screen that contains two narrow, parallel slits. These slits serve as a pair of coherent light sources because waves emerging from them originate from the same wave front and therefore are always in phase. The light from the two slits produces a visible pattern on screen consisting of a series of bright and dark parallel bands called fringes.

Another simple, yet ingenious, arrangement for producing an interference pattern with a single light source is known as Lloyd's mirror.

Interference in thin films

Interference effects are commonly observed in thin films, such as the thin surface of a soap bubble or thin layers of oil on water. The varied colors observed when incoherent white light is incident on such films result from the interference of waves reflected from the two surfaces of the film.

Another method for observing interference in light waves is to place a planoconvex lens on top of a flat glass surface. With this arrangement, the air film between the glass surfaces varies in thickness from zero at the point of contact to some value. The circular fringes, discovered by Newton, are called Newton's rings**.**

Compact disks (CD's) and digital video disks (DVD's) have revolutionized the computer and entertainment industries by providing fast access; high-density storage of text, graphics, and movies; and high-quality sound recordings. The data on these disks are stored digitally as a series of zeros and ones, and these zeros and ones are read by laser light reflected from the disk. Strong reflections (constructive interference) from the disk are chosen to represent zeros and weak reflections (destructive interference) represent ones.

<table>
<tr><td rowspan="18">Wave Optics</td><td rowspan="9">Inter-ference effects</td><td rowspan="5">Coherent urces</td><td>Constant phase</td><td>Interference pattern</td></tr>
<tr><td rowspan="2">Resultant amplitude</td><td>Destructive interference</td></tr>
<tr><td>Constructive interference</td></tr>
<tr><td>Laser</td><td>Illuminate multiple slits</td></tr>
<tr><td colspan="2">Monochromatic beam</td></tr>
<tr><td>Incoherent sources</td><td></td><td></td></tr>
<tr><td>Young's double-slit experiment</td><td>Fringes</td><td>Lloyd's mirror</td></tr>
<tr><td rowspan="2">Thin films</td><td>Newton's rings</td><td>Plano-convex lens</td></tr>
<tr><td>Compact disks (CD's)</td><td>Digital video disks (DVD's)</td></tr>
<tr><td>Diffraction</td><td>Fraunhofer diffraction</td><td>Path</td><td>Diffraction grating</td></tr>
<tr><td rowspan="8">Polari-zation</td><td>Transverse nature</td><td>Unpolarized wave</td><td>Superposition of waves</td></tr>
<tr><td colspan="2">Linearly polarized</td><td></td></tr>
<tr><td rowspan="3">Selective absorption</td><td rowspan="3">Polaroid</td><td>Polarizer</td></tr>
<tr><td>Analyzer</td></tr>
<tr><td>Malus's law</td></tr>
<tr><td>Polarization by Reflection</td><td>Polarizing angle</td><td>Brewster's law</td></tr>
<tr><td>Scattering</td><td>Reradiation</td><td></td></tr>
<tr><td>Optical activity</td><td>Liquid crystals</td><td>LCD’s(liquid crystal displays)</td></tr>
</table>

Fig. 24. **Thesaurus for Unit 24**

Diffraction

Suppose a light beam is incident on two slits, as in Young's double-slit experiment. If the light truly traveled in straight-line paths after passing through the slits, the waves wouldn't overlap and no interference pattern would be seen. Instead, Huygens's principle requires that the waves spread out from the slits. In other words, the light bends from a straight-line path and enters the region that would otherwise be shadowed. This spreading out of light from its initial line of travel is called diffraction.

One type of diffraction, called Fraunhofer diffraction, occurs when the rays leave the diffracting object in parallel directions. Fraunhofer diffraction can be achieved experimentally either by placing the observing screen far from the slit or by using a converging lens to focus the parallel rays on a nearby screen.

The diffraction grating, a useful device for analyzing light sources, consists of a large number of equally spaced parallel slits. A grating can be made by scratching parallel lines on a glass plate with a precision machining technique. The clear panes between scratches act like slits. A typical grating contains several thousand lines per centimeter.

Polarization of light waves

In Unit 21, we described the transverse nature of electromagnetic waves. The phenomenon of polarization, described in this Unit, is firm evidence of the transverse nature of electromagnetic waves. An ordinary beam of light consists of a large number of electromagnetic waves emitted by the atoms or molecules of the light source. The vibrating charges associated with the atoms act as tiny antennas. Each atom produces a wave with its own orientation, corresponding to the direction of atomic vibration. However, because all directions of vibration are possible, the resultant electromagnetic wave is a superposition of waves produced by the individual atomic sources. The result is an unpolarized light wave.

It's possible to obtain a linearly polarized beam from an unpolarized beam by removing all waves from the beam except those with electric field vectors that oscillate in a single plane. The most common technique for polarizing light is to use a material that transmits waves having electric field vectors that vibrate in a plane parallel to a certain direction and absorbs those waves with electric field vectors vibrating in directions perpendicular to that direction.

In 1932, E. H. Land discovered a material, which he called Polaroid, that polarizes light through selective absorption by oriented molecules.

This material is fabricated in thin sheets of long-chain hydrocarbons, which are stretched during manufacture so that the molecules align.

Polarizing material reduces the intensity of light passing through it. An unpolarized light beam is incident on the first polarizing sheet, called the polarizer. The light that passes through this sheet is polarized vertically. A second polarizing sheet, called the analyzer, intercepts this beam with its transmission axis at an angle to the axis of the polarizer. The expression, known as Malus's law, applies to any two polarizing materials having transmission axes at an angle to each other.

When an unpolarized light beam is reflected from a surface, the reflected light is completely polarized, partially polarized, or unpolarized, depending on the angle of incidence. For angles of incidence between 0° and 90°, however, the reflected light is polarized to some extent. For one particular angle, called the polarizing angle, of incidence the reflected beam is completely polarized. An expression relating the polarizing angle with the index of refraction of the reflecting surface is called Brewster's law.

When light is incident on a system of particles, such as a gas, the electrons in the medium can absorb and reradiate part of the light. The absorption and reradiation of light by the medium, called scattering, is what causes sunlight reaching an observer on Earth from straight overhead to be polarized. You can observe this effect by looking directly up through a pair of sunglasses made of polarizing glass.

Optical Activity

Many important practical applications of polarized light involve the use of certain materials that display the property of optical activity. A substance is said to be optically active if it rotates the plane of polarization of transmitted light. Optical activity occurs in a material because of an asymmetry in the shape of its constituent molecules. For example, some proteins are optically active because of their spiral shapes. Other materials, such as glass and plastic, become optically active when placed under stress.

An effect similar to rotation of the plane of polarization is used to create the familiar displays on pocket calculators, wristwatches, notebook computers, and so forth. The properties of a unique substance called a liquid crystal make these displays (called LCD's, for liquid crystal displays) possible. As its name implies, a liquid crystal is a substance with properties intermediate between those of a crystalline solid and those of a liquid; that is, the molecules of the substance are more orderly than those in a liquid, but less orderly than those in a pure crystalline solid.

1. How it's necessary to consider light to explain the phenomena of interference, diffraction and polarization?
2. What do we need to create destructive interference?
3. What is used as coherent source?
4. How do zeroes and ones are presented on CD's and DVD's?
5. What do we call Fraunhofer diffraction?
6. How it's possible to obtain a linearly polarized beam?

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Интерференционная полоса	*gefrin*
Траектория	*thpa*
Поляризация	*zationpolari*
Источник	*resuoc*
Рассеивание	*teringscat*

2. Match the words in A with the words in B to form word combinations:

A	B
Destructive	*lens*
Thin	*grating*
Plano-convex	*wave*
Diffraction	*films*
Selective	*interference*
Unpolarized	*absorption*

3. Fill in the gaps with the missing words from the list:

diffraction, path difference, coherent sources, unpolarized, interference effects

1. Any random change in the light emitted by the source will occur in the two separate beams at the same time, and _____ can be observed.
2. . If the _____ is either zero or some integral multiple of the wavelength, the two waves are in phase and constructive interference results.
3. The positions of the dark and bright fringes are reversed relative to the pattern obtained from two real _____.
4. In general, _____ occurs when waves pass through small openings, around obstacles, or by sharp edges.
5. If the angle of incidence is either 0° or 90° (a normal or grazing angle), the reflected beam is _____.

UNIT 25
OPTICAL INSTRUMENTS

Read the following texts. Study the thesaurus on fig. 25, answer the questions after the texts

We use devices made from lenses, mirrors, or other optical components every time we put on a pair of eyeglasses or contact lenses, take a photograph, look at the sky through a telescope, and so on. In this Unit we examine how these and other optical instruments work. For the most part, our analyses will involve the laws of reflection and refraction and the procedures of geometric optics. To explain certain phenomena, however, we must use the wave nature of light.

The camera

The single-lens photographic camera is a simple optical instrument. It consists of an opaque box, a converging lens that produces a real image, and a film behind the lens to receive the image. Focusing is accomplished by varying the distance between lens and film - with an adjustable bellows in antique cameras and with some other mechanical arrangements in contemporary models. For proper focusing, which leads to sharp images, the lens-to-film distance depends on the object distance as well as on the focal length of the lens. The shutter, located behind the lens, is a mechanical device that is opened for selected time intervals. With this arrangement, moving objects can be photographed by using short exposure times, dark scenes (with low light levels) by using long exposure times. If this adjustment were not available, it would be impossible to take stop-action photographs. A rapidly moving vehicle, for example, could move far enough while the shutter was open to produce a blurred image. Another major cause of blurred images is movement of the camera while the shutter is open. To prevent such movement, you should mount the camera on a tripod or use short exposure times.

Most cameras also have an aperture of adjustable diameter to further control the intensity of the light reaching the film. When an aperture of small diameter is used, only light from the central portion of the lens reaches the film, so spherical aberration is reduced. The brightness of the image formed on the film depends on the light intensity, so we see that it ultimately depends on both the focal length and diameter of the lens. The ratio the focal length and diameter is called the focal ratio of a lens.

The eye

Like a camera, a normal eye focuses light and produces a sharp image. However, the mechanisms by which the eye controls the amount of light admitted and adjusts to produce correctly focused images are far more complex, intricate, and effective than those in even the most sophisticated camera. In all respects, the eye is a physiological wonder. The eye focuses on an object by varying the shape of the pliable crystalline lens through an amazing process called accommodation.

When the eye suffers a mismatch between the focusing power of the lens-cornea system and the length of the eye so that light rays reach the retina before they converge to form an image, the condition is known as farsightedness (or hyperopia). A farsighted person can usually see faraway objects clearly but not nearby objects. The condition can be corrected by placing a converging lens in front of the eye.

Nearsightedness (or myopia) is another mismatch condition in which a person is able to focus on nearby objects, but not faraway objects. Nearsightedness can be corrected with a diverging lens. The lens refracts the rays away from the principal axis before they enter the eye, allowing them to focus on the retina.

In the eye defect known as astigmatism, light from a point source produces a line image on the retina. This condition arises when either the cornea or the lens (or both) are not perfectly symmetric. Astigmatism can be corrected with lenses having different curvatures in two mutually perpendicular directions.

Optometrists and ophthalmologists usually prescribe lenses measured in diopters.

Optical Instruments	*Camera*	*Single-lens photographic camera*	*Converging lens*	*Adjustable bellows*
				Tripod
		Focusing	*Sharp images*	*Exposure time*
				Shutter
			Blurred images	*Adjustment*
		Aperture	*Spherical aberration*	
			Brightness	
			Focal ratio	
	Eye	*Physiological wonder*	*Cornea*	
			Retina	
		Accommodation	*Farsightedness*	*Lens-cornea*
			Nearsightedness	*Diverging lens*
			Astigmatism	
			Eyeglasses	*Diopter(dpt)*
	Simple magnifier	*Angular magnification*	*Angle subtended*	
	Compound microscope	*Objective*		
		Ocular lens	*Eyepiece*	
	Telescope	*Refracting telescope*	*Curved mirror*	
		Reflecting telescope		
	Michelson interferometer			

Fig. 25. **Thesaurus for Unit 25**

The simple magnifier

The simple magnifier is one of the most basic of all optical instruments because it consists only of a single converging lens. As the name implies, this device is used to increase the apparent size of an object. Clearly, the size of the image formed at the retina depends on the angle subtended by the object at the eye. As the object moves closer to the eye, angle increases and a larger image is observed. The lens allows the object to be viewed closer to the eye than is possible without the lens.

The compound microscope

Greater magnification can be achieved by combining two lenses in a device called a compound microscope. The instrument consists of two lenses: an objective with a very short focal length (< 1 cm), and an ocular lens, or eyepiece, with a focal length of a few centimeters. The basic approach used to analyze the image formation properties of a microscope is that of two lenses in a row: the image formed by the first becomes the object for the second.

The microscope has extended our vision into the previously unknown realm of incredibly small objects, and the capabilities of this instrument have increased steadily with improved techniques in precision grinding of lenses. A natural question is whether there is any limit to how powerful a microscope could be. For example, could a microscope be made powerful enough to allow us to see an atom? The answer to this question is no, as long as visible light is used to illuminate the object. In order to be seen, the object under a microscope must be at least as large as a wavelength of light. An atom is many times smaller than the wavelength of visible light, so its mysteries must be probed via other techniques.

The telescope

There are two fundamentally different types of telescope, both designed to help us view distant objects such as the planets in our Solar System. These two types are (1) the refracting telescope, which uses a combination of lenses to form an image, and (2) the reflecting telescope, which uses a curved mirror and a lens to form an image. Once again, we will be able to analyze the telescope by considering it to be a system of two optical elements in a row. As before, the basic technique followed is that the image formed by the first element becomes the object for the second.

The largest optical telescopes in the world are the two 10-m-diameter Keck reflectors on Mauna Kea in Hawaii. The largest single-mirrored reflecting telescope in the United States is the 5-m-diameter instrument on

Mount Palomar in California. In contrast, the largest refracting telescope in the world, at the Yerkes Observatory in Williams Bay, Wisconsin, has a diameter of only 1 m.

The Michelson interferometer

The Michelson interferometer is an optical instrument having great scientific importance. Invented by the American physicist A. A. Michelson (1852-1931), it is an ingenious device that splits a light beam into two parts and then recombines them to form an interference pattern. The interferometer is used to make accurate length measurements.

1. What are the components of the single-lens photographic camera?
2. How can we prevent blurred images?
3. How the varying of the shape of the pliable crystalline of eye is called?
4. Where do we use the simple magnifier?
5. Describe how a compound microscope works.
6. Why does the Michelson interferometer have great scientific importance?

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Затвор	*tershut*
Диафрагма	*tureaper*
Аберрация	*rationaber*
Яркость	*nessbright*
Диоптрии	*tersdiop*

2. Match the words in A with the words in B to form word combinations:

A	B
Sharp	*magnifier*
Exposure	*lens*
Simple	*images*
Angular	*subtended*
Angle	*time*
Ocular	*magnification*

3. Fill in the gaps with the missing words from the list:

refracting telescope, retina, cameras, optical microscope, simple magnifier

1. Simple _____ usually have a fixed focal length and fixed aperture size.
2. The cornea-lens system focuses light onto the back surface of the eye - the _____ - which consists of millions of sensitive receptors.
3. A _____ provides only limited assistance with inspection of the minute details of an object.
4. The ability of an _____ to view an object depends on the size of the object relative to the wavelength of the light used to observe it.
5. In the _____, two lenses are arranged so that the objective forms a real, inverted image of the distant object very near the focal point of the eyepiece.

PART VI

Modern Physics

UNIT 26
RELATIVITY

Read the following texts. Study the thesaurus on fig. 26, answer the questions after the texts

Most of our everyday experiences and observations have to do with objects that move at speeds much less than the speed of light. Newtonian mechanics was formulated to describe the motion of such objects, and its formalism is quite successful in describing a wide range of phenomena that occur at low speeds. It fails, however, when applied to particles having speeds approaching that of light.

This Unit introduces Einstein's theory of special relativity and includes a section on general relativity. The concepts of special relativity often violate our common sense. Moving clocks run slow, and the length of a moving meter stick is contracted. Nonetheless, the theory has been rigorously tested, correctly predicting the results of experiments involving speeds near the speed of light. The theory is verified daily in particle accelerators around the world.

Experiments show that the speed of the electron - as well as the speed of any other particle that has mass - always remains less than the speed of light, regardless of the size of the accelerating voltage. The existence of a universal speed limit has far-reaching consequences. It means that the usual concepts of force, momentum, and energy no longer apply for rapidly moving objects. Less obvious consequences include the fact that observers moving at different speeds will measure different time intervals and displacements between the same two events. Newtonian mechanics was contradicted by experimental observations, so it was necessary to replace it with another theory.

In 1905, at the age of 26, Einstein published his special theory of relativity. Regarding the theory, Einstein wrote: The relativity theory arose from necessity, from serious and deep contradictions in the old theory from which there seemed no escape. The strength of the new theory lies in the consistency and simplicity with which it solves all these difficulties, using only a few very convincing assumptions.

The principle of Galilean relativity

In order to describe a physical event, it's necessary to choose a frame of reference. For example, when you perform an experiment in a laboratory, you select a coordinate system, or frame of reference, that is at rest with respect to the laboratory. However, suppose an observer in a passing car moving at a constant velocity with respect to the lab were to observe your experiment. Would the observations made by the moving observer differ dramatically from yours? That is, if you found Newton's first law to be valid in your frame of reference, would the moving observer agree with you? According to the principle of Galilean relativity, the laws of mechanics must be the same in all inertial frames of reference.

Speed of light

It's natural to ask whether the concept of Galilean relativity in mechanics also applies to experiments in electricity, magnetism, optics, and other areas. Experiments indicate the answer is no. For example, if we assume that the laws of electricity and magnetism are the same in all inertial frames, a paradox concerning the speed of light immediately arises. In order to resolve this paradox, we must conclude that either (1) the addition law for velocities is incorrect or (2) the laws of electricity and magnetism are not the same in all inertial frames.

In the 19th century, physicists thought that electromagnetic waves also required a medium in order to propagate. They proposed that such a medium existed and gave it the name luminiferous ether. The ether was assumed to be present everywhere, even in empty space, and light waves were viewed as ether oscillations.

The second hypothesis is false - and we now believe that the laws of electricity and magnetism are the same in all inertial frames.

The Michelson-Morley experiment

The most famous experiment designed to detect small changes in the speed of light was first performed in 1881 by Albert A. Michelson (1852-1931) and later repeated under various conditions by Michelson and Edward W. Morley (1838-1923). We state at the outset that the outcome of the experiment contradicted the ether hypothesis. The experiment was designed to determine the velocity of Earth relative to the hypothetical ether. The experimental tool used was the Michelson interferometer. The Michelson-Morley experiment was repeated at different times of the year when the ether wind was expected to change direction, but the results were always the same: no fringe shift of the magnitude required was ever observed.

<table>
<tr><td rowspan="19">Relativity</td><td rowspan="18">Special relativity</td><td>Common sense</td><td>Assumptions</td><td></td></tr>
<tr><td>Addition laws</td><td>Ether hypothesis</td><td>Luminiferous ether</td></tr>
<tr><td>Principle of Galilean relativity</td><td>Frame of reference</td><td>Inertial frames</td></tr>
<tr><td rowspan="9">Einstein's principle of relativity</td><td>Speed of light</td><td></td></tr>
<tr><td>Relativistic mechanics</td><td></td></tr>
<tr><td rowspan="7">Consequences of Special relativity</td><td>Absolute length</td></tr>
<tr><td>Absolute time</td></tr>
<tr><td>Simultaneity and the Relativity of Time</td></tr>
<tr><td>Time dilation</td></tr>
<tr><td>Proper time</td></tr>
<tr><td>Twin paradox</td></tr>
<tr><td>Length contraction</td></tr>
<tr><td rowspan="6">Equivalence of mass and energy</td><td colspan="2">Relativistic momentum</td></tr>
<tr><td rowspan="3">Relativistic energy</td><td>Rest energy</td></tr>
<tr><td>Total energy</td></tr>
<tr><td>Low-yield process</td></tr>
<tr><td>Pair production</td><td>Positron</td></tr>
<tr><td>Pair annihilation</td><td>Antiparticle</td></tr>
<tr><td>General relativity</td><td>Theory of gravitation</td><td>Extreme states of matter</td><td>Black hole</td></tr>
</table>

Fig. 26. **Thesaurus for Unit 26**

In later years, when more was known about the nature of light, the idea of an ether that permeates all of space was relegated to the theoretical graveyard. Light is now understood to be an electromagnetic wave, which requires no medium for its propagation. As a result, the idea of an ether in which these waves could travel became unnecessary.

Einstein's principle of relativity

In 1905 Albert Einstein proposed a theory that resolved this contradiction but at the same time completely altered our notions of space and time. He based his special theory of relativity on two postulates. The first postulate asserts that all the laws of physics are the same in all reference frames moving with constant velocity relative to each other. This postulate is a sweeping generalization of the principle of Galilean relativity, which refers only to the laws of mechanics. From an experimental point of view, Einstein's principle of relativity means that any kind of experiment - mechanical, thermal, optical, or electrical - performed in a laboratory at rest, must give the same result when performed in a laboratory moving at a constant speed past the first one. The postulate 2 asserts that the speed of light in a vacuum has the same value in all inertial reference frames, regardless of the velocity of the observer or the velocity of the source emitting the light.

If we accept Einstein's theory of relativity, we must conclude that uniform relative motion is unimportant when measuring the speed of light. At the same time, we have to adjust our commonsense notions of space and time and be prepared for some rather bizarre consequences. In relativistic mechanics, there is no such thing as absolute length or absolute time. Further, events at different locations that are observed to occur simultaneously in one frame are not observed to be simultaneous in another frame moving uniformly past the first. The principle of relativity states that there is no preferred inertial frame of reference.

Properly describing the motion of particles within the framework of special relativity requires generalizing Newton's laws of motion and the definitions of momentum and energy. These generalized definitions reduce to the classical (nonrelativistic) definitions when velocity (***v***) is much less than speed of light (***c***). The relativistic equation for momentum reduces to the classical expression when ***v*** is small compared with ***c***.

The definition of momentum required generalization to make it compatible with the principle of relativity. Likewise, the definition of kinetic energy requires modification in relativistic mechanics. Einstein found the correct expression for the kinetic energy of an object shows the amazing result that a stationary particle with zero kinetic energy has an energy proportional to its mass.

Pair production and annihilation

In general, converting mass into energy is a low-yield process. Burning wood or coal, or even the fission or fusion processes convert only a very small percentage of the available energy. An exception is the reaction of matter with antimatter. A common process in which a photon creates matter is called pair production. In this process, an electron and a positron are simultaneously produced, while the photon disappears. In order for pair production to occur, energy, momentum, and charge must all be conserved during the process. It's impossible for a photon to produce a single electron because the photon has zero charge and charge would not be conserved in the process. Pair annihilation is a process in which an electron-positron pair produces two photons-the inverse of pair production. Momentum can be conserved only if two photons moving in opposite directions, both with the same energy and magnitude of momentum, are produced.

General relativity

Special relativity relates observations of inertial observers. Einstein sought a more general theory that would address accelerating systems. His search was motivated in part by the following curious fact: mass determines the inertia of an object and also the strength of the gravitational field. Einstein's remarkable theory of gravitation is known as general relativity, in 1916.

One interesting effect predicted by general relativity is that time scales are altered by gravity. A clock in the presence of gravity runs more slowly than one in which gravity is negligible. As a consequence, light emitted from atoms in a strong gravity field, such as the Sun's, is observed to have a lower frequency than the same light emitted by atoms in the laboratory. This gravitational shift has been detected in spectral lines emitted by atoms in massive stars. It has also been verified on Earth by comparing the frequencies of gamma rays emitted from nuclei separated vertically by about 20 m.

General relativity also predicts extreme states of matter created by gravitational collapse. If the concentration of mass becomes very great, as is believed to occur when a large star exhausts its nuclear fuel and collapses to a very small volume, a black hole may form. Here the curvature of space-time is so extreme that all matter and light within a certain radius becomes trapped. There is strong evidence for the existence of a black hole having a mass of millions of Suns at the center of our galaxy.

1. What's the reason of special theory of relativity?
2. What is necessary to do to describe a physical event?
3. What laws of mechanics must be according to the principle of Galilean relativity?
4. Describe the Michelson-Morley experiment.
5. At what speeds Newton's laws are right?
6. What is pair annihilation?
7. What does general theory of relativity predict?

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Относительность	*lativityre*
Предположения	*sumptionsas*
Одновременность	*taneitysimul*
Позитрон	*tronposi*
Античастица	*particleanti*

2. Match the words in A with the words in B to form word combinations:

A	B
Relativistic	*relativity*
Luminiferous	*production*
Rest	*momentum*
Pair	*frames*
General	*ether*
Inertial	*energy*

3. Fill in the gaps with the missing words from the list:

positron, inertial frames, Special relativity, time interval, ether hypothesis

1. _____ is all about relating two such measurements - and this rather innocuous relating of measurements leads to some of the most bizarre consequences in physics.

2. _____ of reference are those reference frames in which Newton's laws are valid.

3. The negative results of the Michelson-Morley experiment not only contradicted the _____, but also showed that it was impossible to measure the absolute velocity of Earth with respect to the ether frame.

4. In relativistic mechanics, the distance between two points and the _____ between two events depend on the frame of reference in which they are measured.

5. The _____ is often called the antiparticle of the electron.

UNIT 27
QUANTUM PHYSICS

Read the following texts. Study the thesaurus on fig. 27, answer the questions after the texts

Although many problems were resolved by the theory of relativity in the early part of the 20th century, many other problems remained unsolved. Attempts to explain the behavior of matter on the atomic level with the laws of classical physics were consistently unsuccessful. Various phenomena, such as the electromagnetic radiation emitted by a heated object (blackbody radiation), the emission of electrons by illuminated metals (the photoelectric effect), and the emission of sharp spectral lines by gas atoms in an electric discharge tube, couldn't be understood within the framework of classical physics. Between 1900 and 1930, however, a modern version of mechanics called quantum mechanics or wave mechanics was highly successful in explaining the behavior of atoms, molecules, and nuclei.

The earliest ideas of quantum theory were introduced by Planck, and most of the subsequent mathematical developments, interpretations, and improvements were made by a number of distinguished physicists, including Einstein, Bohr, Schrodinger, de Broglie, Heisenberg, I Born, and Dirac. In this Unit we introduce the underlying ideas of quantum theory and the wave-particle nature of matter, and discuss some simple applications of quantum theory, including the photoelectric effect, the Compton effect, and x-rays.

Blackbody radiation and Planck's hypothesis

An object at any temperature emits electromagnetic radiation, called thermal radiation. The spectrum of the radiation depends on the temperature and properties of the object. At low temperatures, the wavelengths of the thermal radiation are mainly in the infrared region and hence not observable by the eye. As the temperature of an object increases, the object eventually begins to glow red. At sufficiently high temperatures, it appears to be white, as in the glow of the hot tungsten filament of a light-bulb. A careful study of thermal radiation shows that it consists of a continuous distribution of wavelengths from the infrared, visible, and ultraviolet portions of the spectrum.

By the end of the 19th century, it had become apparent that the classical theory of thermal radiation was inadequate. The basic problem was in understanding the observed distribution energy as a function of wavelength in the radiation emitted by a blackbody. By definition, a blackbody is an ideal system that absorbs all radiation incident on it. The radiated energy varies with wavelength and temperature. As the temperature of the blackbody increases, the total amount of energy it emits increases. Also, with increasing temperature, the peak of the distribution shifts to shorter wavelengths. This shift obeys called Wien's displacement law**.** At long wavelengths, classical theory is in good agreement with the experimental data. At short wavelengths, however, major disagreement exists between classical theory and experiment. In fact, the theory erroneously predicts that the intensity should be infinite, when the experimental data shows it should approach zero. This contradiction is called the ultraviolet catastrophe**,** because theory and experiment disagree strongly in the short-wavelength, ultraviolet region of the spectrum.

In 1900 Planck developed a formula for blackbody radiation that was in complete agreement with experiments at all wavelengths. Planck hypothesized that blackbody radiation was produced by submicroscopic charged oscillators, which he called resonators. He assumed that the walls of a glowing cavity were composed of billions of these resonators, although their exact nature was unknown. Because the energy of each resonator can have only discrete values, we say the energy is quantized.

The key point in Planck's theory is the assumption of quantized energy states. This is a radical departure from classical physics, the "quantum leap" that led to a totally new understanding of nature. It's shocking: it's like saying a pitched baseball can have only a fixed number of different speeds, and no speeds in between those fixed values. When Planck presented his theory, most scientists (including Planck!) didn't consider the quantum concept to be realistic; however, subsequent developments showed that a theory based on the quantum concept (rather than on classical concepts) had to be used to explain a number of other phenomena at the atomic level.

Photoelectric effect and the particle theory of light

In the latter part of the 19th century, experiments showed that light incident on certain metallic surfaces caused the emission of electrons are emitted from the surfaces. This phenomenon is known as the photoelectric effect, and the emitted electrons are called photoelectrons. The first discovery of this phenomenon was made by Hertz, who was also the first to produce the electromagnetic waves predicted by Maxwell.

A successful explanation of the photoelectric effect was given by Einstein in 1905, the same year he published his special theory of relativity. As part of a general paper on electromagnetic radiation, for which he received the Nobel Prize in 1921, Einstein extended Planck's concept of quantization to electromagnetic waves. He suggested that a tiny packet of light energy or photon would be emitted when a quantized oscillator made a jump from an energy state to the next lower state. The work function, which represents the minimum energy with which an electron is bound in the metal, is on the order of a few electron volts.

X- rays

In 1895 at the University of Wurzburg, Wilhelm Roentgen (1845-1923) was studying electrical discharges in low-pressure gases when he noticed that a fluorescent screen glowed even when placed several meters from the gas discharge tube and even when black cardboard was placed between the tube and the screen. He concluded that the effect was caused by a mysterious type of radiation, which he called x-rays because of their unknown nature. Subsequent study showed that these rays traveled at or near the speed of light and that they couldn't be deflected by either electric or magnetic fields. This last fact indicated that x-rays did not consist of beams of charged particles, although the possibility that they were beams of uncharged particles remained.

Quantum Physics	*Quantum mechanics*	*Wave mechanics*		
	Planck's hypothesis	*Blackbody radiation*	*Thermal radiation*	
			Wien's displacement law	*Ultraviolet catastrophe*
		Oscillators	*Resonators*	*Glowing cavity*
		Quantized energy states	*Quantum number*	*Planck's constant*
	Photoelectric effect	*Particle theory of light*	*Photon*	
			Work function	*Photocells*
	X- rays	*Bremsstrahlung*	*Spacing*	
	Compton - effect	*Compton shift*	*Compton wavelength*	*Scattered X-ray*
				Incident X-ray
	Dual nature	*Electromagnetic radiation*	*Wave-particle nature*	
		Wave properties of particles	*De Broglie hypothesis*	
			Davisson-Germer experiment	
		Wave function	*Schrodinger's equation*	
			Uncertainty principle	
		Tunneling	*STM (scanning tunneling microscope)*	*AFM (atomic force microscope)*

Fig. 27. **Thesaurus for Unit 27**

In 1912 Max von Laue (1879-1960) suggested that if x-rays were electromagnetic waves with very short wavelengths, it should be possible to diffract them by using the regular atomic spacings of a crystal lattice as a diffraction grating, just as visible light is diffracted by a ruled grating. X-ray diffraction has proved to be an invaluable technique for understanding the structure of matter. The continuous radiation is sometimes called bremsstrahlung, a German word meaning "braking radiation," because electrons emit radiation when they undergo an acceleration inside the target.

The Compton - effect

Further justification for the photon nature of light came from an experiment conducted by Arthur H. Compton in 1923. In his experiment, Compton directed an x-ray beam of wavelength toward a block of graphite. He found that the scattered x-rays had a slightly longer wavelength than the incident x-rays, and hence the energies of the scattered rays were lower. The amount of energy reduction depended on the angle at which the x-rays were scattered. The change in wavelength between a scattered x-ray and an incident x-ray is called the Compton shift.

The dual nature of light and matter

Phenomena such as the photoelectric effect and the Compton effect offer evidence that when light (or other forms of electromagnetic radiation) and matter interact, the light behaves as if it were composed of particles having energy and momentum. In other contexts, however, light acts like a wave, exhibiting interference and diffraction effects. Light has a dual nature, exhibiting both wave and particle characteristics.

According to de Broglie, electrons, just like light, have a dual particle-wave nature. De Broglie suggested that all material particles with momentum ***p*** should have a characteristic wavelength. Further, de Broglie postulated that the frequencies of matter waves (waves associated with particles having nonzero rest energy) obey the Einstein relationship for photons.

In 1927, three years after de Broglie published his work, C. J. Davisson (1881-1958) and L. H. Germer (1896-1971) of the United States succeeded in measuring the wavelength of electrons. Their important discovery provided the first experimental confirmation of the matter waves proposed by de Broglie.

Wave function

In 1926, the Austrian-German physicist Erwin Schrodinger proposed a wave equation that described how matter waves change in space and time. The Schrodinger wave equation represents a key element in the theory of quantum mechanics. It's as important in quantum mechanics as Newton's laws in classical mechanics. Schrodinger's equation has been successfully applied to the hydrogen atom and to many other microscopic systems.

Uncertainty principle

In 1927, Werner Heisenberg (1901-1976) introduced notion, which is now known as the uncertainty principle. It is physically impossible to measure simultaneously the exact position and exact linear momentum of a particle.

The scanning tunneling microscope

One of the basic phenomena of quantum mechanics - tunneling - is at the heart of a very practical device - the scanning tunneling microscope, or STM - which enables us to get highly detailed images of surfaces with a resolution comparable to the size of a single atom. The STM has, however, one serious limitation: it depends on electrical conductivity of the sample and the tip. A newer microscope - the atomic force microscope, or AFM - overcomes this limitation. It measures the force between a tip and the sample, rather than an electrical current. The AFM has comparable sensitivity for measuring topography and has become widely used for technological applications.

1. What phenomena classical physics can’t explain?
2. What kinds of radiation does thermal radiation compose?
3. What’s the essence of Planck's hypothesis?
4. Describe the photoelectric effect.
5. Why x-rays do not consist of beams of charged particles?
6. What’s the reason of dual nature of light?

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Резонаторы	*natorsreso*
Фотоэлементы	*cellsphoto*
Тормозное излучение	*strahlungbrems*
Период (решетки)	*cingspa*
Туннелирование	*lingtunnel*

2. Match the words in A with the words in B to form word combinations:

A	B
Thermal	*shift*
Particle	*radiation*
Compton	*mechanics*
Dual	*nature*
Uncertainty	*theory*
Quantum	*principle*

3. Fill in the gaps with the missing words from the list:

photons, work function, quantum effects, uncertainty principle, x-rays

1. _____ can be even more bizarre than relativistic effects, but don't despair: confusion is normal and expected.
2. Photoelectrons are created by absorption of a single photon, so the energy of that photon must be greater than or equal to the _____, else no photoelectrons will be produced.
3. We now know that _____ are a part of the electromagnetic spectrum, characterized by frequencies higher than those of ultraviolet radiation and having the ability to penetrate most materials with relative ease.
4. _____ have wave and particle characteristics, perhaps all forms of matter have both properties.
5. To understand the physical origin of the _____, consider the experiment introduced by Heisenberg.

UNIT 28
ATOMIC PHYSICS

Read the following texts. Study the thesaurus on fig. 28, answer the questions after the texts

In this Unit we first discuss the Bohr model of hydrogen, which helps us understand many features of that element but fails to explain finer details of atomic structure. Next we examine the hydrogen atom from the viewpoint of quantum mechanics and the quantum numbers used to characterize various atomic states. Quantum numbers aren't mere mathematical abstractions: they have physical significance, such as the role they play in the effect of a magnetic field on certain quantum states. The fact that no two electrons in an atom can have the same set of quantum numbers - the Pauli exclusion principle - is extremely important in understanding the properties of complex atoms and the arrangement of elements in the periodic table. Finally, we apply our knowledge of atomic structure to describe the mechanisms involved in the production of x-rays, the operation of a laser, and the behavior of solid-state devices such as diodes and transistors.

Early models of the atom

The model of the atom in the days of Newton was a tiny, hard, indestructible sphere. Although this model was a good basis for the kinetic theory of gases, new models had to be devised when later experiments revealed the electronic nature of atoms. J. J. Thomson (1856-1940) suggested a model of the atom as a volume of positive charge with electrons embedded throughout the volume, much like the seeds in a watermelon.

In 1911 Ernest Rutherford (1871-1937) and his students Hans Geiger and Ernest Marsden performed a critical experiment showing that Thomson's model couldn't be correct. In this experiment, a beam of positively charged alpha particles was projected against a thin metal foil. The results of the experiment were astounding. Most of the alpha particles passed through the foil as if it were empty space, but a few particles deflected from their original direction of travel were scattered through large angles. Some particles were even deflected backwards, reversing their direction of travel. When Geiger informed Rutherford of these results, Rutherford wrote, "It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you."

Rutherford explained these astounding results by assuming that the positive charge in an atom was concentrated in a region that was small relative to the size of the atom. He called this concentration of positive charge the nucleus of the atom. Alpha particles themselves were later identified as the nuclei of helium atoms.

Atomic spectra

The hydrogen atom is the simplest atomic system and an especially important one to understand. Much of what we know about the hydrogen atom (which consists of one proton and one electron) can be extended directly to other single-electron ions such as He^+ and Li^{2+}. Further, a thorough understanding of the physics underlying the hydrogen atom can then be used to describe more complex atoms and the periodic table of the elements.

If a voltage applied between metal electrodes in the tube is great enough to produce an electric current in the gas, the tube emits light having a color that depends on the gas inside. (This is how a neon sign works.). When the emitted light is analyzed with a spectrometer, discrete bright lines are observed, each having a different wavelength, or color. Such a series of spectral lines is commonly called an emission spectrum**.** The wavelengths contained in such a spectrum are characteristic of the element emitting the light. Because no two elements emit the same line spectrum, this phenomenon represents a marvelous and reliable technique for identifying elements in a gaseous substance.

In addition to emitting light at specific wavelengths, an element can absorb light at specific wavelengths. The spectral lines corresponding to this process form what is known as an absorption spectrum**.** The absorption spectrum of an element has many practical applications. For example, the continuous spectrum of radiation emitted by the Sun must pass through the cooler gases of the solar atmosphere before reaching the Earth. Because the Greek word for Sun is helios, the new element was named helium.

Atomic Physics	*Early models of the atom*	*Rutherford's experiment*	*Alpha particles*	*Nucleus*
	Atomic spectra	*Hydrogen atom*	*Emission spectrum*	*Continuous spectrum*
			Absorption spectrum	
	Bohr theory of hydrogen	*Energetic state*	*Bohr radius*	*Bohr's Correspondence principle*
			Ground state	*Ionization energy*
	Modi-fication of the Bohr theory	*Principal quantum number*	*Orbital quantum number*	*Shell*
			Spin magnetic quantum number	*Fine structure*
		Electron clouds	*Pauli exclusion principle*	
	Atomic transitions	*Allowed states*	*Forbidden gaps*	
			Stimulated absorption	*Stimulated emission*
		Excited states	*Population inversion*	*Laser*
				Holography
	Solid	*Band gap*	*Valence band*	*Conduction band*
			Holes	*p-n junction*
			Doping	*Donor atoms*
				Acceptor
		Solid–state devices	*Junction transistor*	*Emitter*
				Collector
				Base
			Integrated circuit	*Chip*

Fig. 28. **Thesaurus for Unit 28**

The Bohr theory of hydrogen and its modification

At the beginning of the 20th century, scientists were perplexed by the failure of classical physics to explain the characteristics of spectra. In 1913 Bohr provided an explanation of atomic spectra that includes some features of the currently accepted theory. The equations of his theory is based on the assumption that the electron can exist only in certain allowed orbits determined by the integer ***n***. The orbit with the smallest radius, called the Bohr radius, corresponds to ***n*** = 1. The lowest energy state, or ground state, corresponds to ***n*** = 1. The minimum energy required to ionize the atom - that is, to completely remove the electron - is called the ionization energy.

Newtonian mechanics cannot be used to describe phenomena that occur at speeds approaching the speed of light. Newtonian mechanics is a special case of relativistic mechanics and applies only when v is much smaller than c. Similarly, quantum mechanics is in agreement with classical physics when the energy differences between quantized levels are very small. This principle, first set forth by Bohr, is called the correspondence principle.

Within a few months following the publication of Bohr's paper, Arnold Sommerfeld (1868-1951) extended the Bohr model to include elliptical orbits. Bohr's concept of quantization of angular momentum led to the principal quantum number ***n***, which determines the energy of the allowed states of hydrogen. Sommerfeld's theory retained ***n***, but also introduced a new quantum number, called the orbital quantum number. Another modification of the Bohr theory arose when it was discovered that the spectral lines of a gas are split into several closely spaced lines when the gas is placed in a strong magnetic field. This is called the Zeeman effect, after its discoverer. In order to explain this observation, a new quantum number called the orbital magnetic quantum number.

Finally, very high resolution spectrometers revealed that spectral lines of gases are in fact two very closely spaced lines even in the absence of an external magnetic field. This splitting was referred to as fine structure**.** In 1925 Samuel Goudsmit and George Uhlenbeck introduced the idea of an electron spinning about its own axis to explain the origin of fine structure. The results of their work introduced yet another quantum number, called the spin magnetic quantum number**.**

For more than a decade following Bohr's publication, no one was able to explain why the angular momentum of the electron was restricted to discrete values. Finally, de Broglie gave a direct physical way of interpreting this condition. He assumed that an electron orbit would be stable (allowed) only if it contained an integral number of electron wavelengths. Although the analysis provided by de Broglie was a promising first step, gigantic strides were made subsequently with the development of Schrodinger's wave equation and its application to atomic systems.

Quantum mechanics predicts that the wave function for the hydrogen atom in the ground state is spherically symmetric; hence the electron can be found in a spherical region surrounding the nucleus. This is in contrast to the Bohr theory, which confines the position of the electron to points in a plane. The quantum mechanical result is often interpreted by viewing the electron as a cloud surrounding the nucleus.

The exclusion principle

How many electrons in an atom can have a particular set of quantum numbers? This important question was answered by Pauli in 1925 in a powerful statement known as the Pauli exclusion principle: No two electrons in an atom can ever have the same set of values for the set of quantum numbers.

The Pauli exclusion principle explains the electronic structure of complex atoms as a succession of filled levels with different quantum numbers increasing in energy, where the outermost electrons are primarily responsible for the chemical properties of the element. If this principle weren't valid, every electron would end up in the lowest energy state of the atom and the chemical behavior of the elements would be grossly different.

Atomic transitions

An atom will emit radiation only at certain frequencies that correspond to the energy separation between the various allowed states. At ordinary temperatures, most of the atoms in a sample are in the ground state. If a vessel containing many atoms of a gas is illuminated with a light beam containing all possible photon frequencies (that is, a continuous spectrum), only those photons of energies, and so on, can be absorbed. As a result of this absorption, some atoms are raised to various allowed higher energy levels, called excited states.

An incident photon can cause atomic transitions either upward (stimulated absorption) or downward (stimulated emission). The two processes are equally probable. When light is incident on a system of atoms, there is usually a net absorption of energy, because when the system is in thermal equilibrium, there are many more atoms in the ground state than in excited states. However, if the situation can be inverted so that there are more atoms in an excited state than in the ground state, a net emission of photons can result. Such a condition is called population inversion**.** This is the fundamental principle involved in the operation of a laser. One interesting application of the laser is holography: the production of three-dimensional images of objects.

Energy bands in solids

In solids, the discrete levels of isolated atoms broaden into allowed energy bands separated by forbidden gaps. The separation and electron population of the highest bands determines whether a given solid is a conductor, an insulator, or a semiconductor. An electron can have any energy within an allowed energy band, but cannot have an energy in the band gap**,** or the region between allowed bands. The highest filled band is called the valence band and the next higher empty band is called the conduction band. In quantum terms, electron energies increase if there are higher unoccupied energy levels for electrons to jump to.

A conductor has a highest-energy occupied band which is partially filled, and in an insulator, has a highest-energy occupied band which is completely filled with a large energy gap between the valence and conduction bands. Semiconductor is a material with a small band gap of about 1eV whose conductivity results from appreciable thermal excitation of electrons across the gap into the conduction band at room temperature. The process of adding impurities, called doping, is important in making devices having well-defined regions of different resistivity.

The invention of the transistor by John Bardeen (1908-1991), Walter Brattain (1902-1987), and William Shockley (1910-1989) in 1948 totally revolutionized the world of electronics. For this work, these three men shared a Nobel prize in 1956. By 1960, the transistor had replaced the vacuum tube in many electronic applications. One simple form of the transistor, called the junction transistor**,** consists of a semiconducting material in which a very narrow ***n*** region is sandwiched between two ***p*** regions. This configuration is called a ***pnp*** transistor**.** Another configuration is the ***npn*** transistor. The outer regions are called the emitter and collector, and the narrow central region is called the base.

Invented independently by Jack Kilby at Texas Instruments in late 1958 and by Robert Noyce at Fairchild Camera and Instrument in early 1959, the integrated circuit has been justly called "the most remarkable technology ever to hit mankind." In simplest terms, an integrated circuit is a collection of interconnected transistors, diodes, resistors, and capacitors fabricated on a single piece of silicon known as a chip.

1. What experiment showed that Thomson's model is not right?
2. Why the emission spectrum is reliable technique for identifying elements?
3. What does quantum mechanics predict about electron and nucleus?
4. What's the Pauli exclusion principle consist from?
5. What equally probable processes an incident photon can cause?
6. Why the integrated circuit has been justly called "the most remarkable technology ever to hit mankind"?

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Ядро	*cleusnu*
Подоболочка	*shellsub*
Расщепление	*tingsplit*
Легирование полупроводника	*pingdo*
Эмиттер	*teremit*

2. Match the words in A with the words in B to form word combinations:

A	B
Ground	*gap*
Fine	*transistor*
Population	*inversion*
Band	*circuit*
Integrated	*structure*
Junction	*state*

3. Fill in the gaps with the missing words from the list:

solar spectrum, nucleus, quantum numbers, energetic state, integrated circuits

1. In order to explain why electrons in this outer region of the atom were not pulled into the _____, Rutherford viewed them as moving in orbits about the positively charged nucleus in the same way that planets orbit the Sun.

2. The various absorption lines observed in the _____ have been used to identify elements in the solar atmosphere, including one that was previously unknown.

3. Radiation is emitted by the hydrogen atom when the electron "jumps" from a more energetic initial state to a less _____**.**

4. All these _____ were postulated to account for the observed spectra of elements.

5. _____*s* were invented partly to solve the interconnection problem spawned by the transistor.

UNIT 29
NUCLEAR PHYSICS

Read the following texts. Study the thesaurus on fig. 29, answer the questions after the texts

In 1896, the year that marks the birth of nuclear physics, Henri Becquerel (1852-1908) discovered radioactivity in uranium compounds. A great deal of activity followed this discovery as researchers attempted to understand and characterize the radiation that we now know to be emitted by radioactive nuclei. Pioneering work by Rutherford showed that the radiation was of three types, which he called alpha, beta, and gamma rays. These types are classified according to the nature of their electric charge and their ability to penetrate matter. Later experiments showed that alpha rays are helium nuclei, beta rays are electrons, and gamma rays are high-energy photons.

In 1911 Rutherford and his students Geiger and Marsden performed a number of important scattering experiments involving alpha particles. These experiments established the idea that the nucleus of an atom can be regarded as essentially a point mass and point charge and that most of the atomic mass is contained in the nucleus. Further, such studies demonstrated a wholly new type of force: the nuclear force, which is predominant at distances of less than about $10^{\sim 14}$ m and drops quickly to zero at greater distances.

Other milestones in the development of nuclear physics include:

- the first observations of nuclear reactions by Rutherford and coworkers in 1919, in which naturally occurring **α** particles bombarded nitrogen nuclei to produce oxygen,

- the first use of artificially accelerated protons to produce nuclear reactions, by Cockcroft and Walton in 1932,

- the discovery of the neutron by Chadwick in 1932,

- the discovery of artificial radioactivity by Joliot and Irene Curie in 1933,

- the discovery of nuclear fission by Hahn, Strassman, Meitner, and Frisch in 1938,

- the development of the first controlled fission reactor by Fermi and his collaborators in 1942.

Some properties of nuclei

All nuclei are composed of two types of particles: protons and neutrons. The only exception is the ordinary hydrogen nucleus, which is a single proton. In describing some of the properties of nuclei, such as their charge, mass, and radius, we make use of the following quantities:

- the atomic number ***Z***, which equals the number of protons in the nucleus,

- the neutron number ***N***, which equals the number of neutrons in the nucleus,

- the mass number ***A***, which equals the number of nucleons in the nucleus (nucleon is a generic term used to refer to either a proton or a neutron).

The nuclei of all atoms of a particular element must contain the same number of protons, but they may contain different numbers of neutrons. Nuclei that are related in this way are called isotopes. The isotopes of an element have the same ***Z*** value, but different ***N*** and ***A*** values.

The size and structure of nuclei were first investigated in the scattering experiments of Rutherford. Using the principle of conservation of energy, Rutherford found an expression for how close an alpha particle moving directly toward the nucleus can come to the nucleus before being turned around by Coulomb repulsion. Rutherford concluded that the positive charge in an atom is concentrated in a small sphere, which he called the nucleus, with radius no greater than about 10^{-14}m. Because such small lengths are common in nuclear physics, a convenient unit of length is the femtometer (fm), sometimes called the fermi.

The total mass of a nucleus is always less than the sum of the masses of its nucleons. Also, because mass is another manifestation of energy, the total energy of the bound system (the nucleus) is less than the combined energy of the separated nucleons. This difference in energy is called the binding energy of the nucleus and can be thought of as the energy that must be added to a nucleus to break it apart into its separated neutrons and protons.

Radioactivity

In 1896, Becquerel accidentally discovered that uranium salt crystals emit an invisible radiation that can darken a photographic plate even if the plate is covered to exclude light. After several such observations under controlled conditions, he concluded that the radiation emitted by the crystals was of a new type, one requiring no external stimulation. This spontaneous emission of radiation was soon called radioactivity**.** Subsequent experiments by other scientists showed that other substances were also radioactive.

Three types of radiation can be emitted by a radioactive substance: alpha (**α**) particles, in which the emitted particles are He nuclei; beta (**β**) particles, in which the emitted particles are either electrons or positrons; and gamma (**γ**) rays, in which the emitted "rays" are high-energy photons. A positron is a particle similar to the electron in all respects, except that it has a charge of **+ *e***. (The positron is said to be the antiparticle of the electron.)

The decay rate, or activity ***R***, of a sample is defined as the number of decays per second. Another parameter that is useful for characterizing radioactive decay is the half-life. The half-life of a radioactive substance is the time it takes for half of a given number of radioactive nuclei to decay. The unit of activity R is the curie (Ci). The SI unit of activity is the becquerel (Bq): 1 Bq = 1 decay/s.

Radioactive nuclei decay spontaneously via alpha, beta, and gamma decay. If a nucleus emits an alpha particle ($_2He$), it loses two protons and two neutrons. In order for alpha emission to occur, the mass of the parent must be greater than the combined mass of the daughter and the alpha particle. In the decay process, this excess mass is converted into energy of other forms and appears in the form of kinetic energy in the daughter nucleus and the alpha particle.

Nuclear Physics	*Nuclei*	*Nuclear force*	*Binding energy*	*Coulomb repulsion*
		Atomic number	*Protons*	
		Neutron number	*Neutrons*	*Isotopes*
		Mass number	*Nucleon*	*Unified mass unitt*
		Femtometer	*Fermi*	
	Radio-activity	*Uranium compounds*	*Spontaneous emission*	*Alpha rays*
				Beta rays
				Gamma rays
		Positron	*Antiparticle*	
		Decay rate	*Activity*	*Becquerel (Bq)*
				Curie (Ci)
			Decay constant	*Half-Life*
		Parent nucleus	*Daughter nucleus*	
		Alpha decay		
		Beta decay	*Neutrino*	*Antineutrino*
		Gamma decay		
	Natural radioactivity	*Artificial radioactivity*	*Nuclear reactions*	*Exothermic reactions*
				Endothermic reactions
				Threshold energy
	Medical applications	*Ionizing radiation*	*Radiation damage*	*Somatic damage*
				Genetic damage
		Radiation exposure	*Roentgen*	
		Radioactive tracers	*Geiger counter*	
			Cloud chamber	

Fig. 29. **Thesaurus for Unit 29**

When a radioactive nucleus undergoes beta decay, the daughter nucleus has the same number of nucleons as the parent nucleus, but the atomic number is changed by 1. In 1930 Pauli proposed that a third particle must be present to carry away the "missing" energy and to conserve momentum. Later, Enrico Fermi developed a complete theory of beta decay and named this particle the neutrino ("little neutral one") because it had to be electrically neutral and have little or no mass. In beta decay, an electron and an anti-neutrino are emitted or a positron and a neutrino are emitted.

Very often a nucleus that undergoes radioactive decay is left in an excited energy state. The nucleus can then undergo a second decay to a lower energy state - perhaps even to the ground state - by emitting one or more high-energy photons. The process is similar to the emission of light by an atom. An atom emits radiation to release some extra energy when an electron "jumps" from a state of high energy to a state of lower energy. The photons emitted in the process are called gamma rays**,** which have very high energy relative to the energy of visible light.

Natural radioactivity

Radioactive nuclei are generally classified into two groups: (1) unstable nuclei found in nature, which give rise to what is called natural radioactivity, and (2) nuclei produced in the laboratory through nuclear reactions, which exhibit artificial radioactivity.

Nuclear reactions

It is possible to change the structure of nuclei by bombarding them with energetic particles. Such changes are called nuclear reactions**.** Since the time of Rutherford, thousands of nuclear reactions have been observed, particularly following the development of charged-particle accelerators in the 1930s. These high-energy particles are used to create new particles whose properties are helping to solve the mysteries of the nucleus (and indeed, of the Universe itself).

Nuclear reactions in which there is a release of energy - that is, positive **Q** values - are said to be exothermic reactions. Reactions with negative **Q** values are called endothermic reactions. It can be shown that in order to conserve both energy and momentum, the incoming particle must have a minimum kinetic energy. This minimum value of the kinetic energy of the incoming particle is called the threshold energy**.**

Medical applications of radiation

Radiation absorbed by matter can cause severe damage. The degree and kind of damage depend on several factors, including the type and energy of the radiation and the properties of the absorbing material. Radiation damage in biological organisms is due primarily to ionization effects in cells. The normal function of a cell may be disrupted when highly reactive ions or radicals are formed as the result of ionizing radiation. Also, cells that do survive the radiation may become defective, which can lead to cancer.

Several units are used to quantify radiation exposure and dose. The roentgen (**R**) is defined as that amount of ionizing radiation which will produce 2.08×10^9 ion pairs in 1 cm^3 of air under standard conditions. Radioactive particles can be used to trace chemicals participating in various reactions.

One of the most valuable uses of radioactive tracers is in medicine. Most medical applications of radiation require instruments to make quantitative measurements of radioactive intensity. Various devices have been developed to detect the energetic particles emitted when a radioactive nucleus decays: the Geiger counter; a semiconductor diode detector; a scintillation counter; Track detectors; a cloud chamber.

1. What steps of nuclear physics development do you know?
2. Name values which are used for description of properties of nuclei.
3. What three types of radiation are radiated by radioactive substance?
4. Into what two groups radioactive nuclei are generally classified?
5. How it is possible to change the structure of nuclei?
6. What examples of medical applications of radiation do you know?

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Ядра	*cleinu*
Изотоп	*topeiso*
Радиоактивность	*activityradio*
Период полураспада	*fLie-lHaf*
Антинейтрино	*neutrinoanti*

2. Match the words in A with the words in B to form word combinations:

A	B
Binding	*exposure*
Parent	*reactions*
Gamma	*damage*
Nuclear	*nucleus*
Genetic	*energy*
Radiation	*Decay*

3. Fill in the gaps with the missing words from the list:

Roentgen, nuclear force, isotopes, half-life, nucleon

1. Some _____ don't occur naturally, but can be produced in the laboratory through nuclear reactions.
2. Nuclei are stable because of the presence of another, short-range (about 2 fm) force: the _____, an attractive force that acts between all nuclear particles.
3. A _____ is the time it takes for half of a given number of nuclei to decay.
4. The mass of the electron is much smaller than that of the lightest _____, so we can approximate it as zero when we study nuclear decays and reactions.
5. The _____ is that amount of radiation which deposits 8.76 X 10^{-3} J of energy into 1 kg of air.

UNIT 30
NUCLEAR ENERGY AND ELEMENTARY PARTICLES

Read the following texts. Study the thesaurus on fig. 30, answer the questions after the texts

In this concluding Unit we discuss the two means by which energy can be derived from nuclear reactions: fission, in which a nucleus of large mass number splits into two smaller nuclei, and fusion, in which two light nuclei fuse to form a heavier nucleus. In either case, there is a release of large amounts of energy, which can be used destructively through bombs or constructively through the production of electric power. We end our study of physics by examining the known subatomic particles and the fundamental interactions that govern their behavior. We also discuss the current theory of elementary particles, which states that all matter in nature is constructed from only two families of particles: quarks and leptons. Finally, we describe how such models help us understand the evolution of the Universe.

Nuclear fission

Nuclear fission occurs when a heavy nucleus, such as ^{235}U, splits, or fissions, into two smaller nuclei. In such a reaction, the total mass of the products is less than the original mass of the heavy nucleus.

Nuclear fission was first observed in 1939 by Otto Hahn and Fritz Strassman, following some basic studies by Fermi. After bombarding uranium (Z = 92) with neutrons, Hahn and Strassman discovered two medium-mass elements, barium and lanthanum, among the reaction products. Shortly thereafter, Lise Meitner and Otto Frisch explained what had happened: the uranium nucleus had split into two nearly equal fragments after absorbing a neutron. This was of considerable interest to physicists attempting to understand the nucleus, but it was to have even more far-reaching consequences. Measurements showed that about 200 MeV of energy is released in each fission event, and this fact was to affect the course of human history.

Nuclear reactors

Neutrons are emitted when ^{235}U undergoes fission. These neutrons can in turn trigger other nuclei to undergo fission, with the possibility of a chain reaction. Calculations show that if the chain reaction isn't controlled, it will proceed too rapidly and possibly result in the sudden release of an enormous amount of energy (an explosion), even from only 1g of ^{235}U. An uncontrolled fission reaction, of course, is the principle behind the first nuclear bomb.

A nuclear reactor is a system designed to maintain what is called a self-sustained chain reaction. This important process was first achieved in 1942 by a group led by Fermi at the University of Chicago, with natural uranium as the fuel. Most reactors in operation today also use uranium as fuel. Natural uranium contains only about 0.7% of the ^{235}U isotope, with the remaining 99.3% being the ^{238}U isotope. This is important to the operation of a reactor because ^{238}U almost never undergoes fission. Instead, it tends to absorb neutrons, producing neptunium and plutonium. For this reason, reactor fuels must be artificially enriched so that they contain several percent of the ^{235}U isotope.

A useful parameter for describing the level of reactor operation is the reproduction constant ***K***, defined as the average number of neutrons from each fission event that will cause another event. A self-sustained chain reaction is achieved when ***K***= 1. Under this condition, the reactor is said to be critical. When ***K*** is less than one, the reactor is subcritical and the reaction dies out. When ***K*** is greater than one the reactor is said to be supercritical, and a runaway reaction occurs.

In any reactor, a fraction of the neutrons produced in fission will leak out of the core before inducing other fission events (neutron leakage**)**. If the fraction leaking out is too large, the reactor will not operate.

The neutrons released in fission events are highly energetic, with kinetic energies of about 2 MeV. It is found that slow neutrons are far more likely than fast neutrons to produce fission events in ^{235}U. Further, ^{238}U doesn't absorb slow neutrons. In order for the chain reaction to continue, therefore, the neutrons must be slowed down. This is accomplished by surrounding the fuel with a substance called a moderator.

In the process of being slowed down, neutrons may be captured by nuclei that do not undergo fission. The most common event of this type is neutron capture by ^{238}U. The probability of neutron capture by ^{238}U is very high when the neutrons have high kinetic energies and very low when they have low kinetic energies.

Nuclear fusion

The binding energy of light nuclei (those having a mass number lower than 20) is much smaller than the binding energy of heavier nuclei. This suggests a process that is the reverse of fission. When two light nuclei combine to form a heavier nucleus, the process is called nuclear fusion. Because the mass of the final nucleus is less than the masses of the original nuclei, there is a loss of mass, accompanied by a release of energy. Although fusion power plants have not yet been developed, a worldwide effort is under way to harness the energy from fusion reactions in the laboratory.

All stars generate their energy through fusion processes. Stars are born in regions of space containing vast clouds of dust and gas. Two conditions must be met before fusion reactions in the star can sustain its energy needs: (1) The temperature must be high enough (about 10^7 K for hydrogen) to allow the kinetic energy of the positively charged hydrogen nuclei to overcome their mutual Coulomb repulsion as they collide, and (2) the density of nuclei must be high enough to ensure a high rate of collision.

One of the major problems in obtaining energy from nuclear fusion is the fact that the Coulomb repulsion force between two charged nuclei must be overcome before they can fuse. The fundamental challenge is to give the two nuclei enough kinetic energy to overcome this repulsive force. This can be accomplished by heating the fuel to extremely high temperatures (about 10^8 K, far greater than the interior temperature of the Sun). In addition to the high temperature requirements, there are two other critical factors that determine whether or not a thermonuclear reactor will function: the plasma ion density ***n*** and the plasma confinement time ***t*** - the time the interacting ions are maintained at a temperature equal to or greater than that required for the reaction to proceed. The density and confinement time must both be large enough to ensure that more fusion energy will be released than is required to heat the plasma.

Most fusion experiments use magnetic field confinement to contain a plasma. One device, called a tokamak**,** has a doughnut-shaped geometry (a toroid). This device, first developed in the former Soviet Union, uses a combination of two magnetic fields to confine the plasma inside the doughnut. A strong magnetic field is produced by the current in the windings, and a weaker magnetic field is produced by the current in the toroid.

Elementary particles

The word "atom" is from the Greek word "atomos", meaning "indivisible." At one time, atoms were thought to be the indivisible constituents of matter; that is, they were regarded as elementary particles. Discoveries in the early part of the 20th century revealed that the atom is not elementary, but has protons, neutrons, and electrons as its constituents. Until 1932, physicists viewed these three constituent particles as elementary because, with the exception of the free neutron, they are highly stable. The theory soon fell apart, however, and beginning in 1937, many new particles were discovered in experiments involving high-energy collisions between known particles. These new particles are characteristically unstable and have very short half-lives, ranging between $10^{\sim 23}$ s and $10^{\sim 6}$ s. So far more than 300 of them have been cataloged.

In the last 30 years, physicists have made tremendous advances in our knowledge of the structure of matter by recognizing that all particles (with the exception of electrons, photons, and a few others) are made of smaller particles called quarks. Protons and neutrons, for example, are not truly elementary but are systems of tightly bound quarks.

In the 1920s, the theoretical physicist Paul Adrien Maurice Dirac (1902-1984) developed a version of quantum mechanics that incorporated special relativity. Dirac's theory successfully explained the origin of the electron's spin and its magnetic moment. The general and profound implication of Dirac's theory is that for every particle, there is an antiparticle with the same mass as the particle, but the opposite charge.

The positron was discovered by Carl Anderson in 1932, and in 1936 he was awarded the Nobel prize for his achievement. Anderson discovered the positron while examining tracks created by electron-like particles of positive charge in a cloud chamber.

Practically every known elementary particle has a distinct antiparticle. Among the exceptions are the photon and the neutral pion, which are their own antiparticles. An antiparticle is not identified solely on the basis of opposite charge: even neutral particles have antiparticles.

The beginning of particle physics

The first theory to explain the nature of the nuclear force was proposed in 1935 by the Japanese physicist Hideki Yukawa (1907-1981), an effort that later earned him the Nobel prize. In order to understand Yukawa's theory, it is useful to first note that two atoms can form a covalent chemical bond by the exchange of electrons. Similarly, in the modern view of electromagnetic interactions, charged particles interact by exchanging a photon.

The nuclear force was originally called the strong force. Once the quark theory was established, however, the phrase strong force was reserved for the force between quarks. We will follow this convention: the strong force is between quarks and the nuclear force is between nucleons.

In an effort to substantiate Yukawa's predictions, physicists began looking for the meson by studying cosmic rays that enter the Earth's atmosphere. In 1937, Carl Anderson and his collaborators discovered a particle with mass 106 MeV/c^2, about 207 times the mass of the electron. However, subsequent experiments showed that the particle interacted very weakly with matter and hence could not be the carrier of the nuclear force. This puzzling situation inspired several theoreticians to propose that there are two mesons with slightly different masses, an idea that was confirmed in 1947 with the discovery of the pi meson (π), or simply pion, by Cecil Frank Powell (1903-1969) and Guiseppe P. S. Occhialini (1907-1993). The lighter meson discovered earlier by Anderson, now called a muon, has only weak and electromagnetic interactions and plays no role in the strong interaction.

		Nuclear reactors	Reproduction constant	Self-sustained chain reaction	
				Supercritical	Runway reaction
			Neutron Leakage	Moderator	Neutron capture
	Nuclear fusion	Binding energy	Fusion processes	Light nuclei	
		Thermonuclear fusion reactions	Fusion reactors	Plasma confinement time	
				Plasma ion density	
				Tokamak	Fusion power plants
	Particle physics	Elementary particles	Antiparticle		
		Hadrons	Strong force	Mesons	Pion
				Baryons	Protons
					Neutrons
			Quarks		
		Leptons	Weak force	Muon	
				Neutrino	
				Electrons	
		Strange particles	Strangeness		
		Collider	Colliding-beam accelerators		

Fig. 30. **Thesaurus for Unit 30**

All particles other than photons can be classified into two broad categories, hadrons and leptons, according to their interactions. Particles that interact through the strong force are called hadrons. There are two classes of hadrons, known as mesons and baryons, distinguished by their masses and spins. All mesons are known to decay finally into electrons, positrons, neutrinos, and photons. Leptons (from the Greek leptos, meaning "small" or "light") are a group of particles that participate in the weak interaction. All leptons have a spin of 1/2. Included in this group are electrons, muons, and neutrinos, which are less massive than the lightest hadron.

Many particles discovered in the 1950s were produced by the nuclear interaction of pions with protons and neutrons in the atmosphere. A group of these particles was found to exhibit unusual properties in their production and decay and hence were called strange particles. To explain these unusual properties of strange particles, a law called conservation of strangeness was introduced, together with a new quantum number ***S*** called strangeness**.**

Scientists are convinced that because of the limited energy available in conventional accelerators using fixed targets, it is necessary to build colliding-beam accelerators called colliders. The concept of a collider is straightforward. In such a device, particles with equal masses and kinetic energies, traveling in opposite directions in an accelerator ring, collide head-on to produce the required reaction and the formation of new particles.

Our understanding of physics at short and long distances is far from complete. Particle physics is faced with many questions. The questions go on and on. Because of the rapid advances and new discoveries in the related fields of particle physics and cosmology, by the time you read this book some of these questions may have been resolved and others may have emerged.

1. What are the two ways of getting energy from nuclear reactions?
2. When does nuclear fission occur?
3. Why do reactor fuels must be artificially enriched?
4. What’s the main problem of getting energy from nuclear fusion?
5. Why did physicists regard protons, neutrons and electrons as elementary particles before 1932?
6. What subatomic particles do you know?
7. What’s the concept of collider?

Exercises

1. Rearrange the letters in the anagrams to form equivalents for the Russian words:

Замедлитель	*deratormo*
Кварки	*arksqu*
Адроны	*dronsha*
Лептоны	*tonslep*
Странность	*nessstrange*

2. Match the words in A with the words in B to form word combinations:

A	B
Nuclear	*chain reaction*
Fission	*fission*
Self-sustained	*fragments*
Runaway	*nuclei*
Light	*accelerators*
Colliding-beam	*reaction*

3. Fill in the gaps with the missing words from the list:

fusion reactions, fission fragments, quark, strangeness, moderator

1. The _____, barium and krypton, and the released neutrons have a great deal of kinetic energy following the fission event.
2. The slowing down of the neutrons by the ______ serves the dual purpose of making them available for reaction with ^{235}U and decreasing their chances of being captured by ^{238}U.
3. When ______ occur at the core of a star, the energy that is liberated eventually becomes sufficient to prevent further collapse of the star under its own gravity.
4. The ______ model has reduced the bewildering array of particles to a manageable number and has predicted new quark combinations that were subsequently found in many experiments.
5. The law of conservation of _____ states that whenever a nuclear reaction or decay occurs, the sum of the strangeness numbers before the process must equal the sum of the strangeness numbers after the process.

Список использованной литературы

1. Толстой Д.М. Англо-русский физический словарь. Ок. 60000 терминов. М.: Сов. энциклопедия, 1972. 848 с.
2. INIS: THESAURUS. International Atomic Energy Agency, Vienna, http://www.iaea.org/INIS
3. Jerry S. Faughn, Raymond A. Serway, Chris Vuille, Charles A. Bennett. Serway's College Physics. Seventh edition. USA, 2006. 1008 p.

ПРИЛОЖЕНИЕ. Англо-русский терминологический словарь

Absolute zero – абсолютный нуль
Absorption spectrum – спектр поглощения
AC (Alternating-current) circuits – цепи переменного тока
Acceleration at the Highest point – ускорение в наивысшей точке
Acceleration of gravity – ускорение силы тяжести, ускорение свободного падения
Acceptor atoms – атомы акцепторы
Accommodation – аккомодация
Action potentials – действующий потенциал
Action-at-a-distance – действие на расстоянии
Adding vectors – суммирование векторов
Addition laws – дополнительные законы
Adiabatic process – адиабатический процесс
Adjustable bellows – регулируемый сильфон
Adjustment – регулирование
AFM (atomic force microscope) – атомный микроскоп
Allowed states – разрешённые состояния
Alpha particles – альфа частицы
Aluminum – алюминий
Amber – янтарь
Ammeter – амперметр
Amorphous solid – аморфное тело
Ampere (A) – ампер
Amplitude – амплитуда
Analyzer – анализатор
Angle subtended – стягиваемый угол
Angular momentum – момент импульса
Antineutrino – антинейтрино
Antiparticle – античастица
Aperture – диафрагма
Approximate values – приблизительные значения
Archimedes's principle – принцип Архимеда
Artificial radioactivity – искусственная радиоактивность
Assumptions – предположения
Atmospheric refraction – атмосферная рефракция
Atomic number – атомное число
Atomic transitions – атомные перемещения
Audible wave – звуковая волна
Average power – средняя мощность
Axis – ось

Back emf – обратная ЭДС
Band gap – ширина запрещённой зоны
Bar magnet – стержневой магнит
Baryons – барионы
Base – база (в транзисторе)
Battery – батарея
Becquerel(Bq) – беккерель
Beta decay – бета-распад
Binding energy – энергия связи
Black hole – чёрная дыра
Blackbody radiation – излучение абсолютно чёрного тела
Blades of a turbine – лопасти турбины
Blurred images – смазанное изображение
Bohr radius – боровский радиус
Bohr's Correspondence principle – боровский принцип соответствия
Boiling point – точка кипения
Boltzman's constant – постоянная Больцмана
Breaking point – точка разрушения
Bremsstrahlung – тормозное излучение
Brightness – яркость
British thermal unit (Btu) – британская тепловая единица
Bulb – колба (лампы)
Bulk modulus – объёмный модуль
Buoyant force – выталкивающая сила
Calculations – вычисления
Calorie – калория
Calorimeter – калориметрия
Camera – фотоаппарат (оптика)
Capacitance – ёмкость
Capacitors in series – последовательно соединённые конденсаторы
Carnot engine – двигатель Карно
Case ground – заземление
Celsius temperature scale – температурная шкала Цельсия
Centimeter – сантиметр
Centripetal force – центростремительная сила
Charge carriers – носитель заряда
Charging by friction – заряд трением
Chemical energy – химическая энергия
Chip – чип (в микроэлектронике)
Chromatic aberration – хроматическая аберрация (отклонение)
Circuit breaker – прерыватель цепи
Circular motion – круговое движение
Clockwise – по часовой стрелке
Closed loop – замкнутый контур

Cloud chamber – камеры Вильсона
Coal-fired plant – теплоэлектростанция
Coefficient of linear expansion – коэффициент линейного расширения
Coherent sources – когерентные источники
Collector – коллектор (в транзисторе)
Collider – коллайдер
Colliding-beam accelerator – ускоритель встречного пучка
Collision – столкновение
Commercial generator – промышленный генератор
Common sense – здравый смысл
Compact disks (CD's) – компакт диски
Compass needle – стрелка компаса
Complex DC circuits – сложные цепи постоянного тока
Compound microscope – сложный микроскоп
Compressibility – сжимаемость
Compression – сжатие
Compton shift – комптоновское смещение
Concave mirror – вогнутое зеркало
Conduction band – зона проводимости
Consequences of Special relativity – последствия специальной теории относительности
Conservation of momentum – сохранение количества движения
Conservative fields – консервативные поля
Constructive interference – конструктивная (усиливающая) интерференция
Continuous spectrum – непрерывный спектр
Convection – конвекция
Converging lenses – собирательные линзы
Conversion of units – перевод единиц
Convex mirror – выпуклое зеркало
Copper rod – медный стержень
Cornea – роговая оболочка
Coulomb(C) – кулон
Coulomb repulsion – кулоновское отталкивание
Counterclockwise – против часовой стрелки
Crime scene – место преступления
Critical temperature – критическая температура
Crystalline solid – кристаллическое тело
Curie (Ci) – Кюри
Current loop – электрический контур
Current-carrying conductor – токопроводящий проводник
Curved mirror – изогнутое зеркало

Cycle of day and night – цикл дня и ночи
Cyclic process – циклический процесс
Damped oscillation – затухающие колебания
Dark matter – темная материя
Daughter nucleus – дочернее ядро
Davisson-Germer experiment – эксперимент Дэвиссона-Гермера
De Broglie hypothesis – гипотезы де Бройля
Decay constant – постоянная распада
Deceleration – замедление
Decibel(dB) level – уровень шума в децибелах
Degree Celsius (°C) – градус по шкале Цельсия
Degree of shock – степень поражения
Density – плотность
Destructive interference – деструктивная (ослабляющая) интерференция
Dielectric strength – диэлектрическая сила
Diffraction grating – дифракционная решетка
Diffuse reflection – расплывчатое отражение
Diffusion – диффузия
Digital video disks (DVD's) – цифровые видео диски
Dimensionless – безразмерный
Diopter(dpt) – диоптрия
Dip angle – угол наклона
Direct current (DC) generator – генератор постоянного тока
Direction of conventional current – принятое направление тока
Disorder – неупорядоченность, разупорядочение
Dispersion – дисперсия
Displacement in two dimensions – смещение в двух измерениях
Diverging lens – рассеивающая линза
Donor atoms – атомы доноры
Doping – легирование (полупроводника)
Doppler effect – эффект Доплера
Drag force – сила сопротивления
Drift speed – дрейфовая скорость
Dual nature – двойная (двойственная) природа
Earth's magnetic field – магнитное поле Земли
Einstein's principle of relativity – принцип относительности Эйнштейна
Elastic collision – упругое столкновение
Elastic limit – предел упругости
Electric charge – электрический заряд
Electric clothes dryers – электрические сушилки одежды
Electric ranges – электрические кухонные плиты

Electric stove ovens – электрические сушильные шкафы
Electric stove tops – электрические вытяжные шкафы
Electrical appliances – электрические приборы
Electrical safety – электробезопасность
Electrics motor – электродвигатель
Electromagnetic induction – электромагнитная индукция
Electronic flash units – электронные перепрограммируемые устройства
Electrons – электроны
Electrostatic equilibrium – электростатическое равновесие
Elementary particles – элементарные частицы
Eliminate sparking – зажигание (в автомобиле)
Emf (electromotive force) – ЭДС (электродвижущая сила)
Emission spectrum – спектр излучения, эмиссионный спектр
Emitter – эмиттер (в транзисторе)
Endothermic reactions – эндотермические реакции
Energy conservation – сохранение энергии
Energy stored by an inductor – энергия, накапливаемая катушкой индуктивности
Energy transfer – энергопередача
Enlargement – расширение, увеличение
Entire mass – полная масса
Entropy – энтропия
Environment – окружающее пространство, окружающая среда
Equality of two vectors – равенство двух векторов
Equation of state – уравнение состояния
Equilibrium position – равновесное состояние
Equipotential surfaces – эквипотенциальные поверхности
Equipotentials – эквипотенциалы
Equivalent resistance – эквивалентное сопротивление
Estimates calculations – приблизительные вычисления
Ether hypothesis – гипотеза эфира
Ever-increasing rate – постоянно увеличивающаяся скорость
Excited states – возбуждённые состояния
Exhaust speed – скорость выхлопа
Exothermic reactions – экзотермические реакции
Explosion – взрыв
Exposed conductor – оголённый проводник
Exposure time – время экспозиции

External forces – внешние силы
Eyeglasses – очки
Eyepiece – окуляр
Fahrenheit temperature scales – температурная шкала Фаренгейта
Farad (F) – Фарада
Faraday's law – закон Фарадея
Farsightedness – дальнозоркость
Femtometer – фемтометр (для диагностики фемтосекундного излучения)
Ferromagnetic – ферромагнетик
Fiber-optic devices – волоконно-оптические устройства
Fictitious forces – абстрактные силы
Field – поле
Filament – нить накаливания
Fine structure – тонкая структура
Firing threshold – порог запуска
Fission fragments – осколки деления
Flash device – устройство вспышки
Flat mirrors – плоские зеркала
Fluids in motion – жидкости в движении
Focal length – фокусная длина
Focal point – фокус
Foot – фут (англ. или амер. единица длины)
Foot-pound – фунт-сила
Forbidden gaps – запрещённые энергетические зоны
Forced vibration – вынужденные колебания
Forensic scientists – судебные эксперты
Formulae – формула
Frame of reference – система отсчёта
Fraunhofer diffraction – фраунгоферова дифракция
Free-fall acceleration – ускорение при свободном падении
Freely-falling-objects – свободно падающие объекты
Freezing point – точка замерзания
Frequency – частота
Friction – трение
Fringe – интерференционная полоса
Front side – передняя сторона
Fuel – топливо
Fundamental concepts – фундаментальные понятия
Fundamental quantities – фундаментальные величины
Fun-loving grown-up – любящий забаву взрослый
Fuse – плавкий предохранитель

Fusion power plants – термоядерные электростанции
Gamma rays – гамма-лучи
Gas thermometer – газовый термометр
Gaussian surface – гауссова поверхность
Geiger counter – счётчик Гейгера
General relativity – общая теория относительности
Generator – генератор
Genetic damage – генетический ущерб
Germanium – германий
Giant superconducting magnets – гигантские сверхпроводящие магниты
Glancing collision – косые столкновения
Global warming – глобальное потепление
Glowing cavity – светящаяся полость
Gram (g) – грамм
Gravitation – гравитация
Gravitational constant – постоянная тяготения
Gravity – сила тяжести
Greenhouse effect – парниковый эффект
Ground state – основное состояние
Ground-fault interrupters – выключатель (прерыватель) заземления
Hadrons – адроны
Half-Life – период полураспада
Halfway – пол-оборота
Hard rubber – эбонит
Heat engine – тепловой двигатель
Heat of solidification – теплота затвердевания
Heat pumps – тепловые насосы
Heavy-duty – мощный, с высокой нагрузкой
Henry (H) – Генри
Hertz (Hz) – Герц
High potential – высокий потенциал
Holes – дырки (в полупроводниках)
Holography – голография
Hooke's law – закон Гука
Horizontal motion – горизонтальное движение
Horsepower – лошадиная сила
Hot wire – тепловой (энергетический) провод
Household circuits – бытовые сети
Huygens' principle – принцип Гюйгенса
Hydroelectric plant – гидроэлектростанция
Ice point – точка (температура) таяния льда
Ideal gas law – закон идеального газа
Ignition system – инжекторная система
Illuminate multiple slits – многощелевое излучение
Image distance – расстояние до изображения
Image point – точка изображения

Impact – соударение
Impedance – импеданс
Imperfect images – несовершенные изображения
Impulse – импульс
Incident wave – падающая волна
Incoherent sources – некогерентные источники
Indestructible sphere – неделимая сфера
Index of refraction – показатель преломления
Induced current – индукционный ток
Induced emf – наведённая (индуцированная) эдс
Inductance – индуктивность
Inductive reactance – индуктивное сопротивление
Inductor – индуктор, катушка индуктивности
Inelastic collision – неупругое столкновение
Inert mass – инертная масса
Inertia – инерция
Inertial frame – инерциальная система отсчёта
Infrared waves – инфракрасные волны
Infrasonic wave – инфразвуковая волна
Initial velocity – начальная скорость
Instantaneous angular speed – мгновенная угловая скорость
Insulator – изолятор
Integrated circuit – интегральная схема
Intensity level – уровень интенсивности
Interference – интерференция
Interference pattern – интерференционный узор
Intermolecular forces – межмолекулярные силы
Internal combustion engine – двигатель внутреннего сгорания
Inversely proportional – обратно пропорционально
Ionization energy – энергия ионизации
Ionizing radiation – ионизирующее излучение
Iron core – железный сердечник
Irregular – нерегулярный
Irregularly shaped object – объект неопределённой формы
Irreversible processes – необратимые процессы
Isobaric process – изобарический процесс
Isolated system – изолированная система
Isothermal process – изотермический процесс
Isotope – изотоп
Isovolumetric process – изохорный процесс, процесс с постоянным объёмом
Issue – выход, результат
Jiggling – покачивание
Joule (J) – Джоуль
Junction transistor – плоскостной транзистор

Kelvin (K) – Кельвин
Kelvin temperature scale – температурная шкала Кельвина
Kilogram (kg) – килограмм
Kilowatt-hour (kWh) – киловатт-час
Kinematics – кинематика
Kinetic friction – кинетическое трение
Kirchhoff's rules – правила Кирхгоффа
Laminar flow – ламинарный поток
Latent heat of vaporization – скрытая теплота испарения
Lateral magnification – боковое усиление
Lathes – токарные станки
LCD's(liquid crystal displays) – жидкокристаллические дисплеи
Left-right reversal – смена левой и правой сторон (при зеркальном отражении)
Length contraction – сокращение длины
Lens – линза
Lens-cornea – роговица хрусталика
Lenz's law – закон Ленца
Leptons – лептоны
Light nuclei – лёгкие ядра
Light pipe – светопровод, световод
Light-bulb – лампочка
Like poles – одноимённые полюса
Likelihood – вероятность, правдоподобие
Linear momentum – количество движения
Liquid crystals – жидкие кристаллы
Live wire – подключённый электропровод
Lloyd's mirror – зеркало Ллойда
Load resistance – сопротивление нагрузки
Longitudinal wave – продольная волна
Loudspeaker – громкоговоритель
Low potential – низкий потенциал
Low-yield process – малоэффективный (низкопродуктивный) процесс
Luminiferous ether – светоносный эфир
Magnet – магнит
Magnetic domains – магнитные домены
Magnetic field of a long – продольное магнитное поле
Magnetic flux – магнитный поток
Magnetic resonance imaging – магниторезонансный отображатель
Magnetic tapes – магнитные ленты
Magnetism – магнетизм
Magnetized magnetic material – намагниченный магнитный материал

Magnification – усиление (изменение размера, не увеличение)
Magnitude – величина
Mass – масса
Mass number – массовое число
Matter – материя, вещество
Measurements – измерения
Mechanical equilibrium – механическое равновесие
Medium – среда
Melting – таяние
Merry-go-round – карусель
Mesons – мезоны
Metal prong – металлический зубец
Meter (m) per second per second – метр в секунду в квадрате
Meter per second squared – метр в секунду в квадрате
Meters – измерительные приборы, счётчики
Michelson interferometer – интерферометр Михельсона
Microwave – микроволны
Mirage – мираж
Mirror equation – зеркальное уравнение
Moderator – замедлитель
Molar specific heat – молярная теплоёмкость
Mole (mol) – моль
Momenta – моменты (множ. число)
Momentum (transverse) – импульс
Monochromatic beam – монохроматический пучок
Motion of a pendulum – движение маятника
Motional emf – Движущая ЭДС
Movable piston – подвижный поршень
Multistage rockets – многоступенчатые ракеты
Muon – мю-мезон, мюон
Natural radioactivity – естественная радиоактивность
Nearsightedness – близорукость
Negative of a vector – обратный вектор
Negative vector – отрицательный вектор
Net force – результирующая сила
Neurons – нейроны
Neutrino – нейтрино
Neutron capture – захват нейтронов
Neutron leakage – нейтронная утечка
Newton (N) – Ньютон
Newton-meter (N-m) – ньютон-метр
Nonconducting substances – непроводящие вещества (материалы)

Noninteracting particles – невзаимодействующие частицы
North pole – северный полюс
Nuclear fission – деление ядра
Nuclear fusion – ядерный синтез
Nuclear reactor – ядерный реактор
Nuclei – ядра
Nucleon – нуклон
Nucleus – ядро
Object distance – расстояние до объекта
Objective – объектив
Ocular lens – окулярная линза
Ohm (Ω, omega) – Ом
Ohmic – омический
Ohm's law – закон Ома
Open-circuit voltage – напряжение открытой цепи
Opposing induced emf – противодействующая индуцируемая ЭДС
Opposites in direction – в противоположном направлении
Optical instruments – оптические приборы
Orbital magnetic quantum number – орбитальное магнитное квантовое число
Order-of-magnitude calculations – вычисления порядка величины
Oscillators – генераторы
Osmosis – осмос
Over-damped oscillation – колебания со сверхкритическим затуханием
Pair annihilation – парная аннигиляция
Pair production – парная генерация
Parallel to itself – параллельно самому себе
Parent nucleus – материнское ядро
Particle physics – физика элементарных частиц
Particle theory of light – корпускулярная теория света
Particle-like nature – корпускулярная природа
Pascal (Pa) – Паскаль
Path – траектория, путь
Pauli exclusion principle – принцип исключения Паули
Perfectly inelastic collision – абсолютно неупругие столкновения
Period – период
Permanent magnet – постоянный магнит
Permittivity – диэлектрическая постоянная
Phase change – фазовое превращение
Phase difference – фазовая разница (сдвиг по фазе)

Photocells – фотоэлементы
Photoelectric effect – фотоэлектрический эффект
Photon – фотон
Physics definition – физический смысл, физическое понятие
Physiological wonder – физиологическое явление
Pion – пи-мезон, пион
Planck's hypothesis – гипотеза Планка
Plane wave – плоская волна
Planetary escape speed – вторая космическая скорость
Plano-convex lens – плоско-выпуклые линзы
Plasma confinement time – время удержания плазмы
Plastic comb – пластиковая расчёска
p-n junction – p-n переход
Point charge – точечный заряд
Point source – точечный источник
Polar coordinate system – полярная система координат
Polarizer – поляризатор
Polarizing angle – угол поляризации
Polaroid – поляроид
Population inversion – инверсная заселённость
Positive lens – положительная линза
Positron – Позитрон
Potential difference – разность потенциалов
Potential drop – падение напряжения (потенциала)
Power in an AC circuit – мощность в переменных цепях
Power plant – электростанция
Pressure – давление
Primary coil – первичная катушка
Principal quantum number – основное квантовое число
Principle of Galilean relativity – принцип относительности Галилея
Prism spectrometer – призматический спектрометр
Projectile motion – движение летящего предмета, снаряда
Projection angle – проекционный угол
Propagation of waves – распространение волн
Proper time – собственное время
Protons – протоны
Puff of air – струя воздуха
Pure capacitor – идеальный конденсатор
Pythagorean theorem – теорема Пифагора

Quantized energy states – квантовые энергетические состояния
Quarks – кварки
Radian (rad) – радиан
Radiation – излучение, радиация
Radiation damage – радиационные повреждения
Radiation exposure – радиационное облучение
Radioactive tracers – радиоактивные индикаторы
Radioactivity – радиоактивность
Rainbow – радуга
Randomly – беспорядочно
Rarefaction – разрежение
Rate – темп, скорость, интенсивность изменения
Ray approximation – аппроксимация луча
RC-circuits – RC-цепи
Reactance – реактанс
Reaction force – сила противодействия, сила реакции
Real image – действительное изображение
Recoil – отдача, отскакивание
Rectangular (Cartesian) coordinate system – прямоугольная (декартова) система координат
Reference clock – эталонные часы
Reference frame – система отсчёта
Reference line – линия отсчёта
Reflection – отражение
Refraction (bending) – преломление
Refrigerator – холодильник
Relationship – отношения
Relative velocity – относительная скорость
Relativistic momentum – релятивистский импульс
Released – выпущенный, освобождённый
Reproduction constant – постоянная воспроизводства
Reradiation – вторичное излучение
Resistance – сопротивление
Resistivity – удельное сопротивление
Resistors in parallel – параллельные резисторы (сопротивления)
Resonance – резонанс
Resonant frequency – резонансная частота
Resonators – резонаторы
Rest energy – энергия покоя

Restoring force – восстанавливающая (возвращающая) сила
Resultant vector – результирующий вектор
Retina – сетчатка глаза
Retroreflection – обратное отражение
Reversible processes – обратимые процессы
Right-hand rule – правило правой руки
Rigid object – твердый объект
RL-circuits – RL-цепи
Rms (root mean square) values – среднеквадратичные величины
Rocket propulsion – движущая сила (сила тяги) ракеты
Roentgen – Рентген
Rotation of wheels – вращение колёс
Rotational equilibrium – вращательное равновесие
Runaway reaction – неуправляемая реакция
Same units – одинаковые единицы
Satellite motion – движение спутника
Scalar quantity – скалярная величина
Scattered x-rays – рассеянные рентгеновские лучи
Schrodinger's equation – уравнение Шредингера
Second (s) – секунда
Secondary coil – вторичная катушка
Selective absorption – выборочное поглощение
Self-induced emf – ЭДС самоиндукции
Self-sustained chain reaction – самоподдерживаемая цепная реакция
Semiconductor – полупроводник
Serious injury – серьёзное повреждение, рана
Shape of a parabola – форма параболы
Sharp images – чёткое изображение
Shear modulus – модуль сдвига
Shear stress – деформация сдвига
Shell – оболочка
Shock absorbers – амортизаторы
Shutter – затвор
Silicon – кремний
Silver – серебро
Simple magnifier – простая лупа
Simultaneity – одновременность, синхронность
Single-lens photographic camera – однолинзовая фотокамера
Slip rings – скользящие кольца
Slowing down – замедляющий
Slug – слаг (англ.или амер. единица массы)
Soft spring – мягкая пружина
Solenoid – соленоид

Solid – твердое тело
Solid-state devices – твердотельные устройства
Somatic damage – телесное повреждение
Sound wave – звуковая волна
South pole – южный полюс
Spacing – период (решетки)
Special relativity – специальная теория относительности
Specific heat – удельная теплоёмкость
Specular reflection – зеркальное отражение
Speed – скорость (скаляр)
Speeding up – ускоряющий
Spherical aberration – сферическая аберрация, отклонение
Spin magnetic quantum number – спиновое магнитное квантовое число
Split ring – незамкнутое кольцо
Splitting – расщепление
Spontaneous emission – самопроизвольная эмиссия (испускание)
Spring – упругость, пружина
Square root – квадратный корень
Standard of time – стандартный эталон времени
Standing wave – стоячая волна
Static friction – статическое трение
Stationary frame of reference – стационарная система отсчёта
Steady source – стабильный источник
Steady state – устойчивое состояние
Steam point – точка парообразования
Stiff spring – жёсткая пружина
STM (scanning tunneling microscope) – туннельный микроскоп
Store short-term energy for rapid release – перепрограммируемая память
Straight wire – прямой провод
Straight-line path – прямолинейный путь
Strain – относительная деформация
Strange particles – странные частицы
Strangeness – странность
Streamline – линия тока
Stress – деформация
String – струна
Strong nuclear force – сильная ядерная сила
Strong repulsive – сильный отталкивательный
Subcritical – подкритический
Subshell – подоболочка
Superconductors – сверхпроводимость

Supercritical – сверхкритический
Superposition of waves – наложение волн
Surroundings – окружающая среда
Swinging of a pendulum – раскачивание маятника
Switch – переключатель, коммутатор
System International (SI) – система международная (СИ)
Tangential speed – касательная скорость
Telescope – телескоп
Tensile strain – относительная деформация растяжения
Tensile stress – деформация растяжения
Terminal – зажим, клемма, выход
Terminal speed – предельная скорость
Terminal voltage – напряжение на клеммах
Tesla (T) – Тесла
Thermal conduction – теплопроводность
Thermal contact – тепловой (термический) контакт
Thermal efficiency – КПД (коэффициент полезного действия)
Thermal expansion – тепловое расширение
Thermal physics – теплофизика
Thermometer – термометр
Thermonuclear fusion reactions – термоядерные реакции
Thin films – тонкие плёнки
Thin-lens equation – уравнение для тонкой линзы
Three laws in a nutshell – три закона в единстве
Threshold energy – пороговая энергия
Threshold of hearing – слуховой порог
Threshold of pain – болевой порог
Thrust – реактивная сила
Time dilation – расширение времени
Tokamak – токамак
Tonometer – тонометр (медицинский)
Topspin – верхний спин
Total internal reflection – полное внутреннее отражение
Transformer – трансформатор
Translational kinetic energy – поступательная кинетическая энергия
Transport phenomena – явления переноса
Transverse wave – поперечная волна
Traveling wave – бегущая волна
Triangle method addition – суммирование по методу треугольника
Trigonometry – тригонометрия
Triple point – тройная точка

Tripod – *тренога*
Tune the frequency – *переключатель частоты*
Tuning fork – *камертон*
Tunneling – *туннелирование*
Turbulent flow – *турбулентный поток*
Twin paradox – *парадокс близнеца*
U.S. customary system – *американская общепринятая система*
Ultimate strength – *предел прочности*
Ultrasonic wave – *сверхзвуковая (ультразвуковая) волна*
Ultraviolet (UV) light – *ультрафиолетовый свет*
Ultraviolet catastrophe – *ультрафиолетовая катастрофа*
Uncertainty principle – *принцип неопределённости*
Under-damped oscillation – *колебания с докритическим затуханием*
Unified mass unit – *объединённая единица массы*
Uniform circular motion – *однородное круговое движение*
Units – *единицы (измерения)*
Universal gravitation constant – *универсальная гравитационная постоянная*
Universe – *Вселенная*
Unlike poles – *разноимённые полюса*
Unpolarized wave – *неполяризованная волна*
Unstreched – *нерастянутый*
Up-and-down motion – *движение вверх-вниз*
Uranium compounds – *соединения урана*
Valence band – *валентная зона*
Van der Graaf generator – *генератор ванн-дер-Графа*
Vector quantity – *векторная величина*
Vehicles – *транспортные средства*
Velocity – *скорость (вектор)*
Velocity vs. time graph – *зависимость (график) скорости от времени*
Vibrations – *колебания, вибрации*
Virtual image – *мнимое изображение*
Visible light – *видимый свет*
Volt (V) – *Вольт*
Voltage – *напряжение*
Voltaic cell – *гальванический элемент*
Voltmeter – *вольтметр*
Volume elasticity – *объёмная упругость*
Watt (W) – *Ватт*

Wave front – волновой фронт (фронт волны)
Wave function – волновая функция
Wavelength – длина волны
Wavelets – слабые волны (волны малой амплитуды)
Wave-particle nature – корпускулярно-волновая природа
Weak nuclear force – слабые ядерные силы
Weber (Wb) – Вебер
Weight – вес
Wien's displacement law – закон смещения Вина
Windings – обмотки (катушки или трансформатора)
Wire – электропровод
Wire loop – проволочный контур
Work done on the system – работа сделанная над системой
Work function – работа выхода
Wrench – рывок
X-direction – X-направление
X-rays – рентгеновское излучение
Young's double-slit experiment – двухщелевой эксперимент Юнга
Zeeman effect – эффект Зеемана
Zero net force – нулевая результирующая сила
Zero-point energy – нулевая энергия
Zeroth law of thermodynamics – нулевой закон термодинамики