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Energy

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A rock falling off a cliff is different from the same rock lying on the ground below. The lively child eager to join his playmates after a night's rest and a hearty breakfast is different from the child who can barely keep his eyes open after dinner. A glowing light bulb is different from the same bulb when the electricity is switched off. In each case, an agent **of** change has acted upon the rock, child, and light bulb. It is the same rock, the same child, the same light bulb. The difference is one **of energy**.

Energy is one **of** the most basic ideas **of** science. All occurrences in the universe can be explained in terms **of energy** and matter (see Matter). But the definition **of energy** is not at all simple since **energy** occurs in many different **forms**, and it is not always easy to tell how these **forms** are related to one another and what they have in common. One **of** the best-known definitions **of energy** is the classical definition used in physics: **Energy** is the ability to do work.

Physicists define work in a way that does not always agree with the average person's idea **of** work. In physics, work is done when a force applied to an object moves it some distance in the direction **of** the force. Mathematically, W=Fs, where W is the work done, F is the force applied, and s is the distance moved. If either F or s is equal to zero, W is also equal to zero.

If a person walks up a flight **of** stairs he may regard it as work-he exerts effort to move his body to a higher level. In this instance, he also does work according to the definition accepted by physicists, for he exerts a force to lift himself over a distance-the distance from the bottom to the top **of** the stairs.

However, if a person stands without moving with a 100-pound weight in his outstretched arms, he is not doing any work as physicists define work. He is exerting a force that keeps the 100-pound weight from falling to the floor, but the position **of** the weight remains unchanged. It is not moved any distance by the force. The person is, **of** course, exerting considerable muscular effort to avoid dropping the weight, and the average man would say that he is working very hard indeed. But he is not doing any work according to the definition accepted in physics.

Energy from Gravity

Energy is readily transferred from object to object, especially in the form **of** heat. For this reason it is often necessary to study an entire group **of** objects that may be transferring **energy** back and forth among themselves. Such a group is called a system. The **energy of** a system is the ability **of** the entire system to do work. If the parts **of** a system do work on one another but do not change anything outside the system, then the total amount **of energy** in the system stays the same. However, the amount **of energy** in one part **of** the system may decrease and the amount **of energy of** another part may increase.

Consider a system consisting **of** a jungle with many trees, a vine hanging from the central tree, the earth supporting the trees, and a boy standing beneath the tree from which the vine is hanging. The boy, holding the free end **of** the vine, climbs up the central tree. He then moves several treetops away,

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maintaining the same altitude.

Finally, the boy grasps the vine that is still tied to the central tree and swings down, past the central tree, and up again until he lands in a third tree. An observer watching the boy swinging from one tree to the other will conclude that the system possesses **energy** and can do work.

The necessary elements in this system are the boy, who provides the initial **energy** by climbing the trees; the trees, which support him against the force **of** gravity, which is vertically downward; the Earth, whose gravitational attraction is the force that does the work **of** drawing him downward; and the vine, which supports him so that he remains free to swing upward against the force **of** gravity when his **energy** is great enough. When all these elements occur together, the system is capable **of** doing work; it has **energy**.

As the boy swings by the vine, he is acting like a pendulum (see Pendulum). Like any pendulum, he is exhibiting the difference between two kinds **of energy** -potential **energy** and kinetic **energy**.

As the boy stands at the top **of** the second tree, he is not moving. But the system has **energy** because **of** his location away from the surface **of** the Earth. This **energy** is called potential **energy**.

Gravity is pulling at the boy. When the boy jumps off the tree, gravity pulls him down. He travels faster and faster until, as he sweeps by the Earth, he is traveling very fast. The system has lost potential **energy** and gained **energy** from the speed **of** his motion. The new **energy** is called kinetic **energy**. If the boy were to grab his pet monkey at the bottom **of** the tree, he would be applying a force to the monkey and the monkey would be moved up into the tree with him. When they landed in the tree, the system would again have potential **energy** but no kinetic **energy**.

If a rock rolls down a hill and dislodges another rock which then also rolls down the hill, kinetic **energy** is at work. A hammer driving a nail into a board is an example **of** kinetic and potential energies. The hammer applies several forces in succession to the nail, and the nail is moved deeper and deeper into the board.

If a force is applied to compress a spring, the resulting compressed spring possesses **energy**. It can do work in the process **of** returning to its natural length. For example, it can lift a weight. Engergy **of** this type is called elastic **energy** or deformation **energy**.

Chemical Energy

When several chemicals are mixed together to form gunpowder or dynamite, a violent explosion can occur if care is not taken to prevent this. An explosion can do work against the force **of** gravity, for example, by throwing pieces **of** material into the air. A mixture **of** chemicals that can do work is said to have chemical **energy**. Not all chemical systems that can do work are as dramatically energetic as gunpowder or dynamite, and often the amount **of energy** a chemical system possesses is hard to measure.

To understand chemical **energy** it is necessary to study what happens during a chemical reaction. To begin with, all matter is made up **of** tiny units called atoms. An atom can bond to other atoms to form a group called a molecule. All the substances on Earth-rocks, wood, air, soil, water-are made up **of** atoms or molecules.

For example, one kind **of** atom is the oxygen atom (O). A molecule **of** oxygen gas contains two oxygen atoms (O2). An oxygen atom and two hydrogen atoms combine to form a water molecule (H2O). One kind **of** sand molecule-silicon dioxide (SiO2)-contains one atom **of** silicon (Si) and two atoms **of** oxygen. (See also Chemistry.)

Molecules are formed in chemical reactions. Some molecules give off a great deal **of energy** when

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they are formed from individual atoms. Such molecules are very stable because all that **energy** must be put back into them before they decompose. Other molecules release very little **energy** when they are formed. Such molecules are very unstable. They react easily to form more stable molecules. During these reactions much **energy** is given off. Nitroglycerin-a dense, oily liquid-changes readily to water, carbon dioxide, nitrogen, and oxygen. This reaction is explosive because it occurs very rapidly and because the suddenly formed gases take up much more room than did the liquid nitroglycerin. Other chemical reactions can produce **energy** but not be explosive. They may occur more slowly, and the resulting molecules may take up the same amount **of** room as the original molecules.

Food **energy** is a form **of** chemical **energy**. Plants absorb **energy** from sunlight and store it in **energy**-rich chemicals, such as glucose. This process is called photosynthesis. Animals that eat plants use the chemicals created by photosynthesis to maintain life processes. Other animals may eat plant-eating animals to gain the **energy**-rich chemicals that the plant-eaters formed from the chemicals **of** plants. Since food **energy** is what keeps living things moving, it is clearly able to do work.

Electrical Energy

One **of** the most important kinds **of energy** in the modern technological world is electrical **energy**. Electric currents turn motors and drive machinery. Electric currents provide the **energy of** laborsaving applicances such as electric mixers, power drills, vacuum cleaners, and automatic dishwashers. Clearly, the currents possess **energy**.

Electrical **energy** is linked with the basic structure **of** the atom. According to modern atomic theory an atom has a heavy, positively charged center called the nucleus. One or more light, negatively charged electrons circulate around the nucleus (see Matter). The positive nucleus and the negative electrons attract one another. This attraction keeps most **of** the electrons circulating near the nucleus. But sometimes a neighboring nucleus will also attract the electrons **of** the first atom. This is how a chemical bond is formed. So, in a way, all chemical **energy** is a special, microscopic kind **of** electrical **energy**.

Metals are made up **of** atoms that contain many electrons. Because **of** the peculiar structure **of** metal atoms, the atomic nuclei are not strong enough to hold on to all their electrons (see Crystals). Some **of** the electrons more or less float from nucleus to nucleus. These free electrons can take part in an electric current (see Solid State Physics).

Work must be done to separate positive and negative charges if one is to produce a surplus **of** electrons in one place and nuclei that are missing one or more electrons at another place. When this situation occurs, as in a battery, **energy** is stored. If one end **of** a metal wire is connected to the place where excess electrons are collected (the negative terminal on a battery) and the other end **of** the wire is connected to the place where excess nuclei are collected (the positive terminal on a battery), the electrons **of** the wire flow to join the nuclei. Electrons farther down the wire flow after the first electrons, and the electrons from the battery move into the wire. This total electron flow from the negative terminal **of** the battery through the wire and into the positive terminal is called an electric current. Since a force is applied that makes the electrons move a certain distance down the wire, work is done. (See also Battery and Fuel Cell; Electricity.)

Magnetic **energy** is closely related to electrical **energy**. Magnetic fields are set up whenever electric charges move (see Magnet and Magnetism).

Radiant Energy, or Electromagnetic Waves

Some kinds **of energy** can travel across empty space. Such **energy**, called radiant **energy**, can travel through a vacuum. Radiant **energy** is caused by accelerated electric charges or by electric or magnetic fields that increase or decrease with time.

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The motion **of** these charges and fields disturbs space. The disturbance causes a wave to travel away from the site **of** the original electrical or magnetic motion. The wave consists **of** growing and collapsing electric and magnetic fields which are oriented at right angles to one another. Since waves **of** radiant **energy** consist **of** electrical and magnetic disturbances, they are often called electromagnetic waves.

Light is one form **of** electromagnetic radiation. Other **forms** include radio waves, infrared waves, ultraviolet radiation, X rays, and gamma rays. Some **of** these **forms** have longer wavelengths than light; others have shorter wavelengths. Human eyes are sensitive to light waves only. For this reason, human eyes can detect light from the sun and the stars as well as from other sources in space. But humans cannot see X rays and radio waves, though stars emit these radiations too.

Special instruments that work somewhat like Geiger counters are used to sense X rays from the sun and the stars. Huge radarlike instruments called radio telescopes are sensitive to radio waves. Using these radio telescopes, scientists have been able to detect waves from many parts **of** the universe-from the sun and the stars and from the huge clouds that float in outer space.

All **of** the **forms of** radiant **energy** are able to do work, though it is necessary to use special instruments to measure it. These instruments generally change radiant **energy** to the **energy of** moving electric currents, as in a radio receiver, for example (see Radiation; Light).

Nuclear Energy

Yet another kind **of energy** is locked in the nuclei **of** atoms. The nuclei **of** atoms contain two kinds **of** particles-protons and neutrons. The nuclear particles can store **energy**. Some nuclei spontaneously rearrange, or lose some particles, and emit **energy**. This process is called radioactivity. For example, a radium nucleus can spontaneously eject a cluster **of** two neutrons and two protons (called an alpha particle) and a gamma ray (electromagnetic radiation). These carry away **energy** from the nucleus, which changes into a smaller, more stable form.

Two techniques exist by which nuclear **energy** is released by human intervention. The first makes use **of** elements with very heavy atoms, such as uranium. More **energy** is required to hold together the uranium nucleus than to hold together two nuclei that are half the size **of** a uranium nucleus.

In atom bombs and in fission reactors, free neutrons bombard uranium atoms. When a neutron hits a nucleus, the nucleus splits into two smaller nuclei, releasing a great deal **of energy**. In the reaction, some **of** the neutrons **of** the uranium nucleus fly off and hit other nuclei, causing them to split in two and release more **energy** and more neutrons. The process can continue explosively unless metal rods are inserted in the middle **of** the uranium to capture some **of** the neutrons and slow down the reaction. This sort **of** reaction is called a fission reaction because in it nuclei are broken apart.

The second kind **of** nuclear reaction is harder to produce and control. It makes use **of** the fact that very small nuclei, such as hydrogen and its isotopes, require slightly more **energy** per proton and neutron to exist than do somewhat heavier nuclei. (The situation is exactly opposite to that **of** the uranium nucleus, where the lighter nuclei require less **energy**.) If two hydrogen nuclei can be combined to form one heavier nucleus, **energy** is released. This type **of** reaction goes on in the sun. By a somewhat complicated series **of** reactions, four hydrogen nuclei join together to form a new helium nucleus, giving off a great deal **of energy** in the process. This is the source **of** all the **energy** emitted by the sun (see Sun).

Temperatures in this kind **of** reaction must be very high (in the millions **of** degrees) before the nuclei have enough **energy** to collide with the force needed for them to join together. The reaction is called a thermonuclear fusion reaction. 'Thermonuclear' refers to the heat required for the nuclei to react, and 'fusion' means that in the reaction nuclei join together.

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A thermonuclear fusion reaction occurs when a hydrogen bomb explodes. Scientists are trying to develop a way **of** releasing **energy** by fusion reactions under controlled conditions (see Plasma and Plasma Physics).

Heat Energy

One very common form **of energy** is heat **energy**. Strictly speaking, this is not an additional type **of energy**, since heat **energy** is the kinetic **energy of** the individual molecules in a system. The faster the average motion **of** the molecules, the higher the temperature **of** the system. Heat can do work. When heat is applied to a liquid, the liquid may eventually boil, changing to a gas which takes up more space than does the liquid. And the gas from a boiling liquid can exert great force. It drives the turbines that generate the electricity **of** large cities.

The great importance **of** heat **energy** arises from the fact that most **of** the times that **energy** is used to do work, part **of** the **energy** is wasted as heat. For example, when a hammer is used to pound a nail into a board, much **of** the **energy of** the hammer goes to heating up the nail, the head **of** the hammer, and the parts **of** the board that touch the nail. Only a small part **of** the total **energy** actually moves the nail into the board.

The same is true **of** an automobile engine. Such engines would be much more efficient if all **of** the chemical **energy** generated by the explosion **of** gasoline and air changed to the kinetic **energy** that moves the pistons. Instead, much **of** the chemical **energy** changes to heat **energy**, which is **of** no help in running the car.

Kinetic and Potential Energy

It is possible to regard all the different **forms of energy** as being simply the kinetic or potential **energy of** various atomic or nuclear particles. For example, a stretched spring has **energy**, which is usually called elastic **energy**. This is a useful and correct way to look at the **energy of** a spring.

However, it is also correct to take a smaller view. The spring is made up **of** atoms which contain nuclei and electrons. The nuclei and electrons exert electrical forces on each other. The work done to stretch the spring is used to overcome the electrical forces that hold the atoms close together. The **energy of** the stretched spring can, in this view, be considered as electrical rather than elastic in nature. It is potential **energy** because it exists in the position **of** the particles relative to one another, rather than in their speeds. As soon as the spring is released, the electrical attraction **of** the individual atoms for one another causes them to draw closer together, with the result that the spring snaps together tightly. The potential **energy** changes to the kinetic **energy of** the atoms moving closer together.

The **energy** in a uranium nucleus is potential **energy**, too, because it is caused by the conditions in which the nuclear particles exist rather than by the speed **of** the particles. When a neutron collides with a uranium nucleus, much **of** the potential **energy of** the uranium nucleus is changed to the kinetic **energy of** the newly formed nuclei, **of** the extra neutrons, and **of** the radiation that is given off.

Mass Energy

For hundreds **of** years scientists thought that matter and **energy** were completely different from each other. But early in the 20th century Albert Einstein concluded that mass and **energy** were closely related, that mass could change to **energy** and **energy** could change to mass. Einstein described the relationship between mass and **energy** quantitatively in the famous equation, E=mc2. In this equation E stands for **energy**, m for mass, and c for the speed **of** light. The change in mass that is given by this equation is m=E/c2. Since c2 is a very large quantity, E must be very large indeed for m to be observable. This relationship has been experimentally confirmed. (See also Einstein; Relativity.)

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Chemical and nuclear reactions both involve a change in **energy** linked with a change in mass. Both may involve a reaction in which two entities form two new entities. In a chemical reaction the entities are atoms or molecules. In a nuclear reaction they are nuclei. In both cases the reaction may end up with a loss **of** mass. This loss is converted to **energy**, usually in the form **of** the kinetic **energy** **of** the two new entities.

In a chemical reaction each particle may gain up to 10 eV (electron volts). This corresponds to a loss **of** about 10-31 grams from each particle, an extremely small amount. If 12 grams (almost half an ounce) **of** carbon were involved in the reaction, the loss **of** mass would be only 10-8 grams, an amount that is still too tiny to be observed. For this reason the conversion **of** mass to **energy** in chemical reactions was not noticed by chemists.

In a nuclear reaction the **energy** produced per particle is usually more than 1 MeV (million electron volts). The loss in mass is about a million times larger than the loss in chemical reactions and is readily observable. Nuclear physicists routinely take account **of** the conversion **of** mass to **energy** in their study **of** nuclear reactions. However, the only difference between the loss **of** mass in chemical and nuclear reactions is a difference **of** magnitude. The source **of** both chemical and nuclear reactions is the same: the transformation **of** a certain amount **of** mass into **energy**.

The Changing Forms of Energy

One **of** the most useful facts about **energy** is that it can be changed from one form to another. These changes are happening all the time. Most machines have as their purpose the conversion **of** **energy** from one form to another. Furthermore, even in ordinary activities **energy** changes form. A person opening a door uses chemical **energy** stored in his muscle tissues. This is changed to the elastic **energy of** the muscle fibers. The elastic **energy of** the muscle applies a force-a push-to the door and is changed to the mechanical **energy of** the door as it swings open. If the door bangs against a wall, some **of** its **energy** is changed to sound **energy**.

Over centuries **of** scientific observation, scientists have noticed that **energy** seems to act in certain uniform ways. A regularity exists in its behavior to which no exceptions have been observed. This regularity has been expressed in the law **of** the conservation **of energy**. The law asserts that the total **energy of** an isolated system does not change. The **energy** can be redistributed or can change from one form to another, but the total **energy** remains the same. When a system is not isolated, however, outside forces are able to act on it. In such instances, any change in the **energy of** the system must exactly equal the work done on it by the outside forces.

The law **of** the conservation **of energy** is remarkable because it states that a certain numerical quantity is unchanged throughout all processes. It does not say why or how this happens. It just says that while the **forms of energy** are constantly changing, **energy** itself can neither appear out **of** nowhere nor vanish into nowhere. The conservation **of energy** seems to be one **of** the truly general laws, for it is followed by all observed examples **of** living and nonliving things. Somehow, despite the great diversity **of energy forms**, scientists were able to establish that an amount **of** one kind **of** **energy** had exact equivalents in the other kinds **of energy**.

What makes the law **of** the conservation **of energy** so remarkable is that most **of** the quantities that physicists measure are not necessarily conserved. Velocities, accelerations, temperatures, and chemical units, such as atoms and molecules, are not always conserved. However, the amount **of** matter in a system, like the amount **of energy**, is also conserved unless some **of** the matter is changed to **energy** or some **of** the **energy** is changed to matter. To take account **of** such changes, the law **of** the conservation **of energy** is combined with the law **of** the conservation **of** mass to form an expanded law **of** the conservation **of** mass-**energy** (see Matter).

The simplest examples **of** the conservation **of energy** are provided by systems in which only mechanical forces are acting. A swinging pendulum, such as the boy swinging by the vine in the jungle, continually interchanges kinetic and potential **energy**. At the top **of** the swing, the velocity is

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zero and the **energy** is purely potential. At the bottom **of** the swing, the **energy** is purely kinetic. In intermediate positions, the **energy** is partly potential and partly kinetic. The sum **of** the kinetic and the potential **energy**, however, is constant throughout.

Actually, very few examples exist **of** purely mechanical systems. A pendulum does not keep on swinging forever. After a while the swings get smaller, and eventually they stop. This happens because the mechanical **energy of** the pendulum is changed to heat **energy** by a force called friction. This force changes **energy** to heat whenever two moving pieces **of** matter are in relative motion.

The motion **of** the pendulum is retarded by the frictional forces that it experiences when it moves through the air and rubs against the hook that holds it up. The **energy of** the pendulum is transferred to the molecules **of** the air through which it moves and **of** the hook. Their kinetic or elastic **energy** is increased. The temperature **of** the air and the hook rises. Mechanical **energy** has been changed to heat **energy**.

Frictional forces play a role in most mechanical situations. They may change some or all **of** the mechanical **energy of** the system to heat **energy**. A considerable amount **of** heat may be developed. For example, if a nail is driven into a wall, the work done by the hammer goes into **energy of** deformation (the nail changes the form **of** the wall as it moves through it) and into a large amount **of** heat. The nail and the head **of** the hammer grow hot.

The Laws of Thermodynamics

In the early 19th century the Industrial Revolution was well underway. The many newly invented machines **of** the time were driven by **energy** provided by burning fuel. These machines provided scientists with a great deal **of** information about how heat could be converted to other types **of energy**, how other types **of energy** could be converted to heat, and how heat could do work. Some **of** these observations were condensed into the laws **of** thermodynamics. (Thermodynamics is the branch **of** physics which studies interconversions between heat and mechanical **energy**.)

The first law **of** thermodynamics-a mathematical statement **of** the conservation **of energy**-says that the amount **of** heat added to a system exactly equals any change in **energy of** the system plus all the work done by the system. The equations derived from the first law **of** thermodynamics describe three variables: the internal **energy of** a system, the heat **energy** added to the system, and the work done by the system on its surroundings.

The practical importance **of** the first law **of** thermodynamics is that it shows that the addition **of** heat to a system enables it to do work. This, by definition, means that heat is a form **of energy**. When the first law was proposed, many people found it difficult to accept because they did not believe that heat was a form **of energy**. They thought **of** it as a mysterious fluid. But the first law did describe the action **of** heat engines and **of** many other kinds **of** heat interactions, so it came to be accepted as valid.

The first law says that the total **energy of** the universe remains constant. It does not say what kinds **of energy** can be changed into what other kinds **of energy**. After many false starts, a principle-the second law **of** thermodynamics-was worked out that described the kinds **of energy** conversions that are possible. This law states that conditions in any system tend to change to a condition **of** maximum disorder. (The amount **of** disorder in a system is called entropy.) Work must therefore be done from outside the system to impose more order on the system or to decrease its entropy.

The second law **of** thermodynamics may not seem to make sense, yet it does describe many common experiences. For example, when someone kicks off his shoes, it is far more likely that they will not land in the closet where they belong than that they will land there. To get them where they belong the person must exert work. He must pick them up, carry them to the closet, and place them in their proper location.

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Heat is the most disordered form **of energy**. Therefore, according to the second law only a fraction **of** the heat available can be converted to useful work. Heat engines can transform some but not all **of** the heat available to them into mechanical **energy**. The remainder returns as heat at a lower temperature whether or not it is needed, wanted, or welcome.

Mechanical **energy**, on the other hand, can be completely converted to heat. This is a significant asymmetry. In both conversions the total amount **of energy** is conserved. But the second law **of** thermodynamics describes a restriction in the direction in which the conversions **of energy** can take place.

An automobile engine changes the chemical **energy of** gasoline into heat **energy**. The heat **energy** causes the gas to expand and push on a piston, thereby changing the heat **energy** partially to mechanical **energy**. Much **of** the heat **energy**, however, simply heats up the engine. The mechanical **energy of** the pistons is transferred to the tires, which push against the road's surface and move the car forward. But some **of** the **energy** in the tires is changed to heat **energy** by friction. In this and in all other processes involving conversions **of** heat **energy** to mechanical **energy**, much **of** the original heat **energy** remains.

To illustrate the difference between the second law **of** thermodynamics and the first, consider a pan **of** water that is heated by a burner. The first law **of** thermodynamics would perfectly well allow the water to freeze and the flame **of** the burner to get hotter, just as long as the total amount **of energy** remained the same. The second law **of** thermodynamics asserts that this is impossible. The process must proceed in the direction which transfers heat from the hotter to the colder body. The general direction **of** all processes occurring in the observed universe is that which increases entropy.

The third law **of** thermodynamics concerns a temperature called absolute zero. Absolute zero occurs at -273°C (-460°F). At absolute zero all substances theoretically would possess the minimum possible amount **of energy**, and some substances would possess zero entropy (be completely ordered). The third law states that, while absolute zero may be approached more and more closely, it is impossible actually to reach it (see Cryogenics).

Energy and Modern Physics

Early in this century the rise **of** quantum theory completely changed the notion **of energy**. Quantum theory is as important to 20th-century physics as the theory **of** relativity. Quantum theory states that **energy** occurs not over an infinitely divisible range but in certain distinct and specific amounts, called quanta. Thus, a given amount **of** electromagnetic **energy** cannot be subdivided into smaller and smaller amounts **of energy**. A smallest amount, or quantum, **of energy** exists which cannot be subdivided.

This view is illustrated by the respective ways in which classical physics and modern quantum physics treat a light wave. According to classical theory, the **energy of** a light wave can be made as small as desired by reducing the amplitude **of** the vibrations. According to modern quantum theory, however, the **energy of** a light wave **of** a definite frequency is the combined **energy of** a number **of** quanta. The smallest **energy** the light wave can have occurs when only one quantum is present.

For quantum physics, therefore, a beam **of** a given color **of** light consists **of** a very large number **of** quanta. However, it is impossible to discern the individual light quanta in a beam just as it is impossible to observe the individual molecules in a liquid. In both cases the very large numbers **of** very small objects present an unbroken, continuous appearance. (See also Light; Matter.)

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