MECHANICS AND ENGINEERING

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Mechanics occupies one of the central positions among the sciences that directly contribute to the advancement of scientific engineering. It plays a leading part in the evolution of scientific foundations of engineering by using the arsenal of physical investigation methods, mathematical analysis, and computation techniques. Achievements of space engineering, aviation, hydraulic engineering, machine and instrument manufacture, construction and shipbuilding industries are all based on the profound understanding of laws of mechanics and analysis, which, in turn, is based on data obtained in experimental and theoretical investigations.

Mechanics, which grew from the knowledge accumulated in the process of creating work tools, structures and early machines and understood in antiquity as the science of machines, was in the main developed under the pressure of practical needs of society, related to production, engineering, and the study of motion of celestial bodies (primarily for navigation purposes).

The evolution of mechanics was intimately related to that of mathematical methods whose appearance and subsequent refinements made possible the formulation and solution of more complicated problems of mechanics which, in turn, stimulated the intensive development of mathematical methods. The emergence of mechanics in its present form was itself the result of the simultaneous rapid qualitative advances in two domains: the definition of motions of bodies in terms of mathematical concepts, and the creation of the differential and integral calculus. This made possible the establishment of laws of motion and equilibrium for solid, liquid and gaseous bodies, which constitute the foundations of mechanics.

The success of mechanics, which provided a unique base for explaining an overwhelming majority of natural phenomena and of engineering, stretching from the motion of the Earth, Moon, and other celestial bodies to the working of machines and mechanisms, was so impressive that for some considerable time attempts were made to reduce all phenomena in the universe to mechanical ones. Only toward the end of the nineteenth and the beginning of the twentieth century the increased knowledge of electromagnetism, atomic and nuclear phenomena, emergence of the quantum and relativity theories made it clear that such generalization was basically impossible.

It is important to note that the so-called laws of conservation, which in contemporary physics are considered unassailable, are extensions of laws of classical mechanics on the change of momentum and of moment of momentum, and also of the theorem about kinetic energy. It became necessary to introduce new concepts such as spin, field momentum, and that of the equivalence of mass and energy.

Already at the beginning of the nineteenth century mechanics becomes the theoretical basis for an ever increasing number of applied technical sciences directly related to the development of industry, the exploitation of new technological processes, machine, and industrial equipment. A particular impetus to the development of mechanics was given by problems of railroad transportation and the rapid development of shipbuilding, internal combustion engines, automobiles, and particularly that of aviation.

Mechanics is the most ancient branch of physics. During its long history the opinion that its evolution as a fundamental science must be nearing its end was repeatedly expressed. The latest support for that opinion was provided by the phenomenal successes of computation techniques. It was thought that once the fundamental equation of mechanics had been established, any particular problem could be solved by computers. This was, however, decisively refuted in practice. Contemporary engineering and natural sciences ever present mechanics with new problems related to the discovery of previously unknown phenomena. The elucidation of these requires in the main further development of mechanics itself , as well as of closely related branches of physics, chemistry, biology, and other sciences. The appearance of modern computation facilities at the same time widened the opportunities available to investigators, made possible the overcoming of a number of technical difficulties, and shifted the emphasis to the main problem, which is that of determining the essential aspects of investigated processes or phenomena and to present these in the form of a reasonably simple algorithm ("model") amenable to quantitative computation and to qualitative analysis.

Important results were obtained in the years preceding the second world war in essential fields of engineering and natural sciences, which were based on considerable achievements in the domain of mechanics. Among these should be mentioned: aerodynamics and practical problems of aviation, theories of elasticity and placticity, strength of machines and structures, foundations, general mechanics, the theory of gyroscopes and stability of motion, and the solution of practical problems of automatic control, navigation, and instrument manufacture. Problems of climatic changes and weather forecasting were given a scientific base. Foundations were estabilshed for the mechanics of petroleum industry which provided the basis of rational exploitation of petroleum and gas deposits, and for conveying their products.

The tendency to establish close links between mechanics and other branches of physics appeared at the beginning of this century and are now strongly developed. This led to important developments in the field of combustion, shock waves and explosions, as well as in the solution of physical problems of deformability and strength of solid bodies.

A significant part of these achievements is due to investigations conducted in the Soviet Union, the then unique socialist state. The evolution of Soviet industry, power engineering, mining of minerals, mechanization and improvement of agriculture, as well as of military aviation, tank and rocket engineering was, to a considerable extent, based on achievements in the Soviet Union in the field of mechanics. Mechanics was, in turn, faced with ever new and practical problems that sharply accelerated its progress. This became particularly evident during the war and had played an important part in the victory over fascism. During the most critical period of the war many scientific research institutes were working on problems of mechanics, including those intended to ensure postwar development of the country.

Some of the most important achievements of national engineering are undoubtedly the launching of the first artificial Earth satellite (sputnik), the first flight to the Moon and of the first man into space, and the subsequent further conquest of outer space. An important part in the achievement of this old human dream was, and still is played by mechanics. The great influence of mechanics on the solution of the practical problems of mastering atomic energy and on the creation of a number of computer units should not be left unmentioned.

Mechanics, whose roots are in physics and which is ever closer associated with its other branches, is in conjunction with mathematical methods a powerful tool that draws its main problems from the field of engineering and technology, atmospheric and ocean phenomena, the Earth crust and outer space phenomena, thus ensuring the progress of engineering.

Two fundamental factors had a revolutionary effect on widening the potentialities of contemporary mechanics.

First was the tremendous progress in experimental techniques. Fine optical, spectro- and radiometric, electromagnetic, ultrasonic, and nuclear methods of measurement became available, and a true revolution in this field was caused by the wide use of lasers. All these methods made possible not only the investigation of a phenomenon as a whole but, also, of the deeper internal processes that determine its properties, and the determination of the relation between the mechanical behavior of materials and the fine structure of these.

Second was the very rapid development of computation techniques. The fast modern computer has radically changed the view on the feasibility of solving mathematical problems of mechanics. It became possible to simulate mathematically on such computers entire fields of mechanical phenomena in nature, such as: the motion of liquids and gas between walls of intricate shapes and accompanied by shock waves; deformation and disintegration of solid bodies of diverse shapes, ranging from bulky objects to thin shells, subjected to slow or shock loading; motion of natural and artificial objects in outer space, including guidance of the latter, and many other.

Systems that combine modern experimental techniques with computer facilities for controlling experiments and processing their results open promising developments in mechanics.

Of paramount importance for modern engineering and natural sciences is the study of phenomena occurring under extreme conditions of high speed, high or extremely low temperatures, or such in which mechanical equilibrium and motion substantially depend on electromagnetic emissions, atomic and nuclear processes, chemical reactions which, in turn, affect the conditions of their course.

Problems of mechanics related to plasma provide a striking example of this. Knowledge of the laws of plasma motion is of considerable importance in power and space engineering.

Plasma filaments are generated in strong magnetic fields when attempts are made at producing thermonuclear reactions. Although such filaments are unstable, their life can be considerably extended by producing a magnetic field of necessary configuration. The calculation of such fields and of plasma motion in these is an essential part of modern mechanics. It is interesting that in a number of cases plasma has to be considered as consisting of two interacting fluids, namely, electrons and ions.

The study of technological processes such as cutting, welding and heat treating of metals in which powerful laser beams are used, are directly related to mechanics, and to problems of plasma. At the same time the present-day technique of producing powerful gaseous lasers itself requires gasdynamic investigations.

Sterile plasma formed in an inert gas with a focused continuous laser emission is very effective. A distinctive miniature ball lightning is generated whose blinding luminescence can be maintained by the beam energy as long as desired. This phenomenon, which will undoubtedly be used for practical purposes, is exactly similar to combustion, and essentially the same equations are used in investigations of the two processes. Plasma generated by combustion is, in turn, used for producing new kinds of powerful lasers.

A new branch of technology, plasmachemistry, which is the formation of chemical products at very high temperatures, has already made its appearance. In this a considerable part in solving related technological problems is played by mechanics.

Combustion belongs to the branch of mechanics called thermochemistry. In addition to power generation, the combustion process can be used for producing new kinds of chemical compounds and for developing new technological processes. The solution of practical problems of combustion requires numerous further theoretical and experimental investigations. Among these the problem of flame stability is of some considerable importance.

A new life has been imparted to the branch of mechanics that had dealt for many decades with the over two centuries old theory of machines and mechanisms and the theory of navigational systems, in the first instance that of gyroscopes. Problems of analysis and synthesis of plane and three-dimensional mechanisms useful for practical applications are nearing their complete solution. The main trend in the theory of machines is now oriented toward the investigation of mechanics of robots, manipulators, and pacing machines controlled by computers.

Considerable attention is given at present to vibroacoustics, the analysis of noise and vibration of machines. This is necessary not only for noise suppression but, also, for diagnosing faults and the internal state of machines. Artificially induced vibrations have found useful application in a number of technological processes such as pile sinking, and transportation of objects, in particular up an inclined plane subjected to translational vibrations.

The study of friction and wear of linked machine components has necessitated the investigation of mechanical, chemical, and even electrical properties of lubricants and materials used in machines and bearings. The molecular-mechanical approach to friction made it possible to develop materials with a priori specified properties, for instance, brake materials that retain their properties under conditions of considerable overheating and self-lubricating materials suitable for work in high vacuum (in outer space). Physicochemical modifications of rubbing surfaces and lubricants led to the development of new methods (selective transfer, tribopolymerization) which have considerably reduced friction and at the same time increased the wear resistance of rubbing surfaces. This made it possible to improve the quality of machines and extend their service life, the importance of which for the national economy cannot be overestimated.

Owing to the greatly increased requirements for accuracy and reliability of navigational systems for ships, aircraft and spacecraft, researchers are faced by numerous new problems in the field of hydrodynamics, electrostatics and electrodynamics, cryogenics, and nuclear physics. This example shows the interaction between such a classical branch of mechanics as the theory of gyroscopes and other domains of physics. Flights of automatic spaceships to the Moon and their return to the Earth are vivid proofs of the perfection of Soviet navigational systems.

Strict attention to factors of a mechanical nature is necessary in the production of modern gyroscopic equipment and instruments. This is particularly important in the case of spatial gyrocompass, gyroazimuth and the gyrohorizon for sea ships and aircraft and, also, in the case of gyrostabilizers. Gyro-stabilized space platforms, gyroscopic integrators of apparent accelerations and gyrotachometers used in rockets and spaceships, as well as the large gyroscope for stabilizing meteorological and radio-communication satellites on their orbits.

Note that the understanding of the mechanics of behavior of the Moon which always faces us with the same side led to the practical realization of the so-called passive or gravitational stabilization of a satellite, generally, without the use of gyroscopes.

The mechanics of a rotating rigid body suspended on a string, particularly of one filled with liquid, has been applied in new designs of centrifuges. Effective balancing of rotors of high-speed turbines and other machines can be effected on equipment based on that principle.

The theories of oscillations and of stability, traditional problems of mechanics, were supplemented during the Soviet era by numerous investigations of fundamental importance. The theory of nonlinear oscillations had emerged and found many applications in the study of three-dimensional vibration of solids and liquids with suspended particles, the self-syncronization of rotors of electric motors mounted on a common base, the intermittent jump-like motion of bodies sliding on one another, the fluctuations of water in equalizing tanks of hydroelectric power stations, and in a wide range of radio engineering and control of technological processes. The statistical approach proved to be essential in many investigations of the effect of random forces on oscillating systems.

The theory of stability found useful application in many engineering problems, such as the stability of motion of ships, automobiles, aircraft, and, also, of tracking systems and gyroscopic equipment, and of processes taking place in chemical reactors. However instability is not always unwelcome, on the contrary, it is necessary when self-oscillations of constant amplitude are to be induced by an external energy source. In other cases as, for example, of inertial guidance of ballistic rockets, instability cannot develop owing to the shortness of engine operation during the powered flight phase.

The causes and laws of the origin and development of fluid flow instability (at fairly high speeds, or more precisely, at high Reynolds numbers), in particular those of turbulence onset, are still awaiting a reasonably complete elucidation, in spite of their importance in many problems of physics and engineering.

Important investigations of turbulent motion were, nevertheless, accomplished with the use of similarity and profound statistical methods, or by the numerical solution of general nonstationary equations of viscous fluid flow. Actual determination of turbulent friction in the motion of bodies in fluids, and of the liquid or gas in pipes has been supported by numerous experiments and by semiempirical methods of calculating such flows.

The riddle of turbulence deepened when it was found that the resistance of fluid motion in pipes, and of bodies in the fluid itself under turbulent conditions diminished several times by dissolving in the fluid small doses (up to millionths part of the fluid by weight) of certain high-molecular compounds. This surprising feature is already successfully used in technology, although its mechanism is not yet fully understood.

The study of flow of disperse and nonhomogeneous media, such as suspensions of solid particles in liquids and gases, aerosols, emulsions, and gas-liquid mixtures, represents a considerable part of mechanics. In many cases chemical reactions and boiling occur simultaneously, and it becomes necessary to take evaporation into account. The ability to calculate such processes is necessary for solving numerous problems of chemical industry, thermal and nuclear power generation, of air purification by eliminating noxious admixtures, of removal of petrolum spillage from the water surface. The usefulness of considering in practice the mechanical features of the processes of flocculation and flotation in mining and processing (enrichment) of minerals, as well as in investigations of the mechanics of concentrated fine particle suspensions of the kind of argillaceous solutions used in bore-hole drilling, should be noted.

Investigations of the mechanics of a fluidized bed formed by the passage of gas through a layer of solid particle catalyst are important to the chemical industry. Intensity of chemical reactions is considerably increased by the swelling of the bed, produced by blowing of air from underneath. All particles of the catalyst become suspended and acquire a kind of turbulent motion. However, in practice it is not always possible to achieve this; gas bubbles may break through the bed, while insufficient blowing leads to the fluidization of only a part of the catalyst volume.

Knowledge of mechanical properties of solutions and melts of polymers, the so called anomalous liquids, is important for controlling many processes of chemical technology, in particular the production of filaments and films which play an important part in the national economy. These liquids, in addition to being viscous, have the property of plasticity, which in many instances complicates the calculation and realization of the required technological process.

Achievements in the classical fields of mechanics of incompressible and viscous fluids and of perfect gas should not be underrated. Examples of their usefulness are provided by their application to the motion of hydrofoils, gliding over the surface of quiescent water reservoirs, gliders and local transport aircraft, helicopters, industrial aerodynamics, air-cushion transportation, motion of an isolated wave and of tsunami (seismic sea waves) which carry great destructive energy, to the hydro- and gas dynamic theory of bearings, point explosion in unbounded gas, and the escape of products of explosion in the atmosphere beyond the latter.

Mechanics of the boundary layer play an essential part in the calculation of flow around aircraft wings, of the resistance to motion of objects in water, in the theory of turbomachines (the flow past rotor blades of turbines of hydroelectric and other power-generating plant), and in other problems related to the motion of liquid, gas, and plasma, particularly in magnetohydrodynamic generators, as well as in geophysics.

The cavitational flow of fluid and the theory of cumulation, particularly in connection with the new attempts at compressing deuterium for the purpose of obtaining a thermonuclear reaction continue to attract interest.

Mechanochemical effects develop when bodies move through the air at high speeds such as, for example, obtain during the re-entry of spaceships and equipment into the Earth's atmosphere. The process of ablation, or more precisely, of blowing-off of the ship's shell protective coating which is converted to the state of plasma during the ship's successful return, cannot be determined without preliminary complicated gas- and thermodynamic calculations. Gasdynamic calculations related to the design of supersonic aircraft and rocket engines are no less complicated. The cause of the onset in engine nozzles of large oscillations at sonic frequency, which lead to their destruction, has not been so far satisfactorily explained.

Although considerable successes were recently achieved in the hydrodynamic theory of weather forecasting, the mechanics of the origin and propagation of hurricanes represents one of the unresolved problems. Even such common phenomenon as the thundercloud has not been properly studied, and the feasibility of controlling its behavior and possible means for achieving that have not yet been established. The control of forest fires can also be considered as a problem of mechanics.

Oceanography has not yet fully explained the nature of the recently revealed vortices that propagate for hundreds of kilometers of oceans, carrying with them an appreciable part of the total flow energy in the regions of their existence.

The theory of filtration, i. e. of the seepage of liquids and gas through the pores of strata containing such media is fundamental for the exploitation of oil and gas deposits. The yield of oil fields is known to be often not more than a third of the oil contained in an oil-bearing stratum. With gas it is also far from total. Hence the increase of the effectivness of oil and gas field exploitation requires a determined effort to develop theoretical and experimental research in this branch of mechanics. After the establishment of equations for the filtration of liquid and gas and the solution of many practical problems related to land improvement and hydroelectric power stations construction, the motion of the oil-bearing stratum contour and the displacement of oil by water were investigated. The study of actual properties of strata and of the fluid contained in these led to a new formulation of the theory of the elastic mode which takes into account the compressibility of fluid and the deformability of the stratum, of the theory of gasified liquid filtration, of models of motion in porous strata containing cracks, where the determining effect is the exchange between pores and cracks, and of the theory of motion of anomalous liquids in porous media. Computers are now successfully used for calculating the complex flows that occur during the displacement of oil by water. The construction of buildings for industry, power stations, transport, sport complexes, and high-rise buildings has stimulated the development of methods of stress and stability calculations for various design schemes such as rod lattice systems, plates, and shells, foundations, dams, bulkheads, ship's hulls, aircraft and rocket frames, and television towers.

Investigations of the stress state of shells —bodies in the form of a curved sheet, tank, or dome —are particularly complicated. Considerable mathematical difficulties have to be overcome in the calculation of plates, particularly those loaded by forces applied in their median plane (the plane problem of the theory of elasticity), in the determination of stresses at the place of contact of two bodies, for instance, that of the wheel and rail (the contact problem in the theory of elasticity), and in the calculation of foundations in soils of various properties, such as rock, cohesive or cohesionless soils.

Maximum admissible loads on sandy soils, beyond which the sand begins to flow from under the foundation, are determined by the method of cohesionless body mechanics. Practical problems of this kind include the determination of the maximum pressure of a cohesionless medium on a bulkhead, and the establishment of the shape of a noncrumbling slope.

Structural elements such as rods, plates and shells may lose their stability under compressive loads (including their own weight) and buckle sideways which, as a rule, ends in the destruction of the structure as a whole. Hence, in addition to stress calculation, it is necessary to check stability margins in conformity with the theory of stability of elastic systems. It is significant that structural elements subjected to sudden loads can withstand for a short time stresses that are considerably higher than the critical which lead to failure under slow loading. For example, a cylindrical steel shell subjected to a fairly strong underwater explosion becomes corrugated, not compressed.

If a structure is subjected to periodic loading, its elastic vibration spectrum can be determined by methods of the theory of oscillations so that, if necessary, the occurence of disastrous resonances could be avoided by subsequent changes of parameters. In many instances buildings must withstand load produced by earthquakes, strong hurricanes and explosions. The related calculations are particularly important and require considerable preliminary investigations and the analysis of actual observations, sometimes even the setting-up of special experiments.

In some cases the flow of air around a building induces its swaying, a phenomenon called flutter, which has been the subject of some considerable study. Means for its avoidance are now known. In the past flutter was the cause of many serious aircraft accidents produced by the failure of oscillating wings, and, also, of the destruction of suspension bridges.

The propagation of waves in media, a problem of mechanics, is of considerable practical importance in seismology, the science of earthquakes. The analysis of wave propagation induced, for instance, by an explosion can in some cases be used in prospecting for minerals. Attempts at solving one of the most serious problems, that of predicting earthquakes, by methods of mechanics are continuing.

To reduce the weight of contemporary structures and economize on metal, stresses are allowed to exceed the material elastic limit, which results in its plastic deformation. Stress calculations are often based on the so-called limit load-carrying capacity of a structure. At loads exceeding that limit the structure appears to become a mechanism which ends in its failure.

The laws of plastic deformation of materials —the theory of plasticity —are more complex than those of the theory of elasticity according to which elastic bodies revert to their original shape, once the deforming load is removed. Residual stresses and strains, which are not always desired, may appear in elastico-plastic bodies stressed beyond the elasticity limit.

Plastic deformation of bodies depends, to some extent, on the order in which forces are applied to it; in numerous cases, particularly of equipment and components subjected to high temperatures, creep, the slow increase of strain with time, becomes evident. Considerable importance is attached to calculations based on creep resistance, i.e. the determination of the irreversible deformation in time of chemical industry equipment and various components and units of machines, such as gas turbine blades and rocket nozzles which work in high-temperature environment. Concrete and other building materials are also susceptible to creep.

Plastic deformation is an essential part of many technological processes, such as forging, stamping, drawing, and cutting of metals. This explains the continuing evolution of various variants of the theory of plasticity and creep to suit specific cases of deformation of structural elements, machine components, and materials used in various technological processes.

Research is continuing in the mechanics of viscoplastic and viscoelastic bodies, of media with statistical crack distribution and/or containing inclusions of high hardness, and of bodies whose mechanical properties change with time (the ageing process).

Modern engineering with its characteristic high-intensity operation modes complicated by the action of chemically active media and of radiation, pose some special, until recently unheard of and often contradictory requirements as regards materials. The most important among these relate to mechanical properties of materials used in the manufacture of reliable machines, buildings, equipment, and instruments. Investigation of the process of disintegration of materials, and the prevention of sudden catastrophic failures due to cracks have been given recently considerable attention and their development is continuing. The acuteness of these problems is aggravated by the necessity of using light and at the same time strong structural materials. It is, however, unfortunate that the high-strength materials are particularly suceptible to this kind of failure, and the problem is to find means for increasing the resistance to crack propagation of such materials.

Solution of that problem requires rational bases for controlling the structure of materials which, again, is a problem of mechanics, in essence that of "constructing" the material itself. In this area mechanics is closely interlocked with physics and chemistry of solid bodies. Chemical reactions of materials with surrounding media and those that take place in the material itself can considerably affect their mechanical properties. The simultaneous subjection to chemical reactions and mechanical loads may rapidly lead to failure which might not have ocurred, if these factors of the same intensity were applied separately. These problems represent only a small part of the vigorously developing mechanics of materials. It is, however, fundamental for the development of new materials, including the composites with their truly unique properties.

Prominent among fundamental problems is that of the relation between strain and failure of materials and, also, of their structure with the defects originating during the manufacturing process or arising and developing under service loading. The development on that basis of a theory that would relate the complex processes of deformation and failure of materials is the most important problem of contemporary mechanics.

Closely related to these problems is that of deformation and strength of rock formations which is of considerable importance for the rational design of structures associated with hydraulic engineering and the exploitation of mineral deposits (first of all coal and ores).

The so far insufficiently investigated mechanics of deformation and strength of rock formations saturated by gas and/or liquid should be noted. Related to this is the development of measures for preventing a sudden disastrous eruption of coal, rock, and gas in mines.

Processes in which disintegration is to be achieved with the least possible losses should be mentioned in this connection. Here, again, the problem of mining mechanics related to the sinking of mining shafts and extraction of minerals, and also various problems of technology of chemical, food and agricultural industries can be mentioned.

The complex nature of problems related to the mechanics of technological processes should be stressed. Electric welding is a good example of this. It necessitates the analysis of gasdynamic processes in the arc and of hydrodynamic processes in the melt zone, of hardening and mechanical behavior of highly heated solid metal penetrated by impurities from the melt zone, and in which phase transformations take place. All these factors affect the weld deformability and strength. Finally, the origin of residual stresses and strains with the ensuing possibility of crack formation must be investigated.

At present considerable attention is given to biomechanics, the study of the motion of blood and other biological fluids, mechanics of the cardiac muscle, of kidneys and lungs, to the study of live beings such as fishes and others. In this field mechanics is interlocked with medicine and biology.

Finally, we have the general problem which affects various branches of mechanics and their application, namely the problem of control and optimization of systems and processes. The optimal control of aircraft motion, optimization of designs and structures, selection of the best modes of operation for machines, optimization of the shape of bodies in streams of liquid or gas, and of technological processes are examples of problems of optimal control of mechanical systems.

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In the past mechanics was understood to be the science of motion, equilibrium, and changes of the shape of bodies subjected to the action of forces, and of the forces themselves. The state of aggregation of bodies and their chemical composition were assumed unalterable. Later, practical applications and the logic of evolution of the science itself led to the firm incorporation in it of thermodynamics, while, one might say, the science of motion of the so-called elementary particles and of the nature of electromagnetic waves had disappeared from it. Furthermore mechanics was extended to the study of processes of melting, solidification, evaporation, boiling and condensation, and to heat transfer in general, as well as to that of capillary forces, diffusion and chemical reactions, and in particular to combustion, explosion and detonation. Its methods are now applied to the study of motion in magnetic and electromagnetic fields, while mechanics of materials, particularly of their strength and disintegration, now takes into account the finer aspects of physical and chemical nature, such as the effects of surface-active forces and chemically aggressive media and, also, radioactive and laser radiations.

Mechanics appears to have now permeated all branches of natural science, and can be rightly considered to be one of the cornerstones of modern science and engineering.

Translated by J.J. D.