ISSUES OF TEACHING ELEMENTS OF OPEN SYSTEMS PHYSICS IN HIGHER EDUCATION INSTITUTIONS

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ANNOTATION

The article is devoted to the issues of teaching the elements of physics or thermodynamics of open systems, which are considered one of the new branches of physics, in higher education institutions. The general properties and basic concepts of physical, chemical, biological, and other open systems are analyzed in the article. In open dissipative systems, it is shown that ordered dissipative structures emerge from chaotic states at certain critical values of control parameters. The concept of dynamic systems and the problems of system evolution, which are mathematical models of open systems, are described.

Keywords: Open system, energy dissipation, dissipative structures, dynamic system, attractor, bifurcation, dynamic chaos.

INTRODUCTION

The science of physics, which studies the most general properties and laws of the material world, plays an important role in the formation and development of modern natural science, as it serves as the fundamental basis of many natural sciences. Based on the achievements of modern physics, it is possible to explain various phenomena using the same scientific concepts. One such scientific direction in physics is "Physics of Open Systems", which forms the fundamental scientific basis of the science of synergetics, and serves as a general methodological tool for the interpretation of phenomena occurring in nature and society. However, the knowledge obtained as a result of research in this direction is relatively little covered in the manuals being created in Uzbek. This article is dedicated to introducing teachers and students to the collected scientific data on the physics of open systems and the general properties and concepts of such systems.

MAIN PART

Classical phenomenological thermodynamics, which is taught in higher technical educational institutions, studies equilibrium processes occurring in isolated closed systems.

However, the universe we live in is an open system far from equilibrium, and interpreting the complex processes taking place in it using the concepts of thermodynamics of equilibrium states has been a problem for many years. Closed physical systems tend to evolve toward an equilibrium state with a high system entropy, that is, a high degree of disorder. However, in open systems, ordered structures are formed as a result of self-organization. For example, both life on Earth and the development of complex organisms can be viewed as ordered structures.

The physics of open systems emerged as a new section in the general physics course and formed the scientific basis of synergetics. Systems that exchange energy, matter, or information with the external environment are called open systems. Dissipation occurs in complex open systems. Dissipation refers to the extinction of various actions in the system, the transformation of energy into heat, etc. Since the dissipation process plays an important role in the formation of structures in open systems, these structures are called dissipative structures. In open systems, by changing the flow of energy and matter from outside, it is possible to control the course of processes and direct the evolution of the system towards states far from equilibrium. In the course of non-equilibrium processes, orderly states and dissipative structures can be formed as a result of the loss of system stability from unordered chaotic states at a critical value of the external flow. The complexity of open systems creates conditions for the existence of organized actions in them. To emphasize the importance of the state of organization in the formation of dissipative structures, B.G. Hacken introduced the term synergetics into science. This term means joint organized action. Dissipative structures can be divided into spatial, temporal, and spatiotemporal structures depending on their appearance and nature of order. An example of spatial structure is the Benar cells that form in liquids. If the liquid layer is strongly heated, a temperature gradient is formed between the upper and lower layers. At small values of the temperature gradient, heat is transferred from the lower layer to the upper layer by heat conduction. When the temperature gradient exceeds a certain critical value, a convective flow with a characteristic structure in the form of hexagonal cells appears. Inside the cell, the relatively hot fluid rises to the top, and the relatively cold fluid moves down along the edges of the cell. Convection cells are highly organized structures that result from the collective, organized movement of molecules. The emergence of turbulent flow from laminar flow is also an example of spatial structures. Belousov-Jabotinsky oscillatory chemical reactions and transitions of lasers to the generation mode can be shown to spatio-temporal structures. These processes are also called non-equilibrium kinetic phase transitions. Phase transitions are determined by fluctuations. When approaching the critical value of the controlling parameter in systems whose elements are initially chaotically distributed, inhomogeneous large-scale fluctuations appear against the background of homogeneous fluctuations. They rapidly increase in size and acquire macroscopic values. As a result, instability occurs and the system moves to a state of order. Self-organization of orderly dissipative structures occurs as a result of absorption of negative entropy (negentropy). In this case, the entropy of open systems decreases, that is, $\Delta S < 0$. If an open system is considered as a component of a larger closed system, the total entropy of this large system increases, and the second law of thermodynamics is not violated.

In the physics of open systems, dynamical systems are considered as a mathematical model of such systems. Any system whose state changes over time is called a dynamic system. From the point of view of mathematics, such systems are represented by nonlinear differential equations and reflections. The concepts of phase space and attractors are used to describe dynamic systems. Each state of the system corresponds to a certain point in the space of variables defining the state of the system (phase space). As a result of changes in the state of the system, these points move along certain state trajectories. For dissipative systems, Liouville's theorem does not hold, and the space of variables defining the state becomes smaller with time. As $t \to \infty$, the solutions of the differential equations representing the dissipative systems tend to a set of so-called attractors of the state-determining variable space. Attractors are a mathematical representation of a dissipative dynamical system operating mode and serve as a boundary trajectory to which all initial modes aspire in the space of state-determining variables.

If small perturbations disappear over time, the state of the dynamic system is stable. On the contrary, if small fluctuations in the system become large, such a regime becomes unstable.

If a small perturbation of the state of a two-dimensional dynamical system becomes larger, the trajectory moves away from the equilibrium point along a spiral lying in a plane. At large deviations, a new regime of periodic self-oscillations appears instead of the unstable equilibrium state, due to the nonlinear limitation, and this regime corresponds to the so-called limit cycle attractor in the state plane. If a steady state of equilibrium is established in the system, the attractor consists of a fixed point. If the dynamic system is $n>3$-dimensional, the trajectory of the state spirals away from the equilibrium point in the three-dimensional space, and after reaching a certain value, the trajectory returns to the initial state under the influence of the nonlinear limitation. The process is then repeated due to instability. Two cases can be observed. In the first one, the trajectory becomes closed after a short time, a complex periodic process and there may be attractors called corresponding two-dimensional invariant strings.

In the second case, if the trajectory does not become closed over time ($t \to \infty$), it repeats a non-periodic complex movement (process). This case corresponds to the regime of deterministic, dynamic chaos, and a chaotic attractor corresponds to it. In chaotic attractors, trajectories become entangled without repeating periodic motion. The difference between deterministic, dynamic chaos, and static equilibrium chaos is that if the initial state repeats, the state of dynamic chaos can be restored.

In most one-dimensional representations of a dynamic system, the transition to a state of dynamic chaos occurs through a large number of cascades of bifurcations. Bifurcation refers to the separation of the solutions of the equation representing the system into several branches when the system parameter changes. At small values of the system control parameter (for example, temperature gradient, Reynolds number, etc.), the corresponding equation has a solution, and the asymptotic stability of the system with the ability to dampen internal fluctuations and turbulences is appropriate. At large values of the control parameter, the system departs sharply from the equilibrium state and passes from a homogeneous chaotic state close to equilibrium to an inhomogeneous state, and then through a series of structural exchanges and bifurcations to a state of dynamic chaos.

CONCLUSION

Open systems physics, a relatively new branch of physics, has been developing rapidly in recent years. The new knowledge and scientific information obtained in the field of physics of open systems have already found their reflection in the textbooks of the educational programs of many higher educational institutions of the world. The evolution of open systems is a complex process, and a mathematical model called a dynamic system is used to describe it. The state of any system is defined by state parameters or variables that define the state of the system. From a mathematical point of view, each equilibrium state of the system corresponds to a point in the space of variables defining the state. During the evolution of the system, such points combine to form trajectories. As the system evolves, these trajectories tend toward a set of so-called attractors. As a result of instabilities and bifurcations observed in the system, the system can go into a state of deterministic, i.e., dynamic chaos where the next state can be predicted in advance. Thus, with the help of the concept of dynamic systems, there are opportunities to analyze the evolution of open systems and to predict the states that the system can reach. The achievements of physics science in recent years, enriching the educational programs based on the new knowledge and introducing students to them ensure that the acquired knowledge is perfect and at the level of modern requirements. This article can be used as a reference for physics teachers.

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