Рабочая программа дисциплины

1. **Название дисциплины:**
   Theoretical foundations of acoustics. Part 1
   (Radiation and scattering of acoustic waves)

2. Лекторы (lecturers).

2.1. Rumyantseva Olga Dmitrievna, PhD in Physics and Mathematics, Senior Lecturer, Department of Acoustics, burov@phys.msu.ru, phone +7-495-939-3081

2.2. Sapozhnikov Oleg Anatolievich, Doctor of Science in Physics and Mathematics, Associate Professor, Department of Acoustics, oleg@acs366.phys.msu.ru, phone +7-495-939-2952

3. Аннотация дисциплины (Annotation).
The subject of the course is a systematic description of the basic theoretical concepts and methods of classical linear acoustics that allow to describe the radiation, propagation and scattering of sound waves in unbounded liquid and gaseous media in the presence of inhomogeneities and scatterers. Consideration is accompanied by mathematically rigorous description of the phenomena, as well as an analysis of the assumptions and approximations that are made in the mathematical formulation of the problem. Students will need the knowledge of the theoretical foundations of acoustics in further studies, in particular in special courses and in practical work at the Department of Acoustics.

4. Цели освоения дисциплины.
This course provides a basic systematic knowledge on theoretical acoustics of liquids and gases. The lecturers will help the students to learn how to apply the classical methods of mathematical physics to solve a wide class of problems of radiation and scattering of sound waves. Students will also become familiar with the exact and approximate methods of theoretical investigation of the laws of acoustic wave propagation under the real conditions.

5. Задачи дисциплины.

Objectives of the course are: (1) systematic description of the basic theoretical concepts and methods of classical linear acoustics, (2) study of the characteristic features of radiation and scattering of acoustic waves in liquids and gases.

6. Компетенции.

6.1. Компетенции, необходимые для освоения дисциплины.

ПК-1, ПК-6

It is assumed that the students are familiar with basic methods of mathematical physics, as well as know the basics of acoustics and wave physics.

6.2. Компетенции, формируемые в результате освоения дисциплины.

ПК-3, ПК-4

After listening to the course, the students will learn how to apply the methods of mathematical physics to solve a wide class of problems of classical linear acoustics concerning radiation, propagation and scattering of sound waves.

7. Требования к результатам освоения содержания дисциплины
As a result of the course, the students should know the basic theoretical concepts and methods of classical linear acoustics of liquids and gases, and also should be able to apply methods of mathematical physics to calculate the parameters of sound fields during their propagation under the real conditions.

8. Содержание и структура дисциплины

Вид работы	Семестр			Всего
	7			
Общая трудоёмкость, акад. часов	72			72
Аудиторная работа:				
Лекции (lections), акад. часов	36			36
Семинары, акад. часов				
Лабораторные работы, акад. часов				
Самостоятельная работа, акад. часов	36			36
Вид итогового контроля (зачёт, зачёт с оценкой, экзамен)	экз.			

N раз-дела	Наименование раздела	Трудоёмкость (академических часов) и содержание занятий		Форма текущего контроля
		Аудиторная работа Лекции	Самостоятельная работа	
1	Sound waves	*Lecture №1 (2 hours)* Equations of hydrodynamics of ideal fluids and gases; approximation of linear acoustics. The wave equation and boundary conditions in case of ideal media.	*(2 hours)* Working with lecture material and reading the recommended literature.	Homework (H), Test (T)
		Lecture №2 (2 hours) Plane and spherically-symmetric waves in a homogeneous boundless medium. Wave impedance. Nearfield and farfield of the spherically symmetric wave.	*(2 hours)* Working with lecture material and reading the recommended literature. Solving three problems related to the lecture.	
2	Reflection and refraction of plane waves	*Lecture №3 (2 hours)* Reflection and refraction of plane waves on flat interfaces between liquid and gaseous media.	*(2 hours)* Working with lecture material and reading the recommended literature. Solving three problems related to the lecture.	H, T
		Lecture №4 (2 hours) Reflection and transmission through a layer. Reflection of plane waves from a thin elastic layer having a finite mass.	*(2 hours)* Working with lecture material and reading the recommended literature. Solving three problems related to the lecture.	
3	Sound radiation by simple sources	*Lecture №5 (2 hours)* Sound radiation by a pulsating sphere and a set of monopole sources. Acoustic dipole radiation. Radiation impedance. Green's function and its spatial spectrum for uniform boundless medium. Green's function for half-spaces with rigid and soft boundaries.	*(2 hours)* Working with lecture material and reading the recommended literature. Solving three problems related to the lecture.	H, T
		Lecture №6 (2 hours) Reciprocity theorem. Huygens principle for internal and external regions. The Sommerfeld radiation condition. The Rayleigh integral. Sound radiation by a circular piston diaphragm in a rigid baffle; the directivity pattern.	*(2 hours)* Working with lecture material and reading the recommended literature. Calculation and plotting of the directivity pattern of a circular piston source in a rigid baffle.	
4	Diffraction of sound	*Lecture №7 (2 hours)* Rigorous and approximate methods of solving direct problems of diffraction and scattering. The Kirchhoff approximation.	*(2 hours)* Working with lecture material and reading the recommended literature.	H, T
		Lecture №8 (2 hours) Diffraction on holes, screens, and large obstacles. Babinet's principle.	*(2 hours)* Working with lecture material and reading the recommended literature.	
5	Colloquium on the first part of the course	*(1 hour)* Written test on the first part of the course	*(2 hours)* Preparation for a written test	H, T
		(1 hour)	*(2 hours)* Preparation for an oral questioning	

		Oral questioning and a general discussion on the first part of the course		
6	Sound scattering on three-dimensional objects	*Lecture №9 (2 hours)* Scattering of sound by different objects: an infinite circular cylinder, a sphere and a gas bubble in liquid.	*(2 hours)* Working with lecture material and reading the recommended literature. Solving three problems related to the lecture.	H, T
		Lecture №10 (2 hours) Scattering in inhomogeneous media. The Lippmann-Schwinger equation and the Born-Neumann series. Classification of scatterers. Scattering by small fluctuations of density and compressibility (the Born approximation).	*(2 hours)* Working with lecture material and reading the recommended literature.	
		Lecture №11 (2 hours) The method of boundary integral equations.	*(2 hours)* Working with lecture material and reading the recommended literature.	
7	Sound scattering by uneven surfaces	*Lecture №12 (2 hours)* The angular spectrum method. Scattering on a surface with small random roughness (perturbation theory).	*(2 hours)* Working with lecture material and reading the recommended literature. Solving three problems related to the lecture.	H, T
		Lecture №13 (2 hours) Scattering by large-scale irregularities (Kirchhoff method).	*(2 hours)* Working with lecture material and reading the recommended literature. Solving three problems related to the lecture.	
8	Acoustics of inhomogeneous moving medium	*Lecture №14 (2 hours)* Derivation of equations of acoustics of an inhomogeneous stationary medium. Ray approach to the description of acoustic fields. Derivation of the eikonal equation in acoustics. Definition of acoustic ray. Eikonal equation and transport equation and their physical meaning. Differential equation for the ray. The limits of applicability of geometrical acoustics. Ray pattern in the underwater sound channel. Behavior of rays in a stratified atmosphere.	*(2 hours)* Working with lecture material and reading the recommended literature. Solving three problems related to the lecture.	H, T
		Lecture №15 (2 hours) Derivation of equations of acoustics of an inhomogeneous medium when the medium moves. Sound propagation in a moving medium in the ray approximation.	*(2 hours)* Working with lecture material and reading the recommended literature. Solving three problems related to the lecture.	
9	Sound radiation by moving sources	*Lecture №16 (2 hours)* Physical processes underlying the process of wave radiation by moving sources. Inhomogeneous wave equation for the acoustic field. Solution in the form of retarded Liénard-Wiechert potentials. Sound radiation by a moving point source. Doppler effect. Radiation by a uniformly moving supersonic source, the Mach cone.	*(2 hours)* Working with lecture material and reading the recommended literature. Solving three problems related to the lecture.	H, T
10	Colloquium on the	*(1 hour)*	*(2 hours)* Preparation for a written test	

	second part of the course	Written test on the second part of the course		H, T
		(1 hour) Oral questioning and a general discussion on the second part of the course.	*(2 hours)* Preparation for an oral questioning.	

Предусмотрены следующие формы текущего контроля успеваемости:

1. Homework (H);
2. Tests (T).

9. Место дисциплины в структуре ООП ВПО

1. Дисциплина является обязательной.
2. Вариативная часть, профессиональный блок, дисциплина профиля.
3. Presentation is based on the knowledge gained by the students in earlier disciplines on mathematical physics and an introductory course "Introduction to Acoustics." In addition, there is a connection with the courses "Wave Theory" and "Application of Ultrasound to Medicine" that are presented simultaneously with the current course.

   3.1. Дисциплины, которые должны быть освоены для начала освоения данной дисциплины:
   Mathematical Analysis, General Physics courses

   3.2. Дисциплины, для которых освоение данной дисциплины необходимо как предшествующее:
   Research practice, research work

10. Образовательные технологии

Presentation is carried out mainly in the traditional way (using chalk and blackboard). Several parts of the course are accompanied by presentations using computer projector; features of propagation and scattering of waves are illustrated by images and videos. Before the beginning of each lecture the students are interviewed on the topic of the previous lectures, and then the general discussion is organized. The professor illustrates the discussed subjects by examples from modern scientific research in acoustics and wave physics. During colloquiums a round table is organized on the course, and a written test is carried out with the questions and problems of the theoretical minimum.

11. Оценочные средства для текущего контроля успеваемости и промежуточной аттестации

Questions for the final test on the course “Theoretical foundations of acoustics, Part 1 (Radiation and scattering of acoustic waves)”

1. The hydrodynamics equations for an ideal fluid, their linearization. Wave equation and the boundary conditions in the case of ideal media.
2. Plane and spherically-symmetric waves in a homogeneous boundless medium, their basic properties, the wave impedance. Nearfield and farfield of the spherically symmetric wave.
3. Reflection and refraction of plane waves on flat interfaces between liquid and gaseous media.
4. Radiation from a pulsating sphere. Radiation from a monopole.
5. Sound radiation by a set of monopole sources. Acoustic dipole radiation.
6. Green’s function. Spatial spectrum of Green’s function for uniform boundless medium. Reciprocity theorem.
7. Green’s function for half-spaces with rigid and soft boundaries. The Rayleigh integral.
8. Huygens principle for internal and external regions. The Sommerfeld radiation condition.
9. Sound radiation by a circular piston diaphragm in a rigid baffle; axial field, the directivity pattern.
10. Diffraction on holes and screens in the Kirchhoff approximation. Babinet’s principle.
11. Scattering of sound by an infinite circular cylinder. Directivity pattern. Scattering cross-section.
12. The Lippmann-Schwinger equation and the Born-Neumann series. The Born approximation for scattering.
13. The method of boundary integral equations in the theory of radiation and scattering.
14. The angular spectrum method and its application to the problem of radiation from a plane source.
15. Scattering by a weakly rough surface: Demonstration of the Rayleigh method for calculation by analyzing plane wave scattering by a soft rough surface.

16. Scattering on the surface of large-scale irregularities: the tangent plane method, the calculation of the radiation in the farfield.
17. Approximation of geometrical acoustics for a smoothly inhomogeneous motionless medium: derivation of the eikonal and transport equations.
18. Acoustics of an inhomogeneous moving medium: the scheme of the method of geometrical acoustics, relation between phase and group velocities with the wind velocity.
19. Radiation from a moving point source. Peculiarities of radiation by a supersonic source.
20. Doppler effect for a moving point source.

Examples of problems for homework and tests

Problem 1. Sound intensity is $I = 0.1$ W/m^2. Calculate energy volume density E, acoustic pressure amplitude p_0', displacement amplitude ξ_0, particle velocity amplitude v_0, and acceleration amplitude a_0 for a plane wave of frequency $f = 10$ kHz in water and air. Calculate Mach number. Sound velocity in water is $c = 1500$ m/s, in air $c = 340$ m/s.

Problem 2. Derive the transparency (transmission) coefficient for intensity, W_I, and the reflection coefficient for intensity, V_I, for a plane wave passing through a plane interface between two liquid media.

Problem 3. Calculate the angle of total reflection of sound at a frequency of 100 kHz at the boundary between water and aniline. For the angle of incidence 80° derive the phase of the reflection coefficient and depth of sound penetration into aniline at which the acoustic pressure is reduced e=2.7 times. Sound absorption in the media is supposed to be negligible. Density of water and aniline are, respectively, $\rho_1 = 1$ g/cm^3 and $\rho_2 = 1.022$ g/cm^3, and sound velocities are $c_1 = 1480$ m/s and $c_2 = 1659$ m/s.

Problem 4. Plane wave with wave vector $\vec{k}_0 = k(\sin\theta, 0, -\cos\theta)$ incidents on a flat (in average) surface with a roughness described by the $\varsigma(x, y) = a \cdot \sin^2(gx)$, where $a << \lambda, 2\pi/g << \lambda$. What is the structure of the reflected wave? In what directions will the scattering occur?

Problem 5. In the plane $z = 0$ is given a monochromatic wave. The wave amplitude is constant within a rectangle of dimension a x b: $p = p_0$ at $-a/2 \le x \le a/2$, $-b/2 \le y \le b/2$; in other points of the plane amplitude p is zero. Find an expression for the angular spectrum $F_0(k_x, k_y)$.

Problem 6. Write the equation of continuity (conservation of mass) for liquid or gas and deduce from it the corresponding linearized equation for acoustic perturbations. Assume that sound propagates in an inhomogeneous moving medium, i.e., in the initial unperturbed state velocity, density, entropy, and pressure in the medium depend on the time and coordinates.

12. Учебно-методическое обеспечение дисциплины

Main reading:

1. Krylov V.V. Theoretical Basis of Sound Transmitting and Receiving. – Moscow: MSU, 1989. (in Russian)
2. Isakovich M.A. General Acoustics. – Moscow: Nauka, 1973. (in Russian)

3. Skudrzyk E. The Foundations of Acoustics. Basic Mathematics and Basic Acoustics. Wien, New York: Springer-Verlag, 1971.
4. Rzhevkin S.N. A Course of Lectures on the Theory of Sound. New York: Pergamon Press, 1963. 464 p.
5. Bass F.G., Fuks I.M. Wave Scattering from Statistically Rough Surfaces. – New York: Pergamon Press, 1979. 527 p.
6. Landau L.D., Lifshitz E.M. A Course in Theoretical Physics – Fluid Mechanics, Ch.8 “Sound”. Oxford, New York: Pergamon Press, 1987. 551 p.
7. Vinogradova M.B., Rudenko O.V., Sukhorukov A.P. Waves Theory, 2-nd ed. – Moscow: Nauka, 1990. (in Russian)
8. Krasil’nikov V.A., Krylov V.V. Introduction to Physical Acoustics. – Moscow: Nauka, 1984. (in Russian)
9. Shenderov E.L. Sound Transmitting and Receiving. Leningrad: Sudostroenie, 1989. (in Russian)
10. Blokhintsev D.I. Acoustics of Inhomogeneous Moving Medium. – Moscow: Nauka, 1981. (in Russian)
11. Brekhovskikh L.M. Waves in Layered Media. – Moscow: AN SSSR, 1957. (in Russian)
12. Acoustics by Problems, eds. Gurbatov S.N. and Rudenko O.V. – Moscow: Nauka-Fizmatlit, 1996. (in Russian)

Additional reading:
1. Goryunov A.A., Saskovets A.V. Inverse Scattering Problems in Acoustics. Moscow: MSU, 1989. (in Russian)
2. Hönl H., Maue A.W., Westpfahl K. Theorie der Beugung. – Berlin: Springer-Verlag, 1961. Ch. I, 3a; Ch. II, 1; Ch. III, 1a, 2a, 4a (pt.76).
3. Pierce A. Acoustics: An Introduction to Its Physical Principles and Applications. – Acoustical Society of America, 1989.
4. Ostashev V.E. Sound Propagation in Moving Media. – Moscow: Nauka, 1992. (in Russian)

Periodicals:
Scientific journals on acoustics: the Acoustical Physics and the Journal of the Acoustical Society of America

Online resources: http://acoustics.phys.msu.ru, http://www.akin.ru

13. Материально-техническое обеспечение

The support is in accordance with the requirements of paragraph 5.3 of the educational standard of MSU, the part "Physics". The classes are performed in a classroom of the Faculty of Physics.