

Contents

1. The Ocean as an Acoustic Medium	1
1.1 Sound Velocity in Sea Water	1
1.2 Typical Vertical Profiles of Sound Velocity and Corresponding Conditions of Sound Propagation	2
1.2.1 Underwater Sound Channel (USC)	2
1.2.2 Surface Sound Channel	6
1.2.3 USC with Two Axes	7
1.2.4 Antiwaveguide Propagation	8
1.2.5 Propagation of Sound in Shallow Water	8
1.3 Absorption of Sound	9
1.4 Variability of the Ocean and Its Effect on Acoustics	11
1.4.1 Large-Scale Currents and Frontal Zones	12
1.4.2 Synoptic (Meso-Scale) Eddies	13
1.4.3 Internal Waves	14
1.4.4 Fine Vertical Structure of Waters	16
1.4.5 Small-Scale Turbulence	18
1.5 Ocean Surface	20
1.6 Sound Scattering at the Ocean Surface	21
1.7 Sound Scattering by Air Bubbles	24
1.8 Deep-Scattering Layers (DSL)	26
1.9 Ocean Bottom	27
1.10 Ambient Noise	30
 2. Ray Theory of the Sound Field in the Ocean	 32
2.1 Helmholtz Equation and Its Solution in Two Simple Cases	32
2.2 Refraction of Sound Rays	33
2.3 Horizontal Distance Covered by a Ray	36
2.4 Constant-Gradient Approximation of the Sound Velocity Profile	37
2.5 Sound Intensity, Focusing Factor and Caustics	38
2.6 "Three-Dimensional" Refraction	42
2.7 Snell's Law for the Range-Dependent Ocean	46
 3. Reflection of Sound from the Surface and Bottom of the Ocean.	
Plane Waves	49
3.1 Reflection and Transmission Coefficients at an Interface Separating Two Liquids	49

3.2	Transmission of a Sound Wave from Water into Air and Vice Versa	54
3.3	Sound Wave Reflection from an Ocean Bottom Consisting of Liquid Layers	57
3.3.1	Reflection from a Homogeneous Layer	57
3.3.2	Reflection from an Arbitrary Number of Layers	60
3.4	Sound Reflection from a Solid	62
3.4.1	Analysis of the Reflection Coefficient	65
3.4.2	Surface Rayleigh and Stonely Waves	66
3.5	Reflection from a Continuously Layered Medium	68
4.	Reflection of Sound from the Surface and Bottom of the Ocean. Point Source	70
4.1	Sound Field of an Underwater Source Located near the Water Surface	70
4.1.1	Wave Representations	70
4.1.2	Ray Representation	71
4.1.3	Directional Pattern	72
4.1.4	Radiated Power	74
4.2	Expansion of a Spherical Wave into Plane Waves	76
4.3	Reflected Wave	78
4.4	Lateral Wave	83
4.5	Reflection from the Layered Inhomogeneous Half-Space. Caustics	86
5.	Propagation of Sound in Shallow Water	93
5.1	Ray Representation of the Sound Field in a Layer. Image Sources	93
5.2	Integral Representation of the Field in the Layer	96
5.3	Normal Modes in the Ocean with a Perfectly Reflecting Bottom	97
5.4	Relation Between the Different Representations of the Field	102
5.5	Normal Modes in a Two-Layered Liquid	103
5.6	Averaged Decay Law	106
5.6.1	Homogeneous Layer	108
5.6.2	Layer with Negative Refraction	109
6.	Underwater Sound Channel	111
6.1	Simple Ray Theory of the USC. Trapping Coefficient of the USC	111
6.1.1	"Linear" Model of the USC	112
6.1.2	Travel Time	115
6.2	Canonical Underwater Sound Channel	117
6.3	Convergence Zones	119
6.4	Field of a Point Source in the Underwater Sound Channel as a Sum of Normal Waves (Modes)	122
6.5	Integral Representation of the Sound Field in the USC	124

6.6	Transformation of the Integral Representation into the Sum of Normal Modes	126
6.6.1	Linear Waveguide	127
6.7	Normal Modes in the WKB Approximation. Phase Integral ...	131
6.7.1	Normal Modes and Rays	136
6.7.2	Spatial Periods of Interference	140
7.	Range-Dependent Waveguide	146
7.1	Normal Modes in an Almost Stratified Medium. Reference Waveguide Method	146
7.2	Adiabatic Approximation. Ray Invariant	148
7.2.1	Ray Invariant	149
7.2.2	An Example of Using the Ray Invariant	152
7.2.3	Conditions for the Validity of the Adiabatic Approximation and Ray Invariant	154
7.3	Rays in a Horizontal Plane	157
7.3.1	The Case of a Coastal Wedge	157
7.4	Parabolic Equation Method	160
8.	Antiwaveguide Sound Propagation	166
8.1	Linear Antiwaveguide Adjacent to Water Surface	166
8.2	Symmetric Antiwaveguide. Quasi-Modes	169
8.3	Symmetric Antiwaveguide. Lateral Wave	178
9.	Scattering of Sound at Rough Surfaces	182
9.1	Rayleigh Parameter	182
9.2	Method of Small Perturbation (MSP)	183
9.3	Average Intensity	186
9.3.1	An Infinite Surface	186
9.3.2	Bounded Scattering Surface. Far Zone	187
9.3.3	Correlation Function of the Scattered Field	189
9.4	Scattering Coefficient for the Ocean Surface	193
9.5	Frequency Spectrum of the Scattered Field	196
9.6	Reflection Coefficient in the Specular Direction	200
9.7	Method of Tangent Plane. Basic Concept	202
9.8	Average Field	204
9.9	Scattering Coefficient of High-Frequency Sound	207
9.9.1	Scattering Pattern	210
9.10	Frequency Spectrum	213
9.11	Sound Scattering from a Surface with Two Scales of Roughness	215
9.12	Surface Channel with a Rough Boundary	218
9.12.1	Attenuation Along a Single Ray	219
9.12.2	Averaged Decay Law for a Coherent Field	221
9.13	Fore-reverberation of Sound in the Ocean	222

10. Sound Propagation in the Random Ocean	226
10.1 Amplitude and Phase Fluctuations	226
10.1.1 Phase Fluctuations	226
10.1.2 Amplitude Fluctuations	232
10.2 Scattering of Sound by Random Inhomogeneities	234
10.2.1 Average Intensity of a Scattered Field	235
10.2.2 Volume Scattering Coefficient	238
10.3 Phase Fluctuations due to Internal Waves	241
10.4 Fluctuations in Multipath Propagation	246
 11. Scattering and Absorption of Sound by Gas Bubbles in Water ..	249
11.1 Sound Scattering by a Single Ideal Bubble	249
11.2 Scattering and Absorption of Sound by a Real Bubble	253
11.3 Dispersion of Sound Velocity	257
 References	261
 Subject Index	267