

Contents

1	Introduction	1
1.1	Crystalline Undulator: Basic Ideas	1
1.2	Why a Crystalline Undulator?	4
1.3	Is This Realistic?	6
1.3.1	Feasibility of CU	7
1.3.2	Methods of Preparation of CU	9
2	Related Phenomena	13
2.1	Radiation from Relativistic Charges: Classical, Quantum and Quasiclassical Approaches	13
2.1.1	Classical Description	14
2.1.2	Quantum Description	15
2.1.3	Quasi-classical Description of Radiation Emission	17
2.2	UR from an Ideal Planar Undulator	18
2.2.1	General Formalism	18
2.2.2	Spectral Distribution in the Forward Direction	23
2.2.3	Spectral Distribution Integrated over the Emission Angles	25
2.3	Channeling in Straight Crystals	27
2.3.1	Crystallographic Axes and Planes	28
2.3.2	Continuous Potential Model	29
2.3.3	Positron Versus Electron Channeling	33
2.3.4	Classical Versus Quantum Description	35
2.4	Channeling in Bent Crystals	36
2.5	Radiative Processes in Crystals	38
2.5.1	Bremsstrahlung	38
2.5.2	ChR in Straight and Bent Crystals	43
3	Schemes for Periodic Bending of Crystals	47
3.1	Periodic Bending with AW	48
3.2	Growing of Crystals with PBCh	51

3.3	Periodic Surface Deformations	54
3.3.1	Diamond-Blade Scratching	54
3.3.2	Laser-Ablation Technique	55
3.3.3	Tensile Strips Deposition	57
3.4	Imperfectness of Crystalline Structure Bending	58
3.4.1	Introductory Remarks	59
3.4.2	Periodic Deformations in Bulk: Model and Formalism	60
3.4.3	Periodic Deformations in Bulk: Numerical Results	64
4	Feasibility of a Positron-Based Crystalline Undulator	73
4.1	Channeling Condition in PBCr	73
4.2	Large and Small Amplitude Regimes	75
4.2.1	Influence of Channeling Oscillations on the CU Radiation	77
4.3	Dechanneling and Photon Attenuation	79
4.3.1	Dechanneling Process	80
4.3.2	Photon Attenuation	88
4.3.3	UR in Presence of Dechanneling and Photon Attenuation	89
4.4	Energy Losses	95
4.4.1	Quasi-classical Formalism for the Radiative Energy Loss in CU	96
4.4.2	Calculation of Radiative Energy Losses in PBCr	99
4.4.3	Undulator Effect in the High-Energy Regime	101
4.5	Feasibility of a Positron-Based CU: Summary of the Necessary Conditions	105
4.6	Feasibility of a Positron-Based CU: Historical Survey	108
5	Positron-Based CU: Illustrative Material	113
5.1	Brief Description of the Computer Algorithms	114
5.1.1	Computation of Positron Trajectories in PBCr	114
5.1.2	Computation of Characteristics of the Emitted Radiation ...	115
5.1.3	Test Calculation of the ChR Spectrum	116
5.2	CUR for 0.5 GeV Positrons	116
5.3	CUR for 5 GeV Positrons	121
5.4	Estimation of Brilliance of CUR	126
5.4.1	Optimal Length of CU	127
5.4.2	Numerical Results for Brilliance	129
5.5	Emission from Imperfect CU	134
5.5.1	Emission from CU with a Varied Amplitude: Formalism ...	134
5.5.2	Averaged Spectra: Numerical Results	135
5.5.3	Concluding Remarks	141

6	CUs for Electrons and Heavy Particles	143
6.1	Electron-Based CU	143
6.1.1	Electron-Based Versus Positron-Based CU	143
6.1.2	Electron-Based CU: High-Energy Regime	148
6.1.3	Electron-Based CU: Low-Energy Regime	153
6.2	Crystalline Undulators for Heavy Projectiles	164
6.2.1	Dechanneling and Energy Losses	164
6.2.2	Photon Attenuation, Channeling Condition and Large-Amplitude Regime	167
7	Experimental Studies of CUR	179
7.1	Experiments with Positrons	180
7.1.1	Experiments at IHEP	180
7.1.2	Planned Experiments at CERN and INFN	185
7.1.3	Perspectives of the Experiments at DAΦNE BTF	186
7.2	Experiments with Electrons at MAMI	188
7.2.1	Experiments with 855 and 1,508 MeV Electrons	189
7.2.2	Experiments with $\varepsilon = 195 \dots 855$ MeV Electrons	191
8	Stimulated Emission from CU	195
8.1	Introduction	195
8.2	'Naive' Approach to the CU-Based Gamma-Laser	197
8.2.1	Crude Estimate of the Gamma-Laser Gain	198
8.2.2	One-Crystal Gamma-Ray Amplifier	201
8.3	Gamma-klystron	208
8.3.1	Multicascade Amplifier	211
8.4	Beam Demodulation in CU	212
8.4.1	Diffusion Equation and Its Solution	214
8.4.2	Demodulation Length	218
8.5	A Scheme for CUL	222
8.5.1	Design of the Apparatus	223
8.5.2	Operation Principles of the Device	224
9	Conclusion	227
A	Motion in Periodically Bent Channel	231
A.1	Approximations Related to the Crystal Bending	231
A.2	EM for a Particle Channeling in PBCr	232
A.2.1	EM with Account for Radiation Damping	232
A.2.2	EM with Account for Collisions with Target Electrons and Nuclei	233
A.2.3	A Simplified Model for the Particle Motion in PBCh	236

B	Estimation of the Undulator Parameter due to Channeling Oscillations	241
C	Pöschl-Teller Potential	243
C.1	Pöschl-Teller Potential	243
C.2	Transverse Motion in the Pöschl-Teller Well: Classical Picture	244
C.3	Transverse Motion in the Pöschl-Teller Well: Quantum Effects	245
D	Interplanar Potential within the Molière Approximation	249
	References	253
	Index	267