

Gerd Rudolph • Matthias Schmidt

Differential Geometry and Mathematical Physics

Part I. Manifolds, Lie Groups and
Hamiltonian Systems

Contents

1	Differentiable Manifolds	1
1.1	Basic Notions and Examples	1
1.2	Level Sets	11
1.3	Differentiable Mappings	17
1.4	Tangent Space	21
1.5	Tangent Mapping	28
1.6	Submanifolds	35
1.7	Subsets Admitting a Submanifold Structure	42
1.8	Transversality	47
2	Vector Bundles	53
2.1	The Tangent Bundle	53
2.2	Vector Bundles	57
2.3	Sections and Frames	65
2.4	Vector Bundle Operations	71
2.5	Tensor Bundles and Tensor Fields	78
2.6	Induced Bundles	81
2.7	Subbundles and Quotient Bundles	84
3	Vector Fields	93
3.1	Vector Fields as Derivations	94
3.2	Integral Curves and Flows	97
3.3	The Lie Derivative	109
3.4	Time-Dependent Vector Fields	111
3.5	Distributions and Foliations	115
3.6	Critical Integral Curves	126
3.7	The Poincaré Mapping	137
3.8	Stability	141
3.9	Invariant Manifolds	154
4	Differential Forms	165
4.1	Basics	165

4.2	Integration and Integral Invariants	176
4.3	De Rham Cohomology	185
4.4	Riemannian Manifolds	194
4.5	Hodge Duality	198
4.6	Maxwell's Equations	203
4.7	Pfaffian Systems and Differential Ideals	207
4.8	Constraints in Classical Mechanics	213
5	Lie Groups	219
5.1	Basic Notions and Examples	219
5.2	The Lie Algebra of a Lie Group	227
5.3	The Exponential Mapping	235
5.4	Adjoint Representation and Killing Form	243
5.5	Left-Invariant Differential Forms	248
5.6	Lie Subgroups	256
5.7	Homogeneous Spaces	260
6	Lie Group Actions	269
6.1	Basics	269
6.2	Killing Vector Fields	276
6.3	Proper Actions	281
6.4	The Tubular Neighbourhood Theorem	286
6.5	Free Proper Actions	290
6.6	The Orbit Space	295
6.7	Invariant Vector Fields	302
6.8	On Relatively Critical Integral Curves	307
7	Linear Symplectic Algebra	315
7.1	Symplectic Vector Spaces	315
7.2	Subspaces of a Symplectic Vector Space	318
7.3	Linear Symplectic Reduction	322
7.4	The Symplectic Group	324
7.5	Compatible Complex Structures	328
7.6	The Lagrange-Graßmann Manifold	332
7.7	The Universal Maslov Class	338
7.8	The Kashiwara Index	346
8	Symplectic Geometry	353
8.1	Basic Notions. The Darboux Theorem	354
8.2	Hamiltonian Vector Fields and Poisson Structures	360
8.3	The Cotangent Bundle	370
8.4	Coadjoint Orbits	377
8.5	Coisotropic Submanifolds and Contact Structures	382
8.6	Generalizations of the Darboux Theorem	394
8.7	Symplectic Reduction	399
8.8	Symplectomorphisms and Generating Functions	403
8.9	Elementary Morse Theory	415

9	Hamiltonian Systems	427
9.1	Introduction	428
9.2	Examples	437
9.3	The Time-Dependent Picture	441
9.4	Regular Energy Surfaces and Symplectic Capacities	447
9.5	The Poincaré Mapping and Orbit Cylinders	454
9.6	Birkhoff Normal Form and Invariant Tori	462
9.7	Stability	473
9.8	Time-Dependent Systems. Parametric Resonance	478
9.9	On the Arnold Conjecture	487
10	Symmetries	491
10.1	Momentum Mappings	492
10.2	The Witt-Artin Decomposition	504
10.3	Regular Symplectic Reduction	509
10.4	The Symplectic Tubular Neighbourhood Theorem	515
10.5	Singular Symplectic Reduction	522
10.6	Examples from Classical Mechanics	532
10.7	A Model from Gauge Theory	549
10.8	The Energy Momentum Mapping	556
11	Integrability	569
11.1	Basic Notions and Examples	569
11.2	Lax Pairs and Coadjoint Orbits	578
11.3	The Arnold Theorem	584
11.4	Action and Angle Variables	589
11.5	Examples	603
11.6	Small Perturbations	612
11.7	Global Aspects. Monodromy	617
11.8	Non-commutative Integrability	627
12	Hamilton-Jacobi Theory	641
12.1	The Hamilton-Jacobi Equation	642
12.2	The Method of Characteristics	650
12.3	Generalized Hamilton-Jacobi Equations	653
12.4	Morse Families	658
12.5	Stable Equivalence	668
12.6	Maslov Class and Caustics	675
12.7	Geometric Asymptotics. The Eikonal Equation	692
12.8	Geometric Asymptotics. Beyond Lowest Order	709
References		729
Index		741