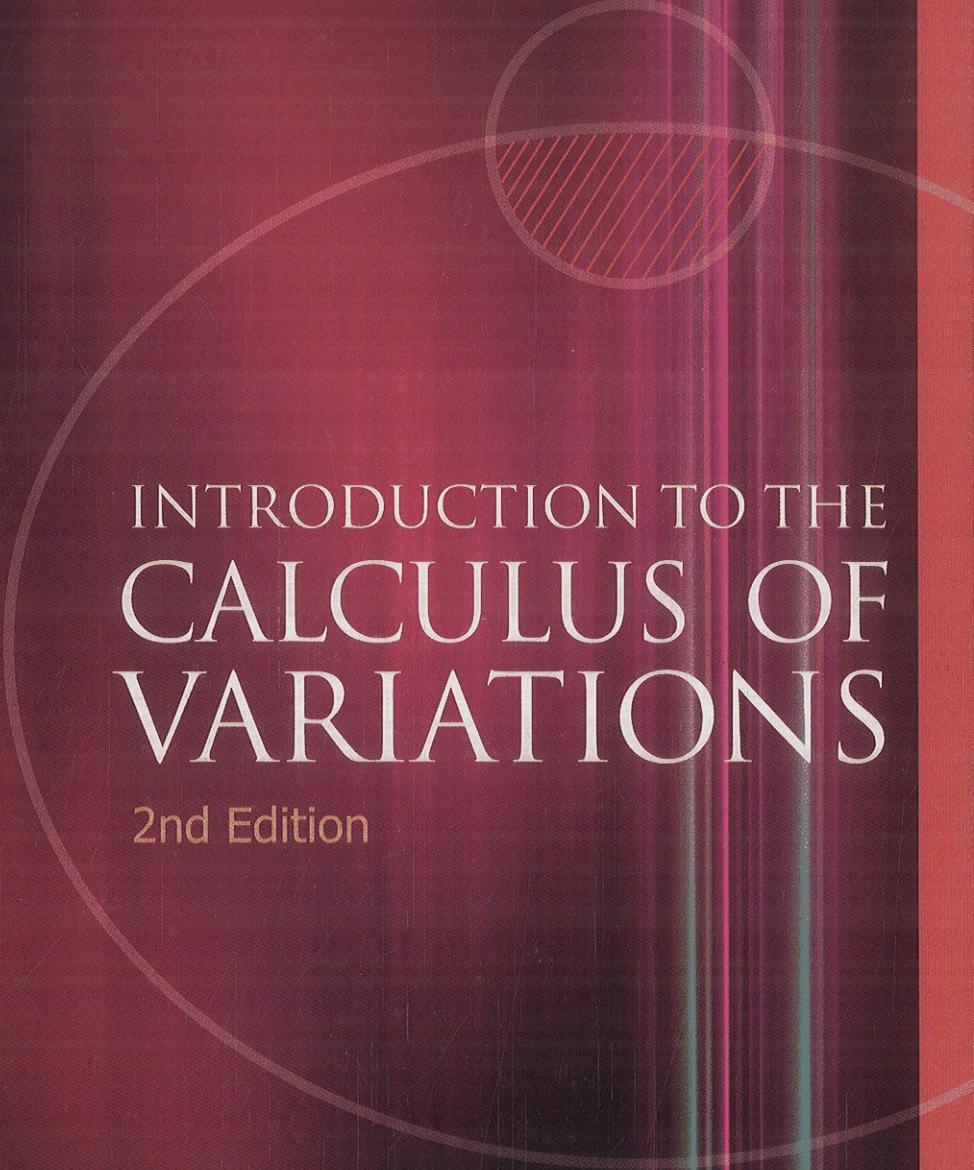


BERNARD DACOROGNA



INTRODUCTION TO THE  
CALCULUS OF  
VARIATIONS

2nd Edition

Imperial College Press

# Contents

Prefaces to the English Edition	ix
Preface to the French Edition	xii
<b>0 Introduction</b>	<b>1</b>
0.1 Brief historical comments . . . . .	1
0.2 Model problem and some examples . . . . .	3
0.3 Presentation of the content of the monograph . . . . .	7
<b>1 Preliminaries</b>	<b>13</b>
1.1 Introduction . . . . .	13
1.2 Continuous and Hölder continuous functions . . . . .	14
1.2.1 Exercises . . . . .	18
1.3 $L^p$ spaces . . . . .	19
1.3.1 Exercises . . . . .	26
1.4 Sobolev spaces . . . . .	29
1.4.1 Exercises . . . . .	42
1.5 Convex analysis . . . . .	45
1.5.1 Exercises . . . . .	48
<b>2 Classical methods</b>	<b>51</b>
2.1 Introduction . . . . .	51
2.2 Euler-Lagrange equation . . . . .	53
2.2.1 Exercises . . . . .	64
2.3 Second form of the Euler-Lagrange equation . . . . .	66
2.3.1 Exercises . . . . .	68
2.4 Hamiltonian formulation . . . . .	69
2.4.1 Exercises . . . . .	76
2.5 Hamilton-Jacobi equation . . . . .	77
2.5.1 Exercises . . . . .	81

2.6 Fields theories . . . . .	81
2.6.1 Exercises . . . . .	86
<b>3 Direct methods: existence</b>	<b>87</b>
3.1 Introduction . . . . .	87
3.2 The model case: Dirichlet integral . . . . .	89
3.2.1 Exercise . . . . .	92
3.3 A general existence theorem . . . . .	92
3.3.1 Exercises . . . . .	99
3.4 Euler-Lagrange equation . . . . .	101
3.4.1 Exercises . . . . .	107
3.5 The vectorial case . . . . .	107
3.5.1 Exercises . . . . .	115
3.6 Relaxation theory . . . . .	118
3.6.1 Exercises . . . . .	121
<b>4 Direct methods: regularity</b>	<b>125</b>
4.1 Introduction . . . . .	125
4.2 The one dimensional case . . . . .	126
4.2.1 Exercises . . . . .	131
4.3 The difference quotient method: interior regularity . . . . .	133
4.3.1 Exercises . . . . .	139
4.4 The difference quotient method: boundary regularity . . . . .	140
4.4.1 Exercise . . . . .	143
4.5 Higher regularity for the Dirichlet integral . . . . .	144
4.5.1 Exercises . . . . .	146
4.6 Weyl lemma . . . . .	147
4.6.1 Exercise . . . . .	150
4.7 Some general results . . . . .	150
4.7.1 Exercises . . . . .	152
<b>5 Minimal surfaces</b>	<b>155</b>
5.1 Introduction . . . . .	155
5.2 Generalities about surfaces . . . . .	158
5.2.1 Exercises . . . . .	166
5.3 The Douglas-Courant-Tonelli method . . . . .	167
5.3.1 Exercise . . . . .	173
5.4 Regularity, uniqueness and non-uniqueness . . . . .	173
5.5 Nonparametric minimal surfaces . . . . .	175
5.5.1 Exercise . . . . .	180

<b>6 Isoperimetric inequality</b>	<b>181</b>
6.1 Introduction . . . . .	181
6.2 The case of dimension 2 . . . . .	182
6.2.1 Exercises . . . . .	188
6.3 The case of dimension $n$ . . . . .	189
6.3.1 Exercises . . . . .	196
<b>7 Solutions to the Exercises</b>	<b>199</b>
7.1 Chapter 1. Preliminaries . . . . .	199
7.1.1 Continuous and Hölder continuous functions . . . . .	199
7.1.2 $L^p$ spaces . . . . .	203
7.1.3 Sobolev spaces . . . . .	210
7.1.4 Convex analysis . . . . .	217
7.2 Chapter 2. Classical methods . . . . .	224
7.2.1 Euler-Lagrange equation . . . . .	224
7.2.2 Second form of the Euler-Lagrange equation . . . . .	230
7.2.3 Hamiltonian formulation . . . . .	231
7.2.4 Hamilton-Jacobi equation . . . . .	232
7.2.5 Fields theories . . . . .	234
7.3 Chapter 3. Direct methods: existence . . . . .	236
7.3.1 The model case: Dirichlet integral . . . . .	236
7.3.2 A general existence theorem . . . . .	236
7.3.3 Euler-Lagrange equation . . . . .	239
7.3.4 The vectorial case . . . . .	240
7.3.5 Relaxation theory . . . . .	247
7.4 Chapter 4. Direct methods: regularity . . . . .	251
7.4.1 The one dimensional case . . . . .	251
7.4.2 The difference quotient method: interior regularity . . . . .	254
7.4.3 The difference quotient method: boundary regularity . . . . .	256
7.4.4 Higher regularity for the Dirichlet integral . . . . .	257
7.4.5 Weyl lemma . . . . .	259
7.4.6 Some general results . . . . .	260
7.5 Chapter 5. Minimal surfaces . . . . .	263
7.5.1 Generalities about surfaces . . . . .	263
7.5.2 The Douglas-Courant-Tonelli method . . . . .	266
7.5.3 Nonparametric minimal surfaces . . . . .	267
7.6 Chapter 6. Isoperimetric inequality . . . . .	268
7.6.1 The case of dimension 2 . . . . .	268
7.6.2 The case of dimension $n$ . . . . .	271
<b>Bibliography</b>	<b>275</b>

viii

**Index**

**CONTENTS**

**283**