Contents

1.1 What is a measurement? 1 1.2 Representing ideas 6 1.3 Models of the measurement process 10 1.4 Units, standards and scales 22 1.5 Measurement and the scientific method 26 1.6 Measurements as parameters of control 30 1.7 Measurements as parameters of control 30 1.7 Measurements and the body of knowledge 38 2 Science and technology of measuring instruments 42 2.1 The role of technology 42 2.2 The dual nature of machines 44 2.3 The importance of improving instrument performance 46 2.4 Instrument design 49 2.5 Innovation and invention 59 2.6 Availability of materials 66 2.7 Availability of processes and machines of manufacture 77 2.8 Availability and use of theories and principles 88 2.9 Instrument designers and builders 88 2.10 Development of the instrument industries 103 2.11				Page
Acknowledgments xv 1 Measurements for knowledge and control 1 1.1 What is a measurement? 1 1.2 Representing ideas 6 1.3 Models of the measurement process 10 1.4 Units, standards and scales 22 1.5 Measurement and the scientific method 26 1.6 Measurements as parameters of control 30 1.7 Measurements and the body of knowledge 38 2 Science and technology of measuring instruments 42 2.1 The role of technology 42 2.2 The dual nature of machines 44 2.3 The importance of improving instrument performance 46 2.4 Instrument design 59 2.5 Innovation and invention 59 2.6 Availability of materials 66 2.7 Availability of processes and machines of manufacture 77 2.8 Availability of motories and principles 73 2.9 Instrument designers and builders 103 2.10 Development of the instrument industries	Fo	reword		ix
Acknowledgments1Measurements for knowledge and control11.1What is a measurement?11.2Representing ideas61.3Models of the measurement process101.4Units, standards and scales221.5Measurement and the scientific method261.6Measurements as parameters of control301.7Measurements as parameters of control301.8Measurements and the body of knowledge382Science and technology of measuring instruments422.1The role of technology422.2The dual nature of machines442.3The importance of improving instrument performance492.4Instrument design592.5Innovation and invention592.6Availability of materials662.7Availability of processes and machines of manufacture732.9Instrument designers and builders882.10Development of the instrument industries1032.11Observatories, laboratories and presarch institutions1222.12Economic considerations: costs and benefits1313Ancient times to Middle Ages: birth of the first instruments1423.1Introductory remarks142	Pro	eface		xi
1 Measurements for knowledge and control 1.1 What is a measurement? 1 1.2 Representing ideas 6 1.3 Models of the measurement process 10 1.4 Units, standards and scales 22 1.5 Measurement and the scientific method 26 1.6 Measurements as parameters of control 30 1.7 Measuring instrument sophistication as an expression of degree of science applied 35 1.8 Measurements and the body of knowledge 38 2 Science and technology of measuring instruments 42 2.1 The role of technology 42 2.2 The dual nature of machines 44 2.3 The importance of improving instrument performance 46 2.4 Instrument design 59 2.5 Innovation and invention 59 2.6 Availability of processes and machines of manufacture 67 2.8 Availability and use of theories and principles 73 2.9 Instrument designers and builders 103 2.10 Development of the instrument industries 103 </td <td>Ac</td> <td>knowle</td> <td>dgments</td> <td>xv</td>	Ac	knowle	dgments	xv
1.1 what is a measurement? 1.2 Representing ideas 6 1.3 Models of the measurement process 10 1.4 Units, standards and scales 22 1.5 Measurement and the scientific method 26 1.6 Measurements as parameters of control 30 1.7 Measurements ophistication as an expression of degree of science applied 35 1.8 Measurements and the body of knowledge 38 2 Science and technology of measuring instruments 42 2.1 The role of technology 42 2.2 The dual nature of machines 44 2.3 The importance of improving instrument performance 46 2.4 Instrument design 59 2.5 Innovation and invention 59 2.6 Availability of motesses and machines of manufacture 73 2.9 Instrument designers and builders 88 2.10 Development of the instrument industries 102 2.11 Observatories, laboratories and research institutions 122 2.12 Economic considerations: costs and benefits 131	1	Measurements for knowledge and control		1
1.2 Representing ideas 10 1.3 Models of the measurement process 10 1.4 Units, standards and scales 22 1.5 Measurement and the scientific method 26 1.6 Measurements as parameters of control 30 1.7 Measurements cophistication as an expression of degree of science applied 35 1.8 Measurements and the body of knowledge 38 2 Science and technology of measuring instruments 42 2.1 The role of technology 42 2.2 The dual nature of machines 44 2.3 The importance of improving instrument performance 46 2.4 Instrument design 44 2.5 Innovation and invention 59 2.6 Availability of materials 66 2.7 Availability of processes and machines of manufacture 73 2.8 Availability and use of theories and principles 73 2.9 Instrument designers and builders 103 2.10 Development of the instrument industries 103 2.11 Observatories, laboratories and research instituti		1.1	What is a measurement?	
1.3Models of the measurement process101.4Units, standards and scales221.5Measurement and the scientific method261.6Measurements as parameters of control301.7Measuring instrument sophistication as an expression of degree of science applied351.8Measurements and the body of knowledge382Science and technology of measuring instruments422.1The role of technology422.2The dual nature of machines442.3The importance of improving instrument performance462.4Instrument design592.5Innovation and invention592.6Availability of processes and machines of manufacture732.9Instrument designers and builders882.10Development of the instrument industries1032.11Observatories, laboratories and research institutions1222.12Economic considerations: costs and benefits1313Ancient times to Middle Ages: birth of the first instruments1423.1Introductory remarks142		1.2	Representing ideas	
1.4Units, standards and scales221.5Measurement and the scientific method261.6Measurements as parameters of control301.7Measuring instrument sophistication as an expression of degree of science applied351.8Measurements and the body of knowledge382Science and technology of measuring instruments422.1The role of technology 2.2422.3The importance of improving instrument performance462.4Instrument design 2.5592.5Innovation and invention 2.6662.6Availability of materials 2.9662.7Availability of processes and machines of manufacture 2.9732.9Instrument designers and builders 2.10882.10Development of the instrument industries 2.111033Ancient times to Middle Ages: birth of the first instruments1423.1Introductory remarks142				
1.5Measurement and the scientific method261.6Measurements as parameters of control301.7Measuring instrument sophistication as an expression of degree of science applied351.8Measurements and the body of knowledge382Science and technology of measuring instruments422.1The role of technology422.2The dual nature of machines442.3The importance of improving instrument performance462.4Instrument design592.5Innovation and invention662.6Availability of processes and machines of manufacture732.9Instrument designers and builders882.10Development of the instrument industries1032.11Observatories, laboratories and research institutions1222.12Economic considerations: costs and benefits1313Ancient times to Middle Ages: birth of the first instruments1423.1Introductory remarks142		1.4		
1.6Measurements as parameters of control301.7Measuring instrument sophistication as an expression of degree of science applied351.8Measurements and the body of knowledge382Science and technology of measuring instruments422.1The role of technology422.2The dual nature of machines442.3The importance of improving instrument performance462.4Instrument design592.5Innovation and invention592.6Availability of materials662.7Availability of processes and machines of manufacture672.8Availability of processes and principles882.10Development of the instrument industries1032.11Observatories, laboratories and research institutions1223.1Introductory remarks142		1.5		
1.7Measuring instrument sophistication as an expression of degree of science applied351.8Measurements and the body of knowledge382Science and technology of measuring instruments422.1The role of technology422.2The dual nature of machines442.3The importance of improving instrument performance462.4Instrument design592.5Innovation and invention592.6Availability of processes and machines of manufacture672.8Availability and use of theories and principles882.10Development of the instrument industries1032.11Observatories, laboratories and research institutions1222.12Economic considerations: costs and benefits1423.1Introductory remarks142		1.6		30
degree of science applied331.8Measurements and the body of knowledge382Science and technology of measuring instruments422.1The role of technology422.2The dual nature of machines442.3The importance of improving instrument performance462.4Instrument design592.5Innovation and invention592.6Availability of materials662.7Availability of processes and machines of manufacture672.8Availability and use of theories and principles732.9Instrument designers and builders882.10Development of the instrument industries1032.11Observatories, laboratories and research institutions1223.1Introductory remarks142		1.7	Measuring instrument sophistication as an expression of	
1.8Measurements and the body of knowledge382Science and technology of measuring instruments422.1The role of technology422.2The dual nature of machines442.3The importance of improving instrument performance462.4Instrument design492.5Innovation and invention592.6Availability of materials662.7Availability of processes and machines of manufacture672.8Availability and use of theories and principles732.9Instrument designers and builders882.10Development of the instrument industries1032.11Observatories, laboratories and research institutions1223.1Introductory remarks142				
2.1The role of technology of measuring instruments422.2The dual nature of machines442.3The importance of improving instrument performance462.4Instrument design492.5Innovation and invention592.6Availability of materials662.7Availability of processes and machines of manufacture672.8Availability and use of theories and principles732.9Instrument designers and builders882.10Development of the instrument industries1032.11Observatories, laboratories and research institutions1222.12Economic considerations: costs and benefits1423.1Introductory remarks142		1.8		38
2.1The fole of technology442.2The dual nature of machines442.3The importance of improving instrument performance462.4Instrument design492.5Innovation and invention592.6Availability of materials662.7Availability of processes and machines of manufacture672.8Availability and use of theories and principles732.9Instrument designers and builders882.10Development of the instrument industries1032.11Observatories, laboratories and research institutions1222.12Economic considerations: costs and benefits1313Ancient times to Middle Ages: birth of the first instruments1423.1Introductory remarks142	2	Science and technology of measuring instruments		
2.2The dual nature of machines442.3The importance of improving instrument performance462.4Instrument design492.5Innovation and invention592.6Availability of materials662.7Availability of processes and machines of manufacture672.8Availability and use of theories and principles732.9Instrument designers and builders882.10Development of the instrument industries1032.11Observatories, laboratories and research institutions1222.12Economic considerations: costs and benefits1313Ancient times to Middle Ages: birth of the first instruments1423.1Introductory remarks142		21	The role of technology	42
2.3The importance of improving instrument performance462.4Instrument design492.5Innovation and invention592.6Availability of materials662.7Availability of processes and machines of manufacture672.8Availability and use of theories and principles732.9Instrument designers and builders882.10Development of the instrument industries1032.11Observatories, laboratories and research institutions1222.12Economic considerations: costs and benefits1313Ancient times to Middle Ages: birth of the first instruments1423.1Introductory remarks142				
2.4Instrument design472.5Innovation and invention592.6Availability of materials662.7Availability of processes and machines of manufacture672.8Availability and use of theories and principles732.9Instrument designers and builders882.10Development of the instrument industries1032.11Observatories, laboratories and research institutions1222.12Economic considerations: costs and benefits1313Ancient times to Middle Ages: birth of the first instruments1423.1Introductory remarks142				
2.5Innovation and invention592.6Availability of materials662.7Availability of processes and machines of manufacture672.8Availability and use of theories and principles732.9Instrument designers and builders882.10Development of the instrument industries1032.11Observatories, laboratories and research institutions1222.12Economic considerations: costs and benefits1313Ancient times to Middle Ages: birth of the first instruments1423.1Introductory remarks142				
2.6Availability of materials662.7Availability of processes and machines of manufacture672.8Availability and use of theories and principles732.9Instrument designers and builders882.10Development of the instrument industries1032.11Observatories, laboratories and research institutions1222.12Economic considerations: costs and benefits1313Ancient times to Middle Ages: birth of the first instruments1423.1Introductory remarks142			•	
2.7Availability of processes and machines of manufacture672.8Availability and use of theories and principles732.9Instrument designers and builders882.10Development of the instrument industries1032.11Observatories, laboratories and research institutions1222.12Economic considerations: costs and benefits1313Ancient times to Middle Ages: birth of the first instruments1423.1Introductory remarks142				
2.8Availability and use of theories and principles752.9Instrument designers and builders882.10Development of the instrument industries1032.11Observatories, laboratories and research institutions1222.12Economic considerations: costs and benefits1313Ancient times to Middle Ages: birth of the first instruments1423.1Introductory remarks142			Availability of processes and machines of manufacture	
2.9Instrument designers and builders002.10Development of the instrument industries1032.11Observatories, laboratories and research institutions1222.12Economic considerations: costs and benefits1313Ancient times to Middle Ages: birth of the first instruments1423.1Introductory remarks142		2.8	Availability and use of theories and principles	
2.10Development of the instrument industries1032.11Observatories, laboratories and research institutions1222.12Economic considerations: costs and benefits1313Ancient times to Middle Ages: birth of the first instruments1423.1Introductory remarks142				
2.11Observatories, laboratories and research institutions1222.12Economic considerations: costs and benefits1313Ancient times to Middle Ages: birth of the first instruments1423.1Introductory remarks142				
2.12Economic considerations: costs and benefits1513Ancient times to Middle Ages: birth of the first instruments1423.1Introductory remarks142		2.11	Observatories, laboratories and research institutions	
3 Ancient times to Middle Ages: birth of the first instruments 142 3.1 Introductory remarks 142		2.12	Economic considerations: costs and benefits	131
3.1 Introductory remarks	3	Ancient times to Middle Ages: birth of the first instruments		142
147		31	Introductory remarks	
				147

viii Contents

	3.3	The Dark Ages (c300-c1300 AD)	148	
	3.4	Renaissance – rebirth of learning and the arts		
		(14th and 15th centuries)	151	
	3.5	Time interval and time of day	153	
	3.6	Weights and measures	165	
	3.7	Astronomy and surveying	189	
	3.8	The beginning of other instrumentation	209	
4	Exerimental science becomes established: Middle Ages -1800 AD			
	4.1	Emphasis on observation	219	
	4.2	First foundations of electricity	226	
	4.3	Further development of mechanics	246	
	4.4	Blossoming of optical instruments	262	
	4.5	Growth of the instrument range	274	
	4.6	Recording and registration	286	
5	Grow	th of electrical methods: the 19th century	292	
	5.1	Expansion of measurement technique	292	
	5.2	Electrical method	297	
	5.3	Control and computation	341	
	5.4	Recording and registration	353	
	5.5	Optical instrumentation	367	
	5.6	Mechanics	376	
	5.7	Still more measurements	378	
6	The first half of the 20th century: 1900-1950			
	6.1	Data galore	389	
	6.2	Electronic technique	394	
	6.3	Accurate mechanism and mathematics	418	
	6.4	Instrument systems emerge	422	
	6.5	Recording data	435	
	6.6	Further growth in sensing instrumentation	445	
	6.7	Measurement in the empirical sciences	451	
Bil	Bibliography			
-	Appendix 1 Biographies relevant to instrument history			
Aŗ	pendix	2 Collections containing instruments	486	
Ine	dex		498	