CHEMICAL KINETICS

EDITED BY

C.H. BAMFORD

M.A., Ph.D., Sc.D. (Cantab.), F.R.I.C., F.R.S. Formerly Campbell-Brown Professor of Industrial Chemistry, University of Liverpool

The late C.F.H. TIPPER

Ph.D. (Bristol), D.Sc. (Edinburgh) Senior Lecturer in Physical Chemistry, University of Liverpool

AND

R.G. COMPTON

M.A., D.Phil. (Oxon.) Lecturer in Physical Chemistry, University of Liverpool

VOLUME 23

KINETICS AND CHEMICAL TECHNOLOGY



ELSEVIER AMSTERDAM-OXFORD-NEW YORK-TOKYO 1985

Contents

$ \begin{array}{llllllllllllllllllllllllllllllllllll$	Preface		ix
1. Introduction.12. Thermodynamics.52.1 Introduction.52.2 The first law.52.2.1 Energy changes in a reaction62.2.2 The effect of temperature on the enthalpy change in a reaction2.3 The second law.82.3.1 Entropy.82.3.2 Free energy functions and criteria for equilibrium82.4 The third law92.4.1 Standard entropies.92.4.2 Calculation of the Gibbs free energy change as a function of temperature102.4.3 Equilibrium constants.102.4.4 Relationship between ΔG and the equilibrium constant of a reaction.112.4.5 Equilibrium constants in real gas systems; fugacity.122.5 Example132.5.1 Thermodynamic data132.5.2 Calculation of ΔH^{\oplus} as $f(T)$.142.5.3 Calculation of ΔG and K as functions of T .152.5.4 An alternative procedure.162.5.5 Calculation of the equilibrium composition of a mixture, allowing for real gas effects172.6 Sources of thermodynamic data and estimation methods183. Chemical reaction kinetics.193.1 Definition of terms193.2 Chemical kinetics and diffusion control214. Transport processes224.1 Introduction.224.2 Heat transfer24	Chapter 1 ((J.A. Barnard)	
2. Thermodynamics.52.1 Introduction.52.2 The first law.52.2.1 Energy changes in a reaction62.2.2 The effect of temperature on the enthalpy change in a reaction72.3 The second law.82.3.1 Entropy.82.3.2 Free energy functions and criteria for equilibrium82.4 The third law.92.4.1 Standard entropies.92.4.2 Calculation of the Gibbs free energy change as a function of temperature102.4.3 Equilibrium constants.102.4.4 Relationship between ΔG and the equilibrium constant of a reaction.112.4.5 Equilibrium constants in real gas systems; fugacity.122.5 Example132.5.1 Thermodynamic data132.5.2 Calculation of ΔH^{\oplus} as $f(T)$.142.5.3 Calculation of ΔH^{\oplus} as functions of T .152.5.4 An alternative procedure.162.5.5 Calculation of the equilibrium composition of a mixture, allowing for real gas effects172.6 Sources of thermodynamic data and estimation methods183. Chemical reaction kinetics.193.1 Definition of terms193.2 Chemical kinetics and diffusion control214. Transport processes224.1 Introduction.224.2 Heat transfer24	Fundamen	tal aspects of the design of industrial chemical reactors	1
2.1Introduction.52.2The first law.52.2.1Energy changes in a reaction62.2.2The effect of temperature on the enthalpy change in a reaction72.3The second law.82.3.1Entropy.82.3.2Free energy functions and criteria for equilibrium82.4The third law92.4.1Standard entropies.92.4.2Calculation of the Gibbs free energy change as a function of temperature102.4.3Equilibrium constants.102.4.4Relationship between ΔG and the equilirbium constant of a reaction.112.4.5Equilibrium constants in real gas systems; fugacity.122.5Example132.5.1Thermodynamic data132.5.2Calculation of ΔH^{\oplus} as $f(T)$.142.5.3Calculation of ΔG and K as functions of T .152.5.4An alternative procedure.172.6Sources of thermodynamic data and estimation methods183Chemical reaction kinetics.193.1Definition of terms193.2Chemical kinetics and diffusion control214Transport processes224.1Introduction.224.2Heat transfer24			1
2.2The first law.52.2.1Energy changes in a reaction62.2.2The effect of temperature on the enthalpy change in a reaction72.3The second law.82.3.1Entropy.82.3.2Free energy functions and criteria for equilibrium82.4The third law92.4.1Standard entropies.92.4.2Calculation of the Gibbs free energy change as a function of temperature102.4.3Equilibrium constants.102.4.4Relationship between ΔG and the equilibrium constant of a reaction112.4.5Equilibrium constants in real gas systems; fugacity.122.5Example132.5.1Thermodynamic data132.5.2Calculation of ΔH^{\oplus} as $f(T)$ 142.5.3Calculation of ΔG and K as functions of T .162.5.5Calculation of ΔG and K as functions of a mixture, allowing for real gas effects172.6Sources of thermodynamic data and estimation methods183Chemical reaction kinetics.193.1Definition of terms193.2Chemical kinetics and diffusion control214.1Introduction.224.2Heat transfer24	2. Ther	modynamics	-
2.2.1 Energy changes in a reaction62.2.2 The effect of temperature on the enthalpy change in a reaction72.3 The second law82.3.1 Entropy82.3.2 Free energy functions and criteria for equilibrium82.4 The third law92.4.1 Standard entropies92.4.2 Calculation of the Gibbs free energy change as a function of temperature102.4.3 Equilibrium constants102.4.4 Relationship between ΔG and the equilibrium constant of a reaction112.4.5 Equilibrium constants in real gas systems; fugacity122.5 Example132.5.1 Thermodynamic data132.5.2 Calculation of ΔH^{\ominus} as $f(T)$ 142.5.3 Calculation of ΔG and K as functions of T152.5.4 An alternative procedure172.6 Sources of thermodynamic data and estimation methods183. Chemical reaction kinetics193.1 Definition of terms193.2 Chemical kinetics and diffusion control214.1 Introduction224.1 Introduction224.2 Heat transfer24	2.1	Introduction.	5
2.2.2 The effect of temperature on the enthalpy change in a reaction 2.3 The second law	2.2		
2.3The second law82.3.1Entropy82.3.2Free energy functions and criteria for equilibrium82.4The third law92.4.1Standard entropies92.4.2Calculation of the Gibbs free energy change as a function of temperature102.4.3Equilibrium constants102.4.4Relationship between ΔG and the equilirbium constant of a reaction112.4.5Equilibrium constants in real gas systems; fugacity122.5Example132.5.1Thermodynamic data132.5.2Calculation of ΔH^{\oplus} as $f(T)$ 142.5.3Calculation of the equilibrium composition of a mixture, allowing for real gas effects172.6Sources of thermodynamic data and estimation methods183.1Definition of terms193.2Chemical kinetics and diffusion control214.1Introduction224.2Heat transfer24		2.2.1 Energy changes in a reaction	-
2.3.1 Entropy.82.3.2 Free energy functions and criteria for equilibrium82.4 The third law92.4.1 Standard entropies92.4.2 Calculation of the Gibbs free energy change as a function of temperature102.4.3 Equilibrium constants102.4.4 Relationship between ΔG and the equilirbium constant of a reaction112.4.5 Equilibrium constants in real gas systems; fugacity122.5 Example132.5.1 Thermodynamic data132.5.2 Calculation of ΔH^{\oplus} as $f(T)$ 142.5.3 Calculation of ΔG and K as functions of T152.5.4 An alternative procedure162.5.5 Calculation of the equilibrium composition of a mixture, allowing for real gas effects172.6 Sources of thermodynamic data and estimation methods183. Chemical reaction kinetics193.1 Definition of terms193.2 Chemical kinetics and diffusion control214. Transport processes224.1 Introduction224.2 Heat transfer24			
2.3.2 Free energy functions and criteria for equilibrium82.4 The third law92.4.1 Standard entropies92.4.2 Calculation of the Gibbs free energy change as a function of temperature102.4.3 Equilibrium constants102.4.4 Relationship between ΔG and the equilirbium constant of a reaction112.4.5 Equilibrium constants in real gas systems; fugacity122.5 Example132.5.1 Thermodynamic data132.5.2 Calculation of ΔH^{\oplus} as $f(T)$ 142.5.3 Calculation of ΔG and K as functions of T 152.5.5 Calculation of the equilibrium composition of a mixture, allowing for real gas effects172.6 Sources of thermodynamic data and estimation methods183.1 Definition of terms193.2 Chemical kinetics and diffusion control214. Transport processes224.1 Introduction224.2 Heat transfer24	2.3		
2.4The third law92.4.1Standard entropies92.4.2Calculation of the Gibbs free energy change as a function of temperature102.4.3Equilibrium constants102.4.4Relationship between ΔG and the equilirbium constant of a reaction112.4.5Equilibrium constants in real gas systems; fugacity122.5Example132.5.1Thermodynamic data132.5.2Calculation of ΔH^{\oplus} as $f(T)$ 142.5.3Calculation of ΔG and K as functions of T 152.5.4An alternative procedure162.5.5Calculation of the equilibrium composition of a mixture, allowing for real gas effects172.6Sources of thermodynamic data and estimation methods183Chemical reaction kinetics193.1Definition of terms193.2Chemical kinetics and diffusion control214Transport processes224.1Introduction224.2Heat transfer24			
2.4.1 Standard entropies.92.4.2 Calculation of the Gibbs free energy change as a function of temperature.102.4.3 Equilibrium constants.102.4.4 Relationship between ΔG and the equilirbium constant of a reaction.112.4.5 Equilibrium constants in real gas systems; fugacity.122.5 Example132.5.1 Thermodynamic data132.5.2 Calculation of ΔH^{\oplus} as $f(T)$.142.5.3 Calculation of ΔG and K as functions of T.162.5.4 An alternative procedure.162.5.5 Calculation of the equilibrium composition of a mixture, allowing for real gas effects172.6 Sources of thermodynamic data and estimation methods183. Chemical reaction kinetics.193.1 Definition of terms193.2 Chemical kinetics and diffusion control214. Transport processes224.1 Introduction.224.2 Heat transfer24			
2.4.2 Calculation of the Gibbs free energy change as a function of temperature	2.4		-
temperature102.4.3 Equilibrium constants.102.4.4 Relationship between ΔG and the equilirbium constant of a reaction.112.4.5 Equilibrium constants in real gas systems; fugacity.122.5 Example132.5.1 Thermodynamic data132.5.2 Calculation of ΔH^{\oplus} as $f(T)$.142.5.3 Calculation of ΔG and K as functions of T152.5.4 An alternative procedure.162.5.5 Calculation of the equilibrium composition of a mixture, allowing for real gas effects172.6 Sources of thermodynamic data and estimation methods183. Chemical reaction kinetics.193.1 Definition of terms193.2 Chemical kinetics and diffusion control214. Transport processes224.1 Introduction.224.2 Heat transfer24			9
2.4.3 Equilibrium constants.102.4.4 Relationship between ΔG and the equilirbium constant of a reaction.112.4.5 Equilibrium constants in real gas systems; fugacity.122.5 Example132.5.1 Thermodynamic data132.5.2 Calculation of ΔH^{\oplus} as $f(T)$.142.5.3 Calculation of ΔG and K as functions of T.152.5.4 An alternative procedure.162.5.5 Calculation of the equilibrium composition of a mixture, allowing for real gas effects172.6 Sources of thermodynamic data and estimation methods183. Chemical reaction kinetics.193.1 Definition of terms193.2 Chemical kinetics and diffusion control214. Transport processes224.1 Introduction.224.2 Heat transfer24		2.4.2 Calculation of the Gibbs free energy change as a function of	10
2.4.4 Relationship between ΔG and the equilibium constant of a reaction.112.4.5 Equilibrium constants in real gas systems; fugacity.122.5 Example132.5.1 Thermodynamic data132.5.2 Calculation of ΔH^{\oplus} as $f(T)$.142.5.3 Calculation of ΔG and K as functions of T.152.5.4 An alternative procedure.162.5.5 Calculation of the equilibrium composition of a mixture, allowing for real gas effects172.6 Sources of thermodynamic data and estimation methods183. Chemical reaction kinetics.193.1 Definition of terms193.2 Chemical kinetics and diffusion control214. Transport processes224.1 Introduction.224.2 Heat transfer24		temperature	
reaction112.4.5 Equilibrium constants in real gas systems; fugacity122.5 Example132.5.1 Thermodynamic data132.5.2 Calculation of ΔH^{\oplus} as $f(T)$ 142.5.3 Calculation of ΔG and K as functions of T152.5.4 An alternative procedure162.5.5 Calculation of the equilibrium composition of a mixture, allowing for real gas effects172.6 Sources of thermodynamic data and estimation methods183. Chemical reaction kinetics193.1 Definition of terms193.2 Chemical kinetics and diffusion control214. Transport processes224.1 Introduction224.2 Heat transfer24		2.4.3 Equilibrium constants.	10
2.4.5 Equilibrium constants in real gas systems; fugacity.122.5 Example132.5.1 Thermodynamic data132.5.2 Calculation of ΔH^{\oplus} as $f(T)$.142.5.3 Calculation of ΔG and K as functions of T152.5.4 An alternative procedure.162.5.5 Calculation of the equilibrium composition of a mixture, allowing for real gas effects172.6 Sources of thermodynamic data and estimation methods183. Chemical reaction kinetics.193.1 Definition of terms193.2 Chemical kinetics and diffusion control214. Transport processes224.1 Introduction.224.2 Heat transfer24			11
2.5Example132.5.1Thermodynamic data132.5.2Calculation of ΔH^{\oplus} as $f(T)$ 142.5.3Calculation of ΔG and K as functions of T152.5.4An alternative procedure162.5.5Calculation of the equilibrium composition of a mixture, allowing for real gas effects172.6Sources of thermodynamic data and estimation methods183.Chemical reaction kinetics193.1Definition of terms193.2Chemical kinetics and diffusion control214.Transport processes224.1Introduction224.2Heat transfer24			
2.5.1 Thermodynamic data132.5.2 Calculation of ΔH^{\oplus} as $f(T)$ 142.5.3 Calculation of ΔG and K as functions of T152.5.4 An alternative procedure162.5.5 Calculation of the equilibrium composition of a mixture, allowing for real gas effects172.6 Sources of thermodynamic data and estimation methods183. Chemical reaction kinetics193.1 Definition of terms193.2 Chemical kinetics and diffusion control214. Transport processes224.1 Introduction224.2 Heat transfer24	9 5		
2.5.2 Calculation of ΔH^{\oplus} as $f(T)$.142.5.3 Calculation of ΔG and K as functions of T.152.5.4 An alternative procedure.162.5.5 Calculation of the equilibrium composition of a mixture, allowing for real gas effects.172.6 Sources of thermodynamic data and estimation methods183. Chemical reaction kinetics.193.1 Definition of terms193.2 Chemical kinetics and diffusion control214. Transport processes224.1 Introduction.224.2 Heat transfer24	2.0		
2.5.3 Calculation of ΔG and K as functions of T.152.5.4 An alternative procedure.162.5.5 Calculation of the equilibrium composition of a mixture, allowing for real gas effects.172.6 Sources of thermodynamic data and estimation methods183. Chemical reaction kinetics.193.1 Definition of terms193.2 Chemical kinetics and diffusion control214. Transport processes224.1 Introduction.224.2 Heat transfer24		2.5.1 Inermodynamic data	
2.5.4 An alternative procedure.162.5.5 Calculation of the equilibrium composition of a mixture, allowing for real gas effects.172.6 Sources of thermodynamic data and estimation methods183. Chemical reaction kinetics.193.1 Definition of terms193.2 Chemical kinetics and diffusion control214. Transport processes224.1 Introduction.224.2 Heat transfer24		2.5.2 Calculation of ΔH as $I(T)$	
2.5.5 Calculation of the equilibrium composition of a mixture, allowing for real gas effects			
allowing for real gas effects172.6Sources of thermodynamic data and estimation methods183.Chemical reaction kinetics193.1Definition of terms193.2Chemical kinetics and diffusion control214.Transport processes224.1Introduction224.2Heat transfer24			10
2.6Sources of thermodynamic data and estimation methods183.Chemical reaction kinetics.193.1Definition of terms193.2Chemical kinetics and diffusion control214.Transport processes224.1Introduction224.2Heat transfer24			17
3. Chemical reaction kinetics.193.1 Definition of terms193.2 Chemical kinetics and diffusion control214. Transport processes224.1 Introduction224.2 Heat transfer24	26		
3.1Definition of terms193.2Chemical kinetics and diffusion control214.Transport processes224.1Introduction224.2Heat transfer24			
3.2Chemical kinetics and diffusion control214.Transport processes224.1Introduction224.2Heat transfer24			
4. Transport processes 22 4.1 Introduction 22 4.2 Heat transfer 24			
4.1 Introduction. 22 4.2 Heat transfer 24			
4.2 Heat transfer			
4.2.1 Introduction 24	1.4	4.2.1 Introduction.	24
4.2.2 Modes of heat transfer			
4.2.3 Overall heat transfer coefficients and log mean temperature		4.2.3 Overall heat transfer coefficients and log mean temperature	
difference		difference	25
4.3 Conductive heat transfer	43		
4.3.1 Fourier's law	1.0		
4.3.2 Thermal conductivities of substances			

4.4 Convective heat transfer	29
4.4.1 Natural and forced convection	29
4.4.2 Heat transfer to reaction vessels	30
4.4.3 Heat transfer to a single particle	31
4.4.4 Heat transfer to packed beds	31
4.4.5 Heat transfer to gauzes	32
5. Radiative heat transfer	32
6. Mass transfer	33
6.1 Introduction	33
6.2 Equimolar counter-diffusion	33
6.3 Diffusion through a stagnant fluid	33
6.4 Diffusion coefficients	35
6.5 Mass transfer across a phase boundary	35
6.5.1 Introduction	35
6.5.2 Film coefficients and overall coefficients	36
	38
6.6.1 Introduction	38
6.6.2 Mass transfer to a single particle	38
6.6.3 Mass transfer to packed beds	38
6.6.4 Mass transfer to gauzes	39
7. Pressure drop in reactors	39
7.1 Pressure drop in empty tubes	39
7.2 Pressure drop in packed beds 4	10
Appendix 1	10
Appendix 2	13
References	13

Chapter 2 (J.A. Barnard)

Туре	of ideal reactor.	47
1.	Introduction	47
	The batch reactor	48
	2.1 Introduction	48
	2.2 The design equation	49
	2.3 Production rate in a batch reactor.	51
	2.4 Non-isothermal operation	53
	2.5 Example	55
	2.5.1 Isothermal operation	56
	2.5.2 Adiabatic operation	56
	2.5.3 General non-isothermal case	58
	2.6 The semi-batch reactor	58
3.	The tubular reactor	62
	3.1 Introduction	62
	3.2 The tubular reactor with plug flow	64
	3.2.1 The design equation	66
	3.2.2 Non-isothermal operation	68
	3.2.3 Example	71
	3.2.4 Conversion in a reversible reaction	75
	3.3 The tubular reactor with axial mixing; the dispersion model	77
	3.4 The tubular reactor with laminar flow	78
	3.4.1 Introduction	78
	3.4.2 The design equation	79
4	The continuous stirred tank reactor	83
ч.	4.1 Introduction.	83
	Introduction	00

4.2	The design equation	84
4.3	Tanks in series	87
4.4 (Comparison of the performance of various types of reactor	90
4	4.4.1 Plug-flow reactor and single continuous stirred tank	90
4	4.4.2 Single continuous stirred tank and two tanks in series	91
4.5 (Conversion in a reversible reaction	94
5. Reacto	or stability	94
5.1 I	Introduction	94
5.2	The theory of self-heating leading to explosion in a closed system	95
5.3 \$	Self-heating in a continuous stirred tank reactor	100
5.4 (Other systems	104
Appendix 1		107
Appendix 2		109
References .		111

Chapter 3 (B.W. Brooks)

Kinet	ic trea	tment and reactor performance for complex reactions	113
		duction	113
2.	Type	s of complex reactions	113
	2.1	Reversible reactions	113
	2.2	Parallel reactions	116
	2.3	Consecutive reactions.	117
	2.4	Consecutive-parallel reactions.	119
	2.5	Consecutive-parallel reactions with reversible steps	120
3.	Nume	erical procedures and approximations	121
	3.1	Stationary state approximations	122
	3.2	Chain reactions	123
4.	Mode	l formulation and parameter estimation	124
5.	Multi	component feeds	128
	5.1	Lumping	128
6.	Chem	ical reactions with mass transfer	129
7.	Polyn	nerisation reactions	131
	7.1	Addition polymerisation without chain termination	132
	7.2	Free-radical polymerisation	134
	7.3	Emulsion polymerisation	135
	7.4	Condensation polymerisation.	136
8.	React	ion selectivity and reactor choice	137
	8.1	Maximum yields	139
	8.2	Physical constraints	140
	8.3	Flow patterns	140
	8.4	Temperature effects	142
	8.5	Polymerisation reactors	143
		8.5.1 Addition polymerisation	143
		8.5.2 Condensation polymerisation.	145
		8.5.3 Physical effects	146
	8.6	Optimisation	146
Nom	Nomenclature		
Refe	ences		150
Chap	ter 4 (W.J. Thomas)	
Catal	ytic an	d non-catalytic heterogeneous reactions	153

2.	The	importance of pore structure and surface area in heterogeneous	
	cataly	/sis	153
	2.1	Chemical reaction influenced by intraparticle diffusion	154
	2.2	Effect of intraparticle diffusion on experimental parameters	158
	2.3	Non-isothermal reactions in catalyst pellets	160
	2.4	Criteria for diffusion control of a catalytic reaction	163
3.	Mode	els of porous solids	165
	3.1	Wheeler's semi-empirical pore model	165
	3.2	Mathematical models of porous structures	166
		3.2.1 The dusty gas model	166
		3.2.2 The random pore model	167
4.	Effec	t of mass and heat transfer on catalytic selectivity	168
	4.1	Influence of intraparticle diffusion on selectivity	168
	4.2	Effect of interparticle mass transfer on catalytic selectivity	173
5.	Non-o	catalytic gas—solid reactions	174
	5.1	A general model of gas—solid reactions	175
	5.2	Shrinking core model	177
6.	Indus	strial reactors employed for heterogeneous catalytic and gas-solid	
	reacti	ions	180
	6.1	Fixed-bed reactors.	180
		6.1.1 Adiabatically operated fixed-bed catalytic reactors	182
		6.1.2 Non-isothermal fixed-bed catalytic reactors	186
	6.2	Fluidised beds	191
	6.3	Trickle-bed reactor	194
	6.4	Catalyst monolith reactors	196
	6.5	Non-catalytic gas—solid reactors	198
Refe	ences		202

Chapter 5 (S.P.S. Andrew)

Non-catalytic heterogeneous reactions.	205
1. Introduction	205
2. Spatially non-uniform homogeneous reactions	205
3. Gas-liquid reactions with gaseous product.	206
ii dub inquita iouotiono interinquita producti i i i i i i i i i i i i i i i i i i	206
o. Enquia inquia reactions and inquia production of the total of tota	211
of Enquire inquire featuring with bonne products () () () () () () () () () (212
7. Gas-solid reactions with gaseous product	212
8. Solid-to-gas transformations	213
9. Gas-solid reactions with solid product	213
10. Liquid–solid reactions with liquid product.	215
11. Liquid-solid reactions with solid product	216
	218
13. Solid–solid reactions with liquid product	219
	219
	220
	222

Chapter 6 (S.P. Waldram)

Non-ideal flow in chemical reactors.	223
1. Introduction	223
2. The Laplace transform	224

3.	The r	esidence time distribution	224
	3.1	Introduction.	224
	3.2	Transient testing techniques using tracers.	229
		3.2.1 Idealised impulse response test. $C_{A_{in}}(t) = \delta(t) \dots \dots \dots$	231
		3.2.2 Idealised step response test. $C_{A_{in}}(t) = u(t) \dots \dots \dots$	231
		3.2.3 Since wave response tests. $C_{A_{in}}(t) = A \sin kt$	232
		3.2.4 Cross correlation techniques	232
		3.2.5 Two-station measurement techniques	233
	3.3	Observations on transient testing techniques. An example of a tracer	
		test	233
4.	Theo	retical prediction of tracer responses and prediction of reactor	
	perfo	rmance	238
	4.1	Predicting tracer responses and $E(t)$ curves	239
	4.2	Predicting conversion from RTD data	241
	4.3	The concept of macromixing and micromixing	245
5.	Mode	els for non-ideal flow in chemical reactors	249
	5.1	The tanks-in-series model	249
	5.2	The laminar flow reactor.	255
	5.3	The recycle reactor	257
	5.4	The dispersion model	260
	5.5	Further models of flow-mixing systems	267
6.	Some	comments on estimating parameters in flow-mixing systems	267
		ure	269
Appe	ndix 1		271
		e transform, transfer functions and systems moments	271
		2	277
		conversion from a reactor system in which a first-order reaction is	
		e. Use of the system transfer function.	277
	-		279
			2.0
Index			283