

# Contents

## Chapter 1 Review of Nuclear Physics

1-1	The Constituents of Nuclei . . . . .	1
1-2	Particle Wavelengths . . . . .	1
1-3	Nuclear Radii . . . . .	2
1-4	Nuclear Mass . . . . .	3
1-5	Binding Energy . . . . .	3
1-6	Excited States in Nuclei . . . . .	5
1-7	Radioactivity . . . . .	7
1-8	The Decay of Excited States . . . . .	9
1-9	Nuclear Reactions . . . . .	11

## Chapter 2 Interaction of Neutrons with Matter

2-1	Cross Sections . . . . .	17
2-2	Neutron Interactions and Macroscopic Cross Sections . . . . .	20
2-3	Cross Sections of Mixtures and Molecules . . . . .	22
2-4	Angular Distributions and Differential Cross Sections . . . . .	22
2-5	Center-of-Mass Coordinates . . . . .	24
2-6	Mechanisms of Neutron Interactions . . . . .	31
2-7	The Total Cross Section . . . . .	34
2-8	Elastic Scattering . . . . .	42
2-9	Transport Cross Section . . . . .	54
2-10	Nonelastic Cross Section . . . . .	57
2-11	Inelastic Scattering . . . . .	57
2-12	Absorption Reactions . . . . .	61
2-13	Neutron Producing Reactions . . . . .	66
2-14	The Doppler Effect . . . . .	68
2-15	On Cross-Section Compilations . . . . .	74

## Chapter 3 Nuclear Fission

3-1	The Mechanics of Fission . . . . .	82
3-2	Practical Fission Fuels . . . . .	86
3-3	Cross Sections of Fissionable Nuclei . . . . .	89
3-4	The Products of Fission . . . . .	92
3-5	Energy Release from Fission . . . . .	103
3-6	Reactor Power, Fuel Burnup, and Fuel Consumption . . . . .	105

## **Chapter 4 Neutron Chain-Reacting Systems**

4-1	Multiplication Factor . . . . .	109
4-2	Neutron Balance and Conditions for Criticality . . . . .	109
4-3	Conversion and Breeding . . . . .	110
4-4	Types of Nuclear Reactors . . . . .	113
4-5	General Considerations of Reactor Design . . . . .	116

## **Chapter 5 The Diffusion of Neutrons**

5-1	Interaction Rates and Neutron Flux . . . . .	118
5-2	Neutron Current Density . . . . .	122
5-3	The Equation of Continuity . . . . .	123
5-4	Fick's Law . . . . .	125
5-5	Physical Interpretation of Fick's Law . . . . .	128
5-6	Validity of Fick's Law . . . . .	129
5-7	The Diffusion Equation . . . . .	132
5-8	Boundary Conditions for the Steady-State Diffusion Equation . . . . .	133
5-9	Elementary Solutions of the Steady-State Diffusion Equation . . . . .	137
5-10	General Diffusion Problems . . . . .	144
5-11	The Diffusion Length . . . . .	153
5-12	The Reciprocity Theorem . . . . .	155

## **Chapter 6 Neutron Moderation without Absorption**

6-1	Energy Loss in Elastic Collisions . . . . .	167
6-2	Collision and Slowing-Down Densities . . . . .	171
6-3	Moderation of Neutrons in Hydrogen . . . . .	171
6-4	Lethargy and $\xi$ . . . . .	174
6-5	Moderation of Neutrons for $A > 1$ . . . . .	176
6-6	Nonmonoenergetic Sources . . . . .	182
6-7	Slowing Down in Mixtures of Nuclides . . . . .	183
6-8	Multiscattered Neutrons . . . . .	185
6-9	Space-Dependent Slowing Down—Fermi Age Theory . . . . .	187
6-10	Boundary Conditions for the Age Equation . . . . .	190
6-11	Solutions to the Age Equation . . . . .	192
6-12	Physical Significance of Fermi Age . . . . .	196
6-13	Validity of Age Theory—Slowing Down in Hydrogen . . . . .	199
6-14	Measurement of Neutron Age . . . . .	201
6-15	Inelastic Scattering in the Slowing Down of Neutrons . . . . .	204
6-16	Methods of Calculating Age . . . . .	207

6-17	Elastic Moderation Time . . . . .	207
6-18	Slowing-Down Kernels . . . . .	208

## **Chapter 7 Neutron Moderation with Absorption and Fission**

7-1	Hydrogen and an Infinite Mass Absorber . . . . .	216
7-2	Moderators with $A > 1$ ; The NR and NRIM Approximations . . . . .	222
7-3	Temperature Dependence of Resonance Escape . . . . .	229
7-4	Widely Spaced and Narrow Resonances . . . . .	230
7-5	Slowing Down with Weak Absorption . . . . .	232
7-6	Numerical Computations of Resonance Escape . . . . .	233
7-7	Measurements of Resonance Escape . . . . .	235
7-8	Space-Dependent Moderation with Absorption . . . . .	236
7-9	Fast Fission . . . . .	238

## **Chapter 8 Low-Energy Neutrons**

8-1	Thermal Neutron Spectra . . . . .	243
8-2	Interaction Rates for Thermal Neutrons . . . . .	251
8-3	Reactor Power . . . . .	257
8-4	Average $\eta$ in a Thermal Flux . . . . .	258
8-5	Diffusion of Thermal Neutrons . . . . .	260
8-6	Thermalization Time . . . . .	264
8-7	Age from Indium Resonance to Thermal . . . . .	266
8-8	Slowing Down and Diffusion . . . . .	268
8-9	Measurements of the Thermal Diffusion Parameters . . . . .	270

## **Chapter 9 Fermi Theory of the Bare Thermal Reactor**

9-1	Criticality of an Infinite Homogeneous Reactor . . . . .	282
9-2	The One-Region Finite Thermal Reactor . . . . .	285
9-3	Criticality for Other Reactor Geometries . . . . .	292
9-4	The Critical Equation . . . . .	299
9-5	Large Reactors . . . . .	301
9-6	Practical Applications of the Critical Equation . . . . .	302
9-7	Dependence of Critical Mass on Size and Composition . . . . .	307
9-8	Optimum Reactor Shapes . . . . .	309
9-9	Quasi-Homogeneous Reactors . . . . .	310

**Chapter 10 Multiregion Reactors—The Group Diffusion Method**

10-1 One Group of Neutrons . . . . . 319  
 10-2 Two-Group Method . . . . . 323  
 10-3 Two-Group Calculations of Nonuniform Reactors . . . . . 342  
 10-4 The Multigroup Method . . . . . 346  
 10-5 Reflector Savings . . . . . 354  
 10-6 Totally Reflected Reactors . . . . . 355  
 10-7 Experimental Determination of Critical Reactor Parameters . . . . . 359

**Chapter 11 Heterogeneous Reactors**

11-1 Eta . . . . . 371  
 11-2 Thermal Utilization . . . . . 371  
 11-3 Resonance Escape Probability . . . . . 390  
 11-4 The Fast Effect . . . . . 401  
 11-5 The Value of  $k_{\infty}$  . . . . . 407  
 11-6 Other Reactor Parameters . . . . . 408

**Chapter 12 Reactor Kinetics**

12-1 Infinite Reactor with No Delayed Neutrons . . . . . 418  
 12-2 Mean Generation Time with Delayed Neutrons . . . . . 420  
 12-3 Infinite Reactor with Delayed Neutrons . . . . . 421  
 12-4 Response of a Bare Reactor to a Step-Change Reactivity . . . . . 428  
 12-5 The Value of  $\beta$  . . . . . 436  
 12-6 The Stable Period . . . . . 437  
 12-7 The Prompt Jump . . . . . 439  
 12-8 The Prompt Critical Condition . . . . . 441  
 12-9 Small Reactivities . . . . . 441  
 12-10 Large Negative Reactivities; Scram and Shutdown . . . . . 442  
 12-11 Linear Change in Reactivity . . . . . 443

**Chapter 13 Changes in Reactivity**

13-1 Changes in Temperature—Temperature Coefficients . . . . . 448  
 13-2 Fission-Product Poisoning . . . . . 467  
 13-3 Burnup and Conversion . . . . . 479  
 13-4 Reactor Properties Over Life—Estimating Core Life . . . . . 480

## **Chapter 14 Control Rods**

14-1	Control-Rod Worth . . . . .	499
14-2	One Central Rod—Modified One-Group Theory . . . . .	503
14-3	Two-Group Theory of Control Rod . . . . .	506
14-4	The Eccentric Control Rod . . . . .	509
14-5	Ring of Rods . . . . .	512
14-6	Noncylindrical Rods . . . . .	517
14-7	Many Rods . . . . .	517

## **Chapter 15 Perturbation Theory**

15-1	Reactivity and Perturbations . . . . .	524
15-2	Some Mathematical Preliminaries . . . . .	525
15-3	One-Group Perturbation Theory . . . . .	530
15-4	Two-Group Perturbation Theory . . . . .	534
15-5	Physical Interpretation of the Adjoint Flux. . . . .	541
15-6	Some Applications of Perturbation Theory . . . . .	543
15-7	Orthogonality and Adjointness . . . . .	547

## **Appendix I Miscellaneous Constants and Data . . . . . 555**

## **Appendix II Special Functions . . . . . 562**

II-1	The Delta Function—Singular Source Distributions . . . . .	562
II-2	The Exponential Integral Function. . . . .	564
II-3	The Functions $E_n(x)$ . . . . .	564
II-4	The Error Function . . . . .	565
II-5	Bessel Functions . . . . .	566

## **Index . . . . . 573**