# Contents

*Preface* vii

1. Meteoritic Presolar Grains and Their Significance 1

   1.1 Presolar isotopic signatures and their carriers . . . . . 3
   1.2 The discovery of presolar stellar grains . . . . . 8
   1.3 Meteorites carrying stellar grains . . . . . 10
   1.4 Types of presolar grains . . . . . 11
      1.4.1 Diamonds . . . . . 13
      1.4.2 Silicate grains . . . . . 14
      1.4.3 Silicon carbide grains . . . . . 14
      1.4.4 Graphite grains . . . . . 16
      1.4.5 Oxide grains . . . . . 17
      1.4.6 Silicon nitride grains . . . . . 17
   1.5 New information from presolar grains . . . . . 18
      1.5.1 Stellar evolution, nucleosynthesis and mixing . . . . 18
      1.5.2 Physical and chemical properties of the gas around stars and supernovæ . . . . . 20
      1.5.3 The interstellar medium, molecular clouds and early solar system . . . . . 22
   1.6 Outline . . . . . 24
   1.7 Exercises . . . . . 24

2. Basics of Stellar Nucleosynthesis 25

   2.1 Hydrogen burning, and the life of most stars . . . . . 27
      2.1.1 The *pp* chain . . . . . 29
      2.1.2 The CNO, NeNa and MgAl cycles . . . . . 32

2.2 Helium burning, and the evolution of stars of low mass . . . 36
2.3 The $\alpha$ process: C, Ne and O burnings, and the evolution of stars of high mass . . . 39
2.4 The $e$ process: Si burning, and supernova explosions . . . 40
2.5 The production of elements heavier than Fe . . . 45
2.5.1 The $s$ process . . . 49
2.5.2 The $r$ process . . . 51
2.5.3 The $p$ process . . . 56
2.6 Exercises . . . 57

3. Laboratory Analysis of Presolar Grains 59

3.1 The isolation of diamond, graphite and SiC grains . . . 59
3.2 Looking at presolar grains . . . 62
3.3 Isotopic measurements with mass spectrometers . . . 63
3.3.1 Noble-gas extraction . . . 65
3.3.2 Secondary Ion Mass Spectrometry (SIMS) . . . 65
3.3.3 The advent of Resonant Ionization Mass Spectrometry (RIMS) in trace element analysis . . . 68
3.4 Location and analysis of rare types of presolar grains . . . 71
3.5 Concluding remarks . . . 74
3.6 Exercises . . . 75

4. The Origin of Presolar SiC Grains 77

4.1 Classification of SiC grains on the basis of their C, N and Si compositions . . . 77
4.2 Where did mainstream presolar SiC grains come from? . . . 81
4.2.1 Theoretical modelling of AGB and C(N) stars . . . 83
4.3 Carbon and nitrogen in mainstream SiC grains and in AGB stars . . . 88
4.4 The Ne-E(H) anomalous component . . . 94
4.5 The presence of $^{26}$Al . . . 98
4.6 The puzzle of the silicon isotopic composition of mainstream SiC grains . . . 99
4.7 Titanium isotopic composition of mainstream SiC grains . . . 105
4.8 A, B, X, Y and Z: The minor SiC grains populations . . . 108
4.8.1 The Y and Z populations . . . 108
4.8.2 The A and B populations . . . 109

4.8.3 The X population . . . . . 110
4.9 Exercises . . . . . 111

5. Heavy Elements in Presolar SiC Grains 113

5.1 Modelling the $s$ process in AGB stars . . . . . 114
5.1.1 The neutron source in AGB stars . . . . . 115
5.1.2 The production of a $^{13}$C pocket . . . . . 117
5.1.3 The current model . . . . . 121
5.1.4 The neutron flux in the $^{13}$C pocket . . . . . 123
5.1.5 The neutron flux in the thermal pulse . . . . . 124
5.2 SiC grain data and the $s$ process in AGB stars . . . . . 126
5.2.1 Class I: Isotopic ratios involving $p$-only and $r$-only isotopes . . . . . 126
5.2.2 Class II: Isotopic ratios involving isotopes in local equilibrium . . . . . 130
5.2.3 Class III: Isotopic ratios involving isotopes with magic neutron numbers . . . . . 132
5.2.4 Class IV: Isotopic ratios involving isotopes depending on branchings . . . . . 137
5.2.5 Class V: Isotopic ratios involving isotopes produced by radioactive decay . . . . . 141
5.3 The heavy noble gases: Kr and Xe . . . . . 142
5.4 Exercises . . . . . 147

6. Diamond, Graphite and Oxide Grains 151

6.1 Diamond . . . . . 151
6.2 Graphite . . . . . 154
6.3 Oxide grains . . . . . 157
6.4 Exercises . . . . . 162

Appendix A Glossary 165

Appendix B Solutions to Exercises 173

B.1 Chapter 1 . . . . . 173
B.2 Chapter 2 . . . . . 173
B.3 Chapter 3 . . . . . 175
B.4 Chapter 4 . . . . . 177
B.5 Chapter 5 . . . . . 179

B.6 Chapter 6 . . . . . 181

Appendix C Selected Books and Reviews for Quick Reference 183

C.1 Presolar grains . . . . . 183
C.2 Stellar evolution and nucleosynthesis . . . . . 183
C.3 AGB stellar evolution and nucleosynthesis . . . . . 184

*Bibliography* 185

*Index* 207