

Contents

Additional Resources and Tripos Questions	4
1. Introduction	5
1.1 Fundamentals	5
1.2 Room-Temperature Electrical Conductivities of Selected Materials	6
2. Classical Theory	7
2.1 The Drude Model	7
2.2 Measurement of Charge Carrier Density: The Hall Effect	10
2.2.1 The Hall Experiment	10
2.2.2 Charge Carrier Densities Calculated from Measured Hall Coefficients	12
3 Quantum Mechanical Models	13
3.1 Wave-Particle Duality	13
3.2 The Free Electron Model	14
3.2.1 One-dimensional Model	14
3.2.2 Three-dimensional Model	16
3.2.3 Density of Permitted Electronic States in 3D, $D(E)$	17
3.2.4 Density of States in 1D	19
3.2.5 Occupation of Energy Levels	20
3.2.6 Average Electron Energy at Absolute Zero	23
3.2.7 Electronic Conductivity in the Free Electron Model	24
3.2.8 Limitations of the Free Electron Model	26
3.3 Electrons in a Crystal: The Nearly Free Electron Model	27
3.3.1 Introduction of a Periodic Potential	27
3.3.2 Flat Band Diagrams for Different Materials	30
3.3.3 Brillouin Zones and Band Overlap	31
4. Electrical Properties of Metals and Alloys	34
4.1 Pure Metals	34
4.2 Alloys	36
4.2.1 Effect of Solute Concentration (Nordheim's Rule)	36
4.2.2 Mixture Rule	38
4.2.3 Effect of Solute Valency (Linde's Rule)	39
4.3 Example: Effect of Processing and Alloying on the Resistivity of Copper	40
4.4 Selection of Materials for Conductors and Resistors	41
4.5 Thermal Conductivity	43
4.5.1 Metals	43
4.5.2 Non-Metals	44

5. Superconductivity	45
5.1 Introduction	45
5.2 The Meissner Effect	46
5.3 Materials and Manufacture	47
5.4 Applications	49
6. Semiconductors	50
6.1 Semiconductor Band Structure	50
6.2 Effective Mass of an Electron	52
6.3 Holes	53
6.4 Intrinsic Semiconductors	54
6.5 Extrinsic Semiconductors	57
6.6 The Fermi Level in Extrinsic Semiconductors	60
6.7 Temperature Dependence of the Number of Carriers	61
6.8 Temperature Dependence of Conductivity	62
6.9 The Hall Effect in Semiconductors	63
7. Semiconductor Devices	64
7.1 Ohmic and Rectifying Contacts	64
7.2 Metal-Semiconductor Rectifying Contacts	66
7.2.1 Schottky Diodes: Metal – <i>n</i> -type Contacts, $\phi_m > \phi_s$	66
7.2.2. Metal – <i>p</i> -type Contacts, $\phi_m < \phi_s$	69
7.3 Metal-Semiconductor Ohmic Contacts	70
7.3.1 Metal – <i>n</i> -type Contacts, $\phi_m < \phi_s$	70
7.3.2 Thermoelectric Devices	71
7.4 Joining Semiconductors: <i>p-n</i> Junction	73
7.4.1 Reverse Bias	74
7.4.2 Forward Bias	74
7.4.3 Applications of <i>p-n</i> Junctions	76
8. Semiconductor Device Fabrication	77
8.1 Production of Silicon Single Crystals: The Czochralski Process	77
8.2 Semiconductor Doping	79
8.3 Example: Manufacture of a <i>p-n-p</i> Transistor	80
Glossary	82
Symbols, Quantities & Units	85