

## UNIT I:

### Nutrients: Essential and Nonessential

---

- 1. Nutrients: History and Definitions**  
*Martha H. Stipanuk, PhD*  
Discovery of the Nutrients 3  
Setting Criteria for Essentiality 8  
Concerns about Excessive Intakes 10  
Nutrients That Do Not Meet the Strict Criteria for Essentiality 10  
Health Effects of Nutrients and Nonnutrient Components of Food 11  
Use of Nutrients as Pharmacological Agents 11
- 2. Food Components with Health Benefits**  
*Elizabeth H. Jeffery, PhD; Kelly A. Tappenden, PhD, RD; and Anna-Sigrid Keck, PhD, CIP*  
Functional Foods and Dietary Supplements 14  
Carotenoids 16  
Polyunsaturated Fatty Acids 17  
Plant Sterols/Stanol 19  
Polyphenolics 20  
Phytoestrogens 22  
Isothiocyanates 24  
Organosulfurs 25  
Polyols 26  
Dietary Fiber 26  
Prebiotics/Probiotics 27  
Overall Recommendations 28
- 3. Guidelines for Food and Nutrient Intake**  
*Christina Stark, MS, RD, CDN*  
Dietary Reference Intakes 34  
Dietary Advice: Goals and Guidelines 38  
Food Guides 39  
Labeling of Foods and Supplements 42

## UNIT II:

### Structure and Properties of the Macronutrients

---

- 4. Structure, Nomenclature, and Properties of Carbohydrates**  
*Joanne L. Slavin, PhD, RD*  
Monosaccharides or Sugar Residues 50

- Other Classes of Carbohydrate Units 56  
Disaccharides and Oligosaccharides and Their Properties 58  
Polysaccharides of Nutritional Importance 61  
Glycoconjugates of Physiological Interest 65
- 5. Structure, Nomenclature, and Properties of Proteins and Amino Acids**  
*Martha H. Stipanuk, PhD*  
The Proteinogenic Amino Acids 69  
Modifications of Amino Acid Side Chains 74  
Synthesis of Peptides and Proteins 75  
Protein Structure 79  
Stabilization of Protein Conformations 83  
Stable Posttranslational Modifications of Proteins 85  
Regulation of the Amount of Protein and Its Functional State 87
  - 6. Structure, Nomenclature, and Properties of Lipids**  
*J. Thomas Brenna, PhD, and Gavin L. Sacks, PhD*  
The Chemical Classes of Lipids—Their Structure and Nomenclature 91  
Fatty Acids and Food Fats 110  
Physical and Structural Properties of Lipids 112

## UNIT III:

### Digestion and Absorption of the Macronutrients

---

- 7. Overview of Digestion and Absorption**  
*Alan B. R. Thomson, MD, PhD, and Patrick Tso, PhD*  
General Structure and Function of the GI Tract 122  
The Upper GI System 125  
The Small Intestine 128  
The Large Intestine 139
- 8. Digestion and Absorption of Carbohydrate**  
*Armelle Leturque, PhD, and Edith Brot-Laroche, PhD*  
Carbohydrate Components of the Human Diet 142  
Digestion of Starch 142

- Digestion of Dietary Disaccharides 146
- Expression and Processing of the Oligosaccharidases and Disaccharidases 147
- Glycosidic Bonds Not Hydrolyzed by Human Digestive Enzymes 149
- Absorption of Monosaccharides by the Enterocyte 149
- Factors Affecting Carbohydrate Assimilation 152
- Deficiencies of Carbohydrate Assimilation 153
- 9. Digestion and Absorption of Protein**  
*Paul J. Moughan, PhD, DSc, FRSC, FRSNZ, and Bruce R. Stevens, PhD*
- Digestion of Protein in the Gastrointestinal Tract 162
- The Gastric Phase: Denaturation and Initial Hydrolysis of Proteins 162
- Small Intestinal Luminal Phase: Activation and Action of Pancreatic Proteolytic Enzymes 163
- Small Intestinal Mucosal Phase: Brush Border and Cytosolic Peptidases 166
- Absorption of Free Amino Acids and Small Peptides 166
- Metabolism of Amino Acids in Intestinal Epithelial Cells 173
- Use of Free Amino Acids and Peptides for Oral Rehydration Therapy 173
- Physiologically Active Dietary Peptides 173
- Determining Dietary Protein Digestibility 175
- 10. Digestion and Absorption of Lipids**  
*Patsy M. Brannon, PhD, RD; Patrick Tso, PhD; and Ronald J. Jandacek, PhD*
- Luminal Digestion of Lipids 179
- Uptake of Lipid Digestion Products by the Enterocytes 182
- Intracellular Metabolism of Absorbed Lipids 185
- Factors Affecting Formation and Secretion of Chylomicrons 189
- Portal Transport of Long-Chain Fatty Acids 189
- Hormonal Regulation of Lipid Absorption 189
- Disorders of Intestinal Lipid Absorption 189
- Intestinal Fatty Acids and Mucosal Injury 190
- Satiety Effects of Fat Feeding 190
- 11. Dietary Fiber**  
*Joanne L. Slavin, PhD, RD*
- Definition of Fiber 194
- Chemical and Physical Characterization of Dietary Fiber 195
- Physiological Characterization of Dietary Fiber 197
- Major Physiological Effects of Fiber and Structure-Function Relationships 198
- Effects of Fiber on Whole-Body Energy Status 201
- Recommendations for Fiber Intake and Typical Intakes 201
- Dietary Fiber Intake and Disease 202
- Dietary Fiber and Microbiota 203
- UNIT IV:**  
**Metabolism of the Macronutrients**
- 12. Carbohydrate Metabolism: Synthesis and Oxidation**  
*Mary M. McGrane, PhD*
- Overview of Tissue-Specific Glucose Metabolism 209
- Transport of Glucose across Cell Membranes 211
- Glycolysis 213
- Metabolism of Monosaccharides Other Than Glucose 217
- Gluconeogenesis 220
- Regulation of Glycolysis and Gluconeogenesis 224
- Glycogen Metabolism 235
- Pyruvate Dehydrogenase Complex and Citric Acid Cycle 242
- Electron Transport and Oxidative Phosphorylation 246
- ATP Equivalents Produced from the Complete Oxidation of Glucose 248
- Other Pathways of Carbohydrate Metabolism 248
- Dietary Reference Intakes and Typical Intakes of Carbohydrates 252
- 13. Protein Synthesis and Degradation**  
*Tracy G. Anthony, PhD, and Margaret McNurlan, PhD*
- Protein Turnover 256
- Protein Synthesis 259
- Molecular Mechanisms of Protein Degradation 270
- Role of Hormones and Cytokines in Regulation of Protein Turnover 277
- Responses of Protein Turnover to Nutrient Supply 279
- Protein Turnover in Growth and Exercise 280
- Protein Loss with Disuse, Injury, and Disease 281
- Current Challenges in Protein Metabolism 283

- 14. Amino Acid Metabolism**  
*Margaret E. Brosnan, PhD, and John T. Brosnan, DPhil, DSc*  
 Overview of Amino Acid Metabolism 287  
 Amino Acid Pools and Transport 289  
 Amino Acids as Signaling Agents 291  
 Two Themes in Amino Acid Metabolism 292  
 Synthesis of Dispensable Amino Acids 301  
 Interorgan Amino Acid Metabolism 301  
 Metabolism of the Dispensable Amino Acids 302  
 Catabolism of Indispensable Amino Acids 310  
 Neuroactive Amines, Hormones, and Pigments Formed from Amino Acids by Specialized Cell Types 323  
 Nitrogen Excretion 325
- 15. Protein and Amino Acid Requirements**  
*Crystal L. Levesque, PhD, and Ronald O. Ball, PhD*  
 Classification of Dispensable and Indispensable Amino Acids 331  
 Requirement for Protein (Amino Acids) 332  
 Requirements for Individual Amino Acids 337  
 Factors That Affect Amino Acid Requirements 341  
 Food Proteins and Protein Quality 343  
 Typical Intakes of Protein and Amino Acids and Significance of Protein to Energy Ratios 350  
 Effects of Inadequate Protein Intake and Assessment of Protein Status 352  
 How Much Protein is Too Much Protein? 352  
 The Need for Additional Research in Nutritional Science 354
- 16. Metabolism of Fatty Acids, Acylglycerols, and Sphingolipids**  
*Hei Sook Sul, PhD*  
 Biological Roles for Lipids 357  
 Overview of Fatty Acid and Triacylglycerol Metabolism 358  
 Synthesis of Palmitate from Acetyl-CoA 358  
 Transfer of Acetyl-CoA from Inside the Mitochondria to the Cytosol 358  
 Synthesis of Fatty Acids Other Than Palmitate 365  
 Synthesis of Triacylglycerol 367  
 Hydrolysis of Triacylglycerol in Lipoproteins, Uptake of Fatty Acids, and Utilization of Fatty Acids for Energy or Storage as Triacylglycerol 370  
 Mobilization of Stored Triacylglycerol 371  
 Oxidation of Fatty Acids 371  
 $\beta$ -Oxidation of Fatty Acids with an Odd Number of Carbons or with Methyl Side Chains to Generate Propionyl-CoA 376
- Formation of Ketone Bodies from Acetyl-CoA in the Liver as a Fuel for Extrahepatic Tissues** 379
- Phosphatidic Acid and Diacylglycerol as Precursors of the Common Phospholipids 381
- Remodeling of Phospholipids in Situ 386
- Generation of Signaling Molecules by Regulated Phospholipases 386
- Synthesis of Ether-Linked Glycerolphospholipids 387
- 17. Cholesterol and Lipoproteins: Synthesis, Transport, and Metabolism**  
*Hei Sook Sul, PhD, and Judith Storch, PhD*  
 Overview of Cholesterol Metabolism 393  
 Synthesis of Cholesterol and Isoprenoids 394  
 Regulation of Cholesterol Synthesis 396  
 Intracellular Trafficking of Cholesterol Synthesized in Cell versus Cholesterol Taken from Plasma in LDL 398  
 Synthesis of Steroid Hormones from Cholesterol 399  
 Synthesis of Bile Acids and Oxysterols from Cholesterol 400  
 Cholesterol Transport During Enterohepatic Recirculation 400  
 Lipoproteins and Their Metabolism 401  
 Postprandial Lipoprotein Metabolism 407  
 Atherosclerotic Cardiovascular Disease 410  
 Chronic Effects of Dietary Lipids on Plasma Lipoproteins and Lipid Metabolism 412  
 Recommendations and Typical Intakes for Dietary Fat 413
- 18. Lipid Metabolism: Polyunsaturated Fatty Acids**  
*Sarah K. Orr, BSc; Chuck T. Chen, BSc; Arthur A. Spector, MD; and Richard P. Bazinet, PhD*  
 Discovery of Essential Fatty Acids 416  
 Structure of Polyunsaturated Fatty Acids 416  
 Essential Fatty Acid Metabolism 418  
 Essential Fatty Acid Composition of Plasma and Tissue Lipids 421  
 Functions of Polyunsaturated Fatty Acids 423  
 Regulation of Gene Expression by Essential Fatty Acids 428  
 Recommendations for Essential Fatty Acid Intake 428  
 Essential Fatty Acid Deficiency 429  
 Peroxidation of Polyunsaturated Fatty Acids 431

**19. Regulation of Fuel Utilization in Response to Food Intake***Martha H. Stipanuk, PhD*

Regulation of Macronutrient Metabolism at the Whole-Body Level 435

Distributed Control 437

Regulation of Macronutrient Metabolism at the Cellular Level 437

Integrative Pathways for Regulation of Macronutrient Metabolism at the Cellular Level 441

The Metabolic Fates of Macronutrients 444

Stages of Glucose Homeostasis during Prolonged Starvation 454

**20. Regulation of Fuel Utilization in Response to Physical Activity***Martha H. Stipanuk, PhD*

Muscle Structure 461

Muscle Fiber Types 463

The Energy Cost of Movement 464

Skeletal Muscle Fuel Utilization During Rest 465

Fuel Utilization by Working Muscle 465

Fuels for Short Bursts of Super Intense Physical Activity 471

Skeletal Muscle Adaptations in Response to Training and the Consequences for Fuel Utilization and Performance 473

Nutritional and Ergogenic Aids to Training and/or Performance 473

Muscle Fuel Utilization and Health Outcomes 475

Skeletal Muscle Adaptations in Response to Disuse, Aging, and Disease and the Consequences for Fuel Utilization and Well-Being During Normal Daily Life 476

Behavioral Aspects of Control of Energy Intake and Energy Expenditure 504

Biological Control of Energy Intake and Energy Expenditure 506

Afferent Signals 507

Central Nervous System Integration of Satiety and Adiposity Signals 511

Efferent Signals 514

Importance of Diet and Exercise in Prevention of Overweight and Obesity 515

**23. Disturbances of Energy Balance***Darlene E. Berryman, PhD, RD, and Christopher A. Taylor, PhD, RD, LD*

Adipose Tissue in Energy Balance 519

Obesity 520

Lipodystrophy 529

Starvation and Protein-Energy Malnutrition 530

Definitions of PEM 530

**UNIT VI:****The Vitamins****24. Niacin, Riboflavin, and Thiamin***W. Todd Penberthy, PhD***Niacin 540**

Niacin History 540

Niacin Nomenclature, Structure, and Biochemistry 541

Niacin Physiological Function 541

Proteins That Require Niacin 542

Niacin Sources, Chemical Stability, and ADMET 544

Biochemical Assessment of Niacin Nutriture, Dietary Requirements, and High-Dose Responses 547

**Riboflavin 548**

Riboflavin History 548

Riboflavin Nomenclature, Structure, and Biochemistry 548

Riboflavin Physiological Function 549

Proteins That Require Riboflavin 551

Riboflavin Sources, Chemical Stability, and ADMET 552

Biochemical Assessment of Riboflavin Nutriture and Dietary Requirements 553

**Thiamin 554**

Thiamin History 554

Thiamin Nomenclature, Structure, and Biochemistry 555

Thiamin Physiological Function 555

**UNIT V:****Energy****21. Cellular and Whole-Animal Energetics***Darlene E. Berryman, PhD, RD, and Matthew W. Hulver, PhD*

Cellular Energetics 481

Whole-Animal Energetics 490

**22. Control of Energy Balance***Darlene E. Berryman, PhD, RD; Brenda M. Davy, PhD, RD; and Edward O. List, PhD*

Energy Balance 501

Nutrient Balance 502

Relative Stability of Body Weight 504

- Proteins That Require Thiamin** 559
- Thiamin Sources, Chemical Stability, and ADMET 559
- Biochemical Assessment of Thiamin Nutriture and Dietary Requirements 560
- Interdependence of B<sub>3</sub>, B<sub>2</sub>, and B<sub>1</sub>** 561
- 25. Folate, Choline, Vitamin B<sub>12</sub>, and Vitamin B<sub>6</sub>**
- Marie A. Caudill, PhD, RD;*  
*Joshua W. Miller, PhD;*  
*Jesse F. Gregory III, PhD; and*  
*Barry Shane, PhD*
- Folate** 565
- Chemistry of Folate 565
- Sources of Folate 565
- Folate Absorption 566
- Folate Bioavailability 567
- Transport of Folate 567
- Tissue Accumulation of Folate 567
- Folate Turnover 567
- Metabolic Functions of Folate 568
- Folate Deficiency: Symptoms, Metabolic Bases, and Disease 571
- Folate Status Assessment 574
- Folate Dietary Recommendations 575
- Folate Toxicity 576
- Choline** 577
- Choline Chemistry 577
- Food Sources of Choline 577
- Choline Absorption 577
- Choline Bioavailability 578
- Transport of Choline 579
- Metabolism of Choline 579
- Physiological Functions of Choline 583
- Choline Deficiency 585
- Choline and Disease 585
- Choline Homeostasis 586
- Status Assessment of Choline 587
- Dietary Recommendations, Factors Affecting Dietary Requirements, and Dietary Choline Intake 587
- Choline Toxicity 588
- Vitamin B<sub>12</sub>** 588
- Chemistry of Vitamin B<sub>12</sub> 588
- Sources of Vitamin B<sub>12</sub> 589
- Absorption and Bioavailability of Vitamin B<sub>12</sub> 590
- Plasma Transport, Tissue Uptake, and Turnover of Vitamin B<sub>12</sub> 590
- Intracellular Metabolism and Metabolic Functions of Vitamin B<sub>12</sub>** 591
- Vitamin B<sub>12</sub> Deficiency: Symptoms and Metabolic Bases 593
- Vitamin B<sub>12</sub> Requirements 596
- Vitamin B<sub>12</sub> Dietary Intakes 596
- Vitamin B<sub>12</sub> Toxicity 596
- Vitamin B<sub>6</sub>** 597
- Chemistry of Vitamin B<sub>6</sub> 597
- Sources of Vitamin B<sub>6</sub> 597
- Absorption of Vitamin B<sub>6</sub> 597
- Bioavailability of Vitamin B<sub>6</sub> 597
- Metabolism, Turnover, and Transport of Vitamin B<sub>6</sub> 598
- Metabolic Functions of Vitamin B<sub>6</sub> 598
- Vitamin B<sub>6</sub> Deficiency: Symptoms and Metabolic Bases 600
- Vitamin B<sub>6</sub> and Disease Risk 601
- Detection of Vitamin B<sub>6</sub> Deficiency 601
- Vitamin B<sub>6</sub> Requirements 602
- Vitamin B<sub>6</sub> Intake 602
- Vitamin B<sub>6</sub> Toxicity 603
- 26. Biotin and Pantothenic Acid**
- Donald M. Mock, MD, PhD, and Nell I. Matthews, BA*
- Biotin** 610
- Biotin Synthesis 610
- Holocarboxylases and Holocarboxylase Synthetase 610
- Biotin-Containing Carboxylases 611
- Biotin and Gene Regulation 614
- Biotin Digestion and Absorption 615
- Biotin Uptake and Transport in Tissues 616
- Biotin Degradation 617
- Biotin Deficiency 617
- Inborn Errors of Biotin Metabolism 618
- Dietary Sources and Recommended Intakes 619
- Toxicity 619
- Pantothenic Acid** 620
- Pantothenic Acid Synthesis 620
- Dietary Sources and Intake 620
- Digestion, Absorption, and Transport 620
- Metabolism of Pantothenic Acid to CoA and ACP 620
- Functions of CoA and ACP 621
- CoA and Carnitine 621

- Dietary Requirement 622  
 Pantothenic Acid Deficiency 622  
 Purported Therapeutic Uses of Pantothenic Acid 623  
 Toxicity 624
- 27. Vitamin C**  
*Alexander Michels, PhD, and Balz Frei, PhD*  
 Vitamin C Nomenclature, Structure, and Chemical Properties 626  
 Ascorbate 626  
 Food Sources of Vitamin C 628  
 Vitamin C Transport 629  
 Enzymatic Functions of Vitamin C 634  
 Nonenzymatic Functions of Vitamin C 639  
 Vitamin C and Human Health 644  
 Dietary Reference Intakes for Vitamin C 647
- 28. Vitamin K**  
*Reidar Wallin, PhD*  
 Nomenclature of Vitamin K Active Compounds 655  
 Mechanism of Action of Vitamin K 656  
 Antagonism of Vitamin K Action by Clinically Used Inhibitors 659  
 Warfarin Resistance and the Vitamin K-Dependent  $\gamma$ -Carboxylation System 660  
 Sources of Vitamin K 662  
 Vitamin K<sub>1</sub> Conversion to MK-4 in Extrahepatic Tissues 663  
 Bioavailability 663  
 Absorption, Transport, and Metabolism of Vitamin K 664  
 Physiological Roles of Vitamin K-Dependent Proteins 664  
 Vitamin K Deficiency 665  
 Assessment of Vitamin K Status 665  
 Recommendations for Vitamin K Intake 666
- 29. Vitamin E**  
*Robert S. Parker, PhD*  
 Nomenclature and Structure of Vitamin E 670  
 Absorption, Transport, and Metabolism of Vitamin E 670  
 Biological Functions of Vitamin E 675  
 Deficiency, Health Effects, and Biopotency of Vitamin E 677  
 Food Sources and Intake of Vitamin E 679  
 Recommended Intake of Vitamin E and Assessment of Vitamin E Status 680
- 30. Vitamin A**  
*Noa Noy, PhD*  
 Chemistry and Physical Properties of Vitamin A and Carotenoids 683  
 Physiological Functions of Vitamin A 684  
 Absorption, Transport, Storage, and Metabolism of Vitamin A and Carotenoids 688  
 Retinol-Binding Proteins 692  
 Nutritional Considerations of Vitamin A 696
- 31. Vitamin D**  
*Steven K. Clinton, MD, PhD*  
 Dietary and Endogenous Sources of Vitamin D 703  
 Biological Actions of Vitamin D 706  
 Evaluation of Vitamin D Status 708  
 Dietary Sources of Vitamin D 709  
 Solar Contribution to Vitamin D Status 709  
 Vitamin D Toxicity 710  
 Dietary Reference Intakes for Vitamin D 710  
 Vitamin D and Health Outcomes 711  
 Controversy Over Recommendations for Vitamin D Intake and Status Testing 714
- UNIT VII:**  
**The Minerals and Water**
- 32. Calcium and Phosphorus**  
*Sue A. Shaps, PhD*  
 Chemical Properties of Calcium 721  
 Chemical Properties of Phosphate 722  
 Physiological and Metabolic Functions of Calcium and Phosphate 722  
 Hormonal Regulation of Calcium and Phosphate Metabolism 726  
 Calcium and Phosphate Homeostasis 731  
 Dietary Sources, Bioavailability, and Recommended Intakes for Calcium and Phosphorus 736  
 Calcium and Phosphate Deficiency, Excess, and Assessment of Status 740  
 Clinical Disorders Involving Altered Calcium and Phosphate Levels 742
- 33. Magnesium**  
*Jürgen Vormann, Dr. rer. nat.*  
 Chemistry of Magnesium 747  
 Absorption, Bioavailability, and Excretion of Magnesium 747  
 Body Magnesium Content 749  
 Physiological Roles of Magnesium 750

- Food Sources, Recommended Intakes, and Dietary Intakes of Magnesium 751
- Magnesium Depletion 753
- Diagnosis of Magnesium Deficiency 755
- Magnesium Toxicity 755
- Magnesium and Disease Risks 755
- Conclusion 756
- 34. Sodium, Chloride, and Potassium**  
*Hwai-Ping Sheng, PhD*
- Functions and Distribution of Sodium, Chloride, and Potassium 759
- Sodium, Chloride, and Potassium Balance 763
- Regulation of Sodium, Chloride, and Potassium Balance 766
- Interactions Among Systems in Volume Regulation 771
- Sodium and Chloride Imbalance and Its Consequences 772
- Potassium Imbalance and Its Consequences 773
- Nutritional Considerations 774
- 35. Body Fluids and Water Balance**  
*Hwai-Ping Sheng, PhD*
- Physiological Functions of Water 781
- Body Water Compartments 781
- Water Balance 786
- Renal Excretion of Water 790
- Regulation of Water Balance 793
- Water Imbalance and Its Consequences 797
- 36. Iron**  
*Robert R. Crichton, PhD, FRSC*
- Biological Functions of Iron 801
- Proteins of Iron Transport, Storage, and Recycling 803
- Body Iron Compartments and Daily Iron Exchange 807
- Internal Iron Exchange and Cellular Iron Metabolism 807
- External Iron Exchange, Iron Absorption, and Systemic Iron Homeostasis 814
- Dietary Reference Intakes for Iron 818
- Iron Deficiency 820
- Iron Excess 821
- 37. Zinc, Copper, and Manganese**  
*Arthur Grider, PhD*
- Zinc, Copper, and Manganese in Enzyme Systems 828
- Absorption, Transport, Storage, and Excretion of Zinc, Copper, and Manganese 829
- Selected Functions of Zinc, Copper, and Manganese** 838
- Assessment of Zinc, Copper, and Manganese Status and Deficiency Symptoms 841
- Dietary Reference Intakes and Food Sources of Zinc, Copper, and Manganese 842
- Toxicity of Zinc, Copper, and Manganese 845
- 38. Iodine**  
*Elizabeth N. Pearce, MD, MSc, and Hedley C. Freake, PhD*
- Production and Metabolism of Thyroid Hormones 849
- Mechanism of Action of Thyroid Hormones 854
- Physiological Functions of Thyroid Hormones 858
- Iodine Deficiency 861
- Dietary Recommendations, Dietary Intake, and Toxicity 864
- 39. Selenium**  
*Gerald F. Combs, Jr., PhD*
- Chemistry of Selenium 867
- Utilization of Dietary Selenium 870
- The Selenoproteins 874
- Tissue Distribution of Selenium 878
- Nutritional Essentiality of Selenium 878
- Selenium Toxicity 880
- Selenium Anticarcinogenesis 881
- Human Selenium Requirements 881
- Selenium Intakes 884
- 40. Fluoride**  
*Gary M. Whitford, PhD, DMD*
- Dental Fluorosis and Dental Caries 888
- Fluoride Intake 890
- Fluoride Physiology 892
- Acute Fluoride Toxicity 895
- Chronic Fluoride Toxicity 896
- 41. Molybdenum and Beneficial Bioactive Trace Elements**  
*Forrest H. Nielsen, PhD*
- Definition of Ultratrace Elements 899
- Molybdenum 899
- Boron 902
- Chromium 904
- Silicon 906
- Bioactive Ultratrace Elements: Nickel, Vanadium, and Arsenic 906