

Richard W. Hartel · Joachim H. von Elbe
Randy Hofberger

Confectionery Science and Technology



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Preface

In the summer of 1963, the National Confectioners' Association (NCA) decided to conduct a “candy school”, or Resident Course in Confectionery Science, at the University of Wisconsin-Madison. Fifty-five years later, candy school is still going strong, having been led by only two UW-Madison course directors – Dr. Joe von Elbe (1963–1997) and Dr. Rich Hartel (1998-current). Although the course is now run solely by UW-Madison, without the assistance of NCA, it has maintained a preeminent status throughout the candy industry in the United States, and even beyond.

Candy school is a unique collaboration between the candy industry and UW-Madison. Experienced industry instructors work with UW-Madison faculty to provide both the practical application and the scientific basis of candy making. Each day of the course, one, two, or sometimes three, new instructors, all considered to be experts in their area, travel to Madison to impart their knowledge to the next generation of candy technologists. Each instructor first presents a lecture on the candy category of the day, and then leads a practical lab section. These labs are designed to document how ingredients and processing conditions mutually influence candy qualities, the primary objective of candy school. Since failure is often the best learning tool, some of the lab conditions are designed to “fail”.

With these dedicated industry professionals teaching practical candy making, thirty attendees each year gain practical expertise across a broad range of candy categories. Covering everything from hard candy to chocolate in two weeks, attendees are quickly and completely immersed in candy science and technology. Over the years, more and more science has been injected into candy school as our knowledge of the basic principles of candy-making come to light through research.

In 2003, the Food Science Department at UW-Madison began offering a 3-credit senior level course on candy science. Modeled after the summer candy school, students are led through candy school material throughout the semester. A new candy category is covered each week, from hard candy through chocolate. The primary difference between this course and candy school is that it is more of an academic course, as would be expected for BS Food Science graduates. However, these students also get much of the practical candy-making expertise as well.

This book is the culmination of over a decade of trying to bring these courses to everyone, not just those who can afford the two weeks away from work each summer (it used to be a 3-week course for the first 30 years) or a

semester at UW-Madison. Loosely modeled after the candy school curriculum, the volume is divided into three different sections. In the first section, the physico-chemical bases of the ingredients used in confections are covered. In candy school, the content in these chapters is dispersed throughout the course as needed (rather than having a day or 2 of science principles to start the course). The second section covers the sugar-based confections, in the general order of increasing complexity, or increasing number of ingredient additions made to the sweetener. Finally, the third section covers fat-based confections, namely chocolate and compound coatings.

In this book, we hope to provide a comprehensive summary of candy science and technology. The candy chapters have been designed to provide useful information for both the novice and professional. The first sections of each chapter, covering ingredients and manufacturing practices, should be accessible to readers of all levels. These are followed by more technical sections on microstructure and the important scientific principles that go into making that candy, material nominally targeted to more technically trained readers. The final sections cover shelf life and trouble shooting, providing guidance for all candy makers.

As noted above, putting together this book has been a long and arduous path for the authors. In many ways, this book has been a mountain to get over, requiring a monumental effort. Fortunately, we have had help all along the way. We could not have made this happen without considerable support from a whole host of people, too numerous to mention individually.

Primary thanks go to each candy school instructor who reviewed the chapter(s) for which they are responsible. They are acknowledged at the end of each chapter. Various UW-Madison students have been enlisted over the years to help with book preparation, from literature review to figure construction. Although all merit recognition, one student in particular stands out for her contributions to the figures found throughout the book – Sarah Vogel. Her assistance over the past five years to bring a professional touch to the figures has been an enormous help to get us over this book project mountain.

Finally, we especially acknowledge the entire candy industry for supporting the program, without which this book would not have been possible.

For those who haven't yet been to candy school, we hope this book serves to whet your appetite to learn more by attending our two-week course. For those who have been to candy school, we hope this book supplements those huge course notebooks you had to carry (or ship) home.

Madison, WI, USA
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April 2017

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Contents

Part I Ingredient Chemistry and Functionality

1	Chemistry of Bulk Sweeteners	3
1.1	Monosaccharides	4
1.1.1	Glucose/Dextrose	4
1.1.2	Fructose	6
1.1.3	Galactose	6
1.2	Disaccharides	6
1.2.1	Sucrose	6
1.2.2	Maltose	12
1.2.3	Lactose	12
1.3	Invert Sugar	13
1.3.1	Acid Hydrolysis	13
1.3.2	Enzyme Hydrolysis	14
1.4	Sugar Reactions	14
1.4.1	Hydrogen Bonding	14
1.4.2	Reducing Sugars and Mutarotation	15
1.4.3	Browning Reactions	16
1.5	Glucose (Corn) Syrup	20
1.5.1	Glucose Syrup Specifications	20
1.5.2	Production of Glucose Syrups	22
1.5.3	Composition	23
1.5.4	Properties	24
1.6	Polysaccharides	25
1.6.1	Maltodextrin	25
1.6.2	Polydextrose	26
1.6.3	Inulin	26
1.7	Other Natural Sweeteners	26
1.7.1	Honey	26
1.7.2	Maple Syrup	26
1.7.3	Molasses	27
1.7.4	Malt Extract	27
1.8	Alternative Sweeteners	27
1.8.1	Sugar Alcohols	28
1.8.2	Monosaccharide Alcohols	30
1.8.3	Disaccharide Alcohols	31

1.8.4	Hydrogenated Starch Hydrolysate (HSH) and Maltitol Syrups	33
1.9	High Intensity Sweeteners	34
1.9.1	Sucralose	34
1.9.2	Aspartame	34
1.9.3	Acesulfame-Potassium	35
1.9.4	Alitame	35
1.9.5	Thaumatococcus or Talin	36
1.9.6	Neotame	36
1.9.7	Stevia	36
1.9.8	Luo Han Guo (Monk Fruit) Concentrates	36
	References	36
2	Physico-chemical Properties of Sweeteners in Confections ...	39
2.1	Sweetness	39
2.2	Viscosity	40
2.3	Heat of Solution	41
2.4	Specific Optical Rotation	43
2.5	Refractive Index	44
2.6	Density/Specific Gravity	46
2.7	Boiling Point Elevation	48
2.8	Solubility	52
2.8.1	Solubility of Sugars	52
2.8.2	Solubility of Polyols	53
2.8.3	Solubility in Mixed Confectionery Syrups	54
2.9	Glass Transition Temperature	55
2.10	Crystallization Propensity	57
2.10.1	Generating Supersaturation	58
2.10.2	Crystallization	59
2.10.3	Seeding	62
2.11	State of Sugars in Confections	63
2.11.1	Crystal or Glass	64
2.11.2	Cotton Candy	65
	References	66
3	Water	69
3.1	Properties of Water Important in Confections	70
3.1.1	Water Hardness: Dissolved Minerals	70
3.1.2	Metals	70
3.1.3	pH	70
3.1.4	Microbial Content	71
3.2	Water Content in Confections	71
3.2.1	Cook Temperature and Water Content	71
3.2.2	Measuring Water Content	72
3.3	Water Activity and Equilibrium Relative Humidity (ERH) ...	73
3.3.1	Measurement of Water Activity	75
3.3.2	Prediction of Water Activity	76
3.3.3	Water Activity and Microbial Stability	77

3.4	Moisture Absorption or Desorption Profiles	77
3.4.1	Measuring Absorption or Desorption Curves	78
3.4.2	Temperature Effects	79
3.5	Moisture Migration and Shelf Life	79
3.5.1	Moisture Migration	79
3.5.2	Shelf Life	81
	Appendix	82
	References	83
4	Fats, Oils and Emulsifiers	85
4.1	Introduction	85
4.2	Chemistry of Fats and Oils	86
4.2.1	Chemical Structures	86
4.2.2	Chemical Properties	92
4.2.3	Lipid Oxidation	94
4.3	Physical Properties	95
4.3.1	Polymorphism	95
4.3.2	Phase Behavior	98
4.4	Crystallization of Fats	107
4.4.1	Nucleation	107
4.4.2	Growth	110
4.4.3	Polymorphic Transition	111
4.5	Modification Technologies	111
4.5.1	Hydrogenation	112
4.5.2	Fractionation	113
4.5.3	Interesterification	115
4.6	Emulsifiers	117
4.6.1	Use of Emulsifiers in Confections	117
4.6.2	Emulsifier Types and Characterization	118
	References	122
5	Starches, Proteins, Pectin, and Gums	125
5.1	Starch	125
5.1.1	Description, Size and Shape	125
5.1.2	Separation of Starches	127
5.1.3	Property of Starches	127
5.1.4	Modified Starches	130
5.2	Proteins	132
5.2.1	Protein Chemistry	133
5.2.2	Functional Properties	137
5.2.3	Proteins Used in Confections	139
5.3	Pectin	144
5.3.1	Pectin Chemistry	144
5.3.2	Testing Pectins	146
5.4	Gums	146
5.4.1	Agar: Agar	147
5.4.2	Alginates	147
5.4.3	Carrageenan (Irish Moss)	148

5.4.4	Gum Arabic	148
5.4.5	Gum Tragacanth	149
5.4.6	Guar Gum	149
References		150
6	Other Ingredients	151
6.1	Colors	151
6.1.1	Regulatory Aspects	151
6.1.2	Properties of Certified Dyes	153
6.1.3	Colors Exempt from Certification	156
6.2	Flavor and Flavoring Materials	158
6.2.1	Sources of Flavors	159
6.2.2	Flavor Balance	160
6.2.3	Flavor Sensation	160
6.2.4	Flavoring Materials	162
6.2.5	Storage of Flavoring Materials	166
6.3	Acids in Candies	166
6.3.1	Acids Used as Acidulants	167
6.3.2	Sourness	169
6.3.3	Buffer Salts	170
6.4	Antioxidants	173
6.4.1	Mechanism of Oxidative Rancidity	173
6.4.2	Action of Antioxidants	173
6.5	Glazes and Waxes	174
6.5.1	Glazes or Lacquers	174
6.5.2	Waxes	177
6.6	Fruit and Fruit Products	177
6.6.1	Composition of Fruits	177
6.6.2	Jams, Preserves and Purées	177
6.6.3	Candied and Preserved Fruits	179
6.6.4	Dried Fruits	180
6.7	Nuts	180
6.7.1	Composition	180
6.7.2	Varieties of Nuts	181
6.7.3	Summary	185
References		185

Part II Sugar-Based Confections

7	Compressed Tablets and Lozenges	189
7.1	Introduction	189
7.2	Formulations and Ingredients	191
7.2.1	Base	191
7.2.2	Binder	191
7.2.3	Lubricant	192
7.2.4	Disintegrant	192
7.2.5	Acids	192
7.2.6	Flavors	193

7.2.7	Colors	193
7.2.8	Actives	194
7.3	Processing	194
7.3.1	Lozenges/Wafers	195
7.3.2	Tablets	196
7.4	Product Characteristics	202
7.4.1	Microstructure	203
7.4.2	Porosity and Density	205
7.4.3	Mechanical Properties	207
7.4.4	Stability	209
7.5	Problems and Trouble Shooting	209
7.5.1	Pitting	209
7.5.2	Capping	210
7.5.3	Scoring	210
7.5.4	Variations in Size or Shape	210
	References	210
8	Hard Candy	211
8.1	Introduction	211
8.2	Formulations and Ingredients	213
8.2.1	Sweeteners	213
8.2.2	Flavors	214
8.2.3	Colors	215
8.2.4	Organic Acids	216
8.2.5	Fats	216
8.2.6	Fruit Juice	216
8.2.7	Dairy Ingredients	217
8.3	Processing	217
8.3.1	Typical Process Steps	218
8.3.2	Other Hard Candy Technologies	227
8.3.3	Rework	234
8.4	Product Characteristics	234
8.4.1	Chemical Changes	235
8.4.2	Microstructure	236
8.4.3	Stability/Shelf Life	239
8.5	Trouble Shooting	243
8.5.1	Appearance	243
8.5.2	Eating Quality	243
	References	244
9	Fondants and Creams	245
9.1	Introduction	245
9.2	Formulations and Ingredients	246
9.2.1	Crystalline Sweetener	246
9.2.2	Doctoring Agent/Crystallization Control Additive	247
9.2.3	Humectants, Texture and Shelf Life Enhancers	247
9.2.4	Flavors	247
9.2.5	Colors	248
9.2.6	Frappé	248
9.2.7	Fats	248

9.2.8	Preservatives	248
9.2.9	Invertase	249
9.3	Manufacturing	249
9.3.1	Fondant	249
9.3.2	Powdered Fondant	253
9.3.3	Creams	253
9.4	Product Characteristics	257
9.4.1	Microstructure and Product Properties	258
9.4.2	Invertase	263
9.4.3	Stability and Shelf Life of Fondants and Creams	266
9.5	Potential Problems and Trouble Shooting	268
9.5.1	Hard Fondant or Cream	268
9.5.2	Soft Fondant/Cream	269
9.5.3	Sticky Fondant/Cream	269
9.5.4	Coarse Fondant/Cream	269
9.5.5	White Surface Discoloration	270
	Appendix A.9.1 Calculation of Crystalline and Liquid Phases of Fondant	270
	References	272
10	Caramel, Fudge and Toffee	273
10.1	Introduction	273
10.2	Formulations and Ingredients	274
10.2.1	Sweeteners	274
10.2.2	Dairy Ingredients	275
10.2.3	Fats	277
10.2.4	Emulsifiers	278
10.2.5	Hydrocolloids	279
10.2.6	Salts	279
10.2.7	Added Flavors	279
10.2.8	Added Colors	280
10.2.9	Inclusions	280
10.3	Processing	280
10.3.1	Mixing and Emulsification	281
10.3.2	Cooking and Browning	282
10.3.3	Cooling and Forming	285
10.4	Product Characteristics	287
10.4.1	Color and Flavor Generation	287
10.4.2	Microstructure	289
10.4.3	Shelf Life	292
10.5	Troubleshooting	294
10.5.1	Cold Flow	295
10.5.2	Stickiness	296
10.5.3	Hardness	297
10.5.4	Oil Separation	297
10.5.5	Sugar Graining	298
10.5.6	Protein Graining	298
	Appendix	299
	References	299

11	Aerated Confections	301
11.1	Introduction	301
11.1.1	Aerated Confections.	302
11.2	Formulations and Ingredients	305
11.2.1	Air	305
11.2.2	Sweeteners	305
11.2.3	Stabilizers.	306
11.2.4	Humectants	307
11.2.5	Fats.	307
11.2.6	Emulsifiers	308
11.2.7	Texture Modifiers.	308
11.2.8	Fruit Juice.	308
11.2.9	Organic Acids.	308
11.2.10	Flavors	308
11.2.11	Colors.	309
11.2.12	Gelation Aids	309
11.2.13	Active Ingredients	309
11.2.14	Inclusions.	309
11.3	Processing	309
11.3.1	Dissolving and Cooking.	309
11.3.2	Stabilizer Addition.	310
11.3.3	Cooling.	311
11.3.4	Aeration	311
11.3.5	Final Ingredient Addition.	313
11.3.6	Cooling and Forming	313
11.4	Product Characteristics	314
11.4.1	Microstructure	314
11.4.2	Physical Properties.	320
11.4.3	Shelf Life	322
11.5	Troubleshooting	323
11.5.1	Improper Density	323
11.5.2	Product Too Hard or Rubbery	324
11.5.3	Product Too Sticky.	324
11.5.4	Graining During Storage	324
11.5.5	Mold Growth	325
11.5.6	Weeping	325
11.5.7	Shrinkage	325
11.5.8	Problems in Starch Deposited Marshmallows	325
11.5.9	Cold Flow.	326
	References.	326
12	Jellies, Gummies and Licorices	329
12.1	Introduction	329
12.2	Formulations and Ingredients	330
12.2.1	Sweeteners	330
12.2.2	Stabilizers or Hydrocolloids	331
12.2.3	Organic Acids.	333
12.2.4	Flavors	334

12.2.5	Colors	334
12.2.6	Others	335
12.3	Processing	335
12.3.1	Gummies and Jellies	336
12.3.2	Licorice	344
12.4	Product Characteristics	345
12.4.1	Microstructure	346
12.4.2	Flavor Release	355
12.4.3	Shelf Life	356
12.5	Troubleshooting	357
12.5.1	Gummies and Jellies	357
12.5.2	Flour-Based Candy (Licorice and Fruit Twists)	358
12.5.3	Problems with the Starch Mogul	358
	References	359
13	Sugar and Sugar-Free Panned Confections	361
13.1	Introduction	361
13.2	Formulations and Ingredients	363
13.2.1	Centers	363
13.2.2	Pre-coat Material	364
13.2.3	Sugar Shell	364
13.2.4	Colors	366
13.2.5	Flavors	367
13.2.6	Acids	367
13.2.7	Polish and Glaze	367
13.3	Processing	368
13.3.1	Sugar Shell Application	368
13.3.2	Polishing and Glazing	377
13.3.3	Special Decorations	378
13.3.4	Multicomponent Layering	379
13.4	Product Characteristics	379
13.4.1	Microstructure of Panned Sugar Shells	380
13.4.2	Moisture Migration	385
13.4.3	Shelf Life	387
13.5	Troubleshooting	388
13.5.1	Soft-Panned Candies	388
13.5.2	Hard-Panned Candies	389
13.5.3	Polishing and Glazing	390
	References	391
14	Chewing and Bubble Gum	393
14.1	Introduction	393
14.2	Formulations and Ingredients	395
14.2.1	Gum Base	395
14.2.2	Sweeteners	398
14.2.3	Acid	401
14.2.4	Humectants/Softeners	402
14.2.5	Flavors	402
14.2.6	Colors	403

- 14.2.7 High-Intensity Sweeteners..... 403
- 14.2.8 Active Ingredients 404
- 14.3 Gum Manufacture 405
 - 14.3.1 Mixing 405
 - 14.3.2 Forming 408
- 14.4 Product Characteristics 412
 - 14.4.1 Gum Microstructure and Physical Properties 412
 - 14.4.2 Flavor Release 415
 - 14.4.3 Shelf Life..... 417
- 14.5 Troubleshooting 418
 - 14.5.1 Imperfect Shape..... 418
 - 14.5.2 Gritty Texture..... 419
 - 14.5.3 Gum Too Hard or Too Soft 419
 - 14.5.4 Cud Too Small or Large..... 419
 - 14.5.5 Poor Bubble Blowing Capability..... 419
 - 14.5.6 Poor Flavor Release/Retention..... 419
 - 14.5.7 Loses Color/Fades 420
 - 14.5.8 Sweating Gum 420
 - 14.5.9 Sticky Gum 420
- References..... 420

Part III Chocolate and Compound Coatings

- 15 Chocolate..... 423**
 - 15.1 Introduction 423
 - 15.2 Cocoa Bean Production 425
 - 15.2.1 Fermentation 426
 - 15.2.2 Drying 429
 - 15.3 Cocoa Bean Composition and Quality Aspects 429
 - 15.4 Chocolate Processing..... 431
 - 15.4.1 Cleaning and Sorting 431
 - 15.4.2 Winnowing..... 431
 - 15.4.3 Alkalization (Dutching)..... 433
 - 15.4.4 Roasting..... 433
 - 15.4.5 Nib Grinding 434
 - 15.4.6 Cocoa Butter and Cocoa Powder Production..... 435
 - 15.4.7 Milk Processing for Chocolate..... 437
 - 15.4.8 Mixing and Refining of Chocolate Mass..... 438
 - 15.4.9 Conching 441
 - 15.5 Tempering 442
 - 15.5.1 Tempering Methods..... 444
 - 15.5.2 Tempermeters..... 445
 - 15.6 Forming 447
 - 15.6.1 Depositing/Molding..... 447
 - 15.6.2 Enrobing..... 451
 - 15.6.3 Cold Forming Shell Technology 453
 - 15.6.4 Extrusion Forming..... 454
 - 15.6.5 Aeration 455

15.6.6	Panning	455
15.7	Cooling Tunnels	455
15.8	Chocolate Characteristics	457
15.8.1	Flavor	457
15.8.2	Polyphenols and Flavanols in Cocoa and Chocolate	459
15.8.3	Chocolate Rheology	461
15.8.4	Melting Profile	467
15.8.5	Crystallization, Polymorphism and Tempering	470
15.9	Chocolate Stability and Shelf Life	473
15.9.1	Sugar Bloom	473
15.9.2	Bloom on Untempered Chocolate	474
15.9.3	Bloom on Undertempered Chocolate	474
15.9.4	Storage Bloom on Tempered Chocolate	475
15.9.5	Lipid Migration and Fat Bloom	479
15.9.6	Off Flavors	480
15.9.7	Oxidative Deterioration	480
15.10	Rework of Chocolate and Chocolate Confections	481
15.10.1	Reworking Chocolate	481
15.10.2	Reworking Chocolate Confections	481
	References	482
16	Compound Coatings	485
16.1	Introduction	485
16.2	Formulations and Ingredients	486
16.2.1	Ingredients	486
16.2.2	Coating Formulations	490
16.3	Manufacturing	490
16.4	Applications	492
16.5	Compound Coating Characteristics	493
16.5.1	Melting Profile and Fat Modification	494
16.5.2	Phase Behavior	495
16.5.3	Viscosity and Flow Properties	497
16.6	Shelf Life	498
16.6.1	Sugar Bloom	498
16.6.2	Storage Bloom	498
16.6.3	Moisture Uptake	498
16.6.4	Rancidity	499
16.6.5	Off-Flavors	499
	References	499
17	Chocolate Panning	501
17.1	Panning Operations	501
17.1.1	Centers	501
17.1.2	Chocolates and Coatings	502
17.1.3	Pre-coating	503
17.1.4	Chocolate Coating Application	504
17.2	Pan Types	505
17.3	Finishing	507
17.3.1	Polishing	508

17.3.2	Glaze Coat	508
17.3.3	Hard Sugar Shell	508
17.3.4	Powdered Finishes	508
17.4	Storage and Handling.	508
17.5	Trouble Shooting	509
17.5.1	Incomplete Coverage	509
17.5.2	Poor Coverage	509
17.5.3	Bumpy/Rough Surface.	509
17.5.4	Chocolate Not Sticking/Peeling.	509
17.5.5	Doubles	510
17.5.6	Crushed Centers.	510
17.5.7	Bloomed Pieces	510
	References.	510
	Glossary	511
	Index	517

About the Authors

Richard W. Hartel PhD has been a Professor of Food Engineering with the Department of Food Science at the University of Wisconsin-Madison since 1986. He conducts research on phase transitions in foods, primarily sugar confections, chocolate and ice cream. He teaches courses in Food Manufacturing, Food Preservation, Food Functionality, and Candy Science, as well as a freshman career orientation course. He has been involved with the UW Resident Course in Confectionery Technology (candy school) as an instructor since 1987 and as lead coordinator since 1998.

Joachim H. von Elbe PhD Is Professor and Chairman Emeritus with the Department of Food Science at the University of Wisconsin. He served for 38 years teaching courses in food chemistry with emphasis on plant pigments, their use as food and pharmaceutical colorants, and color and texture changes in canned vegetables. In 1963 he introduced, with cooperation with the confectionery industry, a three week candy technology course designed specifically for people in the industry. Since that time the course has been taught annually, and is now known as the UW Resident Course in Confectionery Technology.

Randall (Randy) Hofberger is the principle of R & D Candy Consultants LLC. Previously he had a long career at Nestle Confections USA in technical applications with an emphasis on caramels and chocolates. He has been an instructor at various confectionery courses including UW Resident Course in Confectionery Technology (candy school) and Retail Confectioners International (RCI).

Abbreviations

CMC	Critical micelle concentration
DAG	Diacylglycerol, or diglyceride
DSC	Differential scanning calorimeter
FFA	Free fatty acid
HLB	Hydrophilic-lipophilic balance
MAG	Monoacylglycerol, or monoglyceride
NMR	Nuclear magnetic resonance
PGPR	Polyglycerol polyricinoleate
SFC	Solid fat content
SFI	Solid fat index
TAG	Triacylglycerol, or triglyceride

Part I

Ingredient Chemistry and Functionality

Sweeteners are the primary ingredients in the manufacture of confections. Chemically, the primary sweeteners in confections are carbohydrates, which consist of a group of widely varied chemical substances present in both plants and animals. For example, in dry corn, approximately 55% of the solids are carbohydrates. The word “carbohydrates” itself means hydrated carbon. Thus, carbohydrate chemistry mostly deals with chains of carbon atoms hydrated with water, with a general formula of $C_x(H_2O)_y$.

Although only three atoms are involved, the chemistry of sweeteners can be very complex. Variations such as carbon chain length and branching, among others, allow for the existence of numerous combinations of the three atoms that provide the range of chemical characteristics of carbohydrates. The main groups of interest for confectionery manufacture are monosaccharides (e.g., glucose and fructose), oligosaccharides (e.g., the disaccharides including sucrose, maltose, and lactose, and starch hydrolysates), and polysaccharides (e.g., starches). Oligosaccharides are carbohydrates consisting of 2–20 monosaccharide units joined by glycosidic linkages. Compounds containing three saccharides are trisaccharides, while four to ten are tetra-, penta-, hexa-, hepta-, octa-, nona-, deca-saccharides, respectively. Various oligo- and polysaccharide products are used in confections. However, sweetening power generally decreases as carbon chain length increases (although other factors affect sweetness as well). Most confections con-

tain primarily smaller saccharides, but with a balance of oligosaccharides for functional properties (i.e., control of crystallization).

A wide range of sweeteners is used in the manufacturing of confections and chocolates, with the most common being cane or beet sugar (sucrose), glucose (corn) syrup, high fructose syrup, liquid sugar (67% sucrose dissolved in water), and invert sugar, the hydrolysis product of sucrose. Sugar alcohols (or polyols) are used for “diabetic” candies since they induce no insulin response. High intensity sweeteners are used to enhance sweetness, particularly when sugar alcohols are used.

The original candies probably were sweetened naturally, with materials like honey and maple syrup. As sucrose became more available, confectioners began using it as the primary sweetener in confections, with its hydrolysis product, invert sugar, used as the first doctoring agent (to control crystallization). As the sweetener industry matured, more and more different types of sweeteners have become available that provide excellent control for the confectioner. Knowledge of the physical and chemical properties of carbohydrates has made it possible for the confectionery industry to develop the many products available on the market today.

Sweeteners, beyond providing sweetness to confections, play an important role in determining the texture. Crystallization of sucrose in some products is encouraged, while in others, complex carbohydrates such as glucose (corn) syrup are

added to control or prevent crystallization. Chemical differences between carbohydrates similarly can result in different product characteristics. For example, the color of a number of candies is impacted by the choice of sweetener used in manufacturing. Sweeteners also aid in moisture control. Properly chosen, they either prevent moisture loss or moisture uptake. In addition, they add bulk in candies. The following sections discuss the basic chemistry of saccharides and some of their chemical properties. Their physical properties are the subject of Chapter 2.

1.1 Monosaccharides

Saccharides are composed of three basic building blocks, a carbon chain ($-\text{C}-\text{C}-\text{C}$), hydroxyl groups ($-\text{OH}$), and either an aldehyde ($-\text{CHO}$) or ketone ($-\text{CH}_2\text{COCH}_2-$) group. The chain length for monosaccharides can vary from three carbons in the simplest sugar to as many as seven. The monosaccharides most important to the confectionery industry are those containing six carbons (glucose, fructose). The presence of either an aldehyde or a ketone group in glucose and fructose gives rise to two categories known as aldose and ketose sugars. The structural difference between the two six-carbon sugars is that glucose contains an aldehyde group while fructose contains a ketone group.

The three most important monosaccharides in candies are glucose, fructose and galactose because their free aldehyde group makes them reducing sugars (defined later) and therefore, they can participate in the browning reactions. In older literature, glucose and fructose are referred to as dextrose and levulose, respectively. These terms arise from the direction in which a plane of polarized light is rotated when passing through a solution of each sugar: glucose rotates a plane of light to the right (dextro) and fructose rotates a plane of light to the left (levulo).

The word dextrose is still used in describing dextrose equivalent (DE), an important property that describes the reducing capacity of starch hydrolysate syrups. The confectionery industry uses the term dextrose when pure glucose is used.

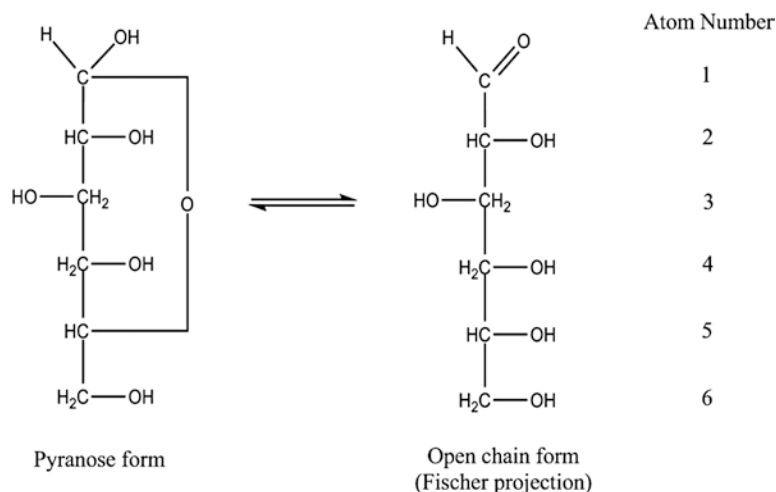
The term “glucose” is often used to describe the hydrolysate product of starch, more correctly called starch hydrolysate or glucose syrup.

1.1.1 Glucose/Dextrose

Glucose is widely distributed in nature, including the blood of animals and in the sap of plants. It also forms the base unit in one of the most important polysaccharides, starch, and is an important component of confectionery sweeteners.

Glucose contains asymmetric carbons, those that have four different substitute groups attached, which gives rise to two isomers, designated as D or L glucose. The structure of D-glucose is shown in Figure 1.1. In solution, glucose exists in the pyranose, or ring, configuration in equilibrium with a small amount of the open chain form. By convention, the assignment of the D-form in glucose, or any other monosaccharide, depends on the configuration of the hydroxyl group around the highest-numbered asymmetric carbon. This is most easily seen in the simplest monosaccharide, glyceraldehyde (Figure 1.2). Glyceraldehyde has a three-carbon chain in which only the number two carbon represents an asymmetric carbon. If the hydroxyl group at carbon 2 is written to the right, the structure represents the D-form, whereas if the hydroxyl group is written to the left, the structure represents the L-form. In Figure 1.1, the open chain form (Fisher projection) of glucose has four asymmetric carbons, while the pyranose form has five asymmetric carbons. If the hydroxyl group around the highest-numbered asymmetric carbon, carbon number 5 in glucose, is written to the right, the D form is represented. The isomer of a D-sugar is designated as the L-sugar (Figure 1.3). The open-chain form of glucose has four asymmetric carbons. Since two isomers exist for each asymmetric carbon, in a six-carbon sugar, 4^2 or 16 isomers are possible, eight of which will be in the D-configuration and eight in the L-configuration. The Fisher projections of all D-sugars with chain length between three and six carbons are illustrated in Figure 1.4. Among this family of monosaccharides, glucose, galactose and xylose

Figure 1.1 Pyranose and open chain forms of D-glucose



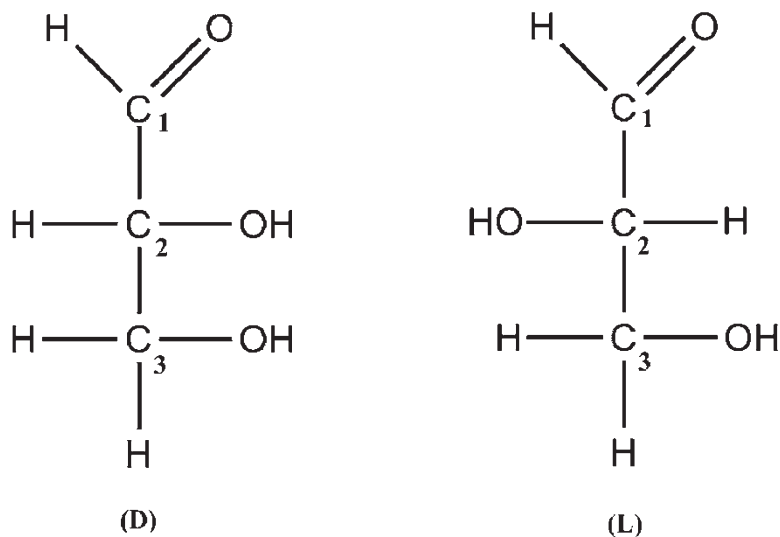
are of particular interest to the confectionery industry.

In solution, glucose molecules continuously change from open chain to ring structure and back again. The formation of the pyranose ring introduces an anomeric carbon in the first position (carbon 1), which allows two different orientations of the hydroxyl group as the ring closes. The two possible forms are designated by a Greek letter prefix as α and β . When the carbon 1 hydroxyl group is *cis*- (meaning on the same side) to the hydroxyl group at the carbon 2, the compound is termed α -D-glucopyranose or α -D-glucose. If the two hydroxyl groups are *trans*-

(meaning on opposite sides) to one another, the compound is β -D-glucopyranose or β -D-glucose. The structures of α - and β -D-glucose are shown in the pyranose form and in the cyclic Haworth configuration in Figure 1.5. In the cyclic form, the pyranose ring is considered to be perpendicular to the plane of the paper, with the substituents written to the right below the plane of the ring and those written to the left above the plane of the ring.

Glucose is present in confections primarily through the use of either sucrose or glucose syrups. At times, however, pure glucose/dextrose may be used. Commercial dextrose is made

Figure 1.2 Structures of D and L glyceraldehyde



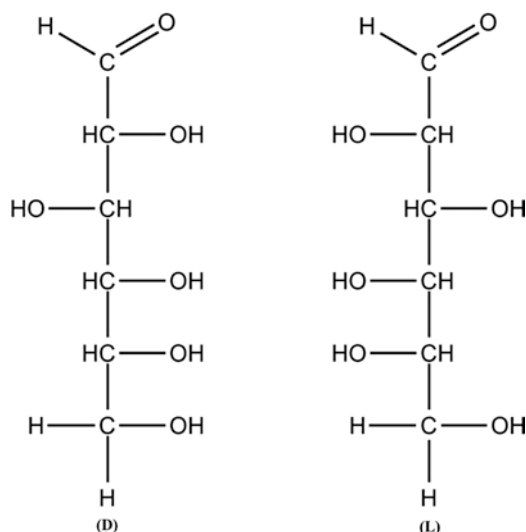


Figure 1.3 D and L isomers of glucose

through purification of fully hydrolyzed starch syrup followed by crystallization and refining. Dextrose crystallizes in different forms, with the monohydrate being the most commonly used. After drying, crystalline dextrose monohydrate is used in a variety of confections. It is often used, for example, directly in pressed tablet confections because of its compression characteristics (see Chapter 7). Anhydrous dextrose is sometimes used in commercial baking chips.

1.1.2 Fructose

The ketose sugar of greatest interest in confections is fructose. Fructose is abundant in nature and occurs in many fruits and vegetables and is a component of honey. Besides honey, it is a component of invert sugar and high fructose glucose (corn) syrup.

The D-forms of fructose in the open-chain, pyranose (six carbon ring), and furanose (five-carbon ring) forms are illustrated in Figure 1.6. These forms coexist in solution, with the pyranose ring form being most prevalent especially at elevated temperatures. As noted above, fructose is also a reducing sugar and, as such, also is found in the α and β isomers.

Until recently, fructose was only available in liquid form; in recent years, processes have been developed for the manufacture of crystalline fructose. However, crystalline fructose is very hygroscopic and care must be exercised in handling to prevent moisture uptake.

The sweetening power of fructose is from 1.3 to 1.7 times greater than sucrose and therefore, it takes less fructose to achieve the same sweetness. Further, since its metabolism does not require insulin, fructose often finds applications in diabetic foods.

1.1.3 Galactose

Galactose is a third monosaccharide of interest in confections. Although it is not used in confections directly, it is of interest because it is one saccharide component of lactose, the milk sugar. The structural comparison of glucose and galactose is shown in the Fischer projection in Figure 1.4.

1.2 Disaccharides

A number of disaccharides are used in confections, although sucrose is far and away the most common. Other disaccharides of interest include maltose and lactose. The chemical structures of these disaccharides are shown in Figure 1.7.

1.2.1 Sucrose

Sucrose is composed of two monosaccharides, α -D-glucose and β -D-fructose, with the glycosidic linkage between the one-carbon of glucose and the two-carbon of fructose. This linkage makes sucrose a nonreducing sugar because it involves the reducing groups of each monosaccharide. Mutarotation is therefore not possible; thus, sucrose cannot participate in the browning reactions unless it is first hydrolyzed (for example, by heat or low pH) into glucose and fructose.

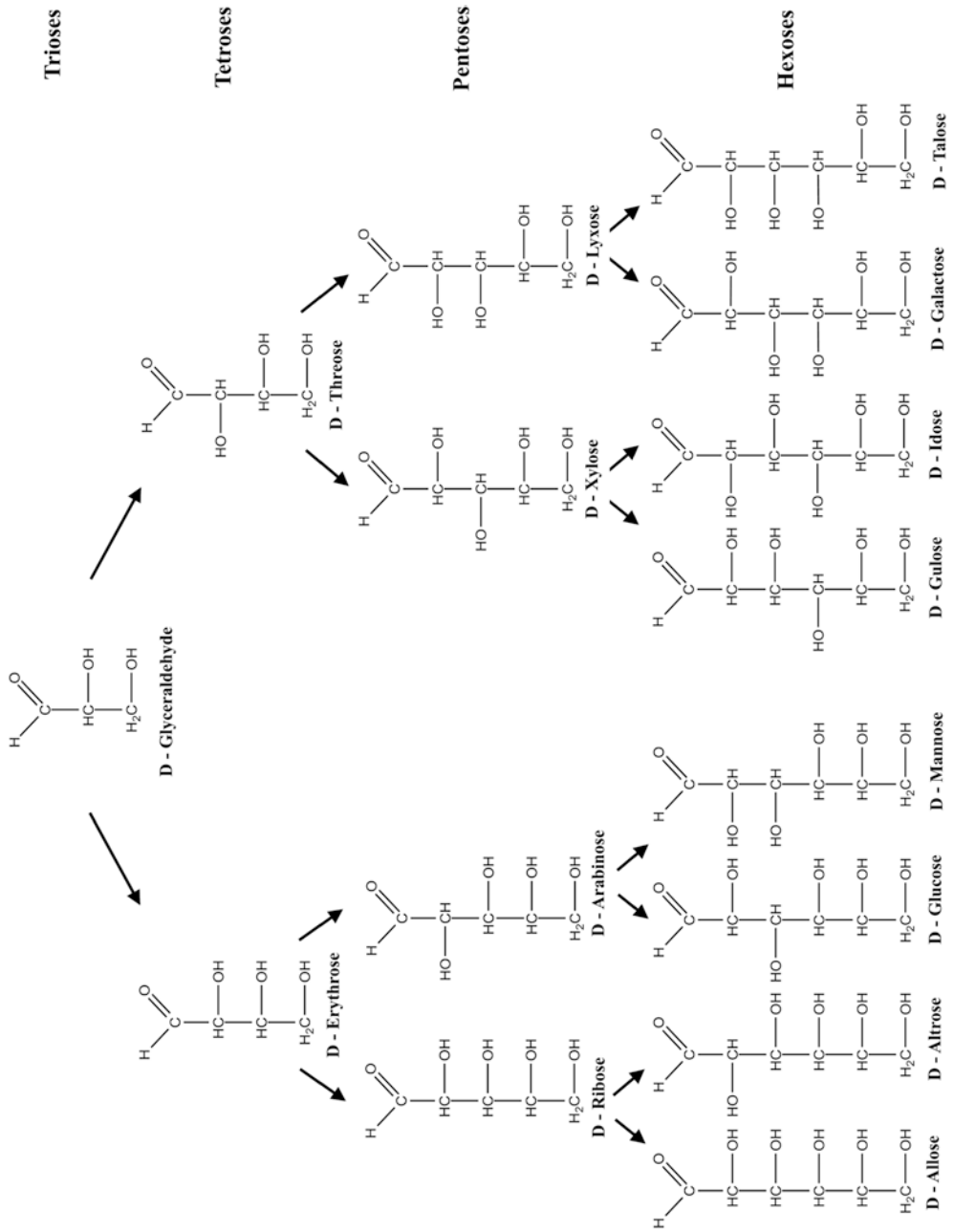


Figure 1.4 Configurational relationship of D-monosaccharides

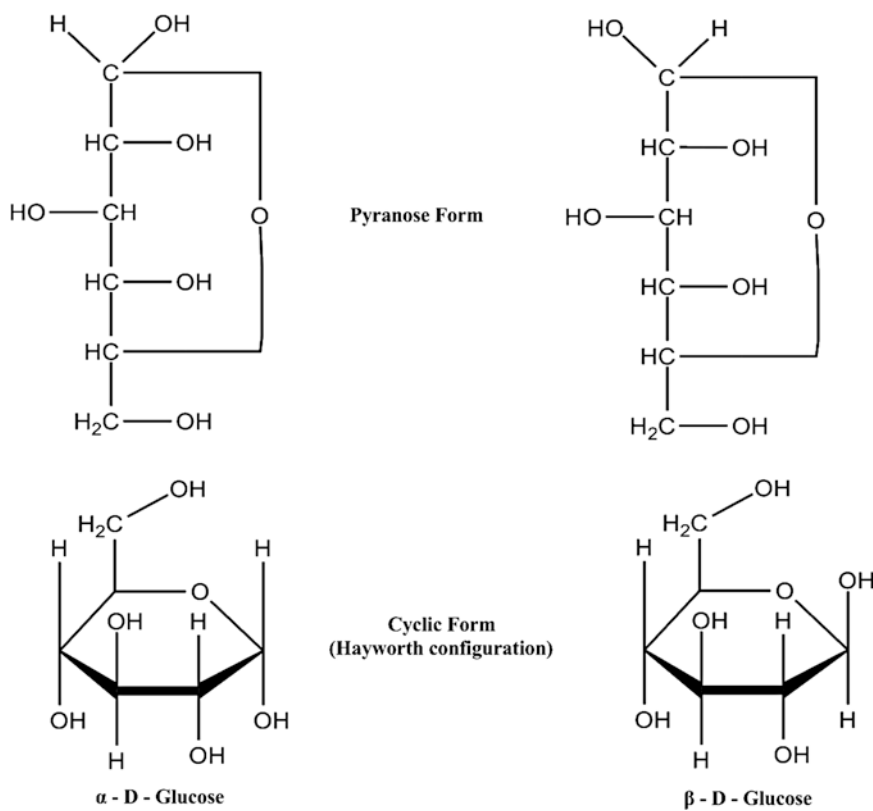


Figure 1.5 Configuration of α - and β -D-glucose

1.2.1.1 Sources of Sucrose

Sugar cane and sugar beets are the two sources of sucrose. Both yield juices rich in sugar that allow, after additional processing, the crystallization of sucrose. In each, the process is complex and a detailed description is beyond the scope of this book. The following summaries give the main steps.

1.2.1.1.1 Cane Sugar

Sugar cane is a tropical grass. It grows up to 7 m tall with stems that reach a diameter of more than 2 cm. At harvest time, the stalks are cut at ground level. Already the next day, sprouts start forming below ground level. Thus, a field of sugar cane, once planted, is self-perpetuating. The pulp in the stalks contains sugar at all times and therefore, there is no real maturity stage. The sugar content increases somewhat with cooler temperatures and decreases with warmer temperatures. Sugar cane typically contains 15% sucrose at optimum

maturity, but still contains 12% sucrose several months before and after optimum maturity. This allows for long harvest seasons. However, it is advantageous to harvest cane with the highest possible sugar content.

At the cane processing factory site, the cane is washed to remove as much dirt and debris as possible. One to 2% sugar is lost during this step in the process. Next, the cane is cut into 10–20 cm long sticks, which is followed by a cutting and hammer action to further reduce the cane. The crushed cane is then passed over several mills, which separate the cane into juice and a fibrous residue, called bagasse. Before the last step of milling, the bagasse is washed with water to achieve maximum extraction. Bagasse is waste material, mostly used for fuel.

The juices obtained during crushing and milling are combined and subjected to clarification. At this stage the juice looks brown and muddy. The dissolved materials are sucrose, invert sugar,

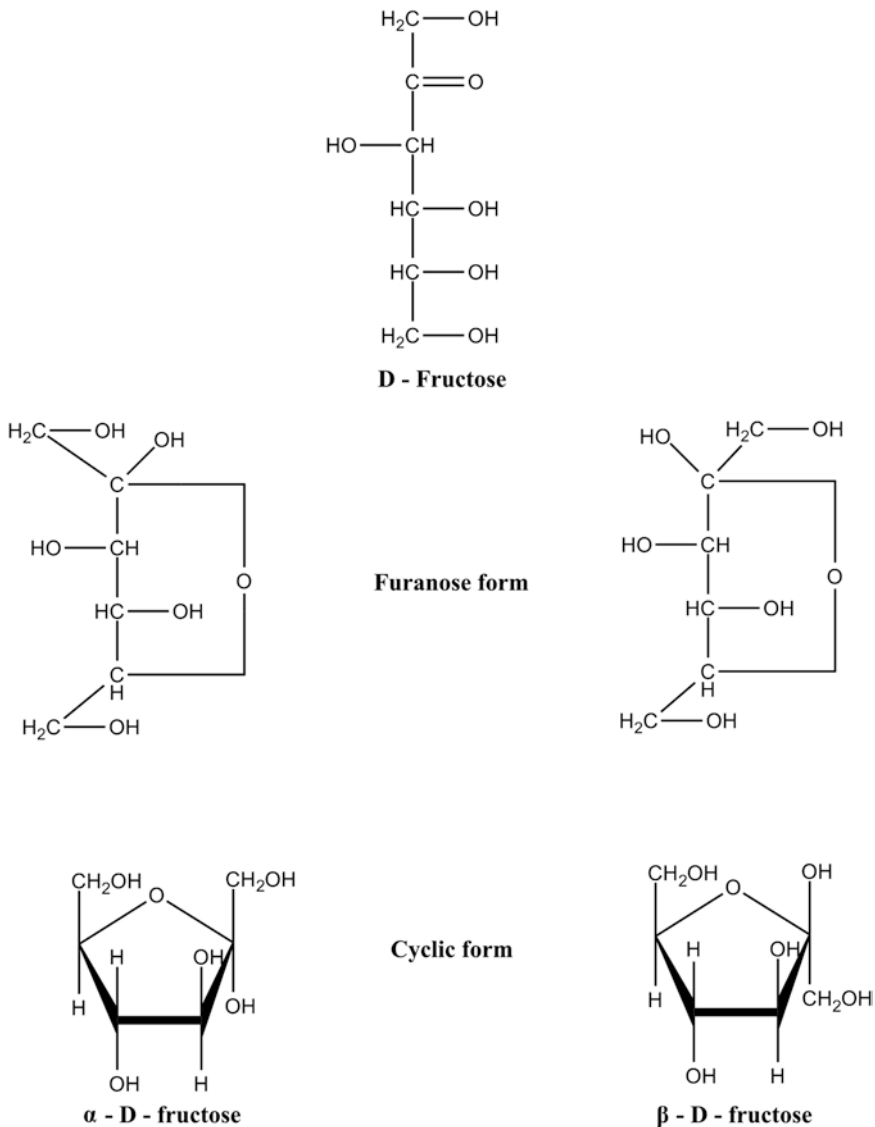
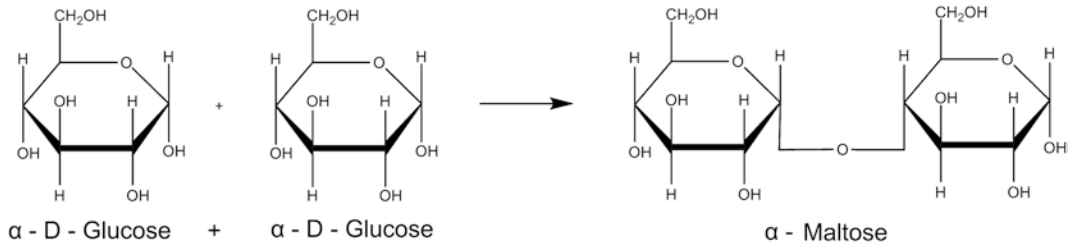
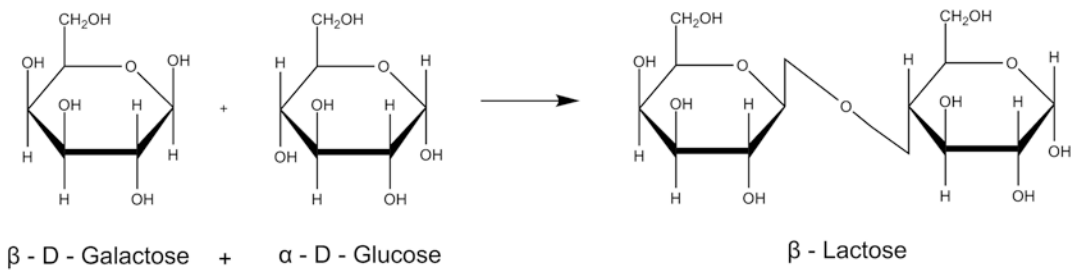
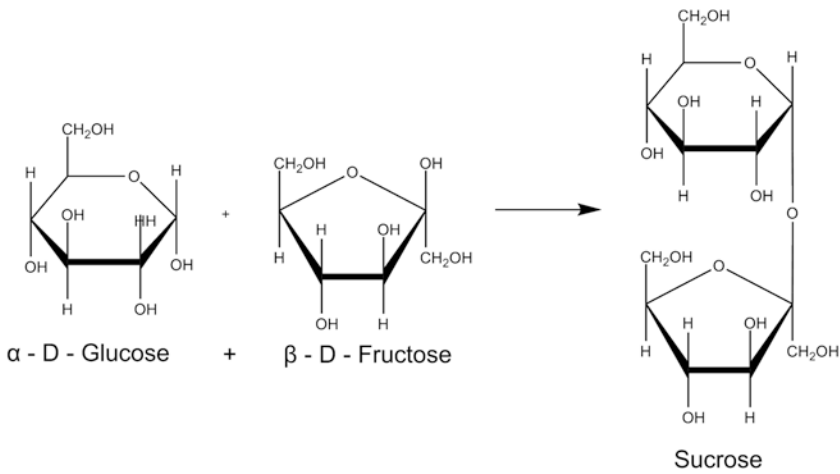


Figure 1.6 Structure of D-fructose and its α and β configurations

salts, silicates, proteins, enzymes, and organic acids. The suspended materials are cane fiber, microorganisms, chlorophyll, gums, starch, waxes, and fat. The first step in clarification is to raise the pH and heat the juice to stop microbial action and to inactivate the enzyme, invertase, which is native to sugarcane. The pH is raised by the addition of lime, which has the added advantage of adding calcium, thus forming and precipitating insoluble calcium salts. Clarification by heat and lime is a process known as “defecation”.

The precipitate, or mud, is removed and returned to the field. Following clarification, the juice is called syrup and is dark brown, almost black, in color.

The crystallization and harvesting of sucrose from syrup is accomplished by further evaporation, crystallization and centrifugation. The products of the initial processing steps are raw sugar (crystalline) and molasses. Raw sugar is shipped from the producing areas to the consuming areas, where it is further refined. Refining consists of a

Maltose**Lactose****Sucrose****Figure 1.7** Common disaccharides

series of washing and crystallization steps, up to three times, until the final sugar crystals are white with purity greater than 99%. Brown sugar is made by adding some molasses back to the refined sugar crystals.

1.2.1.1.2 Beet Sugar

Sugar beets are grown in northern climates. In the U.S., the largest sugar beet area is the Red River Valley, which lies between Minnesota and North Dakota. This region produces more than 30% of all sugar beets. Sugar beets are seeded in the spring and harvested in October. At harvest time, sugar beets weigh, on average, 1 kg. If not processed immediately after harvest, beets are stored in buildings or in piles as high as 9–10 m (29–32 ft) and as long as 1.5 km (1 mile). Sugar losses during storage are minimal and thus, storage of the beets extends throughout the processing season.

Sugar production begins when beets are removed from the storage facility and enter the factory for a thorough washing to remove soil residues. The cleaned beets are sliced with razor sharp knives into cossettes, which then enter a counter-current diffuser containing hot water. The advantage of cutting cossettes is that it allows for maximum surface area and therefore, maximum sugar extraction. The juice leaves the diffuser for further processing. The cossettes are dried and sold as animal feed. The raw juice from the diffuser is clarified with the addition of lime, similar to the process described for sugarcane, with the impurities removed by filtration. The thin juice is then evaporated to remove excess moisture before it enters a vacuum-pan, where additional water is removed and crystallization is initiated by seeding the syrup with pulverized sugar. Centrifugation separates the white crystals from beet molasses. As for sugar cane, several crystallization and centrifugation steps are used to obtain refined white sucrose.

Beet molasses is not suitable for human consumption and can only be utilized as animal feed or for the production of alcohol. For this reason, brown sugars are not made from beet sugar due to the nature of the molasses.

There has been much discussion as to the merits of the use in confections of cane sugar vs. beet sugar. Today's refined sugars from either cane or beet are practically pure sucrose, 99.9% purity and thus, are virtually indistinguishable. In raw sugars, the differences are greater. Cane sugar has a pleasant flavor and smell, whereas raw beet sugar is bitter and has an unpleasant taste. Less refined beet sugar can have a slight odor and cause excessive foaming. The foaming is the result of incomplete removal of proteins and their breakdown products, saponins and mucilages, neither of which is likely to exist in cane sugar. Less refined cane sugar has been found to contain cane wax, which will act as a foam inhibitor.

1.2.1.2 Sugar Forms and Types

Sugars can be purchased in many forms and crystal sizes. The confectionery industry takes advantage of almost every type of sugar produced. Highly refined sugars are used in chocolate, hard candy, and fondant; brown sugars are used for flavor, for example, in caramel and fudges.

Sucrose may be purchased in many granular sizes. The granular structure of crystallized sugar is determined by the size, shape and the distribution of the crystals. Although the names of the different types of sugar differ between suppliers, they generally fall into five classes, as listed in Table 1.1, based primarily on size. Each of these grades of sugar finds application in the candy industry, although most sugar use is either fine or

Table 1.1 Crystal size and names of sugars

Grain size (μm)	Name of sugar type
	Sanding sugar
>650	Confectioners A
	Confectioners AA
380–635	Coarse
	Granulated
	Fine granulated
175–380	Extra fine
	Granulated
	Baker's special
50–175	Industrial fine
	Crushed fine
<25	Powdered sugar

Table 1.2 Composition of sugars

Sugar type	Component (%)				
	Sucrose	Moisture	Invert	Ash	Others
Sanding	99.98	0.015	0.001	0.002	0.002
Granulated	99.94	0.02	0.015	0.01	0.01
Golden C, (light brown)	89.3	2.7	4.2	1.4	2.4
Yellow D (dark brown)	87.9	2.8	4.6	1.7	3.0

coarse granulated. Larger sizes are used for sanding and decorating while smaller sizes are used when the sugar will not be dissolved and recrystallized, as in pastes and lozenges. Smaller sizes are also used in soft panning to ensure a smooth candy surface.

Table 1.2 gives the composition of some sugar types. For the most part, granulated sugars are highly refined to give greater than 99.9% purity. Brown sugars contain less sucrose and more of the components found in molasses. Powdered sugar generally contains a few percent of starch granules to control moisture and prevent clumping.

Today, a specially manufactured fondant sugar is available to the industry. It is prepared with a fine sugar containing about 3% invert sugar and up to 10% maltodextrin. Fondant sugar allows the manufacturing of a fondant (often called rolled or extruded fondant) without boiling and crystallization procedures (see Chapter 9).

Whether from cane or beet, sugars are most often used in solid form. However, liquid sugar, 67% sucrose dissolved in water (based on the solubility of sucrose in water at room temperature, see Chapter 2), is available and is used in some places in the candy industry. It has the advantage of being pumpable and does not require time for dissolution prior to use. For example, large hard candy manufacturers can pump liquid sugar and glucose syrup together into the evaporator to save both time and energy. While liquid sugars allow for tank storage and economical handling procedures, care must be exercised to avoid microbial spoilage due to the high water activity. Further, crystallization (in containers and even pipes) can occur if temperature is reduced substantially below room temper-

ature and the solution becomes supersaturated (see Chapter 2).

1.2.2 Maltose

Maltose is the combination of two α -D-glucose units. The glycosidic linkage is made between the one carbon of one glucose unit and the four carbon of the second glucose unit. This linkage is referred to as a 1–4 α linkage because the hydroxyl group of the carbon number 1 is in the α position. Maltose is therefore an α -glycoside. It is also a reducing sugar.

Maltose is generally found in confections through addition of glucose syrups (high maltose syrups). It is much less sweet than sucrose (about 0.3 times as sweet).

1.2.3 Lactose

Lactose is the disaccharide found in the milk of mammals. It is the combination of a unit of α -D-glucose and β -D-galactose through the four – carbon of glucose. Lactose, therefore, is a β -glycoside. As a reducing sugar, it participates in the Maillard browning reaction, one of its desired effects in caramel, fudge and toffee.

In confections, lactose is usually introduced through a milk ingredient, as in sweetened condensed milk used for caramel or fudge. Lactose powder is available through refining of whey or whey permeate (after separation of whey proteins). Here, the whey or permeate is evaporated to 60–70% total solids, which supersaturates the lactose. The condensed stream fills a lactose crystallizer, which is then cooled over 18–24 h to