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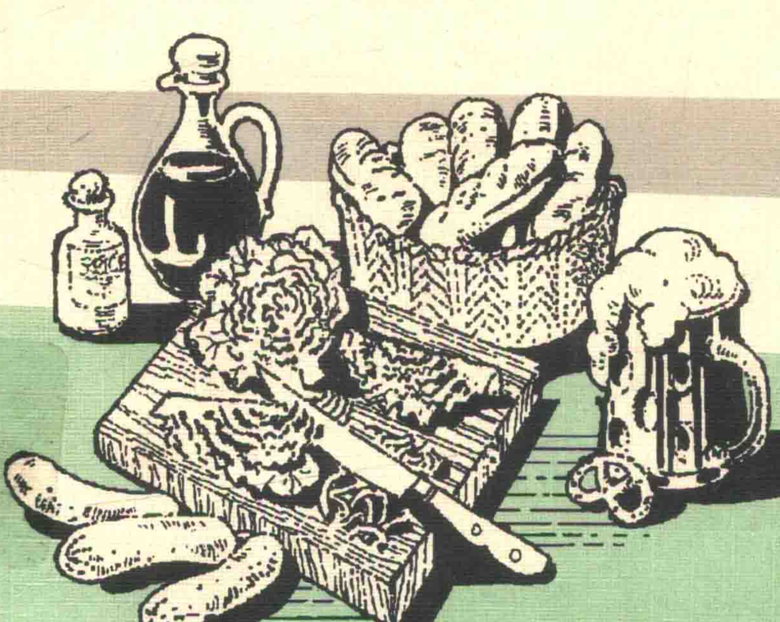
The Chemistry of Its Components

THIRD EDITION

T.P.Coultate



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The Chemistry of Its Components

Third Edition

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Writing a book like this would not be the rewarding task it is without the bluntest group of critics of all, my students. They still haven't come up with a better mnemonic for the hexose sugars but they do continue to find more of the mistakes than anyone else. They also provide an invaluable testing ground for new material and its presentation.

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Tom Coultate

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Chapter 1

Introduction

For the chemists of the 18th and 19th centuries an understanding of the chemical nature of our food was a major objective. They realised that this knowledge was essential if dietary standards, and with them health and prosperity, were to improve. Inevitably it was the food components present in large amounts, the carbohydrates, fats, and proteins, that were first to be described. As physiologists and physicians began to relate their findings to the chemical knowledge of foodstuffs, the greatest need became one for analytical techniques, a demand no less pressing today. The food components that occur in much smaller amounts, the pigments, vitamins, and flavour compounds for example, required 20th century laboratory techniques for their isolation and characterisation. Thus, in spite of the more or less similar importance of the different classes of food components, the extent of knowledge has not advanced evenly.

By the time of World War II it appeared that most of the questions being asked of food chemists by nutritionists, agriculturalists, and others had been answered. This was certainly true as far as questions of the 'what is this substance and how much is there?' variety were concerned. However, as reflected in this book, over the past 20 years or so new questions have been asked and so far only a few answers have been obtained. Food chemists nowadays are required to explain the *behaviour* of food components – on storage, processing, cooking, even in the mouth and during digestion. Much of the stimulus to this type of enquiry has come from the food-manufacturing industry and from the legislative bodies which attempt to control the industry's activities. For example, the observation that the starch in a dessert product provides a certain amount of energy has been overtaken in importance by the need to know which type of starch will give just the right degree of thickening and what is the molecular basis for the differences between one starch and another.

Chapters 6–10 of this book show that with regard to the quantitatively less prominent food components the examination of their properties in food systems is only just beginning. With the obvious exception of the vitamins this delay has been caused, at least in part, by the failure of nutritionists, physiologists, and other scientists to recognise what consumers and the food manufacturing industry have always known, *i.e.* that there is more to the business of feeding people than compiling a list of nutrients in the correct proportions. This is as true if one is engaged in famine relief as it is in a five-star restaurant. To satisfy a nutritional need a foodstuff must be acceptable, and to be acceptable it must first look and then taste 'right'.

In recent years we have become increasingly conscious of two other aspects of our food. As some of us have become more affluent, our food intake is no longer limited by our income and we have begun to suffer from the Western 'disease' of overnutrition. Our grandparents are appalled when our children follow sound dietetic advice and discard the calorie-laden fat from around their sliced ham and food scientists are called upon to devise butter substitutes with minimal fat content. Closely associated with this issue is the intense public interest in the 'chemicals' in our food. Sadly, the general public's appreciation of the terminology of chemistry leaves much to be desired.

It is unlikely that many people would buy coleslaw from the delicatessen if the label actually listed the 'active ingredients':

ethanoic acid,
α-D-glucopyranosyl-(1,2)-β-D-fructofuranose,
p-hydroxybenzyl and indoylmethyl glucosinolates,
S-propenyl and other *S*-alkyl cysteine sulfoxides*,
β-carotene (and other carotenoids),
phosphatidylcholine.

The relationship of this list to the actual recipe will emerge from subsequent chapters.

Whether or not the public's concerns are well founded, there is no doubt that food manufacturers have been forced to take a much less complacent view of food safety issues. It is to be hoped that books such as this one will help to keep the discussions of these issues better informed than they have often been in the past. This book does not set out to be a textbook of nutrition, its author is in no way qualified to make it one. Nevertheless chemists cannot ignore nutritional issues and wherever possible the links between the subtleties of chemical structure of food components and nutritional and health issues have been pointed out. In

* The replacement of "ph" with "f" in the sulphur compounds mentioned in this book is in deference to the rules of the International Union of Pure and Applied Chemistry (IUPAC) rather than to Webster's Dictionary.

this way it is to be hoped that health pundits who campaign for the reduction of this or that element in our diet will have a better appreciation of what exactly it is they are asking for, and what any knock-on effects might be.

The search for the answers to questions of food texture, colour, flavour, and safety as well as simple composition has turned the chemical study of food into a mongrel discipline. Its present vigour, which stimulated the writing of the first edition of this book and has sustained it into subsequent editions, comes from the necessary integration of normally separate scientific disciplines. For example, our understanding of the chemistry of meat (*see* Chapter 5) leans heavily on both cell biology and free-radical chemistry. Similarly, to study the chemistry of food preservation (*see* Chapter 9) requires insights into microbiology as well as nuclear physics with some chemistry in between.

No book on such a diverse subject as food can claim to be comprehensive, but with the inclusion of chapters on minerals and water the organic and biochemists will be seen not to have the field entirely to themselves. The inclusion of a chapter devoted to the undesirable substances that are to be found in our diet should help to ensure that the pursuit of 'naturalness' as a guarantee of 'healthiness' is seen for what it is, a wild goose chase. The success of *Homo sapiens* as a colonist of this planet is to some extent at least owed to an extraordinary ability to adapt his (and her) eating habits to what is available in the immediate environment. Whether that environment is an Arctic waste, a tropical rain forest, or a hamburger-infested inner city, Man has to make dietary compromises in order to survive. The chemical nature of these compromises is what the following eleven chapters are all about.

A brief note on concentrations

The concentrations of chemical components are expressed in a number of different styles in this book, depending on the context and the concentrations. Some readers may find the following helpful.

(a) However they are expressed, concentrations always imply the amount contained, rather than added. Thus "5g of X per 100g of foodstuff" implies that 100g of the foodstuff contains 95g of substance(s) that are *not* X.

(b) The word "per" is often used in its own right but may be replaced by the symbol "/", as in "5g/100g".

(c) The abbreviation "p.p.m." means "parts per million" *i.e.* grams per million grams, or more realistically milligrams per kilogram. A "p.p.b.", or part per billion, corresponds to a microgram per kilogram.

(d) Amounts contained in 100g (or $100cm^3$) are often referred to as simple percentages. Where necessary the terms "w/w", "v/v" or "w/v" are added to indicate whether volumes or weights or both are involved. Thus "5% w/v" means that $100cm^3$ of a liquid contains 5g of a solid, either dissolved or in suspension.

(e) Most often a strictly mathematical style is adopted, with "per" expressed as the power of minus one. Since mathematically:

$$x^{-1} = 1/x$$

5µg kg^{-1} becomes a convenient way of writing 5 micrograms per kilogram. This brief but mathematically rigorous style comes into its own when the rates of intake of substances such as toxins have to be related to the size of the animal consuming them, as in "5 milligrams per day per kilogram body weight", which abbreviates to:

$$5\text{mg day}^{-1}\ \text{kg}^{-1}$$

A quantity, say 10µg, per cubic centimetre, cm^3, would be written: 10µg cm^{-3}.

Chapter 2

Sugars

Sugars, such as sucrose and glucose, together with polysaccharides, such as starch and cellulose, are the principal components of the class of substances we call *carbohydrates*. In this chapter we will be concerned with the sugars and some of their derivatives; the polysaccharides, essentially a special class of their derivatives, will be considered in Chapter 3. The special place of sugars in our everyday diet will be apparent from the data presented in Table 2.1.

The presence of sugars in many foods is usually obvious to the consumer but in others, especially the more elaborate products of the food manufacturing industry, their sweetness may not be sufficient to give them away. It is unfortunate, especially for people that really need the information such as diabetics, that current food labelling usually lumps the sugars together with the polysaccharides to give a total carbohydrate figure.

Although chemists never seem to have the slightest difficulty in deciding whether or not a particular substance should be classified as a carbohydrate, they have been unable to provide a concise, formal definition. The empirical formulae of most of the carbohydrates we encounter in foodstuffs approximate to $(CH_2O)_n$, hence the name. More usefully, it is simpler to regard them as aliphatic polyhydroxy compounds which carry a carbonyl group (and, of course, derivatives of such compounds).

MONOSACCHARIDES

The monosaccharides constitute the simplest group of carbohydrates, and, as we shall see, most of them can be referred to as sugars. The monosaccharides have between three and eight carbon atoms, but only those with five or six carbon atoms are common. The suffix '-ose' is included in the names of monosaccharides that have a carbonyl group, and in the absence of any identification the number of carbon atoms is indicated by terms such as triose, tetrose, and pentose. The prefixes 'aldo-' and 'keto-' are used to show whether the carbonyl group is at the first or a subsequent carbon atom, so that we may refer to, for example, aldohexoses or ketopentoses. To complicate matters further, the two

Table 2.1 *The total sugar contents of a variety of foods and beverages. These figures are taken from 'McCance and Widdowson' (see Appendix II) and in all cases refer to the edible portion. They should be regarded as typical values for the particular food rather than absolute figures which apply to any samples of the same food. The levels of sugars in eggs, meat (cured or fresh), poultry, game and fish, and fats such as butter and margarine are nutritionally insignificant although even traces can sometimes reveal themselves through browning at high temperatures caused by the Maillard reaction, see page 23.*

Food	*Total sugars* (%)	*Food*	*Total sugars* (%)
White bread	2.6	Cabbage (raw)	4.0
Corn flakes	8.2	Beetroot (raw)	7.0
Sugar coated cornflake	41.9	Onions (raw)	5.6
Digestive biscuits	13.6	Cooking apples (raw)	8.9
Gingernuts	35.8	Eating apples (raw)	11.8
Rich fruit cake	48.4	Bananas	20.9
Cow's milk (whole)	4.8	Grapes	15.4
Human milk	7.2	Oranges	8.5
Cheese (hard)	0.1	Raisins	69.3
Cheese (processed)	0.9	Peanuts	6.2
Yoghurt (plain)	7.8	Honey	76.4
Yoghurt (fruit)	15.7	Jam	69.0
Ice cream (dairy)	22.1	Plain chocolate	59.5
Lemon sorbet	34.2	Cola	10.5
Cheesecake (frozen)	22.2	Beer (bitter)	2.3
Beef sausages	1.8	Lager	1.5
New potatoes	1.3	Red wine	0.3
Canned baked beans	5.9	White wine (medium)	3.4
Frozen peas	2.7	Port	12.0

triose monosaccharides are almost never named in this way but are referred to as glyceraldehyde (2,3-dihydroxypropanal) (2.1) and dihydroxyacetone (dihydroxypropanone) (2.2).