the accumulation of empirical values coupled with a rather more detailed chemical examination of the feeding-stuffs. With this plan of experiment one must hope that when an anomalous value for a feeding-stuff occurs, it will be additive or, failing this, that the explanation will be simple, such as failure to neutralize mineral acids in silage. There is room for compromise between the two extremes, so that the main issue is one of emphasis. It is to decide how much effort should be devoted to the biochemical elucidation of the theory of net energy, and how much to the empirical accumulation of net-energy values.

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Assessment of the Energy Value of Human Foods

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The energy value of food is measured in calories, which are physical units of heat. The number of calories a food will provide is usually calculated from the amounts of protein, fat, and carbohydrate in it, and these are estimated by chemical methods. Physiological corrections are then applied to allow for losses in the urine and the faeces. The whole subject is very complicated and the attempts which people have made to assess the energy value of human food can only be described as a comedy of errors. All the methods of assessment in use to-day are based upon work that was carried out over 50 years ago, and it is my object in this paper to go back to the great masters, Rubner and Atwater, to describe what they did and taught, to see how far their disciples have followed in their footsteps, and to discuss their teachings in the light of present knowledge.

I do not propose to deal with the question of losses in preparation or cooking of food, the problem of sampling, or the accuracy of methods of chemical analysis. Any one of these is a subject for a symposium in itself. I shall assume that the food has been sampled, prepared, and analysed in the best possible way and I

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shall confine myself to a discussion of the calculations that are involved in assessing its energy value.

The past

Rubner and Atwater. Rubner worked in Germany and Atwater in America during the last 20–25 years of the 19th century and the first part of the present one. In his early days Atwater spent some time in Germany as Rubner's pupil, and it was undoubtedly this experience that inspired his later work. In many ways the interests of the two men were the same, and they approached their problems in a similar way.

Rubner's most important papers for the present purpose were published in 1885 and 1901 (Rubner, 1885, 1901). He measured the heats of combustion of a number of different proteins, fats and carbohydrates in a bomb calorimeter and also studied the heat of combustion of urine passed by a dog, a man, a boy and a baby living on different diets. He realized that the heat of combustion of protein in the bomb calorimeter was greater than its calorific value to the body because the body oxidizes protein only to urea, creatinine, uric acid and other nitrogenous end-products which are themselves capable of further oxidation. Rubner found that urea has a heat of combustion of 2·52 Cal./g, or 5·4 Cal./g urea nitrogen. He pointed out that urine contains calorific substances other than urea, which have greater heats of combustion, and he found (Rubner, 1901) that the urine passed by the man eating a meat diet and a potato diet gave 7·69 and 7·85 Cal./g N respectively. The urine of the baby living on breast milk gave 12·1 Cal./g N.

Rubner also analysed the faeces of the man who acted as his experimental subject and he found that the loss of energy in the nitrogenous substances in the urine and faeces were 16·3 and 6·9% of the intake respectively, making a total loss of about 23%. Rubner deducted 23% from the value for the heat of combustion of proteins. Table 1 shows how he then arrived at his factor for the calorific value to the body of 1 g protein. He assumed that all proteins contained 15·5% N and he

Table 1. *Derivation of Rubner's factor for protein* ($N \times 6{\cdot}45$)
(Rubner, 1885, 1901)

Meat protein	4·233	Cal./g after correcting for heat of combustion of N end products in urine, and losses of N in faeces
Vegetable protein	4·301	

Wheat and rye are the most important sources of vegetable protein and their proteins contain more N than animal protein. The factor for converting equal parts of wheat and rye N to protein should be 6·0, not 6·45. Hence the calories of wheat + rye are overestimated by 7·9%.

Deduction of 7·9% from 4·301 gives:

$$4{\cdot}301 - 0{\cdot}340 = 3{\cdot}96 \text{ Cal./g}$$

From dietary studies, 60% of protein eaten is animal and 40% vegetable.

$$4{\cdot}233 \times 0{\cdot}6 = 2{\cdot}54$$
$$3{\cdot}96 \times 0{\cdot}4 = 1{\cdot}58$$
$$4{\cdot}12$$

Rubner suggested 4·1 as average factor for animal and vegetable protein, assuming that the factor 6·45 has been used for converting N to protein in all foods.

multiplied the N which he measured by the factor 6·45 to arrive at the amount of protein. He knew, however, that proteins did not all contain the same amount of N; he emphasized that bread is the most important source of vegetable protein, and that wheat protein contains 17·2% N and rye protein 16·3%. By multiplying the N in wheat and rye by 6·45 he had overestimated the amounts of protein by 10·9% and 5·1% respectively, and in arriving at his average factor of 4·1 for converting all the protein in a mixed diet into terms of calories he allowed for this error. In his later (1901) paper Rubner seems to have realized that nearly all proteins contain more than 15·5% N and that his values for the amounts of protein in food were consistently too high; the N in meat, for example, should have been multiplied by 6·25, not 6·45, to arrive at the amount of protein. This error roughly cancelled out the allowance that Rubner made for losses of N in the faeces.

Table 2 shows the derivation of Rubner's factor for converting fat into terms of calories, and Table 3 gives the same information about his factor for carbohydrate. It is to be noted that, although Rubner (1879, 1901) did much work on the

Table 2. *Derivation of Rubner's factor for fat*
(Rubner, 1885)

Type of fat	Heat of combustion (Cal./g)
Olive oil	9·384
Animal fat	9·372
Butterfat	9·179
Mean	9·312

Rubner suggested 9·3 as mean factor.

Table 3. *Derivation of Rubner's factor for carbohydrate*
(Rubner, 1885)

Type of carbohydrate	Heat of combustion (Cal./g)	
Glucose	3·692	
Lactose	3·877	
Sucrose	3·959	Mean 4·035
Starch	4·116	

Carbohydrate in foods is determined 'by difference'.

Percentage of carbohydrate = 100 −((N × 6·45) + ether extract + water + ash).

This calculation underestimates the carbohydrate in cereals because N × 6·45 overestimates the protein.

Rubner suggested 4·1 as average factor for starch + sugar in a mixed diet.

proportion of nutrients in different foodstuffs that were 'digested' and absorbed, he made no allowance for losses in the faeces in deriving his calorie-conversion factors for fat and carbohydrate. The only 'metabolic' allowances that he made were for the heat of combustion of nitrogenous end-products in the urine, and for losses of N in the faeces, but the latter allowance was offset by his use of too high a figure for multiplying the amount of N to obtain the amount of protein.

I think I can safely say that Atwater has contributed more to our knowledge about the assessment of the energy value of human foods than anyone who has ever lived, either before or since his time. He, like Rubner, measured the heats of combustion of different proteins, fats and carbohydrates (Atwater & Bryant, 1900*a*). Atwater & Benedict (1901) studied the energy intake of four men and their energy output in a respiration calorimeter, both at rest and at work. Atwater & Bryant (1900*a*) analysed urine from forty-six persons and measured its heat of combustion. They found that for every gram of N in the urine there was unoxidized material sufficient to yield 7·9 Cal. This value is very close to Rubner's figure and is equivalent to 1·25 Cal./g protein in the food if the person is in N equilibrium. Atwater (1902) also made extensive studies of the 'availability' of nutrients, and he was very careful to distinguish between the terms 'available' and 'digestible' (Atwater, 1900). He regarded the faeces as being made up of two parts, the undigested, unabsorbed food residues, and the 'metabolic products' of digestion. By 'digestible' N, for example, he meant the N in the food minus the N in the undigested food residues, and this he could not measure. By available N he meant the N in the food minus the N in the undigested residues and the metabolic products of digestion together, that is, the N in the food minus the N in the faeces. Atwater used the term 'available' in the sense that later workers have used the term 'digestible', and in discussing Atwater's work I shall use the word 'available' as Atwater defined it.

Three men, aged 32, 29, and 22 years, served as subjects for Atwater's studies on 'availability'. Atwater made a total of fifty experiments on these men, each lasting 3–8 days. They ate what Atwater described as 'mixed diets', which varied in the amount of fat and carbohydrate they contained. Their foods were analysed for N and fat and their faeces were collected and analysed also.

Atwater & Bryant (1900*a*) collected what they could find in the literature, including the results of their own work (Atwater, 1897), on the 'availability' of single food materials to man. From these data they prepared tentative coefficients for the 'availability' of the protein, fat and carbohydrate in the more common classes of food and they applied these coefficients to the 'mixed diets' that their own three subjects had eaten. They then compared the calculated 'availability' of the protein, fat and carbohydrate of the mixed diets with the 'availability' of these nutrients in the diets as found by experiment. They did the same with the results of sixty-one other experiments conducted by Professor C. E. Wait at the University of Tennessee, in which apparently ten men served as subjects, though no detailed description of these experiments is given. They found the 'coefficients of availability' of the protein, fat and carbohydrate in the mixed diets as found by actual experiment to agree very well with the values as calculated by the proposed factors for 'availability'.

Atwater & Bryant (1900*a*) then calculated the 'available energy' derived from proteins, fats and carbohydrates in two ways (Table 4). (1) They took the heat of combustion per g, and multiplied it by the 'percentage availability'. With protein they then subtracted 1·25 Cal./g to allow for unoxidized material in the urine.

Table 4. *Atwater's factors for heats of combustion, availability and 'available energy' values of nutrients*

(Atwater & Bryant, 1900*a*)

Nutrient	Heat of combustion (Cal./g)	Availability (%)	'Available energy' Cal./g available nutrients	Cal./g total nutrients
Protein:				
Animal	5·65	97	4·40*	4·25†
Vegetable	5·65	85	4·40*	3·55†
Fat:				
Animal	9·40	95	9·40	8·95
Vegetable	9·30	90	9·30	8·35
Carbohydrate:				
Animal	3·90	98	3·90	3·80
Vegetable	4·15	97	4·15	4·00

* Heat of combustion less 1·25 to allow for unoxidized material in urine.

† 1·25 deducted after calculation of the fuel value of the available protein, e.g. 5·65 × 0·85 = 4·80, 4·80 − 1·25 = 3·55.

These figures gave the 'available energy' per g total nutrients. (2) They supposed that the values for protein, fat and carbohydrate had already been multiplied by the appropriate 'coefficient of availability' and gave the calorie-conversion factors which should then be used, i.e. the 'available energy' per g 'available' nutrients. From their study of 185 family dietaries Atwater & Bryant (1900*a*) concluded that in the average American diet 61% of the protein, 92% of the fat and 5% of the carbohydrate came from animal sources and the remainder from plant sources. From these figures and those given in Table 4 Atwater & Bryant (1900*a*) proposed that the factors given in Table 5 should be used for calculating the 'available energy' in a mixed diet.

Table 5. *Atwater's factors for heats of combustion, availability and 'available energy' values of nutrients in a mixed diet*

(Atwater & Bryant, 1900*a*)

Nutrient	Heat of combustion (Cal./g)	Availability (%)	'Available energy' Cal./g available nutrients	Cal./g total nutrients
Protein	5·65	92	4·4*	4·0*
Fat	9·40	95	9·4	8·9
Carbohydrate	4·10	97	4·1	4·0

* Corrected for unoxidized material in urine.

One of Atwater's great contributions to knowledge was the analysis of foodstuffs and the compilation of values for the composition of American food materials

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(Atwater & Bryant, 1895, 1906). Over 1000 foods were analysed in his own department and figures for 3000 others, analysed elsewhere, were included in the tables. In these tables the percentage of water, protein (N $\times$ 6·25), fat, carbohydrate 'by difference', and ash were set out, and some values for fibre, sugar, and free acid were also included. A column was then added for 'fuel value per lb.'. 'The fuel values of the different food materials are calculated by use of the factors of Rubner, which allow 4·1 Calories for a gram of protein, the same for a gram of carbohydrates, and 9·3 Calories per gram of fats'. Thus Atwater & Bryant made no allowances for 'availability' in their own tables of food composition; they criticized Rubner rather heavily and perhaps a little unjustly (Atwater & Bryant, 1900*a*), and it seems strange that they should still have been using his calorie-conversion factors 7 years later.

Atwater & Bryant (1900*b*) published some of the same results, however, in a different form. They applied the factors in Table 5 for the 'availability' of nutrients in a mixed diet to the percentages of protein, fat and carbohydrates in the individual foods and thus arrived at the 'actual proportions of available nutrients'. They used the figures given in column 3 of the same table to calculate the amounts of energy which these quantities of nutrients would yield to the body, i.e. the 'available energy'. Thus, when Atwater & Bryant considered the composition of foods in terms of 'available energy' they also considered in terms of 'available' quantities the nutrients from which the energy was derived.

It is a pity that Atwater & Bryant used for individual foodstuffs 'coefficients of availability' which they had devised for mixed diets. They had themselves suggested separate coefficients for different classes of food (Table 4) which would have been much more appropriate for this particular purpose, and this misuse of their own factors has been a source of difficulty and confusion ever since.

The history of calorie conversion factors during the present century. For the first 40 years of this century the only people who were much concerned about calorie conversion factors were those who were responsible for making tables of food composition. Real accuracy, or let us say agreement between different systems, did not become a major issue until food supplies became scarce during the second world war and calculations began to be made of calories exported from the United States and imported into Europe. Then it was found that the calculations made on the two sides of the Atlantic did not agree, and the whole subject came up again, when it was at once realized that it had great practical as well as scientific importance (Maynard, 1944).

The first edition of Sherman's text book, *The Chemistry of Food and Nutrition*, was published in 1911. The eighth edition was published in 1952. Sherman concluded his book with tables showing the percentages of edible organic nutrients in a number of different foods, these figures being taken from Atwater & Bryant's (1906) tables. Figures for the fuel values of the various foodstuffs were also given and these were said to be 'computed from the average percentage of protein, fat and carbohydrate by the use of the latest and most accurate factors' (Sherman, 1928). On the next page it is stated that these factors were for 'protein 4 Calories; fat 9

Calories; carbohydrate 4 Calories per gram'. Thus Sherman took his values for total protein, fat and carbohydrate from one of Atwater & Bryant's publications (1906) and his values for calories from another (1900*b*). The factors 4, 9 and 4 applied to mixed diets, not to individual foods. Furthermore, Sherman did what Atwater never did or suggested doing, which was to consider protein, fat and carbohydrate in terms of the total amounts ingested and the calories derived therefrom as corresponding to the amounts of protein, fat and carbohydrate that were 'available' to the body. This misinterpretation of Atwater's teaching which was begun, as far as I know, by Sherman, has continued to the present time.

With the outbreak of the first world war the need was felt for a series of analyses of the commoner foods eaten in Britain, and Plimmer undertook this work for the Army Medical Authorities. His report (Plimmer, 1921), *Analyses and Energy Values of Foods*, was published in 1921 and it included figures for the water, ash, protein, fat and carbohydrate in about 900 foodstuffs. Plimmer multiplied the N in plant foods, milk and meat by 5·68, 6·38 and 6·25 respectively to obtain the amount of protein. He estimated sugars directly and calculated starch 'by difference'. He then used Rubner's factors 4·1, 9·3, 4·1 for arriving at the calories. Plimmer's values therefore applied to total nutrients and total calories. He used Rubner's factors as Rubner intended them to be used except in one particular. By multiplying each gram of protein in the diet by 4·1 in order to convert it to calories Rubner had assumed that N in all foods had been multiplied by the same figure to convert it to protein (see page 143). Plimmer used more correct figures for converting the N to protein in different classes of food and, to be consistent therefore, he should have made a modification in his factor for converting protein to calories.

In 1940 Chatfield & Adams (1940) published their *Proximate Composition of American Food Materials*. This was largely a compilation from published and unpublished sources. The figures used for converting N to protein in different foods were those given by Jones (1931), who had determined the percentage of N in a number of different proteins; these figures were as nearly correct as possible. For some foods carbohydrate was reckoned 'by difference', and for others the values were based on direct determination of starch, dextrin, sugars, and acids. 'Fuel value is . . . . . calculated on the basis of the conventional physiological values, that is 4 calories per gram of protein and of carbohydrate and 9 per gram of fat'. As in Sherman's tables, therefore, the total amounts of protein, fat and carbohydrate were given, and the calories alone were corrected to allow for the 'availability' of these nutrients. Again the factors used applied to mixed diets and not to individual foods.

When we first prepared our food tables, *The Chemical Composition of Foods*, (McCance & Widdowson, 1940) we had to decide what factors we should use for calculating the calories provided by a food from the amounts of protein, fat and carbohydrate in it. We had abandoned the rather primitive method of calculating the amount of carbohydrate 'by difference', and we estimated separately the glucose, fructose, sucrose, dextrins and starch and expressed the sum of these in terms of glucose as 'available carbohydrate'. We arrived at the amount of protein by multiplying the N in all foods by 6·25. We then used Rubner's factors 4·1, 9·3, and 4·1 for calculating the calories derived from protein, fat and carbohydrate respectively. In this we made a mistake, for Rubner's factor 4·1 for carbohydrate applied to equal parts of sucrose and starch, not to glucose (See Table 3), and our calories from carbohydrate were therefore always too high. This error was pointed out to us by members of the Rowett Research Institute and it was rectified in the second edition of the tables (McCance & Widdowson, 1946), when we used Atwater's value for the heat of combustion of glucose (3·75 Cal./g). In this edition we calculated the protein in cereals as N $\times$ 5·7, thus reviving Plimmer's inconsistency.

The second world war brought a need for tables giving the composition of foods that could be bought in wartime, and the Accessory Food Factors Committee of the Medical Research Council undertook to compile such tables. These were published in 1945 under the title *Nutritive Values of Wartime Foods* (Medical Research Council: Accessory Food Factors Committee, 1945). The figures for protein were calculated by multiplying the amount of N by 6·25, except for wheat and dairy products when 5·7 and 6·38 were used. The figures for the composition of many of the foods were taken from our *Chemical Composition of Foods*, and the values for carbohydrate were based on direct chemical estimations, but all the results were expressed in terms of starch. 'The factors 4, 9, and 4 Calories (kilocalories) per gramme, respectively, of protein, fat and carbohydrate (expressed as starch) were used in calculating energy values'. Sherman's misapplication of Atwater's method and Atwater's own inconsistency were therefore perpetuated in these tables and a new error was introduced. Atwater's factor of 4 for carbohydrate applied, like Rubner's factor of 4·1, to a mixture of starch and sucrose, and by expressing all the carbohydrate as starch and then using 4 as the calorie-conversion factor the calories from carbohydrate were underestimated throughout. This was the opposite mistake to the one which we had made in the first edition of *The Chemical Composition of Foods.*

Various other tables of food composition have been published in different countries during the past 20 or 30 years (e.g. Imperial Bureau of Animal Nutrition, 1938; Commonwealth of Australia: Advisory Council on Nutrition, 1938; Bridges & Mattice, 1942; Fox & Golberg, 1944; Marston & Dawbarn, 1944; Platt, 1945; Bureau of Human Nutrition and Home Economics, 1945; Osmond, 1948), but as far as I know all have followed one or other of the systems for computing calories which have already been described.

The most recent tables of food composition are the *Food Composition Tables for International Use*, published by the Food and Agriculture Organization of the United Nations in 1949 (Chatfield, 1949). In these, the recommendations of the F.A.O. Committee on Calorie Conversion Factors and Food Composition Tables (1947) were followed in most respects and, since these recommendations represent the considered views of the experts at the present time, they are of importance and they will therefore be considered in some detail.

The present

The report of the F.A.O. Committee on Calorie Conversion Factors and Food Composition Tables. This report first deals with the determination of protein. Because of the lack of data about the non-protein N fraction and the misuse of the factor 6·25 the Committee considered that the protein values are incorrect in most current tables of the composition of foods. It recommended that, until more is known about the non-protein N fraction and the amino-acids in foods, N be multiplied by the appropriate figures, which were in the main those originally suggested by Jones (1931). The problem of the method of determining and expressing carbohydrate was considered in some detail. 'The Committee is unanimous in considering that the correct chemical approach is by the extension of analytical work to include all substances covered by "carbohydrates by difference". Further studies of digestibility of these substances are also required. Only when all the constituents of food have been determined and their physiological effects defined, can their rôle in metabolism and their fuel value be accurately described'.

Although the members of the Committee clearly envisaged that the ideal tables of food composition of the future would contain figures for the total amounts of protein (or of amino-acids), of fat and of the different carbohydrates in foods, the report states that 'in assessing or comparing the energy value of different foods or diets the physiological energy value should be used as the basis'. They apparently viewed with approval the principle inaugurated by Sherman of expressing the energy-giving nutrients in terms of the amounts ingested and of applying coefficients of digestibility only to the calories. In arriving at the coefficients of digestibility, account was taken of work done since Atwater's time on the digestibility of wheat and wheat products. The protein, fat and carbohydrate of each food group has its own coefficient of digestibility assigned to it. With fat and carbohydrate the heat of combustion is multiplied by the 'coefficient of digestibility' to obtain the 'physiological energy value'. For protein a correction is applied for loss of oxidizable material in the urine, but this correction is not applied as Atwater & Bryant (1900*a*) recommended. Table 6 shows the two methods. Atwater & Bryant first multiplied the heat of combustion by the coefficient of digestibility and then subtracted 1·25. The F.A.O. Committee first subtracted 1·25 from the heat of combustion and then multiplied by the coefficient of digestibility. It is difficult to see why the Committee should have made this change, which must be incorrect, and for a food with a low coefficient of digestibility there is a considerable difference between the results given by the two methods.

The future

If the past is reviewed in the light of the present it must be concluded that Rubner's disciples have not followed Rubner, and Atwater's disciples have not followed Atwater. In nearly every set of food tables published since the time of the great masters some mistake has been made in interpreting their teaching. There have, moreover, been surprisingly few advances in knowledge about the assessment

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Table 6. *Comparison of the Atwater and F.A.O. methods of calculating the physiological energy value of ingested protein*

(Atwater & Bryant, 1900*a*; Food and Agriculture Organization of the United Nations: Committee on Calorie Conversion Factors and Food Composition Tables, 1947)

Suppose:
- Heat of combustion of protein = 5·65 Cal./g
- Coefficient of digestibility = 0·85
- Correction factor for unoxidized material in urine = 1·25 Cal./g protein

Atwater method:

$$5{\cdot}65 \times 0{\cdot}84 = 4{\cdot}80$$
$$4{\cdot}80 - 1{\cdot}25 = 3{\cdot}55 \text{ Cal./g protein ingested}$$

F.A.O. method:

$$5{\cdot}65 - 1{\cdot}25 = 4{\cdot}40$$
$$4{\cdot}40 \times 0{\cdot}85 = 3{\cdot}75 \text{ Cal./g protein ingested}$$

of the energy value of human food in the past 50 years, especially when one considers all that has been accomplished in other fields. At every point we have to go back to the results of Atwater. Enough is known at the present time, however, to decide upon the principles that should govern any future calculations of energy values. They clearly depend upon the purpose for which the figures are required. Those responsible for feeding the nation are concerned, not so much with scientific accuracy as that calories shall not be lost or gained on their passage across the Atlantic. To them the highest pitch of accuracy is less important than international agreement about the method of computation. On the other hand, they generally require to know the number of calories which a particular foodstuff, e.g. wheat, will provide, so that calorie-conversion factors that are applicable only to mixed diets are particularly misleading.

The maker of food tables is concerned with the analysis of individual foods, and the figures he gives should represent the amounts of protein, fat and carbohydrate he finds in the foods. This being so, his figures for calories, if he decides to include them, should also represent the total number of calories that would be derived from the foods provided the nutrients in them were completely digested. His figures for calories should be given in the same terms as his figures for protein, fat, and carbohydrate. It is no part of his business in the first instance to manipulate his figures to make allowances for 'digestibility', but he may decide to publish all his results in another way, as Atwater & Bryant did, making due allowance for 'digestibility' of nutrients and of the energy derived therefrom. Whether Rubner's factors for protein and fat are the best ones to use for 'total calories' is doubtful. The appropriate figures for heats of combustion of proteins and fats in different classes of food along the lines suggested by the F.A.O. Committee would undoubtedly be more correct. It is perhaps inconsistent to make an allowance for loss of oxidizable material in the urine, but this has become hallowed by convention and no-one has ever questioned it. It seems, however, as though further work on the subject is desirable on persons of different ages, eating a variety of present-day diets, for the figure 1·25

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is based on work done over 50 years ago with unknown diets, the full details of which have never been published.

So far as carbohydrate is concerned the maker of food tables has to consider, not only those whose sole interest is energy, but also doctors and dietitians who wish to design diets for diabetic patients. It is true that some of the pentosans and celluloses may be broken down in the gut and give rise to lower fatty acids, part of which may be absorbed and become a source of calories, and that organic acids in fruits may also be a minor source of energy (Maynard & Galbraith, 1947), but when diabetic diets are required it is the major glycogenic substances—the sugars, dextrins and starch—that are the focus of interest. Even for assessing the energy value of foods the direct determination of 'available carbohydrate' is a step in the right direction, though admittedly it may not take us quite the whole way.

For some purposes, as for example in comparing energy intake with energy expenditure, it is undoubtedly the number of calories derived from the 'available' or 'digestible' portion of the nutrients that is required. How then should this be calculated? The general factors of Atwater (Table 5), which most people have thought should be used in food tables to allow for digestibility, applied to mixed diets and not to individual foods. The F.A.O. Committee stated 'in many tables of food composition in common use, the energy values have been incorrectly computed by misapplication of Atwater's average values, and should be discarded'. The whole problem of absorption of the digestion products of proteins, fats and carbohydrates from the gut is a very difficult one. There is no doubt that one of the main factors in determining the amount of N and fat in the faeces, and hence their 'digestibility', is the amount of fibre or roughage in the diet. If the roughage in the diet remains constant, a person tends to excrete the same amount of N and fat in his faeces every day, whatever his intake of these nutrients, so that the higher his intake of N and fat the higher the apparent digestibility (McCance & Walsham, 1948). If the amount of roughage in the diet is increased but the intake of N and fat is kept constant, the loss of N and fat in the faeces at once rises, and there is a fall in the apparent digestibility (Rubner, 1883; Macrae, Hutchinson, Irwin, Bacon & McDougall, 1942; McCance & Widdowson, 1947). The effect of wholemeal bread on the 'digestibility' of N, which was well known to Rubner, has been demonstrated many times.

It will be recalled that Atwater & Bryant (1900*a*) collected from the literature the results of digestibility experiments with single foodstuffs and from these they devised their 'coefficients of availability'. They applied their proposed 'coefficients of availability' to the protein, fat and carbohydrate in the 'mixed diets' of three men and they compared these results with those which they obtained when they determined the amounts of the nutrients in the food and faeces. Atwater & Bryant's mixed diets would hardly qualify as normal mixed diets by present-day standards in Britain. Examples of two of them are shown in Table 7. Apart from baked beans, not one of them contained any vegetables and none of them any whole wheat bread. In one sense, therefore, Atwater did not put his 'coefficients of availability' to a very severe test and it seems as though digestibility experiments with diets

Table 7. *Examples of 'mixed diets' on which Atwater made his calculations*
(Atwater, 1902)

A	*B*
Beef	Beef, fried
Butter	Beef, dried
Skim milk	Eggs
Bread	Butter
Ginger snaps	Milk
Parched cereal	Rye bread
Sugar	Wheat breakfast food
	Sugar
	Baked beans
	Canned pears

more like those eaten to-day are very necessary before any definite 'coefficients of availability' appropriate to present-day dietary habits can be put forward. Another point that should be mentioned in this connexion is that Atwater & Bryant found very little variation among their three men as regards their ability to digest and absorb the nutrients in their diet. It looks as though they were very fortunate in this respect, for the usual findings in work of this nature on human beings are wide individual variations from one person to another. If Atwater had studied more individuals he would undoubtedly have discovered this.

There is one final problem I should like to state. How should we arrive at the physiological energy value of food during growth? The baby fed on breast milk is a good example. The conventional correction for loss of calorific material in the urine (1·25 Cal./g nitrogen) is not applicable to a baby (Rubner, 1901) and, moreover, the baby retains one-quarter to one-half of the nitrogen in his food, so that the amount of nitrogen in his urine is by no means equivalent to his nitrogen intake. Furthermore, he retains other calorific material in the form of body fat. The child derives no 'energy' from the nitrogen and fat he lays down, in fact, he uses up energy in doing so. The retentions are essential if the child is to grow, and the nitrogen and fat he retains can hardly be regarded as a reserve of 'energy'. How then does one calculate the physiological energy of breast milk?

My conclusion must be confession. We have all made mistakes, even Atwater. But we can console ourselves by thinking that 'the man who makes no mistakes does not usually make anything'. He certainly does not make food tables.

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Some Difficulties in Estimating the Energy Value of Human Diets

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I intend to limit the difficulties for the purpose of this discussion to those likely to be met in estimating the energy value of human diets from tables of food composition.

There are several types of difficulty that might be classified as follows: (1) the problem of fitting the condition of the food to that to which the available average chemical analyses apply, (2) the problem of fitting the description of the food to that in the table of food composition, (3) difficulties relating to the method of expressing carbohydrate, (4) difficulties relating to the choice of factors for conversion of protein, fat, carbohydrate and other energy-yielding food constituents to calories. Errors can be made under some or all of these headings. Sometimes they compensate for each other: sometimes they do not.

The errors that might arise under the first heading seem almost too obvious to

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