THE BALANCE OF ACID-FORMING AND BASE-FORMING ELEMENTS IN FOODS, AND ITS RELATION TO AMMONIA METABOLISM.

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In recent years the ash constituents of foods have come to hold an increasingly prominent place in considerations of food values. It is now generally recognized not only that the food as a whole should supply adequate amounts of each of the chemical elements which is essential to the body structure, but also that these elements should stand in normal quantitative relations to each other.

Conspicuous among the quantitative relations is that between the acid-forming and the base-forming elements of the food. It has long been known that certain foods contain a surplus of base-forming over acid-forming elements as evidenced by the fact that on burning they yield a strongly alkaline ash, whereas other foods lose acid-forming elements in ashing and yet yield a neutral ash showing that acid-forming elements must have predominated in the food.

It was, however, not possible to make any useful quantitative comparisons on the basis of the data which had been obtained by the usual methods and recorded in the accepted tables of ash analyses, because these data represented only the composition of the material which remained after ignition, regardless of the fact that in many cases a large part of the acid-forming elements exist in the food as constituents of the organic matter and pass off during the ignition. This is particularly true of sulphur, which, so far as known, exists in foods chiefly as a constituent of protein and often is expelled almost entirely during the burning, so that the sulphates found in the analysis of the ash represent only a very minor part of the sulphur which was present in the food. Hence any attempt to calculate the relation of acid-forming to base-forming elements from the tables of ash analyses which have been available in the past would give erroneous results except in those cases in which the base-forming elements so far predominate as to prevent loss of acid-forming elements during ashing; and comparisons of different types of food with each other would be misleading.

Another source of error lies in the fact that the usually accepted tables of ash analyses are largely derived from the work of agricultural chemists whose primary object was to determine the constituents removed from the soil by the crop and who, therefore, analyzed the article of food as sold instead of simply the edible portion.

An investigation of the actual quantitative relations of acid-forming and base-forming elements in the edible matter of foods was begun in this laboratory over five years ago and a few of the results first obtained were published in the summer of 1907.[1]

We are now able to present data for a larger number of foods. Of some of these we have made complete ash analyses; in other cases we have accepted previously published results for such constituents as seemed to have been accurately determined and supplemented these with such determinations as were necessary. While it is obviously more systematic to balance the acids and bases by comparisons of data obtained upon the same sample, the compiled data sometimes have the advantage of representing the average of several samples. Hence in Table 1 we give in some cases the results calculated from data partly compiled even though we may have determined the complete data upon a single specimen of the same food. Footnote references attached to the names of the articles of food show the nature of the data in each case. In most of our own work the material selected for analysis consisted of composite samples each representing a mixture of several specimens of the particular food.

Methods of Analysis:—For the determination of *calcium* and *magnesium* the sample was burned in a platinum dish (usually in a muffle), the ash

[1] Sherman and Sinclair: This *Journal*, iii, p. 307.

dissolved in hot, very dilute hydrochloric acid, the solution filtered if not clear, treated with oxalic acid, heated to boiling, a few drops of methyl orange added as indicator, and then ammonia very gradually until the indicator changed color. This neutralization usually required about one-half hour. Finally an excess of ammonium oxalate was added and the solution allowed to stand for four hours, then filtered, washed with one per cent solution of ammonium oxalate, dried, ignited to constant weight and weighed as calcium oxide, with care to avoid absorption of carbon dioxide or moisture.

The filtrate from the calcium oxalate was evaporated to dryness in platinum and ignited carefully to expel ammonium salts without spattering; the residue dissolved in hot water with the addition of a little hydrochloric acid, the solution filtered if necessary, cooled, and the magnesium precipitated by adding acid sodium phosphate solution and then ammonia gradually until distinctly alkaline. Half an hour later an excess of ammonia was added as usual and after allowing to stand in the cold usually for about 12 hours the ammonium magnesium phosphate was filtered, washed with dilute ammonia, ignited to magnesium pyrophosphate and weighed.

For the determination of *sodium* and *potassium* a portion of the sample was burned in platinum at a low temperature (very dull redness) to a white ash. This was taken up with hot water and a little hydrochloric acid, filtered, heated to 95° and treated with a very slight excess of barium chloride solution (added drop by drop with constant stirring), allowed to stand on water bath for one hour, then without filtering, barium hydroxide solution was added in the same manner to alkaline reaction, the solution filtered and residue washed free from chlorides. The filtrate was treated with a few drops of ammonia and an excess of ammonium carbonate, filtered, the filtrate and washings evaporated to dryness, ignited carefully at very dull redness, cooled, dissolved in hot water containing a few drops of hydrochloric acid, filtered, and again evaporated and ignited as before. This purified residue was weighed as sodium and potassium chlorides, then dissolved and the potassium determined by the usual platinic chloride method.

In the determination of *phosphorus* the organic matter was usually oxidized by boiling with nitric and sulphuric acids in a Kjeldahl flask. In order to avoid error from incomplete destruction of phosphatids or from subsequent incomplete precipitation of ammonium phospho-molybdate it is well to use only 10 cc. of concentrated sulphuric acid; then after the organic matter appears to have been largely destroyed add 10 grams of ammonium nitrate and heat until the solution in the flask is reduced to 10 cc. or less, thus ensuring a high temperature which should char any phosphatids which may not have been destroyed by the boiling mixture of sulphuric and nitric acids; if charring occurs more nitric acid is added and the boiling repeated. Finally the acid solution was washed out of the flask, treated with 20 grams ammonium nitrate and the phosphoric acid determined by precipitation first as ammonium phospho-molybdate and subsequently as magnesium ammonium phosphate according to the well-known gravimetric method. In some cases phosphorus was also determined after burning the sample with sodium carbonate and potassium nitrate, this giving the same results as the method of decomposition with acids when both methods are properly performed.

For the determination of *chlorine* the sample was burned at a low temperature with a liberal excess of sodium carbonate in a room kept as free as possible from hydrochloric acid or ammonium chloride fumes, and the chloride was determined gravimetrically by precipitation as silver chloride.

The oxidation of organic matter for the determination of *sulphur* was accomplished sometimes by burning in oxygen in a bomb calorimeter as first suggested by Berthelot, but usually by heating the substance in a nickel crucible with sodium hydroxide and sodium peroxide essentially according to the methods of Osborne and of Folin with such variations in manipulation as were found best adapted to the behavior of the different types of food. Earlier experiments by one of us,[2] had shown that the compressed oxygen method and the peroxide method are both capable of yielding accurate results when properly carried out. After the complete destruction of organic matter and oxidation of sulphur to sulphates, the determination of the latter was made by precipitation as barium sulphate in the usual manner with careful attention to the established precautions.

Table 1 shows the percentages of calcium, magnesium, sodium, potassium, phosphorus, chlorine, and sulphur in the edible portion of a considerable number and variety of food materials.

In order to balance the acid-forming against the base-forming elements we have calculated the volume of a normal acid or alkali solution which would correspond to the amount of each element in 100 grams of the food material, phosphoric acid being calculated as a dibasic acid. By adding together the results obtained for all of the base-forming and for all of the acid-forming elements respectively and comparing the totals we find the excess of acid-forming or of base-forming elements in terms of cubic centimeters of a normal solution per 100 grams of edible food material.

Since, however, the different food materials vary so greatly in their moisture content and food value it may give a more serviceable impression of the relative acid-forming or base-forming tendencies of different food materials if the surplus acid or base be stated for 100 calorie portions rather than for 100 gram portions of the various foods.

Table 2 calculated from the data given in Table 1 shows the excess of acid-forming over base-forming elements or *vice versa* both per 100 grams and per 100 calories of edible food material.

It will be seen from the above tables that all the meats (in-

[2] Sherman: *Journ. Amer. Chem. Soc.*, xxiv, p. 1100.

TABLE I.

Percentages of Calcium, Magnesium, Potassium, Sodium, Phosphorus, Chlorine and Sulphur in edible portion of Foods.

ARTICLE OF FOOD	CALCIUM	MAGNESIUM	SODIUM	POTASSIUM	PHOSPHORUS	CHLORINE	SULPHUR
	percent.	*percent.*	*percent.*	*percent.*	*percent.*	*percent.*	*percent.*
Almonds*	0.270	0.275	0.024	0.756	0.496	0.037	0.185
Almonds†	0.215	0.211	0.022	0.166	0.379	0.005	0.135
Apples†	0.010	0.008	0.015	0.125	0.013	0.004	0.005
Asparagus†	0.029	0.012	0.007	0.165	0.039	0.040	0.040
Bananas†	0.007	0.024	0.015	0.415	0.024	0.200	0.013
Beans, dried*	0.165	0.167	0.189	1.428	0.453	0.007	0.214
Beans, dried†	0.157	0.151	0.193	1.162	0.497	0.030	0.220
Beans, lima, dried†	0.071	0.187	0.245	1.743	0.336	0.025	0.160
Beans, lima, fresh†	0.029	0.066	0.089	0.581	0.118	0.009	0.060
Beets†	0.021	0.020	0.074	0.374	0.039	0.040	0.015
Cabbage*	0.049	0.014	0.020	0.243	0.027	0.013	0.067
Cabbage†	0.049	0.016	0.037	0.374	0.039	0.030	0.070
Carrots†	0.055	0.021	0.096	0.291	0.044	0.036	0.022
Cauliflower†	0.122	0.012	0.074	0.224	0.061	0.050	0.085
Celery†	0.071	0.024	0.082	0.307	0.044	0.170	0.025
Cherry juice†	0.018	0.012	0.015	0.125	0.013	0.004	0.006
Chestnuts†	0.029	0.048	0.037	0.415	0.087	0.010	0.068
Corn, sweet dried,†	0.021	0.121	0.148	0.415	0.349	0.050	0.160
Crackers*	0.050	0.059	0.580	0.117	0.111	0.857	0.193
Currants, dried†	0.036	0.024	0.015	0.208	0.044	0.010	0.010
Eel‡	0.039	0.018	0.032	0.241	0.177	0.035	0.135
Eggs†	0.067	0.009	0.148	0.137	0.161	0.100	0.190
Egg white†	0.011	0.009	0.155	0.158	0.013	0.150	0.196
Egg yolk†	0.143	0.012	0.074	0.108	0.044	0.100	0.157
Fish, haddock‡	0.022	0.017	0.099	0.335	0.137	0.241	0.223
Fish, pike‡	0.040	0.031	0.029	0.416	0.213	0.032	0.218
Lemons†	0.036	0.006	0.007	0.174	0.009	0.010	0.012
Lettuce†	0.036	0.006	0.030	0.348	0.039	0.060	0.014
Meat, beef, lean I*	0.014	0.035	0.085	0.359	0.210	0.061	0.237
Meat, beef, lean II*	0.016	0.024	0.082	0.341	0.193	0.048	0.214
Meat, beef, lean†	0.008	0.024	0.067	0.348	0.218	0.050	0.200
Meat, beef, lean‡	0.002	0.024	0.065	0.366	0.170	0.057	0.187
Meat, chicken‡	0.011	0.037	0.095	0.465	0.258	0.060	0.292
Meat, frog‡	0.016	0.024	0.055	0.308	0.186	0.040	0.163
Meat, pork, lean‡	0.008	0.028	0.156	0.254	0.213	0.048	0.204
Meat, rabbit‡	0.018	0.029	0.046	0.398	0.253	0.051	0.199

* Data determined in this laboratory.

† Data partly compiled, partly determined in this laboratory.

‡ Data published by Katz.

TABLE I—Continued.

ARTICLE OF FOOD	CALCIUM	MAGNESIUM	SODIUM	POTASSIUM	PHOSPHORUS	CHLORINE	SULPHUR
	percent.	*percent.*	*percent.*	*percent.*	*percent.*	*percent.*	*percent.*
Meat, veal‡	0.014	0.030	0.086	0.380	0.220	0.067	0.226
Meat, venison‡	0.010	0.029	0.070	0.336	0.249	0.041	0.211
Milk, cow's*	0.124	0.011	0.069	0.154	0.092	0.091	0.031
Milk, cow's†	0.120	0.011	0.051	0.142	0.094	0.120	0.033
Muskmelon†	0.017	0.012	0.061	0.235	0.015	0.041	0.014
Oatmeal*	0.060	0.143	0.072	0.365	0.402	0.027	0.215
Oatmeal†	0.093	0.127	0.081	0.380	0.380	0.035	0.215
Oranges†	0.043	0.012	0.007	0.183	0.022	0.010	0.013
Peaches†	0.007	0.012	0.015	0.208	0.020	0.010	0.010
Peanuts†	0.071	0.169	0.052	0.706	0.392	0.040	0.243
Peas, dried*	0.139	0.150	0.072	0.940	0.370	0.034	0.264
Peas, dried†	0.100	0.145	0.118	0.880	0.397	0.040	0.230
Potatoes I*	0.006	0.022	0.048	0.403	0.042	0.059	0.042
Potatoes II*	0.009	0.027	0.043	0.431	0.047	0.094	0.043
Potatoes†	0.011	0.022	0.019	0.440	0.061	0.030	0.030
Prunes*	0.038	0.046	0.101	0.845	0.080	0.004	0.032
Prunes†	0.043	0.048	0.074	0.996	0.109	0.010	0.030
Radishes†	0.036	0.012	0.082	0.141	0.039	0.050	0.050
Raisins†	0.057	0.009	0.141	0.830	0.126	0.070	0.060
Raspberry juice†	0.021	0.018	0.007	0.141	0.013	0.010	0.007
Rice I*	0.018	0.058	0.109	0.104	0.110	0.133	0.170
Rice II*	0.022	0.044	0.025	0.070	0.080	0.075	0.118
Rice†	0.008	0.027	0.021	0.068	0.089	0.050	0.105
Turnips*	0.023	0.009	0.067	0.101	0.021	0.018	0.046
Turnips†	0.064	0.169	0.059	0.332	0.051	0.040	0.070
Wheat, entire*	0.044	0.170	0.106	0.515	0.469	0.088	0.174
Wheat, entire†	0.044	0.128	0.051	0.431	0.393	0.080	0.170
Wheat, flour*	0.026	0.030	0.069	0.146	0.086	0.076	0.206

* Data determined in this laboratory.
† Data partly compiled, partly determined in this laboratory.
‡ Data published by Katz.

cluding fish) examined show decided excess of acid-forming elements. The meats of different species or of young and mature animals of the same species show very similar results in this respect. The acid-forming elements also predominate in eggs though to a somewhat less degree than in lean meats. Grain products show a much smaller predominance of the acid-forming elements than do meats and eggs when compared on the 100

TABLE 2.

Excess of acid-forming or base-forming elements, calculated from Table 1

ARTICLE OF FOOD	EXCESS ACID OR BASE IN TERMS OF NORMAL SOLUTIONS			
	Per 100 grams		Per 100 calories	
	Acid	Base	Acid	Base
	cc.	*cc.*	*cc.*	*cc.*
Almonds*		12.38		1.86
Almonds†		11.76		1.76
Apples†		3.76		5.98
Asparagus†		0.81		3.65
Bananas†		5.56		5.62
Beans, dried*		23.87		6.92
Beans, dried†		11.58		3.36
Beans, lima, dried†		41.65		12.08
Beets†		10.86		23.57
Cabbage*		4.34		13.76
Cabbage†		7.10		22.51
Carrots†		10.82		23.91
Cauliflower†		5.33		17.48
Celery†		7.78		42.17
Cherry juice†		4.40		
Chestnuts†		7.42		3.19
Corn, sweet, dried†	5.95		1.77	
Crackers*	7.81		1.95	
Currants, dried†		5.97		1.85
Eel‡	9.89		**	
Eggs†	11.10		7.55	
Egg white†	5.24		9.52	
Egg yolk†	26.69		7.08	
Fish, haddock‡	16.07		**	
Fish, pike‡	11.81		**	
Lemons†		5.45		12.32
Lettuce†		7.37		38.69
Meat, beef, lean, I*	13.91		12.10	
Meat, beef, lean, II*	10.05		8.74	
Meat, beef, lean,†	12.00		10.44	
Meat, beef, lean,‡	13.67		11.89	
Meat, chicken‡	17.01		**	
Meat, frog‡	10.36		**	
Meat, pork, lean‡	11.87		**	

* Data determined in this laboratory.

† Data partly compiled, partly determined in this laboratory.

‡ Data published by Katz.

** Data insufficient to permit calculation of acid to calorie basis.

TABLE II—Continued.

ARTICLE OF FOOD	EXCESS ACID OR BASE IN TERMS OF NORMAL SOLUTIONS			
	Per 100 grams		Per 100 calories	
	Acid	Base	Acid	Base
	cc.	*cc.*	*cc.*	*cc.*
Meat, rabbit‡	14.80		**	
Meat, veal‡	13.52		**	
Meat, venison‡	15.83		**	
Milk, cow's*		2.37		3.44
Milk, cow's†		1.26		1.83
Muskmelon†		7.47		18.82
Oatmeal*	12.93		3.23	
Oatmeal†	10.63		2.66	
Oranges†		5.61		10.94
Peaches†		5.04		12.20
Peanuts†	3.9		0.70	
Peas, dried*		7.07		1.98
Peas, dried†		3.36		0.94
Potatoes I*		7.19		8.63
Potatoes II*		5.5		
Potatoes†		7.72		9.26
Prunes*		24.40		8.05
Prunes†		25.55		8.43
Radishes†		2.87		9.79
Raisins†		23.68		6.87
Raspberry juice†		4.91		
Rice I*	8.1		3.35	
Rice II*	7.08		2.05	
Rice†	8.35		2.42	
Turnips*		2.68		6.86
Turnips†		6.80††		9.41
Wheat, entire*	9.66		3.25	
Wheat, entire†	12.39		3.47	
Wheat, flour*	11.61		2.70	

*Data determined in this laboratory.
† Data partly compiled, partly determined in this laboratory.
‡ Data published by Katz.
** Data insufficient to permit calculation of acid to calorie basis.
†† Possible loss of sulphur compounds in drying previous to analysis.

calorie basis or on the basis of dry matter. Milk shows a slight predominance of bases. In vegetables and fruits the predominance of bases is usually much greater, a 100 calorie portion of potato for example furnishing enough bases to almost exactly neutralize the excess of acids from a 100 calorie portion of lean beef. The few nuts so far examined yield different results, the peanuts showing an excess of acid-forming elements while the base-forming elements predominate in almonds and chestnuts. It will be of interest to study other edible nuts and to determine whether the partial or complete substitution of nuts for meat produces a marked effect upon the balance of acid-forming and base-forming elements in the diet as a whole.

METABOLISM EXPERIMENTS.

In addition to the determination of the balance of acid-forming and base-forming elements in a variety of foods our investigation was planned to include a study of the extent to which the acid arising from oxidation of an "acid-forming" food is neutralized by ammonia when such a food is metabolized in the human body. It was desired to study this point upon a healthy man with ordinary articles of food avoiding any extremes of diet or any unusual condition which might interfere with the normal working of the neutralizing mechanism.

First Experiment:—A healthy man (A. O. G.) twenty-seven years old, 5 feet 7 inches (1.70 meters) high, weighing 142 pounds (64.5 kilograms) took for ten days (November 27 to December 7, 1910) a diet which was uniform throughout except that during the first four and the last two days it contained 340 grams of potato while from the fifth to the eighth day inclusive the potato was replaced by amount of rice (80 grams weighed dry) sufficient to furnish approximately the same energy value (about 300 calories). Since 340 grams of the potatoes here used furnished an excess of base-forming over acid-forming elements equivalent to 15 cc. of normal base while 80 grams of the rice contained an excess of acid-forming elements equivalent to 6.7 cc. of normal acid, the change in diet corresponded to the production in the body of 21.7 cc. of normal acid per day. Beginning with the third day of the experiment the urine was collected in 24 hour samples, carefully preserved to prevent ammoniacal fermentation, and the ammonia content of each day's urine was determined by Folin's method. The total nitrogen of the urine was also determined.

The numerical data of this experiment are briefly summarized in Table 3.

TABLE 3.

Average data of first metabolism experiment.

INTAKE PER DAY	DIET WITH POTATOES	DIET WITH RICE	DIET WITH POTATOES
	Third and fourth days	Fifth to eighth days	Ninth and tenth days
Lean beef	228 grams	228 grams	228 grams
Butter	142 grams	142 grams	142 grams
Biscuit (dry)	130 grams	130 grams	130 grams
Almonds	60 grams	60 grams	60 grams
Salt	6 grams	6 grams	6 grams
Sugar	50 grams	50 grams	50 grams
Tea	3 cups	3 cups	3 cups
Potato	340 grams		340 grams
Rice		80 grams	
Estimated calories	2780	2773	2780
Estimated excess acid-forming elements in terms of normal solution	11.0 cc.	32.7 cc.	11.0 cc.
OUTPUT IN URINE—AVERAGE PER DAY			
Nitrogen	12.4 grams	10.9 grams	10.3 grams
Ammonia	0.43 grams	0.52 grams	0.43 grams
Ammonia in terms of normal solution	25.1 cc.	30.5 cc.	25.3 cc.

It will be seen that in this experiment a change in diet which increased the excess of acid-forming elements in the daily food by the equivalent of 21.7 cc. of a normal solution, caused a rise in the daily ammonia excretion corresponding to only 5.4 cc. normal solution. In other words only one-fourth of the extra acid estimated as introduced into metabolism by the change in diet was neutralized by ammonia and eliminated as ammonia salt.

The agreement of results in the first and third periods and the regularity of the data for the individual days (not shown in the condensed table) of the second period make it evident that the relatively small part played by ammonia in the neutralization of the acid cannot be attributed to "lag" in the response of the ammonia metabolism to the change in diet. The response was prompt, both in changing from potato to rice and from rice to potato, but it accounts for only the smaller part of the acid involved.

Second Experiment:—The subject and general plan were the same as in the preceding experiment but the analyses were much more detailed. Each of the seven elements concerned in the balance of acids and bases was determined in each article of food and in the urine from each diet, and each day's urine was also analyzed for neutral or unoxidized sulphur, total nitrogen, and total acidity (by the usual method, with phenolphthalein as indicator) as well as for ammonia. This experiment covered two preliminary and nine experimental days, the latter in three consecutive periods of three days each during which the subject maintained a uniform daily schedule as follows: Arose at 7 a.m. reached laboratory at 8.30, prepared breakfast; at 9 a.m. emptied bladder, and began experimental day with first meal, after which did analytical work in laboratory until 1 p.m., then took second meal and worked in laboratory till 6 p.m., then took third meal and worked again in laboratory until 9 p.m., retired at 10.30 p.m. and slept eight and one-half hours. One liter of water was taken daily in portions of 200 cc. at 10 a.m., 3, 5, 7 and 9 p.m. Somewhat larger amounts of meat, butter and sugar were taken than in the preceding experiment.

The averaged numerical data of this experiment are shown in Table 4.

In this case the change of diet corresponded to an increase of the excess of acid-forming elements equivalent to 28.1 cc. normal acid when estimated directly from the amounts of elements in the foods or to 32.7 cc. normal acid when allowance is made for the unoxidized sulphur of the urine from each diet. Of this the increased ammonia excretion accounts for 10.7 cc. or about one-

TABLE 4.

Average data of second metabolism experiment.

INTAKE PER DAY	DIET WITH POTATO	DIET WITH RICE	DIET WITH POTATO
	First, second and third days	Fourth, fifth and sixth days	Seventh, eighth and ninth days
Lean beef	270 grams	270 grams	270 grams
Butter	150 grams	150 grams	150 grams
Biscuit (dry)	130 grams	130 grams	130
Almonds	60 grams	60 grams	60 grams
Salt	4.2 grams	4.2 grams	4.2 grams
Sugar	80 grams	80 grams	80 grams
Tea	3 cups	3 cups	3 cups
Potato	340 grams		340 grams
Rice		80 grams	
Estimated calories	3011	3004	3011
Calcium	0.38 grams	0.37 grams	0.38 grams
Magnesium	0.48 grams	0.42 grams	0.48 grams
Sodium	4.79 grams	4.66 grams	4.79 grams
Potassium	3.07 grams	1.66 grams	3.07 grams
Phosphorus	1.22 grams	1.12 grams	1.22 grams
Chlorine	7.55 grams	7.29 grams	7.55 grams
Sulphur	1.25 grams	1.20 grams	1.25 grams
Estimated excess acid-forming elements in terms of normal solution	21.9 cc.	52.0 cc.	21.9 cc.
Excess of acid-forming elements estimated after deducting for unoxidized sulphur in urine	9.4 cc.	42.1 cc.	9.4 cc.
OUTPUT IN URINE—AVERAGE PER DAY			
Nitrogen	12.9 grams	12.3 grams	12.5 grams
Calcium	0.20 grams	0.22 grams	0.22 grams
Magnesium	0.11 grams	0.11 grams	0.12 grams
Sodium	4.72 grams	3.96 grams	
Potassium	2.32 grams	1.32 grams	
Phosphorus	0.74 grams	0.75 grams	
Chlorine	5.85 grams	5.27 grams	
Sulphur, total	0.94 grams	0.82 grams	0.86 grams
Sulphur, as sulphate	0.74 grams	0.71 grams	0.74 grams
Ammonia	0.41 grams	0.59 grams	*
Ammonia in terms of normal solution	23.8 cc.	34.5 cc.	*
Acidity in terms of normal solution	21.4 cc.	34.1 cc.	*

* See table 5.

third, while the increased acidity of the urine accounts for 12.7 cc. or about two-fifths.[3]

In view of the fact that there has been a tendency to regard increased ammonia output as a test and measure of surplus acid production in the tissues it is interesting to note that in this experiment the increased acidity of the urine played a larger part in the acid elimination than did the increased ammonia output.

It is also worthy of note that the total phosphorus of the urine was not increased, indicating that the extra acid produced in metabolism did not, under the conditions of this experiment, have the effect of robbing the body of phosphates. Neither was there any marked change in the output of fixed bases beyond that which may readily be attributed to the differing amounts in the two diets.

Some additional points of interest are suggested by an examination of the acidity and ammonia of the urine for the individual days of this experiment as shown in Table 5.

It will be seen that on passing from the diet with potato to that with rice the output of ammonia and the acidity of the urine rose immediately, the first day on the rice diet showing essentially the same results as the second and third days; but on changing back from rice to potato the urine did not regain the characteristics of the potato diet until the second day. This may be accidental but if interpreted at face value it would imply that the body responded very quickly to the intake of an acid-forming diet but did not with equal rapidity return to the more normal metabolism when the more normal diet was resumed.[4]

[3] To determine quantitatively how the body disposed of the acid not accounted for by the increased ammonia and the increased acidity of the urine would lead beyond the scope of this investigation. The possibility of excretion through the intestine is recognized. Analysis of the feces passed on one of the days on each diet showed a difference in balance of acid-forming and base-forming elements which, if accurately representative of the entire periods, would account for most of the excess not accounted for by the ammonia and acidity of the urine. Loss of the feces of the other days through an accident in the laboratory prevented further study of this point. It is possible that a quantitative collection and analysis of the perspiration might also throw light upon the fate of that fraction of the acid produced in metabolism which is not accounted for by the urine.

[4] If the difference in acidity and ammonia between the urines of Febru-

TABLE 5.

Total nitrogen, ammonia and acidity of urine of each day in second metabolism experiment.

	DATE	TOTAL NITROGEN	AMMONIA	ACIDITY
		grams	*grams*	*cc. normal acid*
Diet with potato..	February 21	12.33	0.39	21.7
	February 22	13.06	0.41	17.7
	February 23	13.17	0.41	24.7
Diet with rice.....	February 24	13.12	0.58	34.6
	February 25	12.03	0.59	36.7
	February 26	11.77	0.59	31.0
Diet with potato..	February 27	11.60	0.49	30.6
	February 28	13.36	0.41	21.8
	March 1	12.64	0.44	30.5

On the last experimental day (March 1, 1911) the division of the food into meals was changed and a part of the meat was eaten at breakfast while all of the potato was eaten at luncheon and dinner. This separation of the principal acid-forming from the principal base-forming food was accompanied by an increased urinary acidity and ammonia output on this day as compared with the preceding day or with the first period when the diet was the same but the meat was always eaten in the same meal with potato. No conclusion should be drawn from the metabolism of a single day but it may not be out of place to suggest that the obvious interpretation of this result (if confirmed by further investigation) would be that in order to obtain the full physiological effect of a balancing of acid-forming and base-forming elements, the foods which contain a marked excess of acid-forming elements should be balanced in each meal by foods in which base-forming elements predominate.

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ary 27 and 28 be considered as due to the elimination of acid brought into metabolism by the diet of the preceding days, the relative importance of urinary acidity and ammonia output remain unchanged but the total amount of acid accounted for by the urine is somewhat increased and the estimate of the amount otherwise disposed of becomes smaller.

SUMMARY.

The balance of acid-forming and base-forming elements has been estimated from sixty-three ash analyses representing forty-seven different kinds of food, and expressed as surplus acid or base in terms of cubic centimeters of a normal solution per 100 grams and 100 calories of edible material.

The meats (including fish) show decided predominance of acid-forming elements. The results are very similar for the lean flesh of different species or of young and mature animals of the same species.

The acid-forming elements also predominate in eggs though to a somewhat less degree than in lean meats.

When compared on the basis of dry matter or of the 100 calorie portion, grain products show a much smaller predominance of acid-forming elements than do meats and eggs.

Milk shows a slight predominance of base-forming elements.

Vegetables and fruits show a predominance of base-forming elements, usually much greater than in milk.

In two experiments each of several days duration a healthy man took first an ordinary mixed diet containing sufficient potato to furnish about 300 calories or about one-tenth the total value of the diet, then replaced the potato with rice of the same energy value, and later replaced the rice by potato. The change from potato to rice diet involved an alteration of the estimated balance of acid-forming to base-forming elements equivalent to the introduction of 21.7 cc. of normal acid per day in the first experiment and 32.7 cc. in the second.

The ammonia excretion increased in the first case about 21 per cent and in the second about 44 per cent, but this increase was sufficient only to account for one-fourth to one-third of the acid involved.

In the second experiment, the acidity of the urine was also determined and the effect of the change of diet noted. The acidity of urine increased about 51 per cent and was found to account for a greater proportion of the acid than was accounted for by the ammonia elimination.

In this experiment the increased acidity was not accompanied by any increase in the total phosphorus in the urine.

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