N H Alexander

6

ON THE NATURAL CONSTANTS

OF THE

HEALTHY URINE OF MAN,

AND

A THEORY OF WORK FOUNDED THEREON.

BY

THE REV. SAMUEL HAUGHTON, M.A., F.R.S.,

FELLOW OF TRINITY COLLEGE, DUBLIN.

READ BEFORE THE ASSOCIATION OF THE KING AND QUEEN'S COLLEGE OF PHYSICIANS.

DUBLIN:
PRINTED AT THE UNIVERSITY PRESS,
BY M. H. GILL.
1860.

ON THE NATURAL CONSTANTS

OF THE

HEALTHY URINE OF MAN,

AND

A THEORY OF WORK FOUNDED THEREON.

BY

THE REV. SAMUEL HAUGHTON, M. A., F. R. S.,

FELLOW OF TRINITY COLLEGE, DUBLIN.

READ BEFORE THE ASSOCIATION OF THE KING AND QUEEN'S COLLEGE OF PHYSICIANS.

DUBLIN:
PRINTED AT THE UNIVERSITY PRESS,
BY M. H. GILL.
1860.

[From the Dublin Quarterly Journal of Medical Science, Aug. 1859; and Aug. 1860.]

CONTENTS.

		Page.
1.	Division of Excretions and Work,	2
2.	Daily Excretion of Urea, according to former Writers,	3
3.	Excretion of Urea by Beef-eaters,	5
4.	,, ,, Vegetarians,	6
5.	Parabolic Curve of Urea,	9
6.	Urea excreted by Sheep,	10
7.	Urea found after death in the Pericardium,	10
8.	Daily Excretion of Uric and Hippuric Acid,	11
9.	Daily Excretion of Phosphoric Acid,	12, 13
10.	Excretion of Phosphoric Acid, not due to the Disintegration of the Nervous Centres,	13, 14
11.	Analyses of Food,	19, 20
12.	Comparison of Nitrogen, ingested and excreted,	22
13.	Similar Comparison, by M. Barral,	23
14.	Coefficient of Vital Work (or number of Grains of Urea excreted requisite to keep 150 pounds weight of Man alive) determined,	27
15.	Coefficient of Mechanical Work found,	28
16.	Coefficient of Mental Work (Study),	32
17.	Coefficient of Mental Work (Routine),	32
18.	General Conclusions,	33, 34

ON THE NATURAL CONSTANTS

OF

THE HEALTHY URINE OF MAN,

&c. &c.

THE following investigation was suggested to me by a remark of Bernouilli, to the effect that the total quantity of work of which a healthy man was capable appeared to him to be constant, no matter in what description of labour he was employed. The facts, as he understood them, were against this view: and he was forced reluctantly to give up his opinion. Before I read the opinion of this great man, I had arrived, from reflection and observation, at a similar result; and I think good reasons may be assigned, in the present state of our chemical knowledge, for a reasonable belief in this opinion. It is generally believed that the daily food we consume undergoes a process of oxidation before it is finally removed as waste matter from the system. This may be, and doubtless is, far from the whole truth; but, as far as it goes, it is true, and its investigation to its legitimate consequences must lead to correct views of nutrition and labour. It occurred to me that the natural and proper measure of the value of a given diet was the amount of work it would produce in a healthy animal, such as man. This was Bernouilli's idea, but he applied it simply to mechanical labour of which man was capable, and so fell into error, natural to the deficient knowledge of his time.

The following appears to be a juster view of the subject:—

1. A man in health consumes, per day, a certain amount of food and drink, and excretes per day an equal amount of waste

[a] See vol. xxvii. p. 374.

matter, supposing him to be full grown, in good health, and not gaining or losing flesh:—

2. The excretions are effected in four ways: *per halitum, per cutem, per vesicam, per anum,* and are more highly oxidated than the food and drink consumed.

3. The difference of oxidation of the *ingesta* and *excreta,* converted into work, should account for, and be equal to, the total labour effected per diem.

4. The work done per day may be divided into—

a. The effort necessary to live, or the work spent on the performance of organic functions—*Opera vitalia.*

b. The work, converted into heat, requisite to keep up the animal temperature—*Opera calorifica.*

c. The mechanical work effected by bodily labour—*Opera mechanica.*

d. The unknown, and hitherto unmeasured, work done by the mind—*Opera mentalia.*

It is an opinion of physiologists, and appears to be well founded, that the animal heat is fully accounted for by the oxidation of food effected *per halitum.* There remain, therefore, three excretions to consider, and three kinds of work to account for by their means, viz.:—

Excreta.—1. Per cutem; 2. Per vesicam; 3. Per anum.

Opera.—1. Vitalia; 2. Mechanica; 3. Mentalia.

I shall not attempt, in this communication, to discuss the general question, but shall confine myself to those subjects on which I have experimented directly, viz., the excretions *per vesicam*, and the mechanical labour of body, and work of mind, of which man is capable.

My experiments on urine were all made on the urine of healthy men, and were directed chiefly to the determination of the daily quantities of nitrogen and phosphorus excreted. I was forced into this course of chemical experiments by finding, in various authorities consulted by me, the most various estimates of a quantitative character relative to these subjects. For the convenience of reference, I shall divide my paper into four parts:—

I. The daily discharge of urea in healthy urine of man.

II. The daily discharge of uric acid in healthy urine of man.

III. The daily discharge of phosphoric acid in healthy urine of man.

IV. Comparison of the foregoing with the daily work, bodily and mental, and with the daily food, of man.

Part I.—*The daily discharge of Urea in healthy Urine of Man.*

The earlier writers on this subject refer the quantity of urea either to the fluid ounce, or to 1000 parts: both of these modes of estimating urea have been properly discarded by later writers, who estimate the quantity of urea discharged per twenty-four hours, considering this to be the natural period of man's cycle of labour, food, and rest.

The English medical writer on Urine who appears to be held in most repute is the late Dr Golding Bird, whose work has passed through five editions. He does not appear to have ever made any experiments himself, but is content to quote[a] from Becquerel's work.

I.—*Daily Urea.*

Daily urea of man, ...	270 grains.
Daily urea of woman, ...	240 ,,

The following determinations of urea in 1000 parts have been given by other writers:—

II.—*Urea in* 1000 *Grains.*

Berzelius, ...	30·10	grains.	
Lehmann, ...	31·45	,,	
Ditto, ...	32·91	,,	
Ditto, ...	32·90	,,	
Becquerel (man), ...	13·84	,,	1019 sp.gr.
Ditto (woman), ...	10·36	,,	1015 ,,
Simon, ...	12·46	,,	1011 ,,
Ditto, ...	14·58	,,	1012 ,,

The discrepancies in the foregoing results show that it is absolutely necessary to fix upon some standard of comparison, such as the total quantity per twenty-four hours; otherwise our results will be vitiated by the drinking of a glass or two more or less of water per day, and by other trivial causes. Lehmann's three results are stated to be derived from twenty-four hours' urine of a well-fed and healthy young man, but the total quantity passed is not stated.

[a] Fifth Edition, page 75.

Elsewhere M. Lehmann obtained the following interesting results from experiments made on himself:—

III.—*Urea per* 24 *Hours of M. Lehmann.*

Animal Diet.	Mixed Diet.	Vegetable Diet.	Non-Nitrogenous Diet.
821 grs.	501½ grs.	347 grs.	238 grs.

The following results, given by M. Lecanu, are also referred to a period of twenty-four hours:—

IV.—*Urea per* 24 *Hours, determined by M. Lecanu.*

Adult men, ...	431·9 grs.
Adult women, ...	294·2 „
Very old men (84–86), ...	124·8 „
Children (under 8), ...	138·2 „

Bischoff also has determined the daily quantity of urea passed by a well-fed man, of thirty-one years of age.

V.—*Urea per* 24 *Hours, at* 31 *Years of Age, by M. Bischoff.*

Urea, ... 585 grs.

On the preceding Tables the following remarks may be made:—

No. I. is to be rejected altogether, as it is totally erroneous by defect, and the deficiency must have arisen from the use of some imperfect method of determining the urea, such as by the nitrate or oxalate.

No. II. is unintelligible without a statement of the total quantity of urine passed per day in each case.

No. III. I believe to be excellent, as far as it goes, but it rests upon experiments made upon a single individual.

No. IV. omits to state the diet of the individuals experimented upon, and is, therefore, less interesting than it would otherwise have been.

No. V. agrees admirably with my own results.

The foregoing summary contains, I believe, all that was known on this subject at the time I commenced my experiments, which I should never have undertaken had I found it possible to obtain reliable information in the books.

I made some preliminary trials as to the various methods in use among chemists for the determination of urea quantitatively, and found Liebig's volumetric process, by means of nitrate of mercury, to give the most accurate and consistent results.

Having decided on the mode of analysis to be employed, I divided my subjects for experiment into two classes:—

1. Well-fed, flesh-eating, wine-drinking men.
2. Well-fed, water-drinking vegetarians.

The following Tables contain the result of my experiments:—

Table A.—*Beef-eaters.*

No.	Urea, per Day.	Urine, per Day.	Specific Gravity.	Urea, per fluid ℥.	Solids, per Day.
	Grains.	Ounces.		Grains.	Grains.
1	465·09	34	1023·8	13·70	817·25
2	677·25	62	1019·0	10·11	1065·69
3	644·62	52	1018·5	12·40	998·55
4	554·00	50	1015·8	11·08	818·00
5	630·00	45	1028·2	14·00	1330·20
6	484·30	41	1024·8	11·81	1051·25
Mean,	**575.87**	**47.3**	**1021.7**	**12.18**	**1013.49**

No. 1. Age, 37; weight, 126 lbs.; occupation, walks 5 miles per day, studies 5 hours per day; food, 8 oz. fresh meat; 8 oz. white bread; 10 oz. vegetables.

No. 2. Age,. 35; weight, 126 lbs.; occupation, partridge-shooting, office-work 3 hours, anxious about business matters; food, mixed diet.

No. 3. Age, 19; weight, 126 lbs.; occupation, studies 5 hours; walking and athletic games, 2 hours; won the prize for the long jump at the Trinity College Foot Races; food, mixed.

No. 4. Age, 39; weight, 174 lbs.; occupation, walks 2 miles, office-work, 6 hours; food, mixed.

No. 5. Age, 40; weight, 189 lbs.; occupation, walks 4 miles, studies 4 hours; food, mixed.

No. 6. Age, 40; weight, 145 lbs.; occupation, walks 5 miles, studies 2 hours; food, mixed.

From the preceding results it follows that 576 grains of urea per day is the natural discharge, *per vesicam*, of the class of men experimented upon. This agrees with Bischoff's and Lehmann's experiments made upon themselves.

I shall make no observation at present on the range from 100 grains below to 100 grains above the average, as I do not believe it to depend on any single circumstance, such as weight, bodily exercise, &c., but upon a combination of circumstances which I hope fully to discuss in the concluding part of this paper.

I have also to add that every one of these specimens of urine gave, on the addition of nitric acid, at 50° Fahr., after standing twenty-four hours, a precipitate of crystals of nitrate of urea. This circumstance I do not believe to be a proper test of excess of urea in urine.

The following Table contains the corresponding results of my experiments on vegetarians:—

Table B.—*Vegetarians.*

No.	Urea, per Day.	Urine, per Day.	Specific Gravity.	Urea, per fluid ℥.	Solids, per Day.
	Grains.	Ounces.		Grains.	Grains.
1	367·50	70	1014·00	5·25	1012·90
2	578·81	81	1014·76	7·14	1236·87
3	315·00	45	1015·23	7·00	712·50
4	366·12	56	1012·41	6·54	717·08
5	342·55	43	1017·17	7·87	775·60
Mean,	**393.99**	**59**	**1014.71**	**6.76**	**890.99**

No. 1. Age, 63; weight, 173 lbs.; occupation, walks 3 miles per day, office-work 1 hour; food, 1 egg, 6 oz. bread, vegetables *ad lib.*, 16 fl. ℥ milk, 40 fl ℥. water.

No. 2. William Wall, 16th Regt. (2nd Battalion), in Military Prison, Dublin. Age, 22; weight, 132 lbs.; occupation, 3 hours' shot drill, 1¼ hour ordinary drill, 3½ hours oakum picking; food, breakfast, 8 oz. oatmeal, ½ pint of milk,—dinner, 9 oz. Indian meal, ½ pint of milk,—supper, 8 oz. of bread, ½ pint of milk.

No. 3. William Tysack, Military Train, in Military Prison, Dublin. Age, 31; weight, 146 lbs.; occupation and food, same as last.

No. 4. Thomas M'Donald, 18th Regt. (2nd Battalion), in

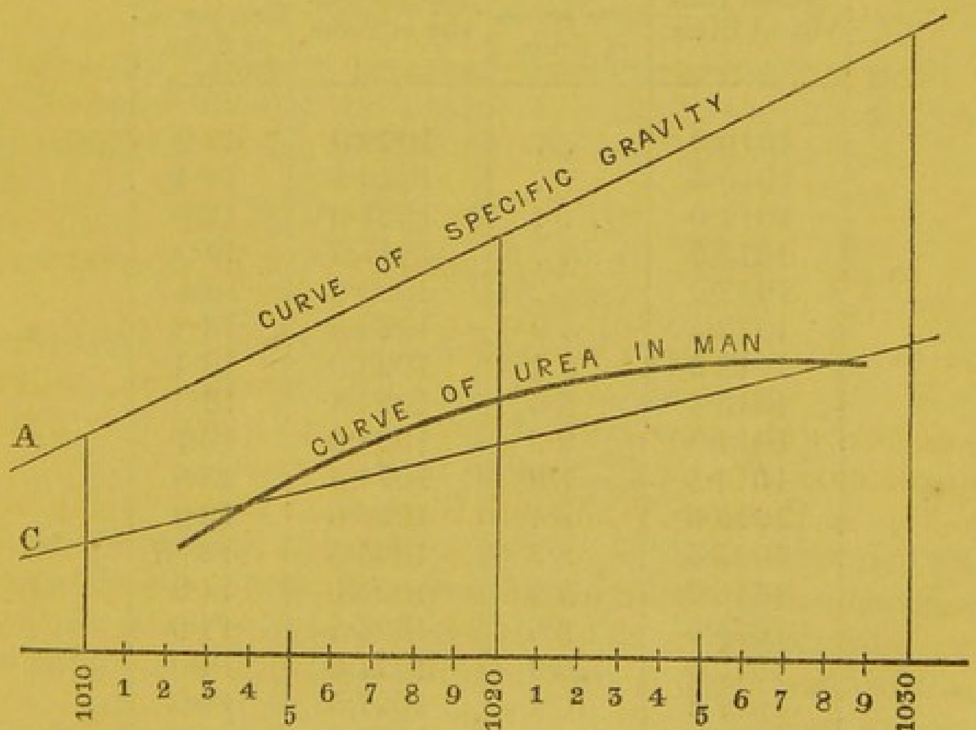
Military Prison, Dublin; age, 22; weight, 146 lbs.; occupation and food, same as last.

No. 5. Same man as No. 3, a fortnight subsequent.

From the preceding, it follows that 394 grains is the natural discharge of urea from a well-fed vegetarian per day. No. 2 appears to be exceptional, and above the usual average; but, even allowing for this, it would appear that the average for vegetarians is considerably above what is considered usually by medical men in this country as the proper average of well-fed men, on the authority of Golding Bird. It is quite certain that a physician, applying Bird's rule in his private practice, would, probably, pronounce 90 well-fed men, out of every 100 who consulted him, to be labouring under diabetes insipidus: although, from the foregoing experiments, they should be entitled to be considered as in the enjoyment of excellent health.

I shall now attempt to connect the quantity of urea in healthy urine with the specific gravity.

The result of all my experiments is shown in the annexed diagram, in which the base line represents the specific gravity, and the vertical ordinates, the number of grains per fl. ℥, either of solids or urea.



The right line A, marked *Curve of specific gravity*, is drawn by making the ordinate equal the abscissa, minus 1000; thus, 1015 sp. gr. has an ordinate of 15 units measured off; 1020 sp. gr. has an ordinate of 20, and so on.

The line C is formed by dividing the ordinates of the line A in half; and the *curve of urea in man* is formed by taking for each specific gravity observed, an ordinate equal to the number of grains of urea per fl. ℥ corresponding.

This curve of urea intersects the line dividing the ordinates of the curve of specific gravity in half, at points corresponding to the specific gravities 1014 and 1028. If, therefore, the specific gravity of healthy urine be 1014 or 1028, the number of grains of urea per fl. ℥ will be 7 or 14 respectively. For all specific gravities intermediate between these limits, the number of grains of urea per fl. ℥ will be *greater* than half the excess of the specific gravity above 1000; and for specific gravities *below* 1014 and *above* 1028, the number of grains of urea per fl. ℥ will be *less* than half the excess of specific gravity above 1000.

The following Table contains the summary of all my experiments on this subject:—

Table *derived from Experiment, showing the relation between the Specific Gravity of Healthy Urine, and the Quantity of Urea contained in it.*

Specific Gravity of Urine.	Grains of Urea per oz. of Urine.	Specific Gravity of Urine.	Grains of Urea per oz. of Urine.
1010·0	. . .	1020·0	12·2
1010·5	. . .	1020·5	12·4
1011·0	. . .	1021·0	12·6
1011·5	. . .	1021·5	12·9
1012·0	. . .	1022·0	13·1
1012·5	5·0	1022·5	13·3
1013·0	5·7	1023·0	13·4
1013·5	6·6	1023·5	13·5
1014·0	7·2	1024·0	13·7
1014·5	7·8	1024·5	13·8
1015·0	8·4	1025·0	13·9
1015·5	8·8	1025·5	13·95
1016·0	9·2	1026·0	14·0
1016·5	9·6	1026·5	14·0
1017·0	10·0	1027·0	14·0
1017·5	10·4	1027·5	14·0
1018·0	10·9	1028·0	14·0
1018·5	11·2	1028·5	13·95
1019·0	11·5	1029·0	13·9
1019·5	11·9	1029·5	. . .

It is evident from the diagram, p. 7, that the curve which represents the relation of the quantity of urea in healthy urine to the specific gravity of the latter is not a right line; or, in other words, that the quantity of urea is not *proportional* to the specific gravity.

The curve laid down in the diagram is a representation of the Table, and may be algebraically expressed by a parabolic curve, as follows:—

Let y denote the grains of urea per fl. ℥ in any specimen of urine, not containing either sugar or albumen; and let x denote the excess of specific gravity above 1000. Then,—

$$y = A + Bx + Cx^2. \qquad (1)$$

And, since when $x = 14$, $y = 7$; and when $x = 28$, $y = 14$; and the curve then reaches its highest point, it is easy to show that,—

$$\begin{aligned} A &= -14 \\ B &= 2 \\ C &= -\tfrac{1}{28} \end{aligned} \qquad (2)$$

From these values it can be shown that the curve of urea (1) may be put into the form,—

$$[28 - x]^2 = 28\,[14 - y], \qquad (3)$$

which is the equation of a parabola whose parameter is 28.

It is easy to verify this equation by the Table already given. For example, let the specific gravity be 1018, then we have,—

$$\begin{aligned} (28 - 18)^2 &= 28\,(14 - y) \\ 100 &= 28\,(14 - y) \\ y &= 10{\cdot}5 \text{ grs.} \end{aligned}$$

Let specific gravity $= 1024$, then,—

$$\begin{aligned} (28 - 24)^2 &= 28\,(14 - y) \\ 16 &= 28\,(14 - y) \\ y &= 13{\cdot}43 \text{ grs.} \end{aligned}$$

These results, and others similar to them, obtained from the parabolic curve (3), differ slightly from those found directly by experiment, and given in the Table, showing that the parabolic curve does not accurately represent the curve of urea; but it evidently does so within a degree of approximation much less than is required by medical men, for whose purposes the following bedside rule may prove quite sufficient:—"*Half the excess of the specific gravity of urine* (*not containing either sugar or albumen*), *above* 1000, *is the number of grains of urea per fluid* ℥."

This rule gives the line C, p. 7, for the curve of urea, with which it agrees at the specific gravities of 1014 and 1028.

The following determination of urea in sheep's urine may prove interesting, for comparison with the urine of man; the range of specific gravity is greater, and the proportion of urea to specific gravity is also greater:—

	Specific Gravity.	Urea, Grains, per fluid ℥.
Urine of ram, ...	1057·06	37·33
Urine of ewe, ...	1008·93	6·41

Before concluding this part of my paper relating to urea, I may add the following interesting facts, although they do not properly belong to the subject of healthy urine. I examined carefully for urea, having first got rid of albumen, the serous effusion of the pericardium of two subjects, both women, one of whom had died of Bright's disease, with dropsy; and the other had perfectly healthy kidneys. The result of the examination was as follows:—

	Grains, per fluid ℥.
1. Subject with diseased kidneys, . . .	3·05
2. Subject with healthy kidneys, . . .	1·31

The difference in the two cases is sufficiently striking, and the total quantity of urea in the dropsical effusion of No. 1 must have been very great; yet the quantity in the case No. 2 is also so large as to make us hesitate as to the conclusions to be drawn from the qualitative determination of the presence of urea found, on a post-mortem examination, in the pericardium, or in the ventricles of the brain.

Part II.—*The daily discharge of Uric Acid in healthy Urine of Man.*

The following Tables contain the results I obtained from my experiments, with respect to Uric and Hippuric acids. They are so different from those usually received that they would require explanation, which I should offer, were it not that I believe that both uric and hippuric acids are accidental in healthy urine, though the former is always found in small quantity; the latter, hippuric acid, occurred to me only once, though it was carefully sought in each case. When I say that uric acid is accidental in healthy urine, I do not mean to say that it occurs like chlorine and sulphuric acid, the quantity of which depends directly on the chloride of sodium, and sulphate of alumina and potash consumed with the food; but I do mean, that no uric acid whatever should occur in the urine of a man in perfect health, but that all the nitrogen of the urine should pass off in the form of urea, a more highly oxidated product than uric acid.

The following determinations of uric acid passed in twenty-four hours have been given:—

VI.—*Uric Acid discharged per Day.*

	Grains.
Becquerel,	8·10
Neubauer,	5·08
Ditto,	7·63
Lehmann,	18·17

It is stated by Liebig, that 7·5 grains of hippuric acid are discharged by the urine per day; this is quite at variance with my results, as will appear from the following Tables:—

Table C.—*Uric Acid per Day (Beef-eaters).*

No.	Grains per Day.
1,	1·02
2,	11·88
3,	1·04
4,	7·40
5,	5·29
6.	0·71
Mean,	**4.55**

Table D.—*Uric Acid per Day (Vegetarians).*

No.	Grains per Day.
1,	0·50
2,	0·71
3,	1·69 partly hippuric acid.
4,	2·48
5,	2·03 partly hippuric acid.
Mean,	**1.48**

When we consider that the quantity of urea passed by the persons considered in these Tables, per day, is 576 grains, and 394 grains, respectively, we may fairly consider the uric acid discharged simply in the light of a minute fraction of nitrogen, which has escaped complete oxidation, and as a matter rather of chemical than physiological interest.

The only case in which I detected hippuric acid was that of William Tysack (Nos. 3 and 5, Tables B and D). His urine had a remarkable smell, compounded of that of sweet hay and apple-juice, and differed in its sensible qualities from the other urines examined.

All the preceding experiments were made on not less than from 20 to 50 ounces of urine, and I am certain that all the uric acid was obtained.

Part III.— *The daily discharge of Phosphoric Acid in healthy Urine of Man.*

There is no subject respecting which more difference of opinion exists than with reference to Phosphoric acid eliminated by the kidneys; some investigators considering that it is as accidental in its character, and as dependent on food, as chlorine or sulphuric acid; while others regard it as the direct product of the disintegration of nervous tissue, and, as such, entitled to our regard as the measure of nervous work done by the system. In whatever point of view it is to be considered, it is obviously important to determine its daily amount in the case of healthy men, under different conditions as to food and work of mind and body. I therefore determined its absolute amount per day with much care; and, in my later experiments, ascertained also the proportion in which it occurred combined with alkalies, as well as that in which it was found in combination with lime and magnesia.

The following Tables are divided, as before, into the flesh-fed and vegetarian subjects:—

Table E.—*Discharge of Phosphoric Acid per Day* (*Beef-eaters*).

No.	Phosphoric Acid.	Weight.
	Grains.	lbs.
1	47·14	126
2	43·28	126
3	40·78	126
4	38·10	174
5	23·72	189
6	29·43	145
Mean,	**37.07**	

I have placed the weights of the several subjects in connexion with their respective discharges of phosphoric acid, and I think it will be admitted that there is no direct proportion between them, such as would be the case, were the discharge of phosphoric acid dependent simply on a waste of albuminous or other tissues proportional to the mass of the individual considered.

Table F.—*Discharge of Phosphoric Acid per Day* (*Vegetarians*).

No.	Total Phosphoric Acid.	In combination with Earths.	In combination with Alkalies.
	Grains.	Grains.	Grains.
1	30·00		
2	32·47	5·92	26·55
3	22·78		
4	27·54	6·30	21·24
5	20·70	3·46	17·24
Mean,	**26.70**	**5.23**	**21.67**

I have reason to believe that the proportion of phosphoric acid, in combination with alkalies, to that in combination with earths, given above, viz., 4 to 1, is the same in well-fed men as in vegetarians, and that it may be confidently used in drawing conclusions with respect to this subject.

To show how ill founded the idea is, that the waste of nervous matter in the system gives rise exclusively to the discharge of phosphoric acid, the following calculations may prove of some interest. Adopting Vauquelin's determination of the phosphorus in the brain at 1·5 per cent, and taking the weight of the brain and spinal cord from the most recent experiments, at 51 ounces, we find, the following chain to determine the total phosphoric acid existing in these nervous centres at any given moment:—

Term of demand, 1 man.
1 — 51 ℥ nervous matter.
1000 — 15 ℥ phosphorus.
32 — 72 ℥ phosphoric acid.
16 — 7000 grs. phosphoric acid.

= 753·04 grs.

This quantity of phosphoric acid in the nervous system of a well-fed man, discharging 37 grains per day, *per vesicam*, would only last for twenty days; and although the brain is better supplied with blood than any other portion of the body, it is quite incredible that the process of renovation can proceed at such a rate as to replace all its phosphorus in twenty days.

On the other hand, we may fairly conclude that only the phosphoric acid, in combination with lime and magnesia, can be considered as having its origin in the wear and tear of the bony tissue; and, assuming the average weight of bone-earth in a man of 150 lbs. to be 10 lbs., we find the following chain to determine the number of years in which his bones can be removed *per vesicam*, and replaced by suitable food:—

Term of demand,	1 man.
1	150 lbs.
150	10 lbs. bone earth.
156	72 lbs., PO_5.
1	7000 grs. PO_5.
5	1 day.
365	1 year.
	= 17·70 years.

Whatever may be thought of the idea that our bones are replaced in the manner here supposed, the result obtained is certainly less improbable than the former. I give them both, without attaching weight to them, as examples of the uses to which the analyses of healthy urine may be turned.

The following summary contains the results of my experiments on the eleven specimens of urine of twenty-four hours, examined by me. I made several careful determinations of the relation between specific gravity and the total quantity of solid matter per fluid ℥, and I found my experiments agree so closely with the Table published in Dr. Golding Bird's work, and deduced from Dr. Christison's formula, that I adopted the results of that Table in all my subsequent experiments.

Table G.—*Well-fed Beef-eaters.*

No. 1.

	Grains per Day.
1. Urea,	465·09
2. Uric acid,	1·02
3. Fixed salts, earthy,	23·46
,, alkaline,	214·54
4. Difference,	113·14
Total,	817·25
A. Chlorine,	26·30
B. Phosphoric acid,	47·14

Table G—*continued.*

No. 2.

	Grains per Day.
1. Urea, ...	677·25
2. Uric acid, ...	11·88
3. Fixed salts, earthy, ...	22·68
,, alkaline, . .	221·94
4. Difference, ...	131·94
Total, . .	1065·69
A. Chlorine, ...	49·42
B. Phosphoric acid, ...	43·28

No. 3.

1. Urea, ...	644·62
2. Uric acid, ...	1·04
3. Fixed salts, earthy, ...	11·96
,, alkaline, . .	222·04
4. Difference, ...	118·89
Total, . . .	998·55
A. Chlorine, ...	12·70
B. Phosphoric acid, . . .	40·78

No. 4.

1. Urea, ...	554·00
2. Uric acid, ...	7·40
3. Fixed salts, earthy, ...	15·00
,, alkaline, . .	145·00
4. Difference, ...	96·60
Total, . . .	818·00
A. Chlorine, ...	40·00
B. Phosphoric acid, . . .	38·10

No. 5.

1. Urea, ...	630·00
2. Uric acid, ...	5·29
3. Fixed salts, ...	405·00
4. Difference, ...	289·91
Total, . .	1330·20
A. Chlorine, ...	79·20
B. Phosphoric acid, . . .	23·72

TABLE G—*continued.*

No. 6.

	Grains per Day.
1. Urea,	484·30
2. Uric acid,	0·71
3. Fixed salts,	297·25
4. Difference,	268·99
Total,	1051·25
A. Chlorine,	36·08
B. Phosphoric acid,	29·43

TABLE H.—*Well-fed Vegetarians.*

No. 1.

1. Urea,	367·50
2. Uric acid,	0·50
3. Fixed salts, earthy,	20·30
,, alkaline,	364·00
4. Difference,	260·60
Total,	1012·90
A. Chlorine,	115·90
B. Phosphoric acid,	30·00

No. 2.

1. Urea,	578·81
2. Uric acid,	0·71
3. Fixed salts,	421·20
4. Difference,	236·15
Total,	1236·87
A. Sulphuric acid,	40·65
B. Phosphoric acid, with earths,	5·92
,, with alkalies,	26·55

No. 3.

1. Urea,	315·00
2. Uric acid,	1·69
3. Fixed salts,	261·00
4. Difference,	134·81
Total,	712·50
A. Sulphuric acid,	18·88
B. Phosphoric acid,	22·78

Table H—*continued.*

No. 4.

	Grains per Day.
1. Urea, ...	366·12
2. Uric acid, ...	2·48
3. Fixed salts, ...	249·20
4. Difference, ...	99·28
Total, ...	717·08
A. Sulphuric acid, ...	23·50
B. Phosphoric acid, with earths,	6·30
,, with alkalies,	21·24

No. 5.

1. Urea, ...	342·55
2. Uric acid [and Hippuric], .	3·04
3. Fixed salts, ...	252·30
4. Difference, ...	177·71
Total, ...	775·60
A. Sulphuric acid, ...	21·00
B. Phosphoric acid, with earths,	3·46
,, with alkalies,	17·34

Part IV.—*Comparison of the foregoing with the daily work, bodily and mental, and with the daily food of Man.*

Before deducing any inferences from the excretion of urea, uric acid, and phosphoric acid, established in the three preceding parts of this paper, a preliminary inquiry suggests itself, which, if decided in the negative, would go far to render any inferences deduced from the urine of but secondary value.

I take for granted that the substances excreted by the urine of a healthy man result from the wear and tear of tissue of every kind in the body; and that, in a state of health, this excretion is exactly compensated for by the assimilation of an equal amount of the same substances ingested.

This hypothesis would be readily granted, if it included all the *excreta*—per cutem, per halitum, per anum, per vesicam, provided the *ingesta* also included all received by the stomach, lungs (and skin?)—but, in restricting my hypothesis to the urine, I was aware that I differed from many physiologists, and that the *onus probandi* rested upon me. I, accordingly, undertook a number of observations on the food taken by the persons experimented on in the preceding part of this paper, particularly with reference to the nitrogen received in their food compared with the nitrogen excreted by the urine. The results of these observations I shall now detail, previously to deducing any inferences from the excretions of the urine. I determined the water lost by drying each article of food at 212° F., and afterwards analyzed the dried product for nitrogen, by burning in a tube with soda lime, and collecting the ammonia in muriatic acid. The quantity of nitrogen was found by adding bichloride of platinum, and afterwards weighing the double chloride of platinum and ammonium on a weighed filter; or by the weight of platinum after ignition; or by both methods. I always found, when the ignition of the double chloride was conducted slowly, that the results were identical with those given by the direct weighing of the ammoniaco-platino-chloride.

Experiments on Food.

1. *Lean roasted Mutton;* leg; 5 days dead before cooking, 2 days cooked—

114 grs., dried at 212° F., gave 48·10 grs.

Solids = 48·19 per cent.

2. *Lean roasted Mutton;* leg, nearer the shank end; more fat and fascia than in No. 1; 5 days killed, 1 day cooked—

89 grs., dried at 212°, gave 28·10 grs.

18·10 grs. of the latter, burned with soda lime, gave of platinum 12·70 grs.

Solids = 31·57 per cent.
Nitrogen = 10·02 „

3. *Lean roasted Mutton;* leg, nearer the loin; very little fat or fascia; 5 days killed, 1 day cooked.

123·75 grs., dried at 212° F., gave 62·80 grs.

13·30 grs. of the latter, burned in tube, gave of platinum 11·70 grs.

Solids = 50·75 per cent.
Nitrogen = 12·56 „

4. *Lean raw Mutton;* loin; 5 days killed.

118·75 grs., dried at 212° F., gave 38·90 grs.

14·65 grs. of the latter gave of platinum 11·53 grs.

Solids = 32·76 per cent.
Nitrogen = 11·21 „

5. *Lean roasted Beef;* sirloin; 5 days killed, 1 day roasted.
98·12 grs., dried at 212° F., gave 37·45 grs.
14·97 grs. of the latter gave of am. plat. chloride, 30·15 grs.
Solids = 38·16 per cent.
Nitrogen = 12·64 „

6. *Lean raw Beef;* sirloin; 7 days killed.
164·93 grs., dried at 212° F., gave 50·75 grs.
13·80 grs. of the latter gave of am. plat. chloride, 28·13 grs.
Solids = 30·77 per cent.
Nitrogen = 12·80 „

[The following experiments are useful, as showing the proportion of the water and fat of lean beef and mutton lost by roasting.

A. *Lean raw Beef;* lap; 5 days killed, weighing 2339 grs. became by roasting (1 day cold) 1573·75 grs., and on the second day 1551·45 grs.
Roasted solids (1st day) = 67·28 per cent.
„ (2nd day) = 66·33 „

B. *Lean raw Mutton;* loin; 5 days killed, and weighing 2287·3 grs., became by roasting (one day cold) 1368·3 grs., and on second day 1345·0 grs.
Roasted solids (1st day) = 59·82 per cent.
„ (2nd day) = 51·83 „]

7. *Best white Bread;* 2 days old; white wheat.
106 grs., dried at 212° F., gave 65·20 grs.
20·90 grs. of the latter gave of platinum 3·10 grs.
Solids = 61·51 per cent.
Nitrogen = 2·12 „

8. *Prison white Bread;* second quality, probably made from red wheat; 2 days old.
52·25 grs., dried at 212°, gave 32·05 grs.
18·10 grs. of the latter gave of am. plat. chloride, 6·40 grs., and of platinum 2·80 grs.
Solids = 61·34 per cent.
Nitrogen = 2·21 „

9. *Prison Oatmeal.*
94·01 grs., dried at 212° F., gave 86·53 grs.
16·85 grs. of the latter gave of am. plat. chloride 7·30 grs., and of platinum 3·30 grs.
Solids = 92·03 per cent.
Nitrogen = 3·04 „

10. *Prison Indian Meal.*
96·22 grs., dried at 212° F., gave 82·55 grs.
15·07 grs. of the latter gave of platinum 1·65 grs.
Solids = 85·20 per cent.
Nitrogen = 1·56 „

11. *Boiled Cauliflower;* 1 day cooked.
203·18 grs., dried at 212° F., gave 22·25 grs.
20·33 grs. of the latter gave of am. plat. chloride 11·40 grs.
Solids = 10·95 per cent.
Nitrogen = 3·50 ,,

12. *Prison Milk.* Dr. Apjohn favoured me with the results of his own experiments, made by direct analysis on two specimens of the milk supplied usually to the Dublin market, and on a specimen procured direct from the cow. From these carefully conducted experiments it would appear that, if the adulteration of milk be merely water, the specific gravity affords a direct measure of the nitrogen present. The nitrogen was determined by him in the same manner as by myself, viz., by the corresponding weight of platinum procured.

No. 1,	Sp. gr. 1025;	Platinum per 1000 grs.	21·80 grs.
No. 2,	,, 1027;	,,	23·62 ,,
No. 3 (pure)	,, 1035;	,,	32·48 ,,

The prison milk examined by me had a specific gravity of 1024·9, and also contained 177 grs. (equivalent to glucose) of sugar per pint.

Collecting together the preceding data, the following Tables may be constructed, showing respectively the quantity of water and of nitrogen in the several articles of food experimented upon.

TABLE J.—*Quantity of Water and Solid Matter in Articles of Food.*

No.	Food.	Solids per cent.	Water per cent.
1.	Mutton (roast), . .	42·19	57.81
,,	,, ,,	31·57	68·43
,,	,, ,,	50·75	49·25
2.	Mutton (raw), . . .	32·76	67·24
3.	Beef (roast), . . .	38·16	61·84
4.	Beef (raw), ...	30·77	69·23
5.	Bread (1st quality), .	61·51	38·49
6.	Bread (2nd quality) .	61·34	38·66
7.	Oatmeal, ...	92·03	7·97
8.	Indian Meal, . . .	85·20	14·80
9.	Cauliflower, . . .	10·95	89·05

The following remarks may be made on this Table:—

The per-centage of water in roast mutton varies much more than it does in roast beef, probably on account of the more variable proportion of fat distributed in the cellular matter between the muscular fibres.

The average of the three specimens of roast mutton [solids, 41·50 per cent.; water, 58·50] comes very near that found for roast beef.

The close agreement between the two specimens of bread is what might be expected from the facts recorded by chemists respecting the "water of panification."

Table K.—*Per-centage of Nitrogen found in Articles of Food, previously dried at* 212° F. (except the milk).

No.	Food.	Nitrogen per cent.	No.	Food.	Nitrogen per cent.
1.	Mutton (roast), .	10·02	7.	Bread (2nd quality),	2·21
2.	" "	12·56	8.	Oatmeal, . . .	3·04
3.	Mutton (raw), . .	11·21	9.	Indian Meal, . .	1·56
4.	Beef (roast), . .	12·64	10.	Cauliflower, . .	3·50
					per 1000 gr.
5.	Beef (raw), . . .	12·80	11.	Milk (sp. gr. 1035),	4·64
6.	Bread (1st quality),	2·12	12.	Milk (sp. gr. 1025),	3·11

The specimens of mutton (Nos. 1, 2) gave of solids 31·57 and 50·75 per cent., respectively; from which, and other similar facts, I infer that the mutton that contains least water and fat is not only the best for that reason, but that also its muscular fibre contains more nitrogen when dried. The poor fatty mutton, 2 or 2½ years old, with pale muscle, that abounds in the Dublin markets, is the result of our so-called improved breeding of sheep, possessed of high fattening qualities, but is very inferior to the dark-fibred 3 or 3½ year old mutton, now, alas! almost extinct; this inferiority depends on a double cause, the excess of water, and the deficiency of nitrogen. The difference in the nitrogen contained in the two qualities of bread, though slight, is, I believe, real, as it is probable that there is a greater quantity of gluten in our red than in our white wheats.

It is now necessary, by the aid of the preceding Tables, to calculate the quantity of nitrogen, or of its equivalent urea, taken as food by the subjects of Tables A and B: I am able to do so in the case of No. 1 of Table A, and of Nos. 2, 3, 4, 5, of Table B. The food used daily by No. 1, Table A, during some time preceding, and during the experiments, was as follows:—

I. Roast beef (cold), . . . 8 oz.
II. White bread, . . . 8 oz.
III. Boiled cauliflowers, . 10 oz.
IV. Milk (sp. gr. 1025), . 1 pint.

By the aid of the chain rule, which is admirably adapted to such calculations, I find the equivalent of these four articles of diet in grains of urea, as follows:—

I.

	8 oz. cold roast beef.
16	7000 grs. ,, ,,
10000	3816 grs. dried at 212°.
10000	1264 grs. nitrogen.
28	60 grs. urea.

362 grs.

II.

	8 oz. white bread.
16	7000 grs. ,,
10000	6151 grs. dried at 212°.
10000	212 grs. nitrogen.
28	60 grs. urea.

98 grs.

III.

	10 oz. boiled cauliflower.
16	7000 grs. ,,
10000	1095 grs. at 212° F.
1000	35 grs. nitrogen.
28	60 grs. urea.

36 grs.

IV.

	1 pint milk.
8	70000 grs.
10000	218 grs. platinum.
98	14 grs. nitrogen.
28	60 grs. urea.

58 grs.

Adding together the preceding results, we find—

I. Cold roast beef, 8 oz.,	equivalent to	362	grs. urea.
II. White bread, 8 oz.,	,,	98	,, ,,
III. Boiled cauliflower, 10 oz.,		36	,, ,,
IV. One pint of milk,	,,	58	,, ,,

Total equivalent of urea ingested, **554** grs.

Let us now compare this quantity of urea with that excreted *per vesicam* and *per anum*.

The fæces passed per day amounted to 5 oz., the analysis of which gave the following results:—

305·45 grs., dried at 212° F., gave 80·05 grs.

28·15 grs. of the latter gave of am. plat. chloride, 30·75 grs.

From these data I find—

Solids = 26·21 per cent.
Nitrogen = 6·86 ,,

From this we obtain the total urea equivalent to the nitrogen thus excreted.

5 oz. fæces.
16 — 7000 grs.
10000 — 2621 grs. at 212° F.
10000 — 686 grs. nitrogen.
28 — 60 grs. urea.

84·28 grs.

Combining this result with that given in Table A, we find—

1. Urea, excreted *per vesicam* = 465·09 grs.
2. Equivalent of urea, excreted *per anum*, . . = 84·28 grs.

Total, ... **549·37**

The close agreement of this result with that obtained from an analysis of the food entitles me to assume that the nitrogen used in the body is naturally excreted by the kidneys, and that the surplus taken in food, and not used or required by the body is thrown out as a mere excretion *per anum*.

I am aware that this result differs widely from the statements made in Carpenter's Physiology, and other books, on the authority of Barral and other experimenters, who divide the nitrogen excreted from the body into two nearly equal portions, one of which is discharged *per vesicam et anum*, and the other *per cutem et halitum*.

M. Barral's results are as follow:—

Subject.	Nitrogen in food.	Nitrogen excreted.		
		Per vesicam.	Per anum.	Per cutem et halitum.
M. Barral, æt. 29, in summer wt. 105 lbs.	432·3 grs.	168·3 grs.	42·2 grs.	220·8 grs.
M. Barral, in winter,	327·3 „	151·3 „	20·1 „	155·9 „
Boy (æt. 6, wt. 33 lbs.)	121·9 „	47·8 „	27·8 „	46·3 „
Man (æt. 59, weight, 129 lbs., ...	421·5 „	234·6 „	38·6 „	148·3 „
Unmarried Woman, æt. 32, wt. 135 lbs.,	345·8 „	154·4 „	12·3 „	179·1 „

I believe that the results of this Table are in error, both by underrating the nitrogen passed in the urine, a mistake commonly committed in estimating urea, and also by overrating the nitrogen taken in food, as I certainly find some difficulty in understanding how M. Barral, only weighing 105 lbs., could possibly consume the equivalent of 926 grs. of urea per day. If any doubt rest on the actual facts as to the nitrogen in the food and urine, of course the result as to the skin and lungs becomes worthless, as it is found simply by difference. I now turn to the case of Nos. 2, 3, 4, 5, of Table B, for which I have accurate analyses of the food and urine, but not of the fæces.

These subjects of experiment, being prisoners in the Military Prison in Dublin, of course could have no access to any food except that allowed by the regulations. I am indebted to my friend, Mr. Tufnell, to whom I take this opportunity of acknowledging my obligations, for the facilities which I experienced in making my observations on this class of subjects.

The food allowed by the prison regulations is the following:—

I.	Oatmeal, . . .	8 oz.
II.	Indian Meal, . .	9 oz.
III.	Bread, ...	8 oz.
IV.	Milk, ...	$1\frac{1}{2}$ pints.

The preceding quantities of food, converted, as before, into their equivalents of urea, give the following results:—

I.

	8 oz. oatmeal.
16	7000 grs. ,,
10000	9203 grs. at 212° F.
10000	304 grs. nitrogen.
28	60 grs. urea.

210·5 grs.

II.

	9 oz. Indian meal.
16	7000 grs. ,,
1000	852 grs. at 212° F.
10000	156 grs. nitrogen.
28	60 grs. urea.

112 grs.

III.

	8 oz. prison bread.
16	7000 grs. ,,
10000	6134 grs. at 212° F.
10000	221 grs. nitrogen.
28	60 grs. urea.

101·6 grs.

The milk used in the prison had a specific gravity of 1024·9, and contained 177 grs. of sugar equivalent to glucose per pint. I therefore adopt for it the same result as that before used, viz., one pint equivalent to 58 grs. of urea.

Combining the preceding results, I find the total food used per day to be equivalent to the following quantity of urea:—

I.	Oatmeal, 8 oz., . .	210·5 grs. urea.
II.	Indian meal, 9 oz., .	112·0 „ „
III.	Bread, 8 oz., . . .	101·6 „ „
IV.	Milk, $1\frac{1}{2}$ pints, . .	87·0 „ „
	Total, . . .	**511·1** grs. urea.

From Table B, it appears that the excreta, estimated as urea, were as follows:—

I.	Excreta *per vesicam*, .	400·62 grs. urea.
II.	Excreta *aliter*, . . .	110·48 „ „
	Total, . . .	511·10

I have no doubt but that the 110 grs., equivalent to 51·6 grs. of nitrogen, were discharged as surplus *per anum*, and that the lungs and skin had nothing to do with their elimination.

Having re-established the fact, that the kidneys are the sole excreting organ intended to be used in health for the elimination of nitrogen from the body, and that the nitrogen so excreted has done its work, it remains for me to show the connexion between the work done and the nitrogen so excreted.

I have already divided the work done into four different heads:—

a. Opus vitale.
b. Opus calorificum.
c. Opus mechanicum.
d. Opus mentale.

Of these, the first two, properly speaking, ought to be considered together, as they are both necessary to the life and health of the individual; but as the second is fully accounted for by the excretion of carbonic acid from the lungs, and in no way relates to the present subject, I shall omit its consideration for the present, and confine myself to the three other descriptions of work. Before doing so, it is necessary to estimate, in the usual manner, the amount of mechanical work done, and then to determine the number of grains of urea to which it is equivalent.

Let us turn first to Table B.

The habits of the subjects of experiment are as follows:—

No. 1, wt. 173 lbs., walks 3 miles per day.

No. 2, 3, 4, 5. Average weight 141 lbs.

1. Shot drill, . . . 3 hours.
2. Ordinary drill, . $1\frac{1}{4}$ hours.
3. Oakum-picking, . $3\frac{1}{2}$ hours.

1. To estimate the work done by a person of a given weight walking, it is only necessary to remember that the effort of walking is equivalent to that of lifting one-twentieth part of the weight of the body through the distance walked; this fact I have established by many observations. We therefore obtain the following formula—

$$\left.\begin{array}{r}\text{Work done in walking estimated in tons}\\ \text{lifted through a foot,}\end{array}\right\} = \frac{5280 \times w \times n}{20 \times 2240} \qquad (4)$$

w and n denoting the weight in lbs., and the distance walked in miles.

2. The work done in shot drill is somewhat more difficult of estimation. From careful observation of the prisoners engaged in this highly uninteresting occupation, I obtained the following results:—

Each man lifts a 32 lb. shot to his breast (3 ft.) from a tressel, carries it through 9 ft. by measurement (4 paces by drill); and lays it down on a similar support; he then returns unloaded, and takes up another shot, and so repeats the double journey; of course, after a certain time, all the 32 lb. shots are transferred from one side to the other of the working gang, and they must then reverse the order of proceeding, and carry back the shots. Six of these double journeys occupy one minute.

Now, as it can be proved that equal work is done in lifting and laying down the shot, we readily obtain the following expression for the work done in the three hours—

$$\text{Work in tons} = \left(\frac{(2w+32)\,a}{20 \times 2240} + \frac{32 + 2h}{2240}\right) \times n \times 180^{m}, \qquad (5)$$

where

w = weight of man in pounds.

a = distance in feet to which the 32 lb. shot is carried.

h = height in feet to which it is lifted.

n = number of double journeys per minute.

Substituting for these their values, we find—

Work of three hours' shot drill in tons lifted through one foot

$$= \left(\frac{(282\,\text{lbs.} + 32\,\text{lbs.})\,9\,\text{ft.}}{20 \times 2240} + \frac{32\,\text{lbs.} \times 6\,\text{ft.}}{2240}\right) \times 6 \times 180 = 160{\cdot}7 \text{ tons.}$$

3. *Oakum-picking.*—If we estimate the mechanical labour of this occupation as less than half that of walking, it will be safe to consider $3\frac{1}{2}$ hours of oakum-picking as equivalent to 5 miles' walking; this estimate I adopt for the present.

From the preceding considerations, the following estimate of the work done in actual mechanical labour by the subjects of experiment of Table B is easily deduced.

No. 1. Work done in walking = 61·1 tons lifted through one foot.

This result is obtained from equation (4).

Nos. 2, 3, 4, 5. (I assume common drill to be the same labour as walking.)

Work done:—

1. Shot drill, ...	160·7	tons lifted one foot.
2. Common drill (4 miles),	66·5	,, ,,
3. Oakum-picking (5 miles),	83·1	,, ,,
	310·3	

All the subjects of Table B may be considered as simply expending force in the act of living, and in working or walking about. From these considerations, I find the following equations:—

$$\begin{aligned} 400 &= Aw + B. \\ 367 &= Aw' + B'. \end{aligned} \qquad (6)$$

In these equations,

400 grs. of urea represent the total work of the Military Prisoners, Nos. 2, 3, 4, 5.

367 grs. of urea represent the total work of No. 1.

w, w', are the weights of the subjects respectively, viz., 141 lbs. and 173 lbs., referred to 150 lbs., as the weight of the standard man.

A denotes the daily discharge of urea in grains requisite to keep the standard man (150 lbs.) alive.

B, B', denote the urea in grains that are equivalent to the mechanical work done by Nos. 2, 3, 4, 5, and No. 1, respectively.

From the estimate of the work already given, we obtain the following additional equation—

$$61\ B = 310\ B'. \qquad (7)$$

Combining equations (6) and (7), we find—

$$\begin{aligned} 400 \times 150 &= A \times 141 + B. \\ 367 \times 150 &= A \times 173 + B'. \\ 61\ B &= 310\ B'. \end{aligned} \qquad (8)$$

Solving for A,

$$A = \frac{310 \times 367 - 61 \times 400}{310 \times 173 - 61 \times 141} \times 150$$

$$= \mathbf{297{\cdot}7} \text{ grs. urea.}$$

This is the excretion of urea requisite to keep 150 lbs. wt. of man alive for four and twenty hours.

In round numbers, it may be called 300 grs.; from which it follows that each pound weight of living man requires an expenditure of work, represented by 2 grs. of urea, per day to keep it alive, and prevent it from becoming subject to the ordinary chemical laws of inert matter.

Substituting in equations (8) for A its value just found, we obtain—

$$400 = 297{\cdot}7 \times \frac{141}{150} + B,$$

$$367{\cdot}5 = 297{\cdot}7 \times \frac{173}{150} + B'.$$

From which it is easy to deduce

$$B = 120 \text{ grs.}$$
$$B' = 24{\cdot}2 \text{ grs.}$$

These numbers express the grains of urea, equivalent to the mechanical work done by Nos. 2, 3, &c., and No. 1, respectively; but the work done is 61 and 310 tons lifted through one foot, respectively; from which it is easy to calculate β, the number of grains of urea requisite to lift 100 tons through one foot, viz.:—

$$\beta = \frac{120 \times 100}{310} = 38{\cdot}71 \text{ grs.},$$

and

$$\beta = \frac{24{\cdot}2 \times 100}{61} = 38{\cdot}67 \text{ grs.}$$

Taking the mean of which, I find—

$$\beta = \mathbf{38{\cdot}69} \text{ grs. of urea.}$$

I have already found that it requires 297·7 grs. of urea to keep 150 lbs. of man alive for 24 hours; the actual value of this vital work may now be calculated, by dividing 297·7 by β, the coefficient in urea of mechanical work—

$$\text{Opus vitale} = \frac{297{\cdot}7 \times 100 \text{ tons}}{38{\cdot}69} = 769{\cdot}45 \text{ tons lifted one foot.}$$

This enormous force is requisite to keep 150 lbs. of man living during 24 hours, and yet it is not all that is required; for, in addition, there is the *Opus calorificum*, or work necessary to keep the skin at a constant temperature of 90° F. The amount of this latter work will vary with climate and season, and appears to depend altogether on the excretion of carbonic acid, and not on that of urea.

No chemist who reflects on the number and power of the chemical affinities that are controlled and kept from acting by the vital force during life, will feel disposed to question the enormous energy which my results tend to attribute to it.

Let us examine these results from another point of view. I have estimated the work done by the prisoners at 310 tons lifted one foot. This is a large amount of work, perhaps as large as can ever be obtained in forced labour, but it falls below what is observed in free labour. I take as an example the paviours, Welsh and Irish, employed in this city, on whom I made careful observations last October, and found the following results:—

Weight of rammer, . . .	5 st. 9 lbs.
Blows of rammer, ...	78 in $2^m\ 45^s$.
Rest, ...	$3^m\ 30^s$.
Height lifted, ...	16 in.
Hours of labour, ...	10 hours.

From these data, it is easy to calculate that the work is equivalent to 352 tons lifted one foot per day; to which must be added the work done in walking to and from the work, and while at work; this is equivalent to one-twentieth of the distance walked, multiplied by the weight of the labourer. The whole mechanical work is, in all probability, less than 400 tons lifted one foot per day. According to the observations of Coulomb, Lamandé, and others, French workmen are not usually capable of this amount of labour, although it is sometimes approached. I select the following instances:—

1. Coulomb estimates the work done per day in pile-driving at 75240 kilogram-metres = 242 tons lifted one foot.

2. Lamandé found the work done in pile-driving, at the building of the bridge of Jena, to be

80635 kilogram-metres = 260 tons lifted one foot.

3. Coulomb determined the daily work of men employed turning a lever at 115920 kilogram-metres

= 374 tons lifted one foot.

4. Coulomb found, on questioning a number of pedlars, that they stated that on an average they carried 44 kilos, 19,000 metres per day. Supposing each pedlar to weigh 55 kilos, this would give 1881000 kilogram-metres horizontally. The one-twentieth part of this is the weight lifted

= 94050 kilogram-metres.
= 303 tons lifted one foot.

The low amount of work done in the case of pile-driving appears to be partly due to the rapid character of the work, and its consequent exhausting effect.

Let us take the work done by the paviours as the average work of well-fed and well-paid labourers, working freely; and, supposing each man to weigh 150 lbs., and calculate how high this work would lift his body in the 24 hours. We find, calling x this height in miles—

$$\frac{x \times 150 \text{ lbs.}}{2240} = \frac{352 \text{ tons}}{5280 \text{ ft.}};$$

or,

$$x = 1{\cdot}005 \text{ miles}.$$

This result is confirmed by the consideration that 20 or 21 miles per day, with rest on Sundays, is the utmost that a skilled pedestrian would undertake as a constant performance, carrying no weights except his clothes. Since the coefficient of traction is 1–20th or 1–21th, this would be equivalent to lifting his body through one mile per day.

This mode of considering the result is independent of the weight of the agent, and will be found useful in almost every kind of labour, as the work done is generally proportional to the weight of the labourer; and it is easily remembered that a man could lift his own body through one mile by the utmost daily labour he is capable of. Let us now consider the height to which the work that keeps a man's body alive for 24 hours is capable of lifting that same body. The vital work on 150 lbs. is measured by 297·7 grs. urea, and 38·69 grs. of urea are equal to 100 tons lifted one foot, from which I find the following chain:—

	1 lb. living man.
150	297·7 grs. urea.
38·69	100 ton-feet.
1	2240 lb. feet.
5280	1 lb. mile.
	2·18 miles.

Therefore, the vital force that keeps a man of any weight alive for 24 hours, is capable of lifting his body through 2·18 miles in the same time.

I may add, as a confirmation of the estimate of vital work (297·7 grs. urea to 150 lbs.), that I tried some experiments on convalescent hospital patients, who took little or no exercise, and were well fed, and that I found 300 grs. urea to be the daily excretion of men weighing 11 stone, or 154 lbs.

It remains now to determine, if possible, the *Opus mentale*, and to give its coefficient in waste of tissue, or discharge of urea. For this purpose, I constructed the following Table:—

Table L.—*Work done, expressed in Urea Grains, and divided into its component parts.*

No.	Total Urea.	Opus vitale.	Opus mechanicum.	Opus mentale, &c. &c.
	grs.	grs.	grs.	grs.
Table B, No, 1, . . .	367·5	343·3	24·2	–
,, Nos. 2, 3, 4, 5,	400·6	279·8	120·8	–
Table A, No. 1, . . .	465·0	250·1	28·7	186·2
,, No. 2, . . .	677·2	250·1	57·4	369·7
,, No. 3, . . .	644·6	250·1	57·4	337·1
,, No. 4, . . .	554·0	345·3	15·8	192·9
,, No. 5, . . .	630·0	375·1	34·5	220·4
,, No. 6, . . .	484·3	287·8	33·0	163·5

In this Table I have calculated the grains of urea corresponding to the vital work from the expression—

$$Opus\ vitale = \frac{297{\cdot}7 \times w}{150}, \qquad (9)$$

where w denotes the weight in pounds.

I have calculated the mechanical work done by the following equation deduced from (5),

$$Opus\ mechanicum = \frac{5280 \times w \times n \times 38{\cdot}69 \text{ grs.}}{20 \times 2240 \times 100}, \qquad (10)$$

n denoting the number of miles walked.

On making this calculation, I have assumed the partridge-shooting of No. 2, and athletic games of No. 3, as each equivalent to 10 miles' walking. The column headed *Opus mentale*, &c., is found by difference, and has now to be discussed.

In the first place, I take Nos. 1, 5, 6, whose mental occupation was almost identical, consisting of high class teaching, and severe study preparatory to it (correcting the statement appended to No. 6, in Table A, as I find on inquiry, that the two hours there mentioned only include the time of preparation, and not the time of teaching, which was also two hours).

If we suppose that mental work, like other work, causes a waste of tissue proportional to the weight of the body, then the coefficient of mental work, or the number of grains of urea that represent one hour's mental work of a man 150 lbs. weight, will be—

$$Opus\ mentale = \frac{150 \text{ lbs.} \times x \text{ grs.}}{n \times w} \qquad (11)$$

where x is the number of grains of urea taken from Table K, n the number of hours' work, and w the weight of the subject in pounds.

From this formula I find—

Coefficient of No.	1 = 44·3	grs. of urea.
,,	5 = 43·7	,,
,,	6 = 42·3	,,
Mean, . .	43·4	grs.

The near approximation of these numbers to each other is very remarkable when we consider that the residual grains of urea, from which they are calculated, are 186·2, 220·4, and 163·5, respectively. It certainly proves that the hypothesis I have made, that the mental work sets up a waste of tissue proportional to the mass of the body, is very near the truth.

The kind of mental work in which Nos. 1, 5, and 6, were engaged, was much more severe than that known by the title of "office-work," the coefficient of which in grains of urea may be computed from No. 4, by dividing 192·9 grs. of urea by 6, the number of hours of occupation, and reducing the result in the proportion of 174 lbs. to 150 lbs.

Coefficient of routine mental work for man of 150 lbs. weight } = 27·71 grs. of urea per hour.

Whether we consider this kind of mental labour, or that already discussed, it is plain that they both indicate a waste of tissue of a higher order than that involved in the common *Opus mechanicum*, as may be seen from the following comparison of a day's labour in each.

1. *Opus mechanicum*, or 150 lbs. lifted one mile, } = 136·5 grs. of urea.
2. *Opus mentale*, or 5 hours' study, ... } = 217·0 grs. of urea.
3. *Opus mentale*, or 8 hours' office work, ... } = 221·7 grs. of urea.

It remains to consider the cases Nos. 2 and 3, which are exceptional, and do not fall under the preceding investigation. This is shown by the following Table, which distributes the work of Nos. 2 and 3 under the heads already recognised, and shows a residuum not accounted for.

Table M.—*Distribution of work done, after deducting the Opera Vitalia et Mechanica.*

	Opus mentale.	Residuum.	Total.
Table A, No. 1, .	182·3 grs.	+ 3·9 grs.	186·2 grs.
,, No. 2, .	69·5 ,,	+ 300·2 ,,	369·7 ,,
,, No. 3, .	182·3 ,,	+ 154·8 ,,	337·1 ,,
,, No. 4, .	192·9 ,,	. . . .	192·9 ,,
,, No. 5, .	218·7 ,,	+ 1·7 ,,	220·4 ,,
,, No. 6, .	167·8 ,,	− 4·3 ,,	163·5 ,,

The large residuum of urea not accounted for in the cases of Nos. 2 and 3, must be attributed to disease or to some state of mind equivalent to disease. I have ascertained, since completing my observations, that No. 2 had passed a small mulberry calculus some months before I experimented on him, a circumstance which excludes his case from a discussion of the constants of healthy urine; yet I believe the main cause of the excessive discharge of urea in his case, and that of No. 3, is to be attributed to a cause which did not escape the observation of the sagacious Prout[a], viz., *anxiety of mind.*

No. 2 was anxious about business matters at the time of my experiments; and No. 3 was at the same time preparing for a competitive examination, the requirements of which exceeded the efforts of the mental constitution with which nature had endowed him; in other words, his mind was overtaxed by the work which he had undertaken, and the consciousness of this caused the anxiety to which I attribute his surplus discharge of urea.

CONCLUSIONS DEDUCED FROM THE PRECEDING DISCUSSION.

1. The quantity of urea passed per day by men in health varies with their food and occupation, the latter being the principal cause, and regulating the other.

2. Men employed only in manual or routine bodily labour, are sufficiently well fed on vegetable diet, and discharge on an average 400 grs. of urea per day, of which 300 grs. are spent in vital, and 100 grs. in mechanical work. This conclusion is in conformity with the experience of the mass of mankind employed in manual labour in all ages and countries.

[a] Stomach and Urinary Diseases, p. 95. Third Edition. 1840.

3. When the work is of a higher order, a better quality of food must be supplied, sufficient to allow of a discharge of 533 grs. per day of urea, of which 300 grs., as before, are spent in vital work, and 233 grs. in mental work and the mechanical work necessary to keep the body in health.

4. The quantity of urea discharged per day varies also with the weight of the individual, which influences the vital and mental work.

5. The habits, weight, and occupation of the individual enable us to account for a range of the diurnal quantity of urea, varying from 300 to 630 grs. per day; and this discharge may be confidently predicted, when the habits and weight are known.

When, in any case, the discharge of urea exceeds that calculable from the preceding data, it must be attributed to ill health, and most generally to that most fatal of all diseases to which man is liable—anxiety of mind—a vague and unscientific expression, which, however, denotes a most real disease.

This fact alone would render the preceding investigation of importance to the physician, as it enables him, in a given case, to pronounce whether there is an excess of urea or not, and a consequent waste of the system. I have shown that the mere quantity will not decide this question, as from 300 to 630 grs. may be discharged by persons in perfect health, according to their peculiar work and physical conditions.

Note.—The following Table has been published by Dr. William D. Moore, of this city, since the first part of my paper was read, in the Dublin Medical Press of the 27th July, 1859, and reached me too late for insertion in my own paper.

Quantity of Urea eliminated during 24 hours, according to Dr. Warncke.

1.	Adult man (mixed diet), . .	33·7 grms.	520 grs.
2.	,, (vegetable diet), .	25·3 ,,	390 ,,
3.	Adult woman (mixed diet), .	26·8 ,,	413 ,,
4.	,, (vegetable diet),	20·1 ,,	310 ,,
5.	Boy (17 years), ...	19·8 ,,	305 ,,
6.	Girl (17 ,,), ...	18·0 ,,	277 ,,

These results, which are the averages of 7 experiments on each individual, are perfectly in accordance with my own results, contained in Tables A and B.

Haughton on Healthy Urine

1860.