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CONTRIBUTIONS TO THE SCIENCE OF NUTRITION

A TRIBUTE TO THE LIFE AND WORK OF MAX RUBNER[1]

By the late Professor GRAHAM LUSK
CORNELL UNIVERSITY MEDICAL COLLEGE

GREAT men are very rare. They are worth knowing. They give impulse and stimulus to lesser men. They make the world more worth while for others to live in because of their presence in it. Max Rubner was the greatest man I ever knew.

He was born in Munich on June 2, 1854, and died recently in Berlin on April 27, 1932, in his seventy-eighth year. Rubner received his early training under Carl Voit in Munich and here he also came to be intimately associated with Pettenkofer. He spent a year with Carl Ludwig at Leipzig, whom he always held in the highest regard. On the recommendation of Pettenkofer he was appointed to the newly established chair of hygiene at Marburg in 1885, thus becoming full professor in his own right at the age of thirty-one. At Marburg he came in contact with several young professors about his own age: Albrecht Kossel, the biochemist; Hans Horst Meyer, the pharmacologist; and Friedrich von Müller, the internist, all of whom became world leaders in their respective subjects. In 1891 he succeeded Robert Koch as professor of hygiene in Berlin and built a new laboratory of hygiene, a building which he retained for his own department when in 1909 he became professor of physiology as successor to Engleman. This position he held for twenty-five years until, at the age of seventy, he was made emeritus.

[1] An address presented before a general session of the American Association for the Advancement of Science at Syracuse, N. Y., June 23, 1932. Dr. Lusk died following a surgical operation on July 18. An obituary notice by Dr. Eugene F. Du Bois was printed in the issue of SCIENCE for August 5.

Though living in retirement during his later years, he continued to write powerful articles, and as one of the secretaries (Planck was the other) of the Prussian Academy of Sciences he frequently presided over its meetings to within a short time before his death.

I have been told that as a young man in Munich he gaily donned the native costume of the Bavarian Tyrol and went forth to walk or climb among the pleasant near-by mountains. Later the rigid formality surrounding a professor in Berlin compelled him to adopt that austerity of formal behavior which the custom of his day required of a man in his position. In the colloquial he behaved *geheimratlich*.

THE ISODYNAMIC LAW

Rubner entered Voit's Munich laboratory at a time when work was progressing with a calorimeter for the simultaneous measurement of the heat production and the respiratory metabolism of a human being. The work with this apparatus continued for six years but must have been unsatisfactory because it was never published.

In 1878 Rubner carried out some respiration experiments upon rabbits and let them fast until they died. He noticed, after long fasting, when they were thin and had lost almost all their body fat, that the protein metabolism greatly increased so that it alone sufficed to maintain the life functions of the animal. This was the premortal rise in protein metabolism. The work gave him the idea that the calories derived from protein replaced those derived from fat in the maintenance of the life of the animal. Further investigation convinced him that the three great groups of foodstuffs—carbohydrates, fats and proteins—were exchangeable in the body in accordance with their caloric equivalents. This was the isodynamic law of Rubner. This conception did not immediately meet with Voit's approval and its publication was delayed until 1883, which caused a sense of grievance on Rubner's part. It must be remembered that he was twenty-four years old at the time when this work impressed upon him the importance of considering metabolism from the standpoint of energy. His contributions to this point of view are of fundamental importance. Voit never conceded that it was the most valuable method of approach in unraveling the problems of nutrition. So it is especially to Rubner's credit that animal calorimetry occupies the position which it holds to-day.

Before Rubner's time it had been customary to subtract the heat value of urea from the heat value of protein itself in order to calculate the calories which are physiologically available in the organism when protein is destroyed. But Rubner knew that not only urea but many other organic substances, such as creatinine, uric acid, etc., were eliminated in the urine. He therefore oxidized the dried excreta and determined how much heat was liberated by burning an amount of dried urine containing 1 gram of nitrogen. From this and other work he calculated that 1 gram of dry protein yielded in metabolism an average of 4.1 calories, 1 gram of fat 9.3 calories and 1 gram of carbohydrate 4.1 calories. These are Rubner's standard values and have been generally employed throughout the world. During the war they were used to calculate the requirements of nations and to estimate the imports and exports necessary for the proper nutrition of nations.

THE LAW OF SURFACE AREA

The law of surface area belongs to this period of Rubner's career. With the data at hand and using the surface area formula of Meeh, he came to the conclusion that the heat production of mammals was proportional to their surface area. He returned valiantly to the defense of this law in a recent paper presented before the Prussian Academy of Science He there gives the following scheme:

TABLE I

BASIS OF RUBNER'S LAW OF SURFACE AREA

Dogs		Mammals		
Weight	Calories per square meter		Weight	Calories per square meter
kilos			*kilos*	
31.2	1036	Hog	128	1074
24	1112	Man	64	1042
19.8	1207	Dog	15	1039
18.2	1097	Guinea-pig	0.5	1246
9.6	1183	Mouse	0.018	1185
6.5	1153			
3.2	1212			
1:10 Variation	1142 Average		1:7111 Variation	1145 Average

Rubner makes an analysis of the work of F. G. Benedict:

TABLE II

BASAL METABOLISM OF MEN

No. of individuals	Class in weights	Average weights	Calories per sq. m. surface in 24 hrs. (Du Bois)
	kilos	*kilos*	
6	40–50	48.7	922
41	50–60	53.4	914
164	60–70	64.5	927
24	70–80	74.7	924
8	80–90	83.7	924
Variation 1:1.7 Average 922			

Rubner says that in the light of such facts he can not understand how Benedict could have reached a negation of the surface area law.

It is only fair to Benedict to quote from his recently published book on "The Physiology of Reptiles" the opening and closing passages which occur under the heading, "Surface Area Law." The opening passage reads:

Perhaps no one finding in this entire study has been any more astounding than the definitely shown fact that, with the single exception of the giant tortoises, the heat production of all our cold-blooded animals is extraordinarily uniform when computed on the basis of the calculated surface area, employing the two-thirds power of the weight times a constant.

This affirmation on page 470 is followed by a negation on page 473 which contains this statement:

It is our intention to analyze in another place the findings of the Nutrition Laboratory on both warm-blooded and cold-blooded animals. . . . It is believed, however, that the apparent relationship between heat production and surface area is wholly fortuitous.

Rubner found that large domestic farm birds, turkey, goose and hen, fall in line with the surface area law of mammals. Small song birds, however, have a higher metabolism. Their breast musculature is very highly developed for the purpose of producing a great volume of song, and this may modify their basal metabolism. "What is the surface area of a bird," Rubner asks? Wings cover highly modified fore extremities and cover part of the body surface, except during flight, when the surface is exposed. Analogies from investigations upon birds are not convincing arguments against the surface area law.

In this latest scientific paper which he sent me last summer Rubner points out that the chemical composition of the dry tissue of fishes, amphibians, reptiles and mammals is almost identical when calculated as free from ash and fat. Thus this tissue in mammals contains 15.1 per cent. nitrogen; in amphibians and reptiles 15.5 per cent.; and in fishes 15.8 per cent. Also the number of gram calories liberated in the combustion of one gram of tissue is nearly the same in all these animals. It therefore appears that there is only one kind of living sustance, which, however, has had its powers modified in different directions in the course of evolution.

When living substance increases in mass, regulating factor concerns the relation between mass and energy production, which factor Rubner calls the law of growth and it is always present in each individual. Except for the high energy metabolism in the early stages of development, this factor follows the law of surface area.

In cold-blooded animals, such as fishes and other aquatic animals, there is a reduction in the energy requirement with every increase in their mass, which fact is comparable with the conditions observed in warm-blooded animals. The relation between mass and energy production can be accounted for only by regulating hormones. Variations in the temperature of living substance has a profound influence on the heat production and closely follows van't Hoff's law on the influence of temperature on chemical reactions. Muscle work may double the energy production. The muscles of fishes have the special function of immediate maximal contractions, even in a cold environment. Possibly fishes may increase the flow of water through their gills during muscular activity, which may endow them with a primitive form of physical regulation of body temperature which combats a rise in their temperature.

If a fish changes into an animal living on land, the energy production is doubled on account of increased muscular exertion. Amphibians and reptiles have a pronounced mechanism for physical regulation in their power to evaporate water, which preserves them from becoming overheated. Benedict indeed has lately shown that this factor may cool a large snake to a temperature below that of its environment.

Rubner thinks that the transition of cold-blooded animals into warm-blooded ones probably takes place through heterothermal types, though there are other possibilities. A characteristic phenomenon is the development of a mechanism of chemical regulation, that is, an increase in heat production in the presence of cold through the union of the heat-producing organs with the brain. Cold on the skin then stimulates the nerve centers which discharge impulses increasing metabolism and maintaining body temperature in the presence of heat loss at the surface. The physical regulation of body temperature takes place in various ways: through varying the distribution of blood at the surface of the body, through sweating or rapid respiration. In birds, in which the muscular effort of flying is very great, loss of heat is promoted by exposure of the body during flight.

Cold-blooded animals like frogs fall into a torpid state during the cold of the winter. With the increase in energy expenditure in the transition from cold-blooded to warm-blooded animals, the mental power expands and life takes on a broader aspect. A warm-blooded animal retains its intelligence at all times, it constantly receives sensations and fills its brain with an untold number of memories, which gives the fundamental background for intellectual work.

Chemical reactions accompany the energy exchange in the living organism. To the morphologist the energy doctrine appears too meager and simple, for it is both formless and colorless, but it has this advantage, that it has been built upon a structure of data which have been determined quantitatively.

At one time Rubner complained that his conception of the "wear and tear" quota of protein metabolism had attracted little attention. The wear and tear quota represents the lowest level of protein metabolism which can be achieved after prolonged administration of a starch-fat diet which is free from protein. However, this fact has been used both in Germany and in America to demonstrate that in many infectious diseases, such as typhoid fever, for example, protein metabolism remains high notwithstanding a starch-cream diet, thus proving a toxic waste of protein in these diseases.

The First Accurate Respiration Calorimeter

Leonardo da Vinci about 1500 wrote, "Motion is the cause of all life." In an address given by Helmholtz in 1869 one reads: "All investigation thus far, respecting the amount of heat which an animal produces when at rest, is in no way at variance with the assumption that this heat exactly corresponds to the equivalent, expressed as work, of the forces of chemical affinity then in action."

We have seen that Rubner became professor of hygiene at Marburg in 1885. In 1889 he had built, largely with his own fine hands, and at a very small actual outlay of money, a self-registering calorimeter, the accuracy of which had been carefully and laboriously checked, and he had demonstrated the age-long problem which Helmholtz had desired to see proved, that the heat production of an animal was exactly that amount which could be calculated from the metabolism data of the period. Thus during 45 days the calorimeter measured 17,349 calories as produced by a dog living in it, whereas 17,406 calories could be computed from the nitrogen in the urine and feces and from the carbon dioxide in the respiration, as being that quantity of heat which should have arisen from the oxidation of materials in the dog's body during the same period of time. The difference between the computed heat and that actually found was only 0.3 per cent.

The most important fact which was hereby established was the proof of the validity of the law of the conservation of energy in the animal body. It followed from this work that no source of energy was available for life except that obtained from the energy of chemical reactions.

In 1892 W. O. Atwater began the construction of a calorimeter for the measurement of the heat production in man, which was first described in 1897. This apparatus, the celebrated Atwater-Rosa calorimeter, demonstrated that the law of the conservation of energy applied also to the human being. It must not be forgotten that Atwater was a pupil in Voit's laboratory when Rubner was assistant there and that he was in frequent touch with Rubner after the latter went to Marburg. Rubner told me that he had personally taught Atwater much that he knew. It is right that the succession of intellectual inheritance should be understood. Recall the names: Lavoisier, Bertholet and La Place, Gay-Lussac, Liebig, Voit, Rubner.

On one occasion Rubner writes concerning growth, "Mute and still, by night and by day, labor goes on in the workshops of life. Here an animal grows, there a plant, and the wonder of it all is not the less in the smallest being than in the largest." And in accord with this expression we find him working with bacteria and yeast cells. The energy doctrine unites the world of living things.

Finally he tells us that though active life is always associated with the utilization of energy, yet no life lasts forever. The energy doctrine teaches that after the completion of an infinitely large number of chemical reactions the labor of life is extinguished. There is one common factor which is shown by a large group of warm-blooded animals—horse, cow, dog, cat, guinea-pig—which is that after reaching maturity an average of about 200,000 calories per kilogram of body substance are expended and then the animal dies. Man, however, has acquired an exceptional position, because during an adult life extending between twenty and eighty years, 775,000 calories per kilogram of body weight are expended before the machine gives way. Rubner believes that recent experiments confirm his results and that length of life, as determined from this standpoint, is a function of evolution and is a contributing factor in the development of the higher animals. The results of this investigation, he says, reveal more clearly to our understanding the secrets of life and death.

Much of what I have said above is taken verbatim from Rubner's own words. I make no apology for doing this. It is right that an American audience should hear and comprehend the voice of a great German master of the science of nutrition.

Personal Memories

The first time I met Rubner I called on him at his laboratory in Berlin and was sent away with an appointment for the next day, a well-known protective device. When I called the following day he took me about his laboratory and I remember the particular pride with which he pointed out the original apparatus with which Helmholtz had made his experiments on sound. At the request of Friedrich von Müller, Rubner wrote an introduction to the German translation (1910) of the second edition of my

"Science of Nutrition," but I never really knew him until he visited me in the United States when he came over to attend the Fifteenth International Congress of Hygiene and Demography, which was held in Washington in 1912. He first visited me in my Adirondack camp, and we gave him a tent in which to sleep. He came provided with a barometer, a hygrometer ("Humidität, hundert Prozent," he would remark as he came to breakfast in the rain) and a pedometer, for he had kept a daily record of the number of steps he had taken for twenty years past in order to write the curve of lessening activity with advancing age. We later learned that he carried a small set of tools in one of his pockets, and when one of our party was slightly injured a first-aid kit appeared from another pocket. He brought his paints with him and went off by himself to paint a picture of St. Regis Lake. He intimated that he had been more comfortable when on a shooting expedition with the Kaiser, and later, when he visited us at our Long Island home, said he could not understand why we should leave it for such a place as the Adirondacks. On Long Island he first tasted lima beans, was delighted with them, and wrote about them on his return to Germany. He had a hobby of collecting old menu cards of dinners, which gave him ideas concerning the changing habits of the diets of the people. I gave a dinner in his honor at the University Club in New York. Nuttall, professor of hygiene at Cambridge, England, who had been his pupil, was seated on my left. He said to him, "I expected to feel like a stranger in America, but I feel nothing of the sort, and when I talk to Lusk it is as though I were back in Munich." He visited the Pacific coast and was surprised and delighted, saying it was finer than Nice where it had been his custom to spend his Easter holidays. He thought the New York Public Library much finer than the Library of Congress in Washington and said our architecture was improving.

Rubner was a tall, well-built man of striking presence. His chief relaxation was attendance at a gathering of artists held regularly on Monday evenings in Berlin. Here, where none of his medical colleagues came, he could find rest for his soul. He sent Mrs. Lusk as a Christmas present a picture he had painted. His eminent pupil, Karl Thomas, told me that Rubner was a man who was very slow to give his confidence to any one, but when he had once given it he never withdrew it and then one could say anything to him. That I also found.

When dining with him once in Berlin I referred to a certain colleague and he replied, "He amounts to nothing. He writes books." I said I was rewriting my own book and asked if he would advise me to stop and he answered, "There are too many books."

He was ruthless in his scientific discussions with Zuntz, but Magnus-Levy, a prominent pupil of Zuntz, has recently written that Rubner's arguments were correct.

A friend said to Rubner, "You should have received the Nobel Prize. You must have stepped on X's toes." "I did," was his only reply. Voit's misunderstanding of him was perhaps due to the fact that the older man did not fully understand the saying of Leonardo da Vinci, "Poor is the pupil who is not greater than his master." Both men rank high in the scale of human achievement in their respective times. Had it not been for this misunderstanding Rubner would have succeeded Voit in physiology at Munich and would have lived there in close companionship with Friedrich von Müller, and undoubtedly Otto Frank, who is a very great physiologist, would have gone to Berlin as the successor of Engleman.

In 1906, when I saw Voit for the last time, I asked him his opinion regarding the theory of the specific dynamic action. The last time I saw Rubner was in the summer of 1930 and I said to him, "Will you not elaborate your statement to me at the International Physiological Congress at Edinburgh in 1923 when you said that the heat production of the specific dynamic action was due to intermediary chemical reactions." He replied, "Nein, es giebt verschiedene Möglichkeiten." In the essentials, however, the presentation of Rubner on the subject in his book, "Die Gesetze des Energieverbrauchs bei der Ernährung," published in 1902, leaves little to be changed. Rubner had the power of arriving at great results through simple means and of drawing correct conclusions from a few well-conducted experiments.

The last visit we made to Rubner was at his home at Pinszwang, a village in the Tyrol just over the Austrian border, a short distance from Füssen, and we thus fulfilled a promise made to him eighteen years before. He was in fine spirits and brought out some excellent wine of which he was very fond. He went with us in the afternoon to Füssen. I can still see his distinguished figure standing at the end of the stone bridge at Füssen as he raised his hat and waved it in farewell.

American Education

Rubner's trip to the United States not only added to the number of his friends here but gave him an insight into conditions which existed in our educational institutions. He wished to attend the last International Physiological Congress held in Boston in 1929, but his physician forbade it. After seeing Karl Thomas he wrote me as follows:

Thomas called upon me immediately after his return from America and brought me good news. I rejoiced over his expression of opinions, which are entirely in accord with my own. In Europe, America is considered exclusively as a land of the dollar. But that is fundamentally false. I have myself seen in what wide circles of society there is no chasing after dollars, and that there is a widespread earnest endeavor in science without thought of money, and that much effort, especially in the young, is dedicated to science in spite of the penurious salaries which are paid.

On July 21, 1930, he wrote me, regretting my decision to retire from active work and then turned again to the subject of the welfare of our teaching profession:

You have still something of importance to accomplish, the improvement in the salaries of professors and the care of professors and their widows in their old age. I am not in favor of luxury, but an existence which is to a certain extent free from care is necessary for our work. In America huge sums are paid to a tenor, to a movie actor, or to a prize fighter. Frederick the Great wished to obtain a distinguished singer for the Berlin opera. The singer demanded a large sum. The King became angry and sent him word that the salary demanded was that which a general received. The singer replied to the King that in future he could get a general to sing for him. Educated men could talk in similar fashion, especially scientists and medical men.

Rubner apparently believed in the old-fashioned definition of *emeritus* as given in the Century dictionary: "In Roman history, a soldier or public functionary, who had served out his time and had retired from service. Such servants were entitled to some remuneration, answering to modern half pay."

PUBLIC SERVICE

At the outbreak of the war in 1914 consultation was held among the scientific men of Germany with regard to the food supply. But their advice was disregarded. In June, 1916, Rubner issued a pamphlet describing how prices of foodstuffs had been enormously increased by middlemen without any regard to the cost of production. He frankly stated that lust for gain had produced conditions which were regardless of the political conditions of the time. His prophetic insight into the situation was disregarded.

Working without assistance in his laboratory, he showed that bran, when left in bread, caused a greater output of nitrogen in the feces than when white bread was taken, and also a larger waste of calories in the feces occurred than after taking the white bread. The nitrogen of the bran was not available for human nutrition and the roughage of bran acted to irritate the digestive apparatus of those with weak stomachs and of old people. Our whole wheat bread faddists have not yet assimilated these to them unwelcome truths.

At the close of the war Rubner was one of those who represented Germany at a conference at Spa. He calculated that the food blockade had cost Germany 800,000 lives and asked that this be taken into consideration when striking the balance in the reparation account. He sent me curves showing the comparable loss in weight of himself and of a prisoner of war. The curves were parallel.

The last letter I had from him was from Berlin, December 14, 1931. It dealt with the present economic situation in Germany, which is so nearly akin to our own that it may be of interest to all of us.

The so-called Necessity-Orders (*Notverordnungen*) have completely changed our internal life. The first discomforts fell upon the public functionaries, who were paid only three times a month and gradually suffered a reduction of 30 to 35 per cent. in their wages. This also reacted severely upon the university professors, whose pay was cut 50 per cent. The middle class is dismissing servants, and every one is seeking smaller and cheaper living quarters.

Those who had lost everything during the time of the inflation and had begun to save are again losing a large part of their property, for industrial investments have fallen to one third of their former value and the state takes in taxes one quarter of the interest of bonds.

The "white collar" class (*Beamtenstand*) is the only one thus affected. There is hesitation to bring about a much more justifiable reduction in the pay of common labor. The price of labor is decreed by the unions and is held high and will be so held, even though it is one of the most important causes of unemployment.

Another factor which appears to me to be necessary is a reduction in the salaries of certain government officials.

There are, however, two most important ways of reducing expenditures: through changes in health insurance and in unemployment insurance. Health insurance has completely failed and leaves every door open for fraud. Since the establishment of health insurance the number of sick has increased threefold, which means that every one can get an illness certificate.

The unemployment insurance is at the moment no better than the health insurance. If every working man were allowed to accept work, even though at a lower wage than formerly, then we would be able to put a large number of workmen into industry. That, however, is impossible because no working man is allowed to accept less than the established wage, and no industry is allowed to pay less than the unions prescribe. To the unemployed and the recipients of charity all social elements must be added, such as the lazy, loafers, thieves, etc., which make between 2 and 3 per cent. of the population of large cities.

Everything which has been set up for the welfare of the working classes has gone to the bad through misuse. One must seek other organizations. I believe that your American arrangement of simple insurance dependent on personal payment is a very good one. Any change with us could be brought about only with great difficulty. But it must be done in the interest of the working man himself, because the present administration of our form of insurance wastes enormous sums of money.

Of course we have very limited means for scientific investigations, but we still have enough for matters of the highest importance. Our real anxiety is for the future.

I have tried to draw in its varied aspects a picture of a great scientific man. It is happy to think that we may all learn many lessons from the life of such a man as Max Rubner. For the whole of the individual life in health and in disease depends upon the energy metabolism. And the whole of the life of the state, for weal or for woe, depends upon the ability to furnish sufficient calories in food to provide the energy required to maintain the individuals composing the state.

THE TOTAL ECLIPSE OF THE SUN OF AUGUST 31, 1932

By Professor FREDERICK SLOCUM

VAN VLECK OBSERVATORY, WESLEYAN UNIVERSITY

THE total eclipse of the sun of August 31, 1932, will cross New England at the height of the vacation season and will attract not only the professional and amateur astronomers but a throng of others to the path of totality.

This path will be about 100 miles wide, extending down across Hudson Bay, the Province of Quebec and New England. A portion of the path is shown in Fig. 1. The eclipse will be total between the heavy lines. The dotted line marks the center of the path, where the duration of totality will be longest, ranging from 102 seconds north of the St. Lawrence River to 98 seconds on the Maine coast.

The duration of totality diminishes very slowly with the distance from the center line. Ten miles from the center line the duration is only 2 seconds less than the maximum; 20 miles from the center line, 8 seconds less than the maximum. On the northeast shore of Cape Cod the eclipse will be total for 60 seconds; tip of Cape Ann, 70 seconds; Portsmouth, N. H., 85 seconds; Portland, Maine, 92 seconds; summit of Mt. Washington, 99 seconds.

FIG. 1

For the White Mountain region the eclipse will begin at 2:19 P. M., Eastern Standard Time. The total phase will occur at 3:30 P. M. and the eclipse will end at 4:33 P. M. For places north of the mountains the corresponding times will be a few minutes less and south of the mountains a few minutes greater. For Daylight Saving Time add one hour to the above times. The moon's shadow will travel across New England at a rate of about 3,000 feet per second.

From weather observations made especially for the purpose during the past seven years, the probability of clear sky in Quebec and New England, except for the White Mountain region, is about 55 per cent. For the higher mountains it is somewhat less. Even if the forenoon is clear, cumulus clouds may form in the afternoon, with broken masses of sufficient density to obscure the sun. There are so many days of this type in August and September that the scientific expeditions will be widely scattered along the line to distribute the risk of clouds. A partial list of eclipse expeditions, with their locations and leaders, follows, in order of position from NW to SE.

PARTIAL LIST OF ECLIPSE EXPEDITIONS, LOCATIONS AND LEADERS

Parent, P. Q. Royal Observatory, Greenwich, England, Dr. J. Jackson; Dominion Observatory, Ottawa, P. Q., Director R. M. Stewart.

St. Alexis, P. Q. University of Toronto Observatory, Professor C. A. Chant.

St. Lawrence River, P. Q. Paris and Marseilles Observatories, Count A. de la Baume Pluvinel.

Montreal, P. Q. McGill University, Professor A. S. Eve; University of London, Professor A. Fowler.