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GUSTAV von BUNGE — A GREAT SCIENTIST AND TEACHER IN DEVELOPMENT OF PHYSIOLOGICAL AND PATHOLOGICAL CHEMISTRY

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Gustav Piers Alexander von Bunge belongs to the interdisciplinary physiological-chemical school of Friedrich Bidder and Carl Schmidt which has been formed at Tartu (Dorpat) University in the middle of XIX century.[1] The development of physiology and other medical sciences gained considerably from the separation, already in 1820 — according to the new University law — of Physiology from Anatomy, and from the foundation of independent Departments of Physiology, Pathology and Semiology — from 1844 the Department of Physiology and Pathology, from 1860 the Department of Physiology. At this Department physiological chemistry was also taught from 1848 on.[2]

The most characteristic feature of this Department was the development of experimental trends in the studies of the functions of the living organism introduced by Alfred Wilhelm Volkmann (1800—1877, in Tartu 1837—1842), and especially by Friedrich Bidder (1810—1894, head of the Department 1842—1869).[3] F. Bidder studied physiology in Berlin for some months in 1834 at Johannes Müller's laboratory.[4] It should be mentioned that appropriate conditions for experimental studies at Tartu University also favoured the development of experimental pharmacology founded by Rudolf Buchheim (1820—1879, in Tartu 1847—1867).[5] The

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[1] **Siilivask, K.** (ed.). History of Tartu University 1632—1982, **II.** The refounding of Tartu University and its activities in 1802—1918. Periodika, Tallinn, 1985; **Алликметс Л., Калнин В., Тяхепылд Л.** (eds.). Медицинский факультет Тартуского государственного университета. Валгус, Таллинн, 1982; **Käbin, I.** Die medizinische Forschung und Lehre an der Universität Dorpat/Tartu 1802—1940. Ergebnisse und Bedeutung für die Entwicklung der Medizin. Nordostdeutsches Kulturwerk, Lüneburg, 1986, 71—129.

[2] **Алликметс Л., Калнин В., Тяхепылд Л.** (eds.). Медицинский факультет Тартуского государственного университета.

[3] **Käbin, I.** Die medizinische Forschung und Lehre an der Universität Dorpat/Tartu 1802—1940.

[4] **Rothschuh, K. E.** Geschichte der Physiologie. Springer, Berlin; Göttingen; Heidelberg, 1953.

[5] **Кяэр-Кингисепп Э. Г.** Развитие экспериментальных исследований на кафедре физиологии Тартуского университета в первой половине XIX столетия. — In: Tartu Ülikooli ajaloo küsimusi, 1977, **VI**, 3—14.

experimental trends in physiological research at the Department of Physiology were continued by Alexander Schmidt (1831—1894; head of the Department 1869—1894). Due to his main studies in blood physiology and biochemistry (blood coagulation) Alexander Schmidt came to be called *Blutschmidt*.[6]

The other important ground for the formation of this interdisciplinary physiological-chemical school was definitely the quick development of chemistry at Tartu University and especially the scientific activity of Carl Ernst Heinrich Schmidt (1822—1884; in Tartu from 1846).[7] C. Schmidt (*Wasserschmidt*) was educated in 1842 at Berlin University at chemical laboratories of Heinrich Rose (an outstanding disciple of J. J. Berzelius's and E. Mitscherlich). His teacher in physiology at this time was the well-known physiologist Johannes Müller.[8] In 1843—1844 C. Schmidt studied chemistry at the laboratory of an outstanding chemist Justus Liebig in Gießen. He completed his studies in chemistry and physiology in 1844—1845 in Göttingen, where his teachers were respectively Friedrich Wöhler and Rudolf Wagner.[9]

On returning to Russia in 1845, C. Schmidt was employed for some months at the Medical Surgical Academy under Nikolai Pirogov. In 1846 he started his work at the Department of Physiology and Pathology of Tartu University under Friedrich Bidder. C. Schmidt and F. Bidder based their joint research on precise methods of analytical chemistry. The result of their systematic work on the chemical mechanism of the physiology of digestion and metabolism were outlined in their monograph *Die Verdauungssäfte und der Stoffwechsel*.[10] This monograph has remained as a handbook for many decades for the succeeding generations of scientists in physiology and physiological chemistry in nutrition, digestion and metabolism.[11] C. Schmidt has made a remarkable contribution to the development of physiological chemistry by presenting the exact chemical analysis of blood, by discovering free hydrochloric acid in gastric juice, by showing that sugar is a regular constituent of blood, etc.[12]

In 1852 when C. Schmidt became Professor of the Department of Chemistry, a second stage of research work opened up for him and his coworkers. This stage was mostly concerned with the all-round chemical analysis of soils, minerals, fertilizers, water and other substances.[13]

In this paper developing some previous papers[14] and our preliminary short report[15] we would like to concentrate our main attention on the

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[6] **Siilivask, K.** (ed.). History of Tartu University; **Käbin, I.** Die medizinische Forschung und Lehre.

[7] **Siilivask, K.** (ed.). History of Tartu University; **Käbin, I.** Die medizinische Forschung und Lehre; **Palm, U.** Keemia arengujooni Tartu Ülikoolis 1802—1918. — In: Tartu Riikliku Ülikooli Keemiaosakond 1947—1972. TRÜ Rotaprint, Tartu, 1972, 5—39.

[8] **Rothschuh, K. E.** Geschichte der Physiologie.

[9] **Siilivask, K.** (ed.). History of Tartu University; **Käbin, I.** Die medizinische Forschung und Lehre; **Palm, U.** Keemia arengujooni.

[10] **Bidder, F., Schmidt, C.** Die Verdauungssäfte und der Stoffwechsel. Mitau; Leipzig, 1852.

[11] **Siilivask, K.** (ed.). History of Tartu University; **Käbin, I.** Die medizinische Forschung und Lehre; **Кяэр-Кингисепп Э. Г.** Развитие экспериментальных исследований; **Palm, U.** Keemia arengujooni.

[12] **Siilivask, K.** (ed.). History of Tartu University; **Palm, U.** Keemia arengujooni.

[13] **Siilivask, K.** (ed.). History of Tartu University; **Palm, U.** Keemia arengujooni.

[14] **Käbin, I.** Die medizinische Forschung und Lehre; **Кривобокова С. С.** Работы Г. Бунге и его учеников в Тартуском университете. — In: Из истории естествознания и техники Прибалтики, II (VIII). Зинатне, Рига, 1970, 179—184.

[15] **Ilomets, T., Tähepõld, L.** Gustav Bunge's contribution to the development of physiological and pathological chemistry. — In: 17th Baltic Conference on History of Science. Baltic Science between the West and the East. Tartu, 4—6 October, 1993. Tartu Ülikool, 1993, 66—71.

scientific, pedagogic and social activity of Gustav v. Bunge, an outstanding disciple from the physiological-chemical school of F. Bidder and C. Schmidt. His versatile personality as well as his remarkable contribution to the development of physiology, physiological and pathological chemistry has not been sufficiently analyzed in details so far. At the same time G. v. Bunge belongs to the great humanists, who pointed out several reasons for the misery from which many fellow-men were suffering at G. v. Bunge's time, and which maintain their actuality also nowadays.

BIOGRAPHY

Gustav Piers Alexander von Bunge[16] was born in 7 January 1844 in Tartu (Dorpat) in the family of the well-known natural scientist Alexander von Bunge (see Gustav v. Bunge's family tree). From 1863 to 1871 he studied chemistry and medicine at Tartu University. His academic activity G. v. Bunge started in 1872 as an assistant at the laboratory of Carl Schmidt, where he received very good preparation and considerable experiences in the field of analytical chemistry. During 1874—1885 G. Bunge worked as an Ordinary Associate Professor of Physiological Chemistry at the Department of Physiology (at that time the head of this Department was Alexander Schmidt). In 1873 G. v. Bunge defended his magisteral dissertation *Ueber die Bedeutung des Kochsalzes und das Verhalten der Kalisalze im menschlichen Organismus*.[17] In 1874 he defended his doctoral dissertation in chemistry *Der Kali-, Natron- und Chlorgehalt der Milch, verglichen mit dem anderen Nahrungsmittel in dem Gesamtorganismus der Säugethiere*.[18] The Doctor's degree in medicine he received in 1882 in Leipzig.[19] In the same year he was awarded the degree of Honourary Doctor of Medicine from Kiev University. In 1885 G. v. Bunge was called to Basel, where he continued his scientific and pedagogic activities as Ordinary Professor of Physiological Chemistry. He died on 5 November 1920 in Basel. There has been established a fountain in memory of G. v. Bunge at Spital street in Basel.[20]

STUDIES ON THE CONTENT OF SODIUM AND POTASSIUM IN ORGANISMS AND IN FOODSTUFFS AND THE ROLE OF THEIR RELATIONS IN MAMMALIAN NUTRITION

G. v. Bunge's main scientific interests and experimental studies were directed to the elucidation of the role of mineral salts in animal and human metabolism and nutrition. In this connection he was especially interested in the role of common salt (sodium chloride, NaCl) and its relation to the potassium salts, as they together have a significant place

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16 **Käbin, I.** Die medizinische Forschung und Lehre; J. C. Poggendorff's biographisch-literarisches Handwörterbuch, **III**. Leipzig, 1898; **IV**. Leipzig, 1904; **Левицкий Г. В.** (ed.). Биографический словарь профессоров и преподавателей Императорского Юрьевского Университета, **II**. Юрьев, 1903; Deutsch-baltisches biographisches Lexikon 1710—1960. Köln; Wien, 1970, 133.

17 **Bunge, G.** Ueber die Bedeutung des Kochsalzes und das Verhalten der Kalisalze im menschlichen Organismus. Zur Erlangung der Würde eines Magisters der Chemie. Mattiesen, Dorpat, 1872, 42; Z. Biol., 1873, **9**, 104—143.

18 **Bunge, G.** Der Kali-, Natron- und Chlorgehalt der Milch, verglichen mit dem anderen Nahrungsmittel in dem Gesamtorganismus der Säugethiere. Zur Erlangung der Würde eines Doctors der Chemie. Mattiesen, Dorpat, 1—41; Z. Biol., 1874, **10**, 295—355.

19 **Käbin, I.** Die medizinische Forschung und Lehre.

20 Ibid.

Table 1

Bunge's generalized data about relations of sodium and potassium in main foodstuffs*

On 1 equivalent of NaO comes:

	Equivalents of K_2O		Equivalents of K_2O
Cow's blood	0.07	Oats	15—21
Protein in hen's egg	0.7	Rice	24
Yolk in hen's egg	1.0	Rye	9—57
Whole organism of mammals	0.7—1.3	Hay	3—57
Carnivorous animal's milk	0.8—1.6	Potatoes	31—42
Mangel	2	Peas	44—50
Breast milk	1—4	Strawberries	71
Herbivorous animal's milk	0.8—0.6	Clover	99
Beef	4	Apples	100
Wheat	12—23	Beans	110
Barley	14—21		

* **Bunge, G.** Lehrbuch der physiologischen und pathologischen Chemie in zwanzig Vorlesungen. Vogel, Leipzig, 1898, 109.

in the mineral content of animals and humans, and as the common salt is the only mineral that is added to our food. Already in his magisteral dissertation and corresponding publication G. v. Bunge set up the following questions: 1) why the herbivorous domestic animals as well as wild ones (deer, chamois et al.) consume quite readily common salt but at the same time carnivorous domestic and wild animals do not like it? 2) why the amounts of sodium chloride in main foodstuffs do not satisfy our needs, although the content of sodium as well as chlorine is sufficient in animal and also in vegetarian food products. In connection with the latter problem he carried out a special study[21] on the content of sodium, potassium and chlorine in plant ashes, referring to the methodical mistakes in former studies in determining sodium in these objects due to the existence of sodium in ashes in an insoluble form. Using his improved method, G. v. Bunge demonstrated the presence of supplementary amounts of insoluble sodium in ashes of garden beans, clover, apples and strawberries. All these comparative studies[22] revealed that in vegetarian foodstuffs the content of potassium exceeds 3—4 times that of sodium (Table 1) and, consequently, in nutrition of herbivorous animals there is an excess of potassium salts which may be the actual cause for supplementary need in common salt for herbivorous animals as well as for humans. To study in more detail this assumption, G. v. Bunge established on his own organism[23] that after taking in of 18.9 g of potassium salts (in phosphoric and citronic forms) during a day there was a loss of 6 g sodium chloride and 2 g of sodium in the urine.

[21] **Bunge, G.** Ueber den Natrongehalt der Pflanzenaschen. — Ann. d. Chem. und Pharmacie, 1874, **172**, 16—27.

[22] **Bunge, G.** Ueber die Bedeutung des Kochsalzes; **Bunge, G.** Der Vegetarianismus. Ein Vortrag. Hirschwald, Berlin, 1885. 2. Auflage 1890; **Bunge, G.** Lehrbuch der physiologischen und pathologischen Chemie in zwanzig Vorlesungen. Vogel, Leipzig, 1887; 4. Auflage 1898.

[23] **Bunge, G.** Ueber die Bedeutung des Kochsalzes; **Bunge, G.** Lehrbuch der physiologischen und pathologischen Chemie.

To explain this G. v. Bunge supposed that the excess of potassium in organism interacts with sodium chloride

$$K_2HPO_4 + 2\,NaCl = 2\,KCl + Na_2HPO_4.$$

As a result there appeared an increased excretion not only of potassium, but also of sodium salts, as was demonstrated in the above-given results of the experiment.

Thus, the herbivorous animals receiving big amounts of potassium salts lose sodium from their organism, which then causes a supplementary need of sodium chloride.

To consider this problem in connection with human nutrition G. v. Bunge paid much attention to the nations and ethnographic groups differing from each other by the characteristics of their nutrition.[24] There are some groups of people (hunters, fishermen, cattle and stock-breeders, nomads) in whose nutrition strongly predominate animal food products comparatively devoid of potassium salts. On the other hand land-cultivators (tillers) and vegetarians use mostly vegetarian foodstuffs. Analyzing carefully many ethnographic explorations and corresponding travel books G. v. Bunge arrived at the conclusion that several nations and groups of people with vegetarian food habits mostly need and use common salt in their nutrition. At the same time people who feed mostly on meat as well as carnivorous animals completely satisfy their need for sodium chloride and do not use any additional amounts of this salt. G. v. Bunge mentioned, for example, that several Finno-Ugric and Indo-Germanic nations lack the word for common salt in their languages. Being interested in this problem also much later G. v. Bunge studied the chemical composition of several surrogates of common salt, which are used by Negro tribes with vegetarian food habits mostly in Middle-Africa and which were brought to him for chemical analysis.[25] It appears that most of these surrogates (5 from 8 analyzed samples) were very rich in sodium chloride, so using them, Negroes can satisfy their needs for common salt.

In conclusion, in these studies G. v. Bunge brought out the dualism of human sodium chloride, its dependence on the character of nutrition and the importance of sodium—potassium ratio in human organism.

STUDIES ON THE CHEMICAL COMPOSITION OF MILK AND ITS ROLE IN MAMMALIAN NUTRITION. LUNIN'S STUDIES

In his studies on the need of inorganic salts in nutrition, G. v. Bunge pointed out[26] that it is greatly dependent on the age of mammalian organism, e. g. in this sense there are clearly pronounced differences between infants and adults. In the former case the increased need in minerals for building up the skeleton, tissues and organs was a priori understandable to Bunge. However, for more detailed study of this need, especially in sucklings during their development, the best approach, according to Bunge, was to examine the chemical content of milk. In comprehensive studies on this subject[27] he established first of all that 1 liter breast milk which is used daily by a suckling of 6—7 kg of weight contains (these data are given in the box):

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[24] **Bunge, G.** Ethnologischer Nachtrag zur Abhandlung über die Bedeutung des Kochsalzes und das Verhalten der Kalisalze im menschlichen Organismus. — Z. Biol., 1874, **10**, 111—132.

[25] **Bunge, G.** Über ein Kochsalz-Surrogat der Negerstämme in Sudan. — Z. Biol., 1901, **41**, 484—486; **Bunge, G.** Die Kochsalz-Surrogate der Negerstämme. — Z. Biol., 1908, **51**, 105—114.

[26] **Bunge, G.** Lehrbuch der physiologischen und pathologischen Chemie.

[27] **Bunge, G.** Der Kali-, Natron- und Chlorgehalt der Milch.

K_2O	—	0.78 g
Na_2O	—	0.23 g
CaO	—	0.33 g
MgO	—	0.06 g
Fe_2O_3	—	0.04 g
P_2O_5	—	0.47 g
Cl	—	0.44 g

During his further comparative studies[28] G. v. Bunge found that the content of these minerals in milk of several mammals is almost the same as in the whole organism of a suckling. These studies were carried out on corresponding ashes and the results are given in Table 2.

The only exception is the content of iron in dog's milk, being considerably smaller than in the whole organism of a suckling puppy (this problem will be discussed further). It must be pointed out that there was a comparatively high content of calcium and phosphorus in the milk of the studied mammals (Table 2).

Table 2

The G. v. Bunge's generalized data obtained by analysis of ashes *

100 parts of ashes contain	Young suckling mammals			Dog's milk	Dog's whole blood	Dog's blood-serum
	Rabbit	Dog	Cat			
K_2O	10.8	8.5	10.1	10.7	3.1	2.4
Na_2O	6.0	8.2	8.2	6.1	45.6	52.1
CaO	35.0	35.8	34.1	34.4	0.9	2.1
MgO	2.2	1.6	1.5	1.5	0.4	0.5
Fe_2O_3	0.23	0.34	0.24	0.14	0,4	0.12
P_2O_5	41.9	39.8	40.2	37.5	13.3	5.9
Cl	4.9	7.3	7.1	12.4	35.6	47.6

* **Bunge, G.** Lehrbuch der physiologischen und pathologischen Chemie in zwanzig Vorlesungen. Vogel, Leipzig, 1898, 92. **Bunge, G.** Eine Bemerkung zur Theorie der Drüsenfunktion. — Archiv für Anat. und Physiol., 1886, Heft 5/6, 539.

Analyzing the results of his comparative studies on the chemical composition of milk, G. v. Bunge revealed a very remarkable fact: the differences in the chemical composition of milk found in several mammal species depend on their growth rate. These data given in Table 3 clearly demonstrate that the milk of quickly growing mammals (cat, dog, sheep, pig) is richer in proteins, ashes (inorganic salts), calcium and phosphorus than that of slowly growing ones (man, horse, cow). G. v. Bunge also assumed that the composition of milk changes with the development of the suckling. So he found[29] that in the milk of a woman 1 month after the delivery the content of proteins was 15 pro mille, and after 9 months 9 pro mille.

Thus, G. v. Bunge's comparative studies of the chemical composition of milk revealed an important relationship between the development of the sucklings of several species and their respective individuums. He pointed out[30] that the epithelial cells of the breast gland are able to assimilate

[28] **Bunge, G.** Lehrbuch der physiologischen und pathologischen Chemie; **Bunge, G.** Eine Bemerkung zur Theorie der Drüsenfunktion. — Archiv für Anat. und Physiol., 1886, Heft 5/6, 539—540.
[29] **Bunge, G.** Der Kali-, Natron- und Chlorgehalt der Milch.
[30] **Bunge, G.** Eine Bemerkung zur Theorie der Drüsenfunktion.

Table 3

Dependence of the chemical composition of milk on the growth rate in several mammals according to G. v. Bunge *

	Time of body weight doubling from the birth (days)	100 parts of milk contain			
		protein	ashes	calcium	phosphoric acid
Man	180	1.6	0.2	0.328	0.473
Horse	60	2.0	0.4	1.24	1.31
Cow	47	3.5	0.7	1.60	1.97
Goat	19	4.3	0.8	2.10	3.22
Pig	18	5.9	—	—	—
Sheep	10	6.5	0.9	2.72	4.12
Dog	8	7.1	1.3	4.53	4.93
Cat	7	9.5	—	—	—

* **Bunge, G.** Lehrbuch der physiologischen und pathologischen Chemie in zwanzig Vorlesungen. Vogel, Leipzig, 1898, 118.

from blood, which has quite different chemical composition as compared to milk, all the inorganic compounds exactly in such proportions as they are needed for the development of the suckling. At the same time G. v. Bunge clearly showed that milk is an irreplaceable source of proteins and minerals, especially of calcium and phosphorus for the developing sucklings.[31]

In connection with the role of breast milk in human nutrition, G. v. Bunge paid much attention to the ability of women to suckle their infants. On the basis of his own experimental data, he repeatedly raised up the demand to fight for infant's nutrition with breast milk.[32] Discussing the causes of woman's inability to suckle[33], he drew the conclusion that the one among those may be alcoholism of parents or only one parent, which is heritable.[34] G. v. Bunge supposes that unability to suckle because of alcoholism, is a sign of degeneration.[35] Although these problems may be arguable and finally not unequivocally settled, the G. v. Bunge's merit is undoubtedly that he pointed out with utmost consistency the high value of breast milk in the nutrition of infants. This problem has been remained quite actual even in present-day pediatrics, medicine and health care.

Very wide recognition has won Nikolai Lunin's dissertation and the corresponding publication[36] carried out in the laboratory of G. v. Bunge and directed to the further development of investigations on the role of inorganic salts and especially of milk minerals in nutrition and metabolism. At this time G. v. Bunge was interested the adult organism's need for minerals. Experimentally this problem may be studied in conditions,

[31] **Bunge, G.** Lehrbuch der physiologischen und pathologischen Chemie, 117—118.
[32] **Bunge, G.** Der Vegetarianismus; **Bunge, G.** Der wachsende Zuckerkonsum und seine Gefahren. — Z. Biol., 1901, **41**, 155—166.
[33] **Bunge, G.** Die zunehmende Unfähigkeit der Frauen ihre Kinder zu stillen: die Ursachen dieser Unfähigkeit, die Mittel zur Verhütung. Reinhardt, München, 1900; 6. Auflage 1909.
[34] **Bunge, G.** Die Alkoholfrage. Ein Vortrag. Vogel, Leipzig, 1885; 2. Auflage 1887.
[35] **Bunge, G.** Die Quellen der Degeneration. Ein Vortrag gehalten am 18 Februar 1910 im Arbeitsbund zu Basel. Reinhardt, Basel, 1910, 1—15.
[36] **Lunin, N.** Ueber die Bedeutung der anorganischen Salze für die Ernährung des Thieres. — Diss. Dorpat, 1880; Z. physiol. Chem., 1881, 5, 31—39.

where all mineral salts are excluded from nutrition, so that the duration of life may be established in these conditions. Such experiments were carried out by J. Foster, an assistant of Carl Voit[37], and they have revealed surprising results. It appears that experimental animals (dogs) on salt-free diet, at the same time receiving proteins, fat and sugar, died earlier (after 26 and 36 days) than other dogs in conditions of complete inanition (40—60 days). In the critical evaluation of these results G. v. Bunge supposed that in salt-free experiments there was not considered the possibility of the formation of sulfuric acid from dietary proteins, which caused the early death of these dogs. To prove his ideas G. v. Bunge gave the possibility for detailed study to N. Lunin.

In his studies N. Lunin used mice, as their life-time is shorter and their need for artificial nutrition is smaller in comparison with the bigger experimental animals (cats, dogs). N. Lunin carried out several series of experiments on mice and got the following main results. 1) 5 mice on completely salt-free diet died in 11—21 days; 2) 5 mice on salt-free diet with added sodium carbonate (for neutralization of sulfuric acid, as had assumed G. v. Bunge) died in 16—30 days; 3) 7 mice on salt-free nutrition, with added sodium chloride instead of sodium carbonate, died in 6—20 days. These results agreed with the assumption of G. v. Bunge about the possible toxic effect of sulfuric acid. Despite the fact that the mice into whose diet was added sodium carbonate died quite early, N. Lunin continued his experimental series; 4) 6 mice on a diet of artificial compounds isolated from milk (casein, milk fat, milk sugar) and added inorganic salts in the same proportion as they are found in milk, died also between 20—31 days; 5) 3 mice on a diet of natural milk. From them 1 died after 47 days due to intestinal closure; 2 others lived normally, increased in body weight and felt well after 2.5 months when the experiment was closed.

We should like to give G. v. Bunge's discussion about the N. Lunin's results as an example of his approach to the scientific facts and his erudition in raising fruitful scientific problems.[38]

Dieses ist eine sehr beachtenswerthe Thatsache. Mit Milch allein können die Thiere leben. Fügt man aber alle Bestandtheile der Milch zusammen, welche nach der gegenwärtigen Lehre der Physiologie zur Erhaltung des Organismus erforderlich sind, so gehen die Thiere rasch zu Grunde. Sollte der Milchzucker durch den Rohrzucker nicht vertretbar sein? Oder sind die anorganischen Bestandtheile in der Milch an die organischen chemisch gebunden und nur in dieser Verbindung assimilierbar? Bei der Ausfällung des Käsestoffes durch Essigsäure war die kleine Albuminmenge der Milch in Lösung geblieben. Sollte dieses Albumin durch den Käsestoff nicht ersetzbar sein? Oder enthält die Milch außer Eiweiß, Fett und Kohlenhydraten noch andere organische Stoffe, die gleichfalls für die Erhaltung des Lebens unentbehrlich sind? Es wäre lohnend, die Versuche fortzusetzen.

Lunin's own conclusion in his dissertation was: "*...da sie* [die Mäuse] *nun aber, wie die obigen Versuche lehren, mit Albuminaten, Fett, Zucker, Salzen und Wasser nicht zu leben vermochten, so folgt daraus, daß in der Milch außer dem Casein, Fett, Milchzucker und den Salzen noch andere Stoffe vorhanden sein müssen, welche für die Ernährung unentbehrlich sind.*"[39] It was the first experimental study in trying to find out compounds unknown so far and necessary for life that led to the discovery of concrete vitamins and explaining their physiological and pathological

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[37] **Forster, J.** Versuche über die Bedeutung der Aschenbestandtheile in der Nahrung. — Z. Biol., 1873, **9**, 297—380.
[38] **Bunge, G.** Lehrbuch der physiologischen und pathologischen Chemie, 99.
[39] **Lunin, N.** Ueber die Bedeutung der anorganischen Salze.

role. Only at the beginning of this century analogous studies by F. G. Hopkins and other scientists followed; this resulted in the Nobel prize in medicine being given to F. G. Hopkins and C. Funk in 1929. In this case Hopkins said in his Nobel prize speech: "It is now generally agreed that the first clear evidence, based upon experiment for the existence of dietary factors of the nature of vitamins came from the school of Bunge at Basel.[40] In 1881 Lunin, one of the workers at this school . . .»[41]

Afterwards to the significance of N. Lunin's work have been dedicated several papers in Russian[42] especially in connection with the tendencies to point out priorities of the Russian scientists, which was characteristic to the historiography in the Soviet Union of this time.

STUDIES ON THE ROLE OF IRON IN NUTRITION, METABOLISM AND IRON-DEFICIENT ANAEMIA AND ON THE ROLE OF CALCIUM IN NUTRITION

Among the other inorganic compounds G. v. Bunge paid special attention to the content, assimilation and metabolism of iron in mammals. In the fourth (last) edition of his textbook of physiological and pathological chemistry[43] there is a separate lecture dedicated to iron, which was absent in earlier editions.

Already in his earlier paper[44] G. v. Bunge considered that the amounts of iron in milk are not sufficient for the further development of the suckling and may lead to the iron-deficient anaemia. In further studies he set up the question: in which form is iron able to absorb and can be assimilated, and from which sources haemoglobin is built up.[45] In this study carried out with the hen-egg yolk he found that iron exists there in bound organic, insoluble in alcohol and aether form. From 200 egg yolks (2258 g) G. v. Bunge isolated 24 g of iron-containing preparation, and demonstrated that it is not an iron salt or iron albuminat but organic (nucleoalbumin) iron complex, and gave it a name "haematogen". G. v. Bunge assumed that this preparation is comparable to nuclein isolated from egg yolk by F. Miescher. Further he carried out comparative elementary analyses of yeast nuclein, his own haematogen (egg-yolk nuclein) and goose haemoglobin (see Table in the box). On the bases of these studies G. v. Bunge supposed that haematogen may serve as a source of iron in haemoglobin synthesis, but for this it had to undergo the complicated metabolic changes.

	Yeast nuclein	Haematogen	Haemoglobin
C	40.81	42.11	54.26
H	5.38	6.08	7.10
N	15.98	14.73	16.21
S	0.38	0.55	0.54
P	6.19	5.19	($0.77 PO_5$)
Fe	—	**0.29**	**0.43**
O	31.26	31.05	20.69

40 Actually at this time G. Bunge as well as N. Lunin were working in Tartu (Dorpat) University.

41 **Hopkins, F. G.** The Earlier History of Vitamin Research. — In: Les Prix Nobel en 1929. Norstedt, Stockholm, 1929.

42 **Кривобокова С. С.** Работы Г. Бунге и его учеников в Тартуском университете; **Мартинсон Э. Э.** 70-летие основания учения о витаминах Н. И. Луниным в Тартуском университете. Эст. гос. изд-во, Таллинн, 1951; **Краснянский Л. М.** Н. И. Лунин — основоположник учения о витаминах. — Биохимия, 1949, **14,** 382; **Ефремов В. В.** Открытие витаминов Н. И. Луниным. — Вопр. питания, 1954, **13,** 3—11; **Черкес Л. А.** Н. И. Лунин и начальные этапы развития витаминологии. — Архив патологии, 1955, **17,** 69—75.

43 **Bunge, G.** Lehrbuch der physiologischen und pathologischen Chemie, 1898, 402—419.

44 **Bunge, G.** Der Kali-, Natron- und Chlorgehalt der Milch.

45 **Bunge, G.** Ueber die Assimilation des Eisens. — Z. physiol. Chem., 1885, **9,** 1, 49—59.

In G. v. Bunge's laboratory C. A. Socin[46] demonstrated that organic iron compounds from hen-egg yolk can be assimilated. In the same laboratory E. Häusermann[47] showed that in rats by nutrition containing iron haemoglobin is formed twice more intensively than when nutrition is iron-free. However, these studies had shown that the formation of haemoglobin is quite intensive also in the case of nutrition of animals with natural foodstuffs containing iron. It is now generally agreed that the absorption of iron and its regulation are complex and have been poorly understood. But the initial suggestions of G. v. Bunge have now been confirmed in the following statement: "Approximately 25% of the heme iron derived from haemoglobin, myoglobin, and other animal proteins is absorbed. In contrast, only 1 to 2% of non-heme iron is absorbed by mechanisms that are complex and poorly understood."[48]

In the next study[49] G. v. Bunge repeated the analysis in ashes of a newborn dog and dog's milk. The results confirmed G. v. Bunge's earlier studies[50] that the content of iron in dog's milk is 6 times lower than in the whole organism of a suckling puppy (0.72 and 0.12 per cent, respectively). This contradiction in iron supply for mammalian sucklings G. v. Bunge explained by the assumption that iron is reserved in the organism during its embryonal development. In a special study[51] G. v. Bunge found a high content of iron in blood-free liver of cats (2.5—35.5 mg per 100 g) and dogs (6.4—7.0 mg per 100 g). So the liver may be the organ where, according to G. v. Bunge, iron is preserved, which opinion has now been well recognized. In further studies it was shown by G. v. Bunge[52] that in the suckling period after birth, in infant rabbits and guinea pigs the content of iron progressively decreases in the ashes of a whole organism and only after being transferred to the vegetarian nutrition the content of iron in the organism gradually begins to increase due to a more higher content of iron in vegetables as compared to milk.

Bearing in mind rational nutrition and especially for natural sources of iron, G. v. Bunge presented original data on the content of iron in cereals.[53] In this study he showed that the bran is rather more rich in iron than rice or white bread, and that iron from bran can be used for haemoglobin synthesis in rats.

In several papers G. v. Bunge pointed out that a deficiency not only in iron but also in calcium may very easily develop in our nutrition.[54] He considered that increasing consumption of sugar, especially by children, may lead to a deficiency in these minerals, which, in its turn, may result in anaemia and teeth caries.[55] Comparing the mineral content of main foodstuffs with that of breast milk, he concluded that the latter is poorer in iron but much richer in calcium than the main other foodstuffs. But as

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[46] **Socin, C. A.** In welcher Form wird das Eisen resorbiert? — Z. physiol. Chem., 1891, 15, 93—139.

[47] **Häusermann, E.** Die Assimilation des Eisens. — Z. physiol. Chem., 1897, **23**, 555—591.

[48] **Cotran, R. S., Kumar, V., Robbins, S. L.** Robbins Pathological Basis of Disease. 4th ed. Saunders, 1989, 687.

[49] **Bunge, G.** Ueber die Aufnahme des Eisens in den Organismus des Säuglings. — Z. physiol. Chem., 1889, **13**, 5, 399—406.

[50] **Bunge, G.** Der Kali-, Natron- und Chlorgehalt der Milch.

[51] **Bunge, G.** Ueber den Eisengehalt der Leber. — Z. physiol. Chem., 1893, **17**, 78—82.

[52] **Bunge, G.** Weitere Untersuchungen über die Aufnahme des Eisens in dem Organismus des Säuglings. — Z. physiol. Chem., 1892, **16**, 3, 173—186; **Bunge, G.** Ueber die Aufnahme des Eisens in dem Organismus des Säuglings. — Z. physiol. Chem., 1893, **17**, 63—66.

[53] **Bunge, G.** Die Assimilation des Eisens aus den Cerealien. — Z. physiol. Chem., 1898, **25**, 36—47.

[54] **Bunge, G.** Lehrbuch der physiologischen und pathologischen Chemie; **Bunge, G.** Der wachsende Zuckerkonsum; **Bunge, G.** Der Kalk- und Eisengehalt unserer Nahrung. — Z. Biol., 1904, **45**, 532—539.

[55] **Bunge, G.** Der wachsende Zuckerkonsum.

Table 4

G. v. Bunge's generalized data about the content of iron (in rising order) and calcium (CaO) in main foodstuffs *

100 g dry stuff contains (mg):

Foodstuff	Fe	CaO	Foodstuff	Fe	CaO
Sugar	0	0	Cabbage (inner leaves)	4.5	—
Hen's egg protein	0	130	Barley	4.5	—
Honey	1.2	7	Almonds	4.9	—
Cherry (red)	1.2	136	Wheat	5.5	65
Rice	1.0—2.5	103	Grapes	5.6	60
Barley-groats	1.4—1.5	—	Bilberries	5.7—6.4	196
Oranges	1.5	575	Potatoes	6.4	100
White bread	1.5	4.6	Peas	6.2—6.6	137
Wheat-flour	1.6	—	Beans (white)	8.3	—
"Reineklaude"	1.8	154	Carrots	8.6	—
Cherry (black)	1.9	123	Wild strawberries	8.1—9.3	873
Apples	1.9	66	Wheat bran	8.8	—
Pears	2.0	9.5	Lentils	9.5	—
Dates	2.1	108	Dandelion	14.3	—
Cow's milk	2.3	1510	Beef	16.9	29
Breast milk	**2.3—3.1**	**243**	Broccoli	20.0	—
Cacao beans	2.5	126	Egg's yolk	10—24	380
Plums	2.8	166	Cabbage (outer leaves)	17—38	—
Raspberries	3.7—3.9	404	Spinach	33—39	—
Figs	3.7—4.0	400	Pig's blood	226	33
Hazel-nuts	4.3	—	Haematogen	290	—
Rye	3.7—4.9	62—71	Haemoglobin	340	—

* **Bunge, G.** Der Kalk- und Eisengehalt unserer Nahrung. — Z. Biol., 1904, **45**, 533.

to calcium, it is important in which form it is present in our foodstuffs. So G. v. Bunge assumed that for assimilation of calcium, especially from milk, a definite role play its combinations with some organic compounds.[56] Bunge's data about the content of iron and calcium in main foodstuffs are given in Table 4.

G. v. Bunge's data[57] about the total content of iron in humans (2.4—3.29 g) and of haemoglobin as a major source of iron (85%) agree with contemporary conceptions. In the laboratory of G. v. Bunge, O. Zinoffsky in his own dissertation[58] carried out an elementary analysis of carefully crystallized haemoglobin. The formula of haemoglobin ($C_{712}H_{1130}N_{214}S_2FeO_{245}$) given by O. Zinoffsky is very close to present-day data.

It may be concluded that the studies by G. v. Bunge given above have made a definite contribution to the iron assimilation, metabolism and genesis of iron-deficiency anaemia, as deficiency of iron is probably the most common nutritional disorder in the world.[59] This G. v. Bunge's merit was characterized in 1983 as follows: "Bunge was . . . father to the concept of iron-deficiency anaemia."[60]

[56] **Bunge, G.** Der Kalk- und Eisengehalt.
[57] **Bunge, G.** Lehrbuch der physiologischen und pathologischen Chemie.
[58] **Zinoffsky, O.** Ueber die Grösse des Hemoglobinmoleküls. Diss. Dorpat, 1885; Z. physiol. Chem., 1886, **10**, 16—34.
[59] **Cotran, R. S., Kumar, V., Robbins, S. L.** Robbins Pathological Basis of Disease, 685.
[60] **Garrison & Morton.** A Medical Bibliography. 1983 (See 3 cit.).

The first complete analyses of human blood were carried out by G. v. Bunge's teacher Carl Schmidt.[61] He was also the first to demonstrate the asymmetrical distribution of sodium and potassium in blood plasma and serum and in blood cells: blood plasma and serum contains considerably more sodium and less potassium as compared to blood cells. Going further in blood analysis G. Bunge paid great attention to the methods for separation of serum and blood cells and to determining their relationship.[62] So he pointed out[63], for example, that blood serum is not simply plasma minus fibrin (*Faserstoff*), but plasma minus fibrinogenlike substances plus decomposition products of blood leukocytes. To get trustworthy results for the real amounts of blood serum and blood cells, he compared the methods of F. Hoppe-Seyler[64] with his own. According to the former, the blood cells separated by centrifugation are washed with the NaCl solution and the content of proteins and haemoglobin is determined in whole blood, in blood serum and in blood cells. As the serum does not contain haemoglobin, the contents of serum and blood cells can be calculated on the basis of the differences in protein and haemoglobin content. Using this method G. v. Bunge found that pig blood contains 56.6% serum and 43.4% blood cells. According to his own method based on differences of sodium content in whole blood, in serum and in blood cells by assuming that in the latter of some animal species sodium is absent, he found in pig blood 56.3% serum and 43.7% blood cells. From these data G. v. Bunge drew the following conclusions: 1) pig and horse blood cells do not contain any sodium; 2) by the method of Hoppe-Seyler one can get trustworthy results.

However, in further analyses of cow and dog blood[65] G. v. Bunge established that in the cells of their blood sodium is also present. Consequently, in these species as well as in humans his method for determining the relationship between serum and cells in blood cannot be used and in these cases more useful is Hoppe-Seyler's method.

The generalized G. v. Bunge's data about the chemical analysis of blood for several species are given in Table 5.

Giving these data in his textbook of physiological and pathological chemistry[66] G. v. Bunge also presented the analogous data of his teacher Carl Schmidt for the human blood chemical composition. In doing so he indicated that Carl Schmidt had got too high values for blood cells (51.302%) due to methodical differences in separating blood plasma and blood cells (at the time of C. Schmidt's analyses the centrifugation was not introduced for the sedimentation of blood cells from whole blood).

G. v. Bunge's comparative studies on blood analysis led him to the conclusion that in different animal species the content of sodium and potassium in blood cells varies to a great extent, while in blood plasma it is rather permanent. This was later confirmed in detail by the studies of E. Abderhalden in G. v. Bunge's laboratory.[67]

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[61] **Schmidt, C.** Characteristik der epidemischen Cholera gegenüber verwandten Transsudationsanomalien. Leipzig; Mitau, 1850.
[62] **Bunge, G.** Zur quantitativen Analyse des Blutes. — Z. Biol., 1876, 12, 191—216.
[63] **Bunge, G.** Lehrbuch der physiologischen und pathologischen Chemie.
[64] **Hoppe-Seyler, F.** Beiträge zur Kenntnis des Blutes. — Med.-chem. Untersuchungen, 1867, Heft II, 189.
[65] **Bunge, G.** Zur quantitativen Analyse des Blutes.
[66] **Bunge, G.** Lehrbuch der physiologischen und pathologischen Chemie.
[67] **Abderhalden, E.** Zur quantitativen vergleichenden Analyse des Blutes. — Z. physiol. Chem., 1898, 25, 65—115.

Table 5

The G. v. Bunge's data about the chemical composition of blood for several species of animals *

1000 units of weight of defibrinated blood contains:

	Pig		Horse		Cow	
	436.8 Blood cells	563.2 Serum	531.5 Blood cells	468.5 Serum	191.2 Blood cells	681.3 Serum
Water	276.1	517.9	323.6	420.1	191.2	622.2
Dry substances	160.7	45.3	207.9	48.4	121.5	59.1
Protein and haemoglobin	151.6	38.1	—	—	123.6	49.9
Other organic substances	5.2	2.8	—	—	2.4	3.8
Inorganic substances	3.9	4.3	—	—	1.5	5.4
K_2O	2.421	0.154	2.62	0.13	0.238	0.173
Na_2O	0	2.406	0	2.08	0.667	2.964
CaO	0	0.072	—	—	0	0.070
MgO	0.069	0.021	—	—	0.005	0.031
Fe_2O_3	—	0.006	—	—	—	0.007
Cl	0.657	2.034	1.02	1.76	0.521	2.532
P_2O_5	0.903	0.106	—	—	0.224	0.181

* **Bunge, G.** Lehrbuch der physiologischen und pathologischen Chemie in zwanzig Vorlesungen. Vogel, Leipzig, 1898, 230.

G. v. Bunge's data on the chemical composition of blood as well as the main results of other studies are given in several following textbooks of physiological chemistry[68] et al.

In connection with the studies about chemical components in blood, G. v. Bunge raised a problem of sodium and potassium ratio in blood and its dependence on nutrition.[69] He suggested that in herbivorous animals receiving big amounts of potassium the latter can supersede sodium from blood cells, but not from plasma or substitude it. However, in a special study[70] G. v. Bunge found that separated blood cells in vitro did not uptake of potassium from surrounding serum enriched with potassium salts. At the same time he pointed out that blood cells maintain their chemical composition constant in spite of great and lasting changes in their environment. This may be considered as one of the first approaches to the homeostasis problem in blood.

G. v. Bunge's discussion about the renal functions[71] led him to the conclusion that chemical composition of urine may greatly vary depend-

[68] **Hoppe-Seyler, F.** Physiologische Chemie in vier Teilen (I—IV). Hirschwald, Berlin, 1877, 1878, 1879, 1881; **Neumeister, R.** Lehrbuch der physiologischen Chemie mit Berücksichtigung der pathologischen Verhältnisse für Studierende und Ärzte. Fischer, Jena, 1893; **Hammarsten, O.** Lehrbuch der physiologischen Chemie unter Mitwirkung von S. G. Hedin, J. E. Johansson, T. Thunberg. Elfte völlig umgearbeitete Auflage. Bergmann, München, 1926; **Abderhalden, E.** Lehrbuch der physiologischen Chemie. 6. Auflage. Urban u. Schwarzenberg, Berlin; Wien, 1931; **Макеев И. А., Гулевич В. С., Броуде Л. М.** Курс биологической химии для медицинских институтов. 4-е изд., перераб. и доп. проф. Л. М. Броуде. Медгиз, Москва, 1947.

[69] **Bunge, G.** Zur quantitativen Analyse des Blutes.

[70] **Bunge, G.** Ueber das Verhalten der Kalisalze im Blute. — Z. physiol. Chem., 1879, 3, 63—69.

[71] **Bunge, G.** Lehrbuch der physiologischen und pathologischen Chemie.

Table 6

The composition of diurnal urine of a young man

	After the feeding with	
	beef	bread
Amount, cm³	1672	1920
Urea, g	67.2	20.6
Uric acid, g	1.398	0.253
Creatinine, g	2.163	0.961
K_2O, g	3.308	1.314
Na_2O, g	3.991	3.923
CaO, g	0.328	0.339
MgO, g	0.294	0.139
Cl, g	3.817	4.996
*SO_3, g	4.674	1.265
P_2O_5, g	3.437	1.658

* The whole sulfuric acid (among this bound) was determined by heating urine in the presence of hydrochloric acid and barium chloride.

ing on the character of nutrition. We should like to give G. v. Bunge's data[72] about diurnal urine content of all main components of a young man after two day's nutrition of beef and of two day's nutrition of bread (Table 6).

From these data it clearly appears that in the case of nutrition by beef the greater amounts of the end products of protein metabolism (urea, uric acid, creatinine) are excreted in urine than in case of nutrition by bread which is now generally agreed upon in present-day biochemistry. It is remarkable that these G. v. Bunge's data were presented 86 years later in the German manual of human physiology.[73]

By calculating acid-base balance for both urines it was found to be acidic, but there were found differences in the content of acids and bases. G. v. Bunge brought out the fact that normal urine can be basic only in case of completely vegetarian nutrition. This analysis is typical for G. v. Bunge in his approaches to the acid-base balance problems in the organism.[74]

G. v. BUNGE'S CONTRIBUTION TO SOME PROBLEMS IN GENERAL BIOCHEMISTRY

Besides the studies mentioned above G. v. Bunge had carried out some investigations of importance for the development of several biochemical areas in general.

In this connection a certain attention should be paid to the large and detailed study in collaboration with the well-known pharmacologist O. Schmiedeberg of the synthesis of hippuric acid in the animal organism.[75] Until then it was repeatedly demonstrated that benzoic acid administered to experimental animals conjugates with glycokoll (glycin) to form

[72] Ibid., 347.
[73] **Schneider, M.** Einführung in die Physiologie des Menschen. — Springer, 1973, 245, Tabelle 45.
[74] **Bunge, G.** Lehrbuch der physiologischen und pathologischen Chemie.
[75] **Bunge, G., Schmiedeberg, O.** Ueber die Bildung der Hippursäure. — Arch. exp. Pathol. Pharmakol., 1876, 4, 233—255.

hippuric acid which then is excreted in urine. This was one of the first sufficiently proved synthetic processes in animals. In their study G. v. Bunge and O. Schmiedeberg set up the aim to get more detailed information about the organ and the conditions in which this synthesis takes place.

For this purpose they started by working out an exact method for the crystallizing and determining benzoic and hippuric acid separately. In the beginning they thought that hippuric acid might be synthesized in the liver as there are also synthesized glycogen, organic conjugates of sulfuric acid et al. Because the experiments of the ligation of liver vessels or extirpation of the liver on mammals were impossible, they carried out their experiments on frogs with extirpated livers. It appeared that after the administration of benzoic acid alone or together with glycine there was detected a synthesis of hippuric acid, so, consequently, in frogs hippuric acid is not synthesized in liver. Then they turned to the possibility of hippuric acid being synthesized in kidneys. In further experiments carried out on dogs with extirpated kidneys they demonstrated that after the administration of benzoic acid there was no detectable formation of hippuric acid. In the following experiments with the ligation of ureters, they found the accumulation of hippuric acid in dog's blood and tissues. By further experiments with extirpated surviving kidneys they demonstrated that blood enriched with benzoic acid and glycin, and flowing through the surviving kidneys contained hippuric acid. All these experiments unequivocally showed that the synthesis of hippuric acid in dogs takes place in their kidneys. In this study it had also been established that for the synthesis of hippuric acid the presence of red blood cells (oxygen supply) and the integrity of the renal tissue are needed.

Although the synthesis of hippuric acid in some species of animals (e. g. in rabbits) may take place also in the liver[76], the study of G. v. Bunge and O. Schmiedeberg had remained as a classical example for studying a synthetic process in the animal organism at that time; it had been presented in many textbooks of biochemistry.[77] G. v. Bunge had also assumed that one of the final products of nitrogen metabolism — uric acid may give a soluble complex with urea[78] and he had introduced a modification to the Bunsen's method for determining urea[79], which substancially shortened and simplified this procedure.

Another example of G. v. Bunge's talent to think and study originally appears in his approaches to the character of biochemical processes which serve as a ground for muscle contraction. At this time it was generally agreed that energy for muscle work (muscle contraction) is supplied by the catabolic processes in the presence of oxygen (in aerobic conditions). In this problem G. v. Bunge paid attention to the several organisms living in oxygen-free conditions in intestines (ascarids) or in mud (blood leech, horse leech) and despite the absence of oxygen are able to move. In several studies[80] G. v. Bunge immediately showed that these organisms studied

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76 **Solomon, W.** Ueber den Ort der Hippursäurebildung beim Pflanzenfresser. — Z. physiol. Chem., 1879, 3, 365—373.

77 **Neumeister, R.** Lehrbuch der physiologischen Chemie; **Hammarsten, O.** Lehrbuch der physiologischen Chemie; **Abderhalden, E.** Lehrbuch der physiologischen Chemie; **Макеев И. А., Гулевич В. С., Броуде Л. М.** Курс биологической химии.

78 **Bunge, G.** Lehrbuch der physiologischen und pathologischen Chemie, 328.

79 **Bunge, G.** Ueber eine Vereinfachung der Bunsen'schen Methods der Harnstoff-Bestimmung. — Z. anal. Chem., 1874, 13, 128—132.

80 **Bunge, G.** Ueber das Sauerstoffbedürfnis der Darmparasiten. — Z. physiol. Chem., 1883—1884, 8, 48—59; **Bunge, G.** Ueber das Sauerstoffbedürfnis der Schlammbewohner. — Z. physiol. Chem., 1888, 12, 565—567; **Bunge, G.** Weitere Untersuchungen über die Athmung der Würmer. — Z. physiol. Chem., 1890, 14, 318—324,

experimentally in oxygen-free (anaerobic) conditions can really live and reveal vivacious motility during several days.

These studies by G. v. Bunge may be considered as bases for the new area in anaerobic metabolic processes in higher organisms, especially in skeletal and smooth muscles. At present it is well known that energy for muscle contraction in anaerobic conditions by several types of muscle work and sport can be actually generated and utilized by the anaerobic glycolysis.

G. v. Bunge's study by using his own exact method of inorganic compounds in ashes of muscle (beef) revealed[81] that in this tissue the content of potassium considerably exceeds that of sodium and the muscle is comparatively rich in phosphorus and iron, but poor in calcium.

Finally, from the viewpoint of evolutional biochemistry it is worth to mention G. v. Bunge's comparative studies of the content of sodium chloride in the cartilage of shark[82] and of cow's embryo and calves of different ages.[83] These data given in the box were discussed by G. v. Bunge on the basis of his concept of descent.[84]

	100 parts of dry cartilage contain	
	Chlor	Sodium
Shark	6.692	9.126
Cow's embryo (1.5 kg)	1.457	—
Cow's embryo (5.5 kg)	1.415	—
Cow's embryo (30.5 kg)	1.151	3.398
Calf (14 days)	0.757	3.245
Calf (10 weeks)	0.686	2.604

The main standpoints developed by G. v. Bunge in connection with this concept and the results obtained were: 1) sodium and potassium are distributed asymmetrically in the earth crust and in sea water due to their different affinity to carbonic and silicic acids, namely, sea water is rich in sodium chloride and poor in potassium salts in comparison with the earth crust; 2) therefore the content of sodium chloride in organisms living in the sea (shark) must be higher than in land inhabitants (vertebrates); 3) as the vertebrates (cow) are derived during their evolution from the sea, the content of sodium chloride in their cartilage presenting the most primitive tissue, must grow smaller during their individual development. Indeed, the results given above agree with G. v. Bunge's concept of descent, and are a good example for G. v. Bunge's ability to draw far-reaching and fruitful conclusions from simple facts.

SOME ASPECTS OF THE SIGNIFICANCE OF G. v. BUNGE'S SCIENTIFIC AND SOCIAL ACTIVITY FOR THE CONTEMPORARY MEDICINE AND HEALTH CARE

In his beloved subject about the role of mineral salts in human nutrition and metabolism G. v. Bunge repeatedly pointed out that the amounts of common salt added to our food are too high.[85] So he calculated that by nutrition with cereals, pea and beans we can get daily 1—2 g of sodium chloride which would completely cover our need. Yet in developed countries

[81] **Bunge, G.** Analyse der anorganischen Bestandtheile des Muskels. — Z. physiol. Chem., 1885, **9**, 1, 60—62.
[82] **Bunge, G.** Ueber die Zusammensetzung des Knorpels vom Haifisch. — Z. physiol. Chem., 1899, **28**, 300—302.
[83] **Bunge, G.** Ueber das Kochsalzgehalt des Knorpels und das biogenetische Grundgesetz. — Z. physiol. Chem., 1899, **28**, 452—458.
[84] **Bunge, G.** Lehrbuch der physiologischen und pathologischen Chemie, 112—114.
[85] **Bunge, G.** Ueber die Bedeutung des Kochsalzes; **Bunge, G.** Lehrbuch der physiologischen und pathologischen Chemie, 111.

most people use daily 20—30 g or even more common salt. In connection with this he raised the question: are our kidneys able to excrete such large amounts of sodium chloride? Of cours, G. v. Bunge could not even imagine how important this problem would become in current concepts in pathogenesis of renal and essential hypertension. In the former case it has been stated: "The kidney is intimately involved in the complex process of sodium homeostasis . . . Sodium retention due to failure of these homeostatic mechanisms is probably the most important factor responsible for hypertension in patients with parenhymal renal diseases, including chronic renal failure."[86] About the mechanisms of essential hypertension representing 90—95 per cent of all types of hypertension it is concluded: ". . . most workers now agree that in persons with a genetic predisposition, high sodium intake predisposes or may lead to hypertension. People living in remote areas in Asia, South America and Africa who have diets very low in sodium chloride show little evidence of essential hypertension. When some of these groups migrate to coastal towns where the salt intake is high, they begin to get their share of hypertension."[87] This is an immediate evidence for the importance of G. v. Bunge's studies and considerations in this field.[88]

No smaller is the importance of studies by G. v. Bunge on the role of potassium salts in potassium-sodium homeostasis and in the acion on the heart. In the contradictory problem in sixties of the last century of the extensive use of meat extracts and meat broth containing comparatively high amounts of potassium salts as nutriment and condiment and its possible stimulating action on nervous and muscle systems G. v. Bunge carried out a special and large experimental study about the action of meat broth and potassium salts on the activity of these systems, especially on the heart.[89]

Until this E. Kemmerich[90] had shown that in experiments on rabbits meat broth, rich in potassium salts, causes an increase in pulse rate. Contrary to this, G. v. Bunge indicated that rabbits are very timorous animals and any manipulation, e. g. injection, causes an increase in their heart activity. Carrying out many experiments on dogs and cats, G. v. Bunge demonstrated[91] that after the intake of quite high amounts of potassium salts per os there is no increasing in pulse rate. In experiments on his own organism he showed that the intake of 12 g potassium salts is also without any effect on the heart rate. However, the administration of potassium salts intravenously or subcutaneously[92] causes paralysis of heart activity. So G. v. Bunge demonstrated[93] that the administration of 0.1 g potassium chloride into the jugular vein of a dog caused pronounced lowering of heart rate and full standstill of the heart. It may be concluded that only in the middle of this century the actual clinical significance of the disbalances of sodium and potassium ratio in the organism established in several studies by G. v. Bunge was understood for cardiology, anaesthesiology and several other branches of medicine.

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86 **Cotran, R. S., Kumar, V., Robbins, S. L.** Robbins Pathological Basis of Disease, 1064.
87 Ibid., 1065.
88 **Bunge, G.** Ueber die Bedeutung des Kochsalzes; **Bunge, G.** Lehrbuch der physiologischen und pathologischen Chemie; **Bunge, G.** Ethnologischer Nachtrag zur Abhandlung.
89 **Bunge, G.** Ueber die physiologische Wirkung der Fleischbrühe und Kalisalze. — Pflüger's Arch., 1871, 4, 235—282.
90 **Kemmerich, E.** Untersuchungen über die physiologische Wirkung der Fleischbrühe, des Fleischextracts und der Kalisalze des Fleisches. — Pflüger's Arch., 1869, 2, 49—70.
91 **Bunge, G.** Ueber die physiologische Wirkung.
92 **Bunge, G.** Lehrbuch der physiologischen und pathologischen Chemie; **Bunge, G.** Ueber die physiologische Wirkung.
93 **Bunge, G.** Lehrbuch der physiologischen und pathologischen Chemie, 142.

G. v. Bunge's contribution to the rational basis of human nutrition and thereby to health care have been discussed above. Here we should like to return to a very interesting report by G. v. Bunge[94] about vegetarianism. Criticizing from the bases of physiology and comparative anatomy many standpoints of vegetarians, he pointed out that it is easier to draw a definite conclusion in astronomy than in physiology of nutrition[95], which view can be completely accepted nowadays.

However, in this report G. v. Bunge brought out a very important advantage of vegetarians — they completely reject alcoholic drinks. In connection with this, in his social activity G. v. Bunge was one of the initiator and consistent fighter against alcoholism, and a tireless propagandist of abstinence. In 1885 he had a report in the assembly hall of Basel University[96] that deserved very wide attention. This report was published in several following editions and was translated into 12 languages. This report G. v. Bunge finished as follows[97]: *Fassen wir alles zusammen, so müssen wir bekennen: Einer allmählichen und vollständigen Beseitigung aller alkoholischen Getränke steht nichts anders im Wege als einzig und allein — der brutale Egoismus. Dieser Egoismus aber wird das Feld nicht behaupten. Es siegt schließlich immer die Selbstlosigkeit: es siegen diejenigen, welche die größten Opfer zu bringen entschlossen sind. Das lehrt die ganze Weltgeschichte. Das sei der Trost, der uns aufrecht erhält bei allem Mißlingen im Leben. Das sei die Quelle der Kraft, auszuharren im Kampfe. — Der Sieg ist unser.* In the following report and publications[98] he repeatedly pointed out that the abuse of alcohol is a definite source for misery and degeneration of humanity. G. v. Bunge has indicated that also tobacco smoking is injurious for humans.[99] We can conclude that all these problems reflecting G. v. Bunge's human social activity have remained acute nowadays in health care as well as in medicine.

G. v. BUNGE AS AN OUTSTANDING TEACHER

Beginning his teaching career as an associate Professor in Physiological Chemistry in 1874 in Tartu, G. v. Bunge continued his pedagogic activities at Basel University in 1885 as an Ordinary Professor of Physiological Chemistry. In 1887 G. v. Bunge published one of the most fascinating and profound manuals of physiological and pathological chemistry of that time[100], followed by several editions and translated into Russian, Polish, English, French, and Italian languages. In 1901 G. v. Bunge published a comprehensive textbook of physiology in two volumes[101] in which the second volume reflects his textbook of physiological and pathological chemistry. A textbook of organic chemistry for physicians was published by G. v. Bunge in 1906, followed by the next editions in 1913 and 1925.[102]

Here we should like to present two appraisals to G. v. Bunge as an outstanding teacher.

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[94] **Bunge, G.** Der Vegetarianismus.
[95] Ibid., 25.
[96] **Bunge, G.** Die Alkoholfrage.
[97] Ibid., 24.
[98] **Bunge, G.** Die zunehmende Unfähigkeit; **Bunge, G.** Die Quellen der Degeneration; **Bunge, G.** Wider den Alkohol. Gesammelte Reden und Abhandlungen 1887—1907. Verlag der Schriftstelle des Alkoholgegnerbundes, Basel, 1907.
[99] **Bunge, G.** Die Tabakvergiftung. Fr. Reinhardt, Basel, 1913.
[100] **Bunge, G.** Lehrbuch der physiologischen und pathologischen Chemie, 1887.
[101] **Bunge, G.** Lehrbuch der Physiologie des Menschen in zwei Bänden. Vogel, Leipzig, 1901; 2. Auflage 1905.
[102] **Bunge, G.** Lehrbuch der organischen Chemie für Mediziner. Vogel, Leipzig, 1906; 2. Auflage 1913; 3. Auflage 1925.

A disciple of G. v. Bunge, the well-known biochemist Emil Abderhalden, in an obituary dedicated to G. v. Bunge has written: *Ebenso genial, wie als Forscher, war Bunge als Lehrer. Niemand konnte sich der Weihe und dem Banne, die über seinen Vorlesungen schwebten, entziehen. In klassischem Deutsch trug der Balte Bunge, einfach in Form und Darstellung, Gebiete aus allen Teilen der Physiologie vor. Ob nun Bunge über Sinnesphysiologie oder über Gehirnphysiologie sprach oder über physiologische Chemie, stets gab er aus Eigenem. Das verlich jeder Vorlesung den eigenartigen Zauber. Bunge hat hunderte von Studierenden für die herrliche Wissenschaft Physiologie begeistert. Bunge ist über den engeren Kreisen seiner Zuhörer hinaus Lehrer von ungezählten Medizinern und Biologen der ganzen Welt geworden und zwar durch sein klassisches, unerreichtes Lehrbuch* (Here we must add that G. Bunge has published at least 3 different fascinating and original textbooks, as shown above). *In ihm hat Bunge's ganzes wunderbares Lehrtalent seine Krone erhalten.*[103]

Gustav Tammann, an outstanding chemist and a disciple of Carl Schmidt, as was also G. v. Bunge, has mentioned in his memories from Tartu University: . . . *in atemloser Stille begann Bunge mit leiser Stimme seine Rede, einen nach Form und Inhalt vollendet ausgearbeiteten Vortrag. Weite Gesichtspunkte, klare und scharfe Darlegung der Fragen, der die glänzende Beantwortung durch die lebendige Beschreibung entscheidender Experimente folgte. Bunge war ein Redner, wie sie nur selten zu hören sind. Mit größter Bescheidenheit seiner Führung wußte er durch die Macht und Klarheit seiner Folgerungen die Zuhörer zu fesseln.*[104]

CONCLUDING REMARKS

Among the several well-known scientists who had worked and taught at Tartu University in the last century[105] an important place undoubtly belongs to Gustav v. Bunge. In his research and teaching G. v. Bunge was definitely peculiar and original, and had his own way. The far-reaching and fruitful conclusions brought by him out of the comparatively simple experimental facts have become subjects for further investigation by several following generations of scientists and remained valuable for the present-day biology and medicine.

G. v. Bunge had always provoked discussing on the basis of scientific facts and he never brought up problems and subjects without being sure in their scientific validity. So he constructed from simple building stones a high building of physiological and pathological chemistry from the top of which far-reaching scientific view goes to the present times.

It may be concluded that together with his teacher Carl Schmidt and his several disciples G. v. Bunge was the father of present day physiological and pathological chemistry. His remarkable scientific and pedagogical contribution to the genesis and development of this science, his versatile personality as well as his consistent social activity had been highly appreciated by the many succeeding scientists and is reflected in the world history of physiology[106] and physiological chemistry.[107]

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[103] **Abderhalden, E.** Gustav v. Bunge †. — Schweiz. med. Wochenschr., 1920, 32, 1193—1194. The authors are grateful to H. Tankler (University of Tartu), who kindly gave us a copy of the orbituary.

[104] **Tammann, G.** Jugenderinnerungen eines Dorpater Chemikers. — Eesti Rohuteadlane [Estonian Pharmaceutist], 1929, 9, 196—198; 10, 226—228.

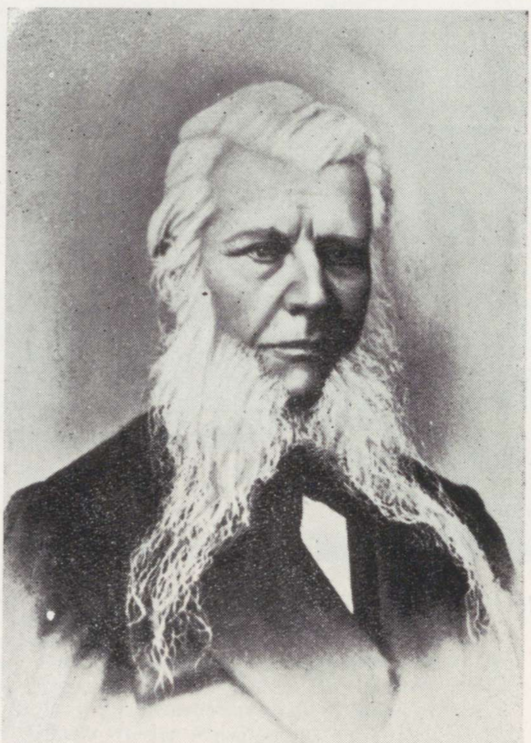
[105] **Siilivask, K.** (ed.). History of Tartu University; **Алликметс Л., Калнин В., Тяхепылд Л.** (eds.). Медицинский факультет Тартуского государственного университета; **Левицкий Г. В.** (ed.). Биографический словарь.

[106] **Rothschuh, K. E.** Geschichte der Physiologie.

[107] **Lieben, Fr.** Geschichte der physiologischen Chemie. Deuticke, Leipzig; Wien, 1935.

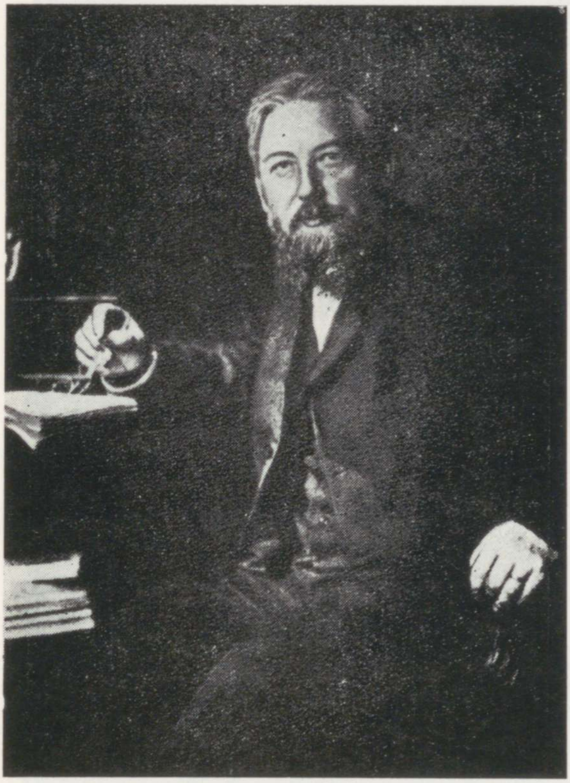
1. Monument to K. E. von Baer on Toomemägi in Tartu.
Photo by E. Sakk.

2. Professor Friedrich Georg Wilhelm Struwe (1793—1864, in Tartu 1810—1838).



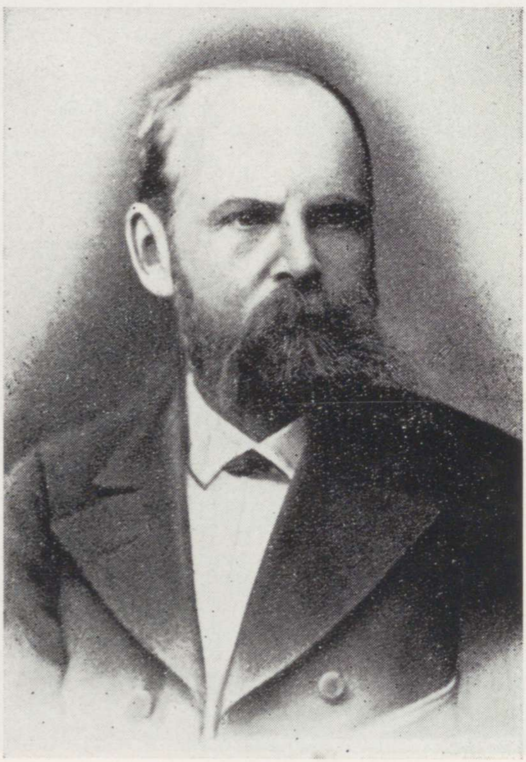
3. Professor Georg Friedrich Karl Heinrich Bidder (1810—1894).

4. Professor Carl Ernst Heinrich Schmidt (1822—1894, in Tartu 1847—1894).

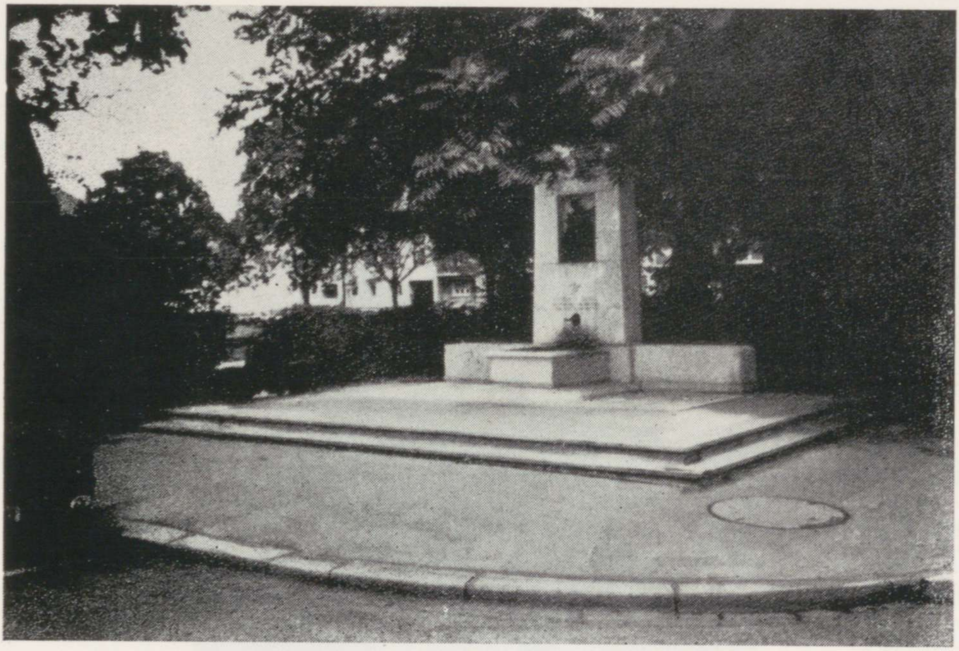


5. Professor Friedrich Ostwald (1853—1932, in Tartu 1871—1881). Nobel prize winner 1909.

6. Professor Rudolf Richard Buchheim (1820—1879, in Tartu 1847—1867). The founde of experimental pharmacology.



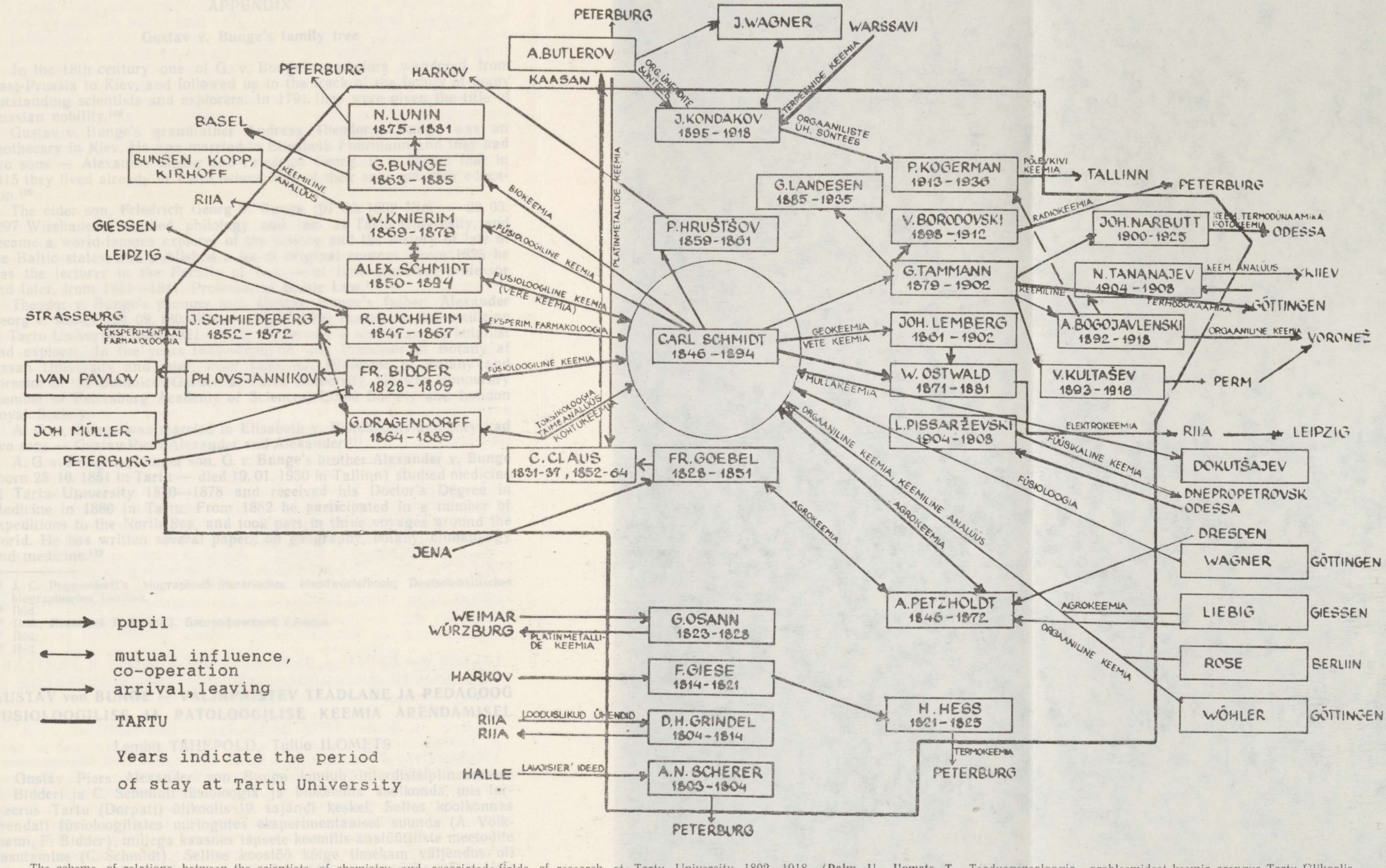
7. Professor Gustav Piers Alexander von Bunge (1844—1920, in Tartu 1863—1885).



8. Monument to G. v. Bunge in Basel. Photo by courtesy of Professor Siegfried Heyden from Switzerland.

9. Professor Johann Ernst Oswald Schmiedeberg (1838—1921, in Tartu 1852—1872).

10. Professor Johann Georg Noël Dragendorff (1836—1898, in Tartu 1864—1889).



The scheme of relations between the scientists of chemistry and associated fields of research at Tartu University 1802—1918. (Palm, U., Ilomets, T. Teadusgenealoogia probleemidest keemia arengus Tartu Ülikoolis. — Rmt.: Teaduslugu ja nüüdisaeg, 1. Tallinn, 1979, 203.)

APPENDIX

Gustav v. Bunge's family tree

In the 18th century one of G. v. Bunge's ancestors wandered from East-Prussia to Kiev, and followed up to the track of the family of many outstanding scientists and explorers. In 1791 they were given the title of Russian nobility.[108]

Gustav v. Bunge's grandfather **Andreas Theodor v. Bunge** was an apothecary in Kiev. He was married to Elisabeth Fuhrmann and they had two sons — Alexander Georg and Friedrich Georg. It is known that in 1815 they lived already in Tartu, where both of their sons got their education.[109]

The elder son, **Friedrich Georg v. Bunge** (01. 03. 1802 Kiev — 28. 03. 1897 Wiesbaden), studied philology and law at Tartu University, and became a world-famous explorer of the history and the history of law of the Baltic states, and published a lot of original sources. From 1825 he was the lecturer in the Faculty of Law — at first associate professor and later, from 1831—1841, Professor of Baltic Law.[110]

Theodor v. Bunge's younger son, Gustav Bunge's father, **Alexander Georg v. Bunge** (24. 09. 1803 Kiev — 06. 07. 1890 Tartu), studied medicine at Tartu University from 1821—1825. He became a world-famous botanist and explorer. In the years 1833—1836 he was Professor of Botany at Kasan University and later, from 1836—67, Professor of Botany and Director of the Botanical Garden at Tartu University. He was Honourary Member of Petersburg Academy of Sciences, Linné Society and London Royal Society.

A. G. v. Bunge was married to Elisabeth v. Pistohlkons and they had two sons — Gustav Piers Alexander and Alexander.[111]

A. G. v. Bunge's younger son, G. v. Bunge's brother **Alexander v. Bunge** (born 28. 10. 1851 in Tartu — died 19. 01. 1930 in Tallinn) studied medicine at Tartu University 1870—1878 and received his Doctor's Degree in Medicine in 1880 in Tartu. From 1882 he participated in a number of expeditions to the North Sea, and took part in three voyages around the world. He has written several papers on geography, botany, climatology and medicine.[112]

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108 J. C. Poggendorff's biographisch-literarisches Handwörterbuch; Deutsch-baltisches biographisches Lexikon.
109 Ibid.
110 Ibid.; **Левицкий Г. В.** (ed.). Биографический словарь.
111 Ibid.
112 Ibid.

GUSTAV von BUNGE — VÄLJAPAISTEV TEADLANE JA PEDAGOOG FÜSIOLOOGILISE JA PATOLOOGILISE KEEMIA ARENDAMISEL

Lembit TÄHEPÕLD, Tullio ILOMETS

Gustav Piers Alexander von Bunge kuulub interdistsiplinaarsesse F. Bidderi ja C. Schmidti füsioloogia ja biokeemia koolkonda, mis formeerus Tartu (Dorpati) ülikoolis 19. sajandi keskel. Selles koolkonnas arendati füsioloogilistes uuringutes eksperimentaalset suunda (A. Volkmann, F. Bidder), millega kaasnes täpsete keemilis-analüütiliste meetodite kasutamine (C. Schmidt). Sellise koostöö kõige ilmekam väljendus oli laialdaselt tuntud F. Bidderi ja C. Schmidti monograafia «Die Verdauungssäfte und der Stoffwechsel» (1852).

G. v. Bunge, C. Schmidti õpilane, sündis 1844 Tartus, õppis Tartu ülikoolis keemiat ja meditsiini (1863—1871) ning pärast ülikooli lõpetamist asus 1872 tööle C. Schmidti assistendina. Aastatel 1874—1885 töötas ta füsioloogilise keemia korralise dotsendina füsioloogia kateedris (juhataja — A. Schmidt). 1873 kaitses G. v. Bunge magistriväitekirja keedusoola tähtsuse ja kaaliumi soolade sisalduse kohta inimorganismis, 1874 doktoridissertatsiooni keemia alal mineraalsoolade sisalduse kohta piimas ning imetajate organismis. 1882 anti G. v. Bungele Leipzigis meditsiinidoktori kraad ja samal aastal meditsiini audoktori kraad Kiievi ülikoolis. 1885 kutsuti G. v. Bunge Baselisse, kus ta jätkas oma teaduslikku, pedagoogilist ja ühiskondlikku tegevust füsioloogilise keemia korralise professorina Baseli ülikoolis. G. v. Bunge suri Baselis 1920.

Artiklis on esitatud G. v. Bunge kõige olulisemate teaduslike ja populaarteaduslike tööde analüüs ning hinnatud nende tähtsust tänapäeva bioloogias ja meditsiinis. On käsitletud järgmisi probleeme: 1) naatriumi ja kaaliumi sisaldus organismides ning toiduainetes ja nende vahekorra tähtsus imetajate toitumises, 2) piima keemiline koostis; piim kui kõikide põhiliste toitainete allikas, eriti fosfori ja kaltsiumi allikas; rinnapiima oluline osa imikute toitumises; on analüüsitud G. v. Bunge õpilase N. Lunini tööd, kus esmakordselt eksperimentaalselt näidati senitundmatute eluks vajalike ainete olemasolu piimas ja mis hiljem viis konkreetsete vitamiinide avastamisele; 3) raua roll toitumises ja elutegevuses, rauavaegusest tingitud kehvveresuse avastamine; 4) vere ja uriini keemilise koostise sõltuvus toitumise iseloomust ja happe-leelistasakaalust; 5) tingimused hipuurhappe sünteesiks neerudes (koos O. Schmiedebergiga); askariidide uurimine näitas, et lihastalitluseks vajalikku energiat võib toota ka anaeroobsete protsesside arvel; võrdlevad uuringud keedusoola sisalduse kohta mere- ja maismaaloomade kõhrkoes (need on tähtsad evolutsioonilises biokeemias); 6) aktuaalsed probleemid tänapäeva tervishoius ja meditsiinis — keedusoola liigtarbimine kui hüpertensiooni esilekutsuv faktor, kaaliumi soolade toime südametegevusele, alkoholism kui degenereerumise põhjus, taimetoitluse kriitika jt. On antud hinnang G. v. Bunge kui väljapaistva pedagoogi tegevusele füsioloogilise keemia, füsioloogia ja orgaanilise keemia sügavasisuliste õpikute autorina ning erakordselt köitva lektorina.

G. v. Bunge koos oma õpetaja C. Schmidti ja oma õpilastega on andnud olulise panuse füsioloogilise ja patoloogilise keemia arengusse. See on kajastunud nimetatud teadusharu paljudes järgnevates õpikutes ja käsiraamatutes, samuti füsioloogia ja füsioloogilise keemia ülemaailmses ajaloos.

ГУСТАВ фон БУНГЕ — ВЫДАЮЩИЙСЯ УЧЕНЫЙ И УЧИТЕЛЬ В ОБЛАСТИ ФИЗИОЛОГИЧЕСКОЙ И ПАТОЛОГИЧЕСКОЙ ХИМИИ

Лембит ТЯХЕПЫЛД, Туллио ИЛОМЕТС

Густав Пирс Александр фон Бунге принадлежит к междисциплинарной физиолого-биохимической школе Ф. Биддера и К. Шмидта, сформировавшейся в Тартуском (Дерптском) университете в середине XIX в. Эта школа развивала экспериментальное направление в физиологических исследованиях (А. Фолкман, Ф. Биддер) в сочетании с точными химико-аналитическими методами (К. Шмидт). Наиболее наглядным результатом такого сотрудничества явилась широко известная монография Ф. Биддера и К. Шмидта «Пищеварительные соки и обмен веществ» (1852).

Г. Бунге, ученик К. Шмидта, родился в 1844 г. в Тарту, изучал химию и медицину в Тартуском университете (1863—1871) и в 1872 г. стал ассистентом К. Шмидта. В период 1874—1885 гг. он работал ординарным доцентом физиологической химии на кафедре физиологии, возглавляемой А. Шмидтом. В 1873 г. Г. Бунге защитил магистерскую диссертацию о значении поваренной соли и содержания калиевой соли в человеческом организме, а в 1874 г. — докторскую диссертацию по химии о содержании минеральных солей в молоке и в организмах млекопитающих. В 1882 г. ему была присуждена степень доктора медицины в Лейпциге и в том же году — степень почетного доктора медицины Киевского университета. В 1885 г. Г. Бунге был приглашен в Базель, где он продолжал свою научную, педагогическую и общественную деятельность ординарным профессором физиологической химии. Г. Бунге умер в Базеле в 1920 г.

В статье перечислены важнейшие открытия и заслуги Г. Бунге, представлен подробный анализ его основных научных и научно-популярных работ, не потерявших своего значения и для современной биологии и медицины. Они затрагивают следующие проблемы:

1. Содержание натрия и калия в организмах и пищевых продуктах, а также важность их соотношения в питании млекопитающих.

2. Химический состав молока; молоко как поставщик всех основных питательных веществ, в частности, фосфора и кальция; ценность материнского молока для вскармливания грудных детей. В этой связи необходимо упомянуть ученика Г. Бунге Н. И. Лунина, впервые экспериментально доказавшего наличие в молоке неизвестных, жизненно необходимых веществ, что впоследствии привело к открытию конкретных витаминов.

3. Роль железа в метаболизме и питании; возможность возникновения железодефицитной анемии.

4. Химический состав крови и мочи в зависимости от характера питания и кислотно-щелочного баланса.

5. Условия синтеза гиппуровой кислоты в почках (в сотрудничестве с О. Шмидебергом); результаты исследований на аскаридах, показавших, что энергия для мышечной работы в этих организмах может быть генерирована за счет анаэробных процессов; сравнительные исследования содержания хлористого натрия в хрящевой ткани представителей морских и наземных животных, имеющие значение для эволюционной биохимии.

6. Актуальные на сегодняшний день проблемы для здравоохранения и медицины — избыточное потребление поваренной соли как фактор развития гипертензии, влияние калиевых солей на сердце, алкоголизм как причина дегенерации, критика вегетарианства и др.

Дана оценка деятельности Г. Бунге как педагога, как автора глубоко содержательных учебников по физиологической химии, физиологии и органической химии для медиков, а также как умеющего увлечь лектора.

Г. Бунге вместе со своим учителем К. Шмидтом и его ученики внесли весьма существенный вклад в развитие физиологической и патологической химии, что отмечено во многих последующих учебниках и руководствах по данной науке и отражено в мировой истории физиологической химии и физиологии.