Igor Gergoff

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B. M. Kedrov

ON THE QUESTION OF THE PSYCHOLOGY OF SCIENTIFIC CREATIVITY

(On the Occasion of the Discovery by D. I. Mendeleev of the Periodic Law)*

In every scientific discovery, we can distinguish at least two aspects: first, the precise course of the discovery with all details and in all its individuality; second, its final result, abstracted from all circumstances and subjective considerations connected with the personal characteristics of the discoverer and the circumstances under which the discovery was made. In this "purified view" the substance of the discovery usually enters into science and establishes itself there in the quality of ascertained truth. Because of this, in the great majority of cases, the history of science does not present information about the specific path that a particular discovery followed; but even if it preserves this information, it is usually only in the form of anecdotes that have come down to us, or fragments about some one moment of the whole discovery, which possibly did not play a decisive role, but was preserved thanks to simple chance.

Such moments, for example, are frequently identified as occurrences of certain sorts of associations that presumably led to the discovery or invention. (The observation by John Watt of the jumping lid of a tea kettle that, according to tradition, gave him the idea of using the force of steam in the steam engine.) Sometimes the association is based on a direct analogy arising suddenly in the consciousness of the discoverer. (The observation by Kekule, from the upper deck of a London omnibus, of the crowds of people scurrying in the streets suggested to his mind, according to his testimony, the similar model of the movement and interaction among the atoms.) Or such moments can be identified when noticing particular phenomena that give rise to hypotheses about their cause. (A falling apple suggesting to a lad — Isaac Newton — the idea of universal gravitation.) And so forth.

All adductions and analogous accounts and testimony concerning events on the path of scientific discovery, even if we admit their trustworthiness (for which, in a number of cases, there is inadequate basis), do not give correctly

*Published on the occasion of the fiftieth anniversary of the death of D. I. Mendeleev, and translated by H. A. Simon (Carnegie Institute of Technology).

a complete and exhaustive idea of the entire process of discovery in its context — particularly of its psychological side. In order to define this idea — in particular, to ascertain completely its precise formulation which occurred at the time of the discovery — it is necessary to establish its sequence of development, getting to know the process of discovery with all of its details, deflections, and zigzags. Unfortunately, up to the present time such information has not been gathered for even a single more or less major discovery.

Comparatively recently (in 1949) in the archives of the D. I. Mendeleev Museum at Leningrad University, work has been carried out extensively toward the investigation of archive materials of the great chemist — in the first instance, materials relating to the discovery of the periodic law, which was made on February 17, 1869 (all dates are given in old style). Mendeleev, an extraordinarily accurate person, kept without exception all documents, even those on first view completely minor and insignificant, and his own rough notes, among which were discovered exceptionally valuable materials directly characterizing the process of discovery of the periodic law. Some of these materials were already published in 1950-1953, part are being published at the present time. Their analysis promises to reveal in great detail the psychological side of the scientific creativity of Mendeleev in relation to the discovery in question. In this paper we turn to the scrutiny of these documents.

* * *

We describe first all the circumstances in which the discovery was made. Mendeleev was writing at this time the second part of his Fundamentals of Chemistry. The first part of this work was completed at the end of 1868, its final chapters being devoted to the group of very strong non-metallic haloids (halogens). Directly after the haloids followed the group of very strong metals — alkaline metals — to which the author allotted the first two chapters of the second part of his work.

It can be assumed that by the middle of February 1869 both chapters were finished, and the task confronted the author, with all insistence, of deciding which group of elements should follow the alkaline metals in the book. But to decide this it was necessary to elucidate which metals adjoined the alkaline closest of all. It is quite clear that this question should have disturbed Mendeleev still earlier, when he was working out the preliminary plans for the second part of his book. At the moment of finishing the first two chapters, it must have arisen with all keenness. To answer it, it was necessary to find some general principle according to which the elements could be arranged in their groups in a definite order, and treated in that order in Fundamentals of Chemistry. Without such a principle, it was impossible to settle a simple practical problem: in what sequence to continue writing the book after finishing the first two chapters of its second part.

In order to present concretely the conditions under which the process of discovery was accomplished, it is necessary to take into account an important peculiarity of the scientific, pedagogic, and social activity of Mendeleev. Always a many-sided scholar, Mendeleev was occupied simultaneously with very diverse — it would almost seem completely incompatible — activities. Thus, during this period, while he was teaching chemistry in the University of St. Petersburg and writing a fundamental work on the elements of this science, Mendeleev was passionately concerned with very practical agricultural questions not having any direct relation with theoretical chemistry.

In the sixth decade of the nineteenth century, under conditions of rapidly developing capitalism in post-reform Russia, there began to spring up all kinds of cooperatives and collective organizations. Mendeleev was an ardent champion of these, for he always fought for the most progressive forms of economic development in his country, relating them to her growth along capitalist lines. But there were adversaries of this new form — skeptics. There was a voluntary economic society in Petersburg in which

Mendeleev was an active worker, which decided to inspect, in a series of districts of central Russia, the organization of some dairy artels. In December 1868, Mendeleev was sent for this purpose on a trip. But he did not succeed, in a single journey, in finishing the inspections he had begun, and could not, therefore, prepare a report for discussion in the Society. At the end of January he named an approximate date (February 20) when he could go out again to finish his inspection of the dairy co-ops. Apparently this date was connected with the fact that at this time Mendeleev intended to finish and give to the printer the first chapters of the second part of his book. In fact, however, hurrying to finish, he succeeded in freeing himself early, and already on February 15 (a Saturday) took a certificate of leave from the university for the time from the 17th to the 28th of February for his trip from Petersburg to Tversk and other districts.

All of this shows that Mendeleev did not at all intend, on the 17th of February, to take up any large scientific question that might consume much time for their solution or that could detain him in Petersburg. Therefore, the discovery of the periodic law, accomplished on this very day, came about completely unexpectedly from the standpoint of the activities on which Mendeleev planned to spend this day as well as the next eleven days.

Thanks to these purely accidental coincidences, on the 17th of February, unexpectedly for Mendeleev, both lines of his activity during this period came in conflict and crossed: first, writing the Fundamentals of Chemistry and, second, his trip to the dairy co-op. Since his trip was agreed upon with the interested organizations, Mendeleev could not avoid his obligation to go on a specific day. This circumstance strictly limited the time he could set aside for solving the problem confronting him — relating to the arrangement of the next materials in the Fundamentals of Chemistry. In other words, Mendeleev achieved the discovery of the periodic law under conditions of the most severe Zeitnöt [time pressure], which gave rise to a very distinctive character and path in its development. The general psychological situation of Mendeleev on the day of the discovery can be compared with the situation of a chess master, caught at the very beginning of a game in Zeitnöt, but striving at all costs to achieve a victory in spite of the unfavorable conditions. Mendeleev achieved this victory thanks to the very great force of his will, subordinating all his activity to a unified contribution to his goal, rapidly choosing suitable as well as correct methods for achieving the whole, with maximum economy of time and force. The condition of Zeitnöt eliminated the possibility of exploring and testing various paths, and did not permit time for a comprehensive, leisurely deliberation about all questions, for postponing them to the following day in order to return to their solution once again.

If a man's willpower plays a large role in all creative acts, which are conscious and goal-oriented, then in this case, where the creative process took its course under conditions of Zeitnöt, the role and influence of willpower on the whole course of the discovery, on its tempo and direction, and even on its very outcome, must necessarily have been greatly magnified. Without this, Mendeleev could not, in the course of a single day (February 17, 1869) have accomplished such a gigantic task, which under other circumstances would have required a minimum of several days or, possibly, even several weeks. It is sufficient to say that for writing an account of the discovery which was made on the 17th of February (in the form of an article) he needed at least ten days.

It goes without saying that willpower alone, however large a role it played, still could not make possible the solution of the problem. Without arousing all his creative forces and talents, without focussing on the solution of one single question, Mendeleev would not have been able to so quickly achieve such a remarkable result. The archive materials that have been discovered permit us to recreate reasonably precisely this moment when the very discovery itself began, and when, as we can suppose, the creative inspiration came to Mendeleev.

On the morning of February 17th, Mendeleev prepared, apparently, to go to the railway station

and, before his departure, ate breakfast. Just the day before, he had finished the first two chapters of the second part of his book, and hence he began to consider in earnest what group of elements he should treat after the alkaline metals. This question continued to trouble him during breakfast. To be sure, the time available to him for a decision was sufficient: the question could be pondered for twelve days, that is, up to the time when Mendeleev would have returned to Petersburg from his business trip. Nevertheless, having remained unsolved earlier, while he was writing the first chapters of the second part of Fundamentals of Chemistry, this question should have gained special acuteness immediately after their completion. Apparently Mendeleev, as if by inertia, persevered in his mind on the initial earlier work on the book, and did not switch over immediately, without delay, to the question of the approaching inquiry.

At the time of this breakfast (the print of a mug placed on the letter is witness for this) Mendeleev received a letter from the secretary of the Voluntary Economic Cooperative relative to the duration of his trip to their dairies. On the back of this letter, where the mug of beverage had stood, he began to make the first calculations, comparing the group of alkaline metals with other groups of metals and calculating the differences of their atomic weights.

The first note shows that at this very moment there flashed across the mind of Mendeleev the idea of comparing chemically dissimilar elements in terms of the magnitudes of their atomic weights. To be sure, the groups first compared did not bring to light any regularity in the differences in the atomic weights of their members; nevertheless, at the first instant there was found the key to the solution of the whole problem. Now it remained to apply it correctly to the whole aggregate of groups and of individual elements. But this was a large, almost boundless, task of exceptional difficulty and highly laborious.

Finding the general key to the solution of the whole problem should have, of course, inspired Mendeleev, not postponing his activity for a moment even though in a state of preparation for departing from Petersburg, to try his luck at following up, explicitly finding the correct path to the solution of the problem. Thus began the first step of discovery.

On a separate piece of paper, Mendeleev began to compare groups of non-metals, since his first attempt to compare the alkaline metals with other groups of metals did not at once give a satisfactory result. Now he wrote:

F = 19	Cl = 35	Br = 80	I = 127
O = 16	S = 32	Se = 79	Te = 128
N = 14	P = 31	As = 75	Sb = 122
C = 12	Si = 28		Sn = 118

In all these cases except one (tellurium), the atomic weights of successive elements in a column decrease, all about the same amount, by a few atomic units. Accordingly reviewing this comparison, Mendeleev had to make sure, first, that adjacent groups did not have very large differences in atomic weights, as shown in the computations on the paper, and, second, that within the boundaries of each group these differences had a definite regularity, which however was not observable in the first attempt to put together two groups of metals. Therefore, noting down in the table the groups of elements, Mendeleev concentrated his attention on an absolutely definite aspect of their relations, which he fixed in mind and distilled out from the notes, and which can be presented in the following fashion (writing down only the differences between the atomic weights of adjacent elements):

F > 3	Cl > 3	Br > 1	I > − 1
O > 2	S > 1	Se > 4	Te > 6
N > 2	P > 1	As > 4	Sb > 4
C > 2	Si > 3		Sn > 4

Mendeleev must have seen these numerical relations in constructing the table of elements, fixing all his attention on detecting observable regularities in the atomic weights of corresponding elements.

The work of attention, work of a strictly selective character, permitted Mendeleev, even in the first steps of the scientific discovery, to detect the existence of a definite regularity. Later, after more than thirty years, he recalled: "To search for something — though it be mush-

rooms — or some pattern — is impossible, unless you look and try" [6;467].

Comparing the discovery of a new law of nature with a search for mushrooms has deep psychological significance. A person, wanting mushrooms, attends with concentration on detecting among many different objects (dry leaves, roots of trees, brushwood, stalks of grass, moss, and so on) the very definite signs that are peculiar to mushrooms. The task, from a psychological standpoint, consists in not passing by these signs, not losing them among other more striking signs, whose detection in this case turns aside the attention of the collector of mushrooms. Just such a task, in essence, stood before Mendeleev in working out the system of the elements: he must detect the regular sequence in the order of groups of elements according to the atomic weights of their members. But for this it was necessary to find and single out, from among the numerous relations among elements — including the relation among their atomic weights — that which would provide a unified arrangement of the groups of elements in a definite order. Toward this relation — the notion of the differences in atomic weights of adjoining groups — Mendeleev turned his attention, extracting it from his general consideration of all the relations among elements and underlining it, as it were, in his memory.

The successful beginning of the research could only stimulate its author to further search for the already sensed lawfulness; while the early success ought to inspire and, accordingly, increase the intensity of all the creative forces of the scientist.

The next important step on the path of discovery of the periodic law was the addition of the alkaline metals to the partial tabulation. This step was connected, above all, with the fact that the starting point for the whole search undertaken by Mendeleev on February 17, 1869, was a drive to determine which group of metals should be treated in the Fundamentals of Chemistry after the alkaline metals, as we have said earlier. Therefore, Mendeleev would sooner or later have to consider these metals, to find their place in the tabulation, and afterwards to concern himself with elucidating what group of metals would be directly adjacent to them if one adhered to the already discovered principle of arranging the elements in an orderly series according to the differences in their atomic weights.

Sketching one (the upper) table, but far from completing it, Mendeleev on the same piece of paper began to construct another (the lower) table, in which he brought together two groups of elements that are very unlike in their chemical character — the haloids and the alkaline metals:

Li = 7	Na = 23	K = 39	Rb = 85	Cs = 133
	F = 19	Cl = 35	Br = 80	I = 127

The values of the differences in atomic weights between rows here, in order, are equal to 4, 4, 5, and 6 — that is, they are consistent with the regularity already discovered.

Finally, according to this same principle, the alkaline-earth metals are immediately adjacent to the alkaline metals:

		Ca = 40	Sr = 87	Ba = 137
Li = 7	Na = 23	K = 39	Rb = 85	Cs = 133

The values of the differences in atomic weights once more show consistency with those which were obtained before: 1, 2, 4. This pattern was the solution of the practical problem, settling the question of which group of metals ought to be treated in the Fundamentals of Chemistry after the alkaline metals.

Precisely this question was the immediate concern of Mendeleev on the eve and on the day of his contemplated journey from Petersburg. As we see, its solution was not reached at once: when the initial attempts at solution did not give positive results, Mendeleev attacked it in a roundabout manner, solving first the question of the arrangement of the groups of non-metals adjacent to the haloids, next the relation of the haloid group with the alkaline metals and, finally, the relation of the alkaline metals with the group of metals adjoining them most closely — which were found to be the alkaline-earth metals. This is a model of the sequential solution of a complex problem by first working out a general initial principle for its solution.

* * *

The above first step in the discovery of the periodic law cannot be understood without taking account of the previous prolonged work of Mendeleev, which served as a preparation for this discovery. This preparatory work had continued for nearly 15 years and extended in all directions.

In the course of this long period, Mendeleev mastered the interactions and relations of the elements and their compounds from every standpoint (resemblances of crystal form, or isomorphism; relations of specific weights and atomic volumes; regularities in all compounds, particularly higher oxides of salts, in correspondence with their theoretical limits; relations among the atomic weights of chemically similar elements belonging to one natural group).

By the end of 1868 this preparatory work had progressed so far that Mendeleev, in the process of writing his Fundamentals of Chemistry, already actually compared two groups of elements — the haloids, which completed the first part of the book:

$F = 19$ $Cl = 35$ $Br = 80$ $I = 127$,

and the alkaline metals, which began the second part:

$Li = 7$ $Na = 23$ $K = 39$ $Rb = 85$ $Cs = 133$.

Within both groups, the elements are already arranged in order of atomic weight, and only one thing was missing — a comparison of both groups on the same basis. Thus it appears that by the middle of February 1869 the discovery of the periodic law had been fully prepared by the previous work of Mendeleev, and only a jolt was need to complete this work, just as a revolutionary leap completes the work of the previous evolution. The events occurring in the life and creative activity of Mendeleev on February 17, 1869, were just such a jolt.

Referring to the discussion earlier of the first stage of the discovery of the law, it should be duly emphasized that the work was not finished at this moment, but only begun. In order to establish a law of nature, it is necessary to make certain that the hypothesis holds generally. One cannot organize an imperfect induction, demonstrating the presence of a regularity if only several phenomena among all those belonging to the subject are conformable to its pattern; it is necessary to show that all these phenomena, without exception, actually exhibit the postulated regularity, that is, that the law holds with the generality required of all genuine laws of nature. As Mendeleev himself expressed it, "Laws of nature do not tolerate exceptions." At the initial stage of this discovery, it embraced not all, but only a few well-known groups of elements containing only two-thirds of the entire number of elements known at that time (42 elements out of 63). The remaining third not yet included in the table of elements offered extraordinary difficulties because they had been incompletely studied and, most important, because of the inaccuracy of the data on the atomic weights of many elements.

When Mendeleev found the answer to the question that had interested him — what group of metals should be treated after the alkaline metals in the Fundamentals of Chemistry — he did not regard his work as finished. Beginning with the sought-for answer to this partial question, Mendeleev went on to a great discovery, discovery of a new fundamental law of nature. Understanding this, Mendeleev could not stop halfway, much less be satisfied with the answer to the part that originally interested him, that is to say, the utilitarian part of the question. The concern was now with carrying out to the end the discovery of the lawfulness, already found in the first approximation. Thus begins the second, decisive stage of discovery.

However, the method initially selected for constructing the table of elements by entering elements in it successively (one after the other), although it was successful in the first stage of discovery, turned out to be inapplicable for the whole set. The point is this: while Mendeleev was operating on the well-known elements, all of them, with few exceptions, took their places in the table; even if their places had to be changed subsequently, such failures were few and did not obscure the whole picture of the organization of the elements which at any moment were included in the table. But when Mendeleev tried by these same means to find a basis for including in the table the poorly studied elements,

the number of necessary corrections, transpositions, and deletions became so great that it began to interfere with the progress of the discovery. To recopy from the beginning in every case the incomplete table, as Mendeleev did in going from the upper to the lower table on the piece of paper, was practically impossible. This would have taken so much time that one could not think of completing the whole work in a single day (for he was still to go out to the cooperatives on the following day). The Zeitnöt mentioned earlier, limiting his time, required finding a more convenient method for quickly carrying to completion the developing discovery.

In all likelihood, under these circumstances the rush of ideas of Mendeleev gave place to a tense — one could say, agonizing — process, searching for the required means that would permit a maximal economy of time and effort, leading to completion of the whole work and not interrupting it halfway. Calling on Mendeleev, it would seem, at just this moment, his friend A. A. Inostrantzev found Mendeleev in a gloomy, depressed state. According to Inostrantzev, Mendeleev began to speak of what was subsequently the embodiment of the periodic system of elements. But at this moment the law was still not formulated and the table still not completed. "It's all formed in my head," said Mendeleev with bitterness, "but I can't express it in the table."

Judging by this testimony of Inostrantzev, there ensued for Mendeleev a certain depression relating to the difficulties that arose in trying to incorporate the poorly known elements in the table, because the principles for incorporating them were lacking. Mendeleev himself, at a much earlier time, wrote in his diary that after a period of enthusiasm he sometimes fell into a sudden slump, or even depression, ending sometimes in tears. Apparently, at this psychologically critical moment of transition from an intense spurt of arduous creative work to the corresponding generally depressed mood, his friend Inostrantzev came upon him.

This slump, possibly, was augmented for Mendeleev further, because, outlining the plans for the whole discovery, he spoke of the necessity for carrying out sufficiently prolonged work on the still incomplete system of elements before it could be regarded as even relatively complete. Meanwhile the necessity of traveling to the cooperative, creating time pressure, ruled out the possibility of carrying out such work at this moment.

Thus, there stood before Mendeleev the task of finding a means for completing the table of elements which would permit him to see at each moment only the latest results of his arrangement of the elements in a clear, as it were "distilled out," view, not obscured by the previous changes and transformations, but, without rewriting each result on paper. This problem was soon brilliantly solved by Mendeleev.

The condition of time pressure demanded finding some method that could serve as the basis for a modifiable system — for example, a system of cards. Mendeleev arrived at this idea. How could the idea come to him? Various associations could play an important role here.

It should be mentioned that Mendeleev loved to play the game of patience, where the thoroughly shuffled cards must then be rearranged according to definite rules, resulting in a definite pattern of disposing them by suit and denomination. The analogy with the distribution of elements turns out to be nearly complete; for at the moment when he considered this problem, two incomplete tables of elements were already written down on paper, and in them was already clearly charted a distribution of elements in two dimensions: horizontally, according to their general chemical properties or chemical similarity (which corresponds to arranging the playing cards according to suit), and vertically, according to the closeness of their atomic weights (which corresponds to arranging the playing cards by denomination). To shift from writing down tables on paper to preliminary distributions of the elements on cards as in patience required only one thing more — to connect the task of arranging the elements in a table with the task of playing patience.

Such an association could occur to Mendeleev not only directly, by analogy to the game of patience, but indirectly, by way of the similar

comparison of the task of classifying chemical objects with the task of arranging playing cards in a systematic order that had already been made earlier by Gerhardt. Mendeleev counted himself one of Gerhardt's convinced adherents, and of course was acquainted with this earlier application, consisting in this: Gerhardt drew the parallel between arranging cards by suit and denomination, on the one hand, and arranging organic substances in homologous and genetic series, on the other. In this way Gerhardt showed that, just as with playing cards one could discover immediately a specific missing card and know exactly what was lacking, so, arranging organic compounds in their homologous and genetic series, one could determine what compounds had still not been discovered and predict what properties they should possess.

As we can see, the bases for Mendeleev's association in this case were more than sufficient.

Sometime later Mendeleev wrote that through his study of compounds he involuntarily acquired the idea that between masses (atomic weights) and the chemical elements (their specific properties) there must necessarily be some relation, and one should therefore search for functional relations between them. "Here I began to sort out, writing down the elements on separate cards with their atomic weights and fundamental properties, comparing elements that were similar in atomic weight, and quickly came to the conclusion that the properties of elements stand in periodic relation to their atomic weights. . ." [6; 467].

From these words it is clear that "sorting out" the cards with the elements written on them was similar to sorting out cards according to suit — "similar elements" — and denomination — "similar atomic weight" (compare the schema below).

In connection with the second stage of the discovery, we can illustrate the role of such psychological phenomena as derive from imagination and memory.

When Mendeleev turned to the cards of elements, the very analogy with patience, which probably came to him directly or indirectly at this moment, ought to have brought into his

Schema for Laying Out "Chemical Patience by Analogy with the Common Card Game of Patience*

		Ca=40	Sr=87	Ba=137
Li=7	Na=23	K =39	Rb=85	Cs=133
	F =19	Cl=35	Br=80	I =127
	O =16	S =32	Se=79	Te=128
	N=14	P =31	As=75	Sb=122
	C =12	Si=28		Sn=118
		Mg=24	Zn=65.2	Cd=112
			Cu=63.4	Ag=108

*Along the horizontal: elements belonging to a single group arranged according to increasing atomic weight (comparable to arranging cards from a single suit according to their denomination, from deuce to ace).

Along the vertical: elements arranged according to their similarity in atomic weight, for dissimilar elements belonging to the different groups; specifically, in order of diminishing atomic weight (comparable to arranging cards of a single denomination— deuces, treys, and so on— according to suit, from hearts to spades).

mind the complete chart of the arrangement of the elements (of course along very general lines, in the form of its rough outline). This outline might organize itself, for example, if only in conceiving that all the elements should be arranged according to family likeness, in groups, in horizontal rows, and also by groups, according to atomic weight, in the vertical columns. It goes without saying that the specific details, for example, the location of this or that poorly known element in some particular spot, could not be determined immediately, but would require a thorough examination, with a study of all the properties and relations of the given element with other elements. However, the general character of the future, and already developing, system of elements would undoubtedly stand out in Mendeleev's consciousness, so that he could visualize already sufficiently clearly the above-mentioned two incomplete tables which he had written down on paper.

Laying out cards in patience presupposes that the player knows beforehand, and holds in mind, the requirements of the game for the order of disposing of the cards, although actually the cards are disposed in a very different order

before his eyes, that is to say, randomly and chaotically. Having in his mind's eye the required arrangement, that is, having recourse to the working of his imagination, the player begins to rearrange the cards so that, gradually and step by step, he brings them to the arrangement which is required by the rules of the game and which he, during this whole time, holds in his mind.

Strictly speaking, this is the path Mendeleev took, although the image of the correctly arranged cards of elements could not stand before him as clearly and definitely as before the player of patience. Nevertheless, since the conditions of "chemical patience" were already defined (grouping the elements according to properties in rows and according to similarity of atomic weight in columns), the idea could grow into a general picture of the future system of elements in its completeness. But this shows that imagination ought to have played, and did play, apparently in the case of Mendeleev, a significant role in the decisive stage of the discovery of the periodic law.

A still more important role was played by Mendeleev's memory processes, which could in many cases be displayed very tangibly. The associational processes themselves, providing the point of origin for the second stage of the discovery — that is, relating to the working out of the system of elements with playing patience — came in entirely, or to a notable degree, through the help of memory. But the circumstance is even more important that the necessity for this kind of association was brought into consideration as a result of the working of the memory of the scientist in the course of the discovery.

We recall that at the beginning of the first stage of discovery Mendeleev encountered difficulty in distributing in the table at least 20 poorly known elements, whose place in the system he could not at this time determine quickly and exactly — and most important — unambiguously. But what is this "place" of an element in the system? It is the sum total of its connections and relations with all the rest of the elements, both those already included in the table and those not yet integrated in it. Accordingly, in order to define the place in the table for any one element, it was necessary to keep in mind all of its significant connections and relations with the rest of the elements, in particular, those chemically similar to it and close to it in atomic weight. In addition, it was necessary to remember all the elements already included in the table, and all those still not integrated with it. Further, it was necessary at every moment to keep in memory and recall the meaning of the properties that were characteristic of the elements newly entered in the system, or of those still being transposed from place to place, because precisely this meaning can and must define their places in the table. Briefly, the work of the memory in the process of creative activity consists primarily in holding in the head the whole aggregate of facts, and to extract from them whatever is necessary at a given moment, and at the same time to fixate the steps already achieved, disclosing the general relations of all the facts as a starting point for further progress.

However, as was said earlier, Mendeleev's main attention should have been directed to revealing and checking the constancy of the difference between the atomic weights of corresponding elements. Naturally, it is impossible to think that one could simultaneously retain in memory the hundreds of facts pertaining to 63 elements, disposed in the table in a definite order. It was necessary at the time of discovery to relieve, as far as possible, the load on memory, in order that all the intellectual work could be directed at the main and fundamental point: finding the actual relations among elements and, in particular, those which gave evidence by their presence of the correct differences in atomic weights. The cards of elements, with the important fundamental properties of the elements marked on them, were just what was needed to produce the greatest possible reduction of memory load in the process of discovery.

There was involved not only remembering and recalling at the right moment the whole collection of facts about the properties of particular elements, but also always keeping in orderly sequence those elements which still had not been placed in the table. This was finally accom-

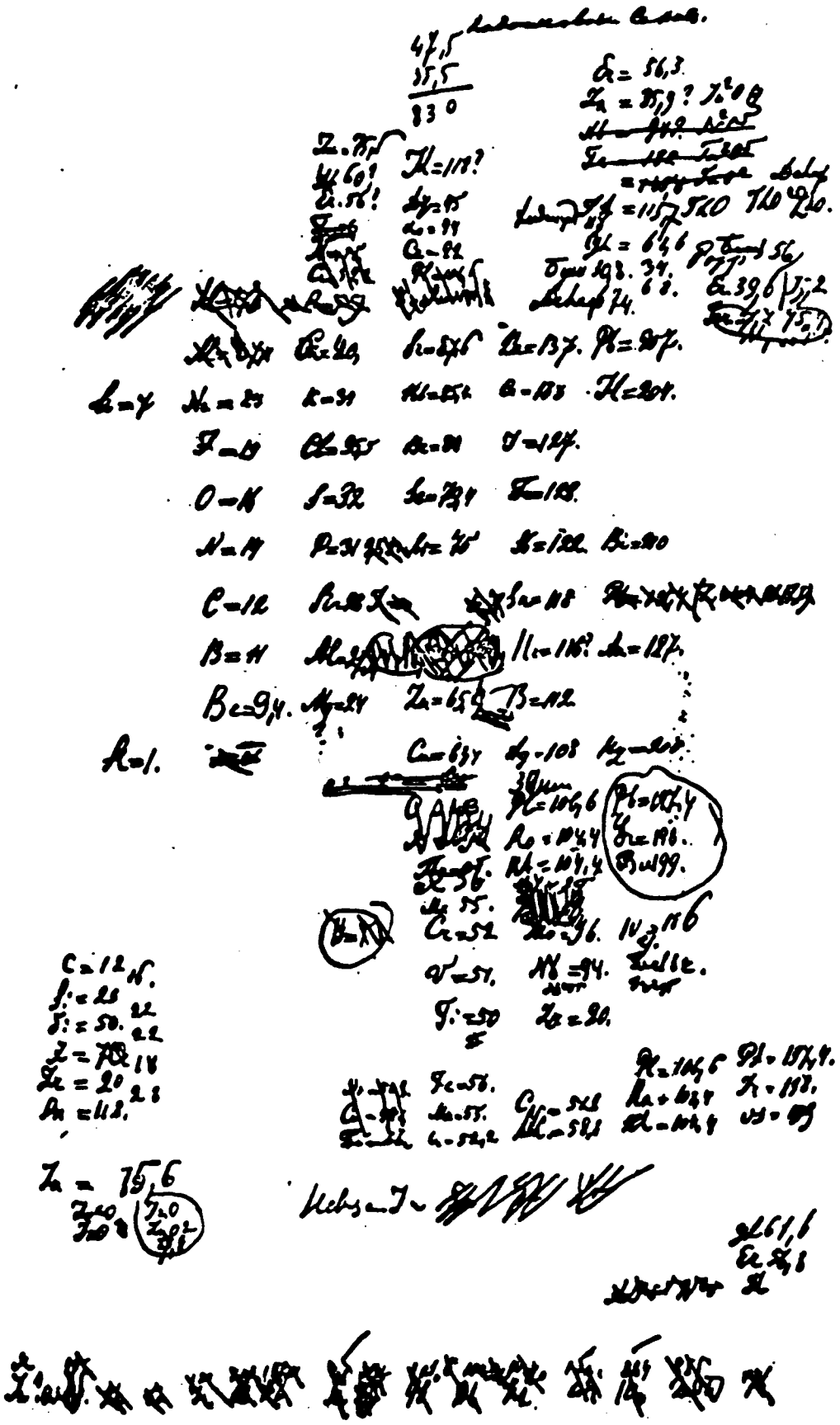

Figure 1

plished, it appears, by laying out the cards of these elements in categories (separate groups), from which were constructed the general sequence of elements destined to follow those already in the table.

Mendeleev noted down the results of his patience from time to time in handwritten tables, in which are recorded the occurrences of all important transpositions and changes arising in the course of discovery, that is, in the course of laying out the "chemical patience" (see Fig. 1). On the margins of this rought draft, Mendeleev, to remember them, wrote down several lists of elements, which at a given moment still remained outside the table; and at the moment of adding them, he struck them from these lists. In this way, at every moment, he could see at a glance, not relying on his memory, both the elements which were already in the table and those which now had the next priority for being entered

in it.

Fixing the process of laying out "chemical patience" with all the changes in its course, the processes for including in the table one new card after another, and for recording them for purposes of memory in lists, afterwards striking them out, let us establish in all detail the whole course of the patience game and, accordingly, the discovery itself in its decisive stage. Thanks to this, it was possible to penetrate into the laboratory, usually hidden from our gaze, of a scientifically creative investigator, and to analyze the act of scientific discovery both as to its logical and its psychological sides.

Several peculiarities of Mendeleev's memory render significant service in investigating the materials relating to the history of the discovery of the periodic law, allowing the chronological sequence in the writing of various documents to be established. It is the case that only an insignificant part of Mendeleev's manuscripts were dated by the author himself. There was no date on most of them, so the only way possible for establishing the date of their writing was to analyze the content of these documents and compare them with other documents of known dates. Nevertheless, in all the manuscripts of Mendeleev, there were important indications as to when these notebooks were put together. These showed a direct relation to the peculiar working of Mendeleev's memory, particularly with respect to forgetting several conventions of notation, and recalling these inaccurately at various stages in his work on the periodic system. Later on, Mendeleev often detected the inaccuracies he had committed (by recalling to memory the right notation, or discovering it from some other source) and corrected his earlier erroneous notation. The notational corrections are still present in the manuscripts.

Thanks to this, knowing the date when a given notation was amended, it is easy to determine the time of writing this or that manuscript in which this notation appears, that is, to know whether it was written before or after this date. For example, Mendeleev began to designate the element niobium in his handwritten plan for the second part of the Fundamentals of Chemistry by Ni, that is, the same symbol as nickel. The last time this was written as Ni was on February 17, 1869, in the list of poorly known elements not yet included in the table (cf. the upper right-hand corner of Fig. 1); on this day Mendeleev paid attention to the fact that he had written the symbol for this element incorrectly, and subsequently he denoted it by the symbol that had been adopted, Nb. Accordingly, the writings in which niobium is designated by Ni belong to times before February 17, 1869, and those in which it is designated by Nb to times after this date.

In just the same way, the element rhodium was denoted at the end of 1868 and the beginning of 1869 by the letter R or the symbol Ro. With this notation the "Tentative System of Elements" was sent to the typesetter on February 17, 1869, but afterwards in the proofs it was changed to Rh, as rhodium was designated from then on. On March 1, 1869, the pages with the corrected symbol Rh were printed and distributed, so that all manuscripts where rhodium was designated by R or Ro must have been written not later than February 28, 1869, and those where it was designated by Rh must have been written after this date.

We mention one more example where the inaccuracy or, better said, unevenness in Mendeleev's memory helps us today to determine the dates of various documents. In the course of the years 1869 and 1870, Mendeleev designated the element palladium by Pl, and only in the corrections to his paper "Natural System of the Elements," written on November 29, 1870, did he amend this symbol to Pd. The journal containing this paper was published on February 4, 1871, but Mendeleev's corrections were made at the beginning of January. Accordingly, finding in any paper of Mendeleev the symbol Pl for palladium shows that it was written not later than the beginning of January 1871, but finding for it the symbol Pd speaks for a later time of writing.

Thus, analysis of the discovery with a sharp eye for the working of the memory of the scientist, its peculiarities and small lapses, opens the possibility not only of establishing several

very important aspects of the course of the whole discovery, but helps in such essential matters for the science of history as determining the time of writing of various documents.

In speaking of Mendeleev's memory processes, it is necessary to mention one interesting circumstance of a peculiar character: Mendeleev sometimes forgot not only minor details, as he himself wrote in his autobiographical notes "List of My Publications," (1) but also very important things.

Thus, at the end of February 1869, analyzing the contents of the "Tentative System of Elements" from the standpoint of correcting the atomic weights of the elements, Mendeleev wrote down, specifically, two columns of elements with even and odd valence, respectively. Putting them in correspondence, the one with the other, made it possible to discover that in the first column at least three elements were missing, which should be placed between the group of haloids (or hydrogen) and the group of alkaline metals. For these, at this time completely unknown, elements with even valences, Mendeleev undertook to write down atomic weights equal to 2, 20, and 36. Essentially, here he had foreseen, if only somewhat dimly, three members of the future inert group — helium, neon, and argon, possessing zero valence.

In the last decade of the nineteenth century there was discovered at first helium (He=4) and argon (Ar=40), and soon after neon (Ne=20) and other inert gases, belonging in the system exactly between the haloids and the alkaline metals. However, Mendeleev spoke of these discoveries as completely unexpected and unforeseen, although a quarter-century earlier he himself came very near to prophesying them. Now he at first generally doubted that argon was an element, since initially a place could not be found for argon in the periodic system. All of this testifies to the fact that after a lapse of 25 years Mendeleev simply forgot completely that he himself in point of fact predicted — though not as definitely as he did for several other then still undiscovered elements — the existence of at least three new elements, members of the future inert group.

* * *

Another very interesting characteristic of the scientific creativity of Mendeleev was clearly displayed on the day of the discovery of the periodic law — his ability to distinguish unerringly between those matters that could and ought to be settled at the given moment, and those that should be postponed because their solution was impossible at that stage of the development and required further investigation — whether lengthy or brief. This ability might be called the skill of solving large and complex problems by separating them out, in an orderly sequence, into parts.

For example, in the course of the discovery, the scientist was faced with the task of assigning to the table four families of metals: iron, palladium, platinum, and cerium. Each of them had three members — joined with iron were also two other metals, chrome and manganese. The immediate attempt to find a place for these metals in the growing system appeared unsuccessful. Then Mendeleev selected the first three families with the two preceding metals belonging to them, out of all the rest of the elements, and made a partial table for them, which he afterwards joined to the whole table (cf. the central part of Fig. 1).

Still applying this method there were explained by Mendeleev's scrutiny little-known elements, the accommodation of which in the table had generally seemed impossible on the first day. Finding himself under time pressure, Mendeleev could not set before himself a task that was impracticable in a single day. Therefore, in the process of discovery, he, as it were, "sifted" in memory all the material and, summarizing it, separated out all that should be detached for further, more thorough and special study with the aim of establishing its place in the general system of elements. Already at the beginning, putting in the heavy elements (cf. the very lowest row of elements in Fig. 1), the table omitted indium, which he transferred to the list of elements with doubtful atomic weights (cf. upper right corner). He was unable to place the family of cerium in the table with the other three

families, and it was therefore, at this stage of the investigation, put at the very top along the margin. By distributing the last part of the elements (with uncertain atomic weight), he showed that four of them "dropped out" as not having a proper place in the system; these were indium, erbium, torium, and ytrium. These Mendeleev placed above the table, together with the family of cerium.

This method, at the end of the first day, showed that at most seven elements of the 63 could not be placed in the system, and required additional investigation (uranium was soon added to them). The whole system had arrived at an incomplete aspect: for 56 elements their place in it was defined, for the remaining seven it was not. This remaining incompleteness of the system was seen clearly by the author; it was not by chance that he called it "Tentative System of the Elements," emphasizing by this its experimental, unfinished character.

Examining the characteristics of Mendeleev's scientific creativity is important from the psychological standpoint. It testifies to Mendeleev's ability to appraise soberly the real alternatives available to him, not undertaking irrelevant tasks, and to plan his creative activity so as to postpone to the future everything that it was impossible to settle at the given moment. In fact, the elements left out of the table (with the addition of uranium) provided the theme for special theoretical and experimental investigations which Mendeleev carried out uninterruptedly in the course of three years: beginning with uranium (summer and winter of 1869), then indium and cerium (autumn of 1870), and finally all the members of the cerium and gadolinium families (from the end of 1870 to the end of 1871). From these remarkable characteristics it is apparent that Mendeleev held no illusions as to how easily or quickly he could complete the work he had begun; and he did not mistake the first tentative solution of a complex problem for the final answer, derived from it. Appraising correctly the import of the tasks he had accomplished, he could see clearly, and plan for, his future work, outlining its full real perspective.

* * *

On the evening of the day of the discovery, when the rough table shown in Fig. 1 was complete, that is, when he had finished his game of patience with the cards of elements, there occurred a remarkably interesting and psychologically highly significant event. Inostrantzev has recounted it. According to his words, for three days and three nights Mendeleev did not lie down to sleep, but worked at his desk, trying to combine the results of his mental constructions in the table, but his attempts to achieve this seemed unsuccessful. Finally, suffering from extreme fatigue, he lay down to sleep and immediately slept deeply. Concerning what happened next, he several times reported to Inostrantzev: "I saw in a dream a table where all the elements fell into place as required. Awakening, I immediately wrote it down on a piece of paper — only in one place did a correction later seem necessary."

Inostrantzev suggested the possibility that this scrap of paper was still preserved (this was said not later than 1919), since it was known that Mendeleev often used for his notes unused half-sheets of stationery from letters he had received [5; 137].

Finding the archive materials not only confirmed this earlier conjecture, but allowed a test of the accuracy of Inostrantzev's account. The dates available on these materials show that the whole discovery, as finally put together and circulated in print in the "Tentative System of Elements," was achieved in just one day — February 17, 1869. Therefore, the account of three sleepless nights appears grossly exaggerated. Hence, it is necessary to clarify what Mendeleev had in mind when he said that "the elements fell into place as required." But for this it is necessary at the outset to determine what table he was speaking about. In any case it could not be the notes that are reproduced in Fig. 1, for there are numerous corrections in these, while according to Inostrantzev, in the table of Mendeleev's dream, "only in one place did a correction later seem necessary." This condition is satisfied by the fair copy of the notes that was sent to the printer [5; 12]. On this there was actually just one correction made later. But if this is so,

then comparing both tables — the notes (see Fig. 1) with the copy sent to the printer — will permit us to decide definitely what the phrase "falling in place as required" means. In the note the elements are arranged in vertical columns, in order of decreasing atomic weight. This results from the fact that in taking arithmetical differences between numbers, one usually places the smaller beneath the larger. When the table was finished, then the following could be seen: the first column began (if we read from left to right, and from top to bottom, as is customary) with lithium (Li = 7), and ended with hydrogen (H = 1), the second column ran from Na = 23 to Be = 9.4, the third (if we leave out the three top elements, lying outside the table) from Ca = 40 to Mg = 24, and so on. But this arrangement does not exhibit the continuity of the whole series, for after H = 1 comes Na = 23, and after Be = 9.4 comes Ca = 40, and so on. The continuity would be preserved in reading from the bottom up, but one doesn't do this. Therefore, Mendeleev could not ignore the fact that the form of his table did not represent entirely successfully the whole pattern of the structure in such a way as to give at a glance the notion of the essence of the law, which can be stated (as Mendeleev formulated it in writing the article in which he first communicated the discovery): "The elements, arranged according to the magnitudes of their atomic weights, exhibit a clear periodicity in their properties" [4; 27 and 326].

We can suppose that, having finished laying out the game of patience and feeling keenly the need for rest, Mendeleev deferred deciding the question of the form of presentation of the system he had constructed, and lay down to rest with the idea of considering this, but still not having eliminated the defects. In this case he could actually have dreamt of a table in which "the elements fell into place as required," that is, in columns reading downward according to increasing rather than decreasing atomic weight. Awakening, he wrote down what he had seen in the dream. This was the fair copy of the table, which he sent to the typesetter.

Pondering this example allows us to draw two inferences about the way the discovery proceeded: first, the creative thoughts of Mendeleev even in his dream could continue his activity in the direction previously pursued, leading to the completion and improvement of the representation he had found earlier. Second, one can surely not speak of the discovery of the periodic law during sleep, although the testimony of Inostrantzev would give grounds for such a conclusion if we accepted it completely on faith and did not subject it to critical examination on the basis of the newly discovered archive materials. Several authors have made this error. As a matter of fact one can affirm, with respect to the more general formulation of the discovery, that it was by no means accomplished by the scientist in his sleep, but in a fully awakened condition.

It is interesting to note that later Mendeleev again changed the form of his table several times, influenced, apparently, by the same circumstances as in the first case. We refer to the change from the vertical form of the table to the horizontal, now generally accepted. In the original form of the table, the elements were arranged in vertical columns, that is, in the way it is customary to arrange numbers for adding or reading off. Mendeleev did this in the beginning because it was necessary to observe in his first plan the differences in atomic weights of the elements. But when the system had been constructed according to the first plan, it should have shown clearly the unbroken sequence of atomic weights of the elements arranged in series; and this fundamental concept could most clearly be expressed by arranging the elements in horizontal rows, from left to right, in the way we are accustomed to write. The change from the original vertical form of the table to the more convenient (for reading) horizontal form was first made by Mendeleev before the end of February 1869, that is, shortly after he made the discovery. This modification, carried further in August and October of the same year, was completed in November 1870, with the construction of the "Natural System of Elements."

* * *

Describing the creative process that led Mendeleev to the discovery of the periodic law allows us to draw several conclusions about this particular discovery, and about scientific creativity in general. First of all, attention should be called once more to the uninterrupted activity of the will, which — during the whole of February 17, 1869 — held all the forces and capabilities of the scientist in a condition of highest alertness, and permitted the discovery to be attained in the furthest measure and with all aspects of it that could be handled with the facts available at that time. By it the sort of "pulsations" of Mendeleev's creative efforts were governed, expressed in an alternate rise and fall of creative energy, with a subsequent still higher rise and new fall, or, better stated, a psychological discharge to finish all the work, changing to a slump, in the course of which the creative activity did not halt completely, but continued developing in the previous direction.

Investigation of the entire process of discovery shows that there was nothing in it that would argue for complete suddenness and unexpectedness of its origins, any incoherence in its course, or the presence of any inexplicable "leaps," surprises or "revelations from Heaven." On the contrary, the newly discovered material allows us to establish this process as a fully connected, strictly ordered growth of the ideas of the scientist, though accomplishing very quickly, in the course of a day, a very important work that under other conditions would have taken very much more time.

For understanding the character and tempo of the course of the discovery, elucidation of the external conditions and circumstances in which it was accomplished has exceptionally great significance. In this connection it is essential to consider scrupulously and to give proper weight to all sorts of details that at first glance appear to be "trifles," not worthy of attention. For example, several historians of chemistry have regarded as entirely unessential the facts relating to Mendeleev's journey to the cooperatives, not even speaking of such "trifles" as the presence of the mark of the cup on the back of the letter received by Mendeleev on February 17, at the moment when he was preparing to go to the station. From just such "trifles" as these, analyzed in relation to the fundamental material concerning the history of the discovery in question, the possibility arises of elucidating such important circumstances as the significantly strong time pressure on Mendeleev on the day of the discovery. This circumstance not only limited the free time of the scientist, but also in the highest degree stimulated the concentration of all his energy on the rapid solution of the problem lying before him. We observe incidentally that it was exactly this consideration of the importance of all "trifles," without exception, for untwining the genuine history of a scientific discovery that impelled the author of this account to search in the personal archives of Mendeleev not only for documents relating directly to the periodic law, but also connecting it with all the other events taking place in February 1869 in the life of the scientist. Thanks to this, among the materials on the question of the social cooperatives (and not at all on chemistry) was discovered the letter of February 17, 1869, mentioned above, on the back of which Mendeleev began to make the first calculations that led him subsequently to discovery of the periodic law.

In this manner the <u>beginning</u> of the discovery was disclosed, the starting point from which it moved to unwind the whole thread during the course of February 17, 1869. Had these kinds of "trifles" been generally excluded from the field of vision, then many of the essentials would have remained unnoticed, and it would have been completely impossible to lay out the whole picture of the discovery in such detail as we are now able to do. Therefore, such a preconceived disregard for so-called "trifles" is intolerable in historical investigations. Only on the basis of a comparative study of <u>all</u> materials, without omission, concerning the event of interest to us can it be correctly established which of the ascertained facts were actually important or even decisive (and which of secondary importance, not playing such a role), because of which they ought to be mentioned in an analysis or account of the history of the events in question.

* * *

In relation to the earlier account, we referred to the question of the relation between the logical (more generally, philosophical) analysis of a scientific discovery and its psychological analysis. The leading thesis here follows the well-known saying of V. I. Lenin: "Not psychology, not phenomenological spirit, but logic — determines the truth" [1; 150]. In fact, for logic (and philosophy in general) the essential question is how far and precisely the results achieved by the whole scientific creativity are objectively correct, in other words, to what extent they are true. It is precisely this question that is of primary interest to the science to whose sphere the discovery in question relates. All that appears idiosyncratic in the process of discovery itself cannot add or subtract anything from the final whole, any more than the completed facade of a building which has been constructed retains the traces of the scaffolding that surrounded it at the time of construction. When the building has been constructed, the scaffolding is removed. Afterwards, only from a strictly construction viewpoint can one have an interest in how this scaffolding was raised.

Contemporaries of a particular discovery, and even more the later generations, only grasp the finally achieved result, but not the concrete, often winding, path by which this result was achieved. On the contrary, psychology is interested not only — and sometimes not as much — in the final result at which the creativity of the scientist arrived, but also in the path of the scientist, with all its detours and zigzags. In the given case, a psychological analysis means a scrutiny of the phenomena of the investigation as a process of natural history, following them as strictly individual events, but with all possible awareness of what they have in common with other similar events in the history of science. From our analysis of this question, we can see wherein lies the difference between the logical and the psychological approaches to the analysis of scientific creativity, though both aspects are interrelated and have many connections, the one with the other.

On the side of logic, the essence of the discovery made by Mendeleev consists in this: Mendeleev climbed up from the level of "specificity" in the study of the chemical elements to the level of "generality." The first level, on which the overwhelming majority of chemists of this time stood, amounted to sorting the elements into natural groups ("specific") without relating them in a single unity. The second level involved laying bare the general law relating all of the elements ("general"), hence relating the groups in which they were already classified. By the sixth decade of the nineteenth century, chemistry had reached such a stage that chemists ought to have discovered and brought about, by some means, a shift from the first level to the second. This was the task placed before chemistry by the objective line of development of the science itself. When this shift was actually realized, its result was embedded in chemistry in the form given by Mendeleev in his formulation of the periodic law ("general"), and it was mainly this which was absorbed into chemistry itself and which could be subjected to logical analysis.

In speaking of the task lying in the road of a developing science, we ought to take into account the fact that various scientists perceive this sort of task in different ways, interpret it, and try to solve it in different ways; that a not insignificant role is played by their personal qualities, their general mentality, their tastes, interests, habits, training, and similar particulars that appear to be completely random in relation to the problem itself set before them for solution, and to its substance and significance for the further development of the science. Here in essence arises the known relation between necessity and chance as the form for manifesting and realizing necessity. Scientific necessity requires the solution of definite problems; the way for these is paved by the whole prior course of scientific knowledge; the further development of the science is impossible without their solution. But the problems of science can only be solved by specific people, with all their individual peculiarities. Therefore, solution of any scientific problem — for example, the dis-

covery of a new law of nature — always takes the form of accident, always showing the imprint of the circumstances under which it was carried out (the individual traits and whole mentality of the scientist, the events of the given discovery, and the external conditions in which it was achieved, and so on). All these are topics for special investigation by psychology. The science itself, in whose sphere the discovery lies, as it were "cleanses" and liberates this discovery from the transient form in which it arose, that is, from all the events which were irrelevant for the science itself, and in the final result saves from the discovery only that which conforms to imminent necessity on the subsequent path of the developing science.

This is the relation between the logical and psychological aspects of the investigation of one and the same scientific discovery.

In connection with our case, various psychological nuances can be illustrated by the example of three scientists who appeared at almost the same time in the sixth decade of the nineteenth century in different countries of Europe. In England, there appeared Newlands, discovering the "law of the octave," which was an approximation to the periodic law. Newlands showed that in the sequence of elements, arranged according to increasing atomic weight, with every eighth element the same properties reappeared, as happens in the case of musical octaves: the higher "Do" stands in the eighth place above the lower. Thus, in the elements Newlands noticed with his mind's "ear," as it were, the periodic sounding of the same note in various octaves in the course of running up the whole scale in sequence. The analogy between the chemical elements and the musical notes was essential for the discovery he made; this analogy provided the individual idiosyncracy which was the unique concrete path, which by the force of its own individuality directed Newlands, although he did not carry the whole discovery through to a conclusion. (The investigation of the causes for this circumstance goes beyond the limits of our paper.)

At the same time as Newlands, De Shancourt in France came very close to discovery of the periodic law. But in contrast with the musical-tone image, which served for Newlands as an analogy to the lawfulness of the chemical elements for which he was groping, the French naturalist resorted to an abstract geometrical image: he compared the periodic repetition of properties of the elements, arranged according to the magnitudes of their atomic weights, with a winding spiral curve ("vis tellurique") on the surface of a cylinder. Possibly, whatever the mental traits of either of the investigators, the character of their personalities and training, the nature of the diversions they preferred, and other circumstances determined that for Newlands the elements would be associated with a musical-acoustical image, while for De Shancourt, with a constructive-geometric visual image. But one way or another, in this or that form, there arose in the sixth decade of the nineteenth century the necessity for insistently probing along this road. For its realization there were traced out in the various cases paths that were influenced to a notable degree by the psychological traits of those men who felt this necessity and undertook to realize it.

A similar situation is shown in the circumstances that led Mendeleev to the establishment of the table of elements, thinking of the relation of the task of working out a general system of the elements with laying out cards in patience, which he loved to play in moments of relaxation. This historical fact — that simultaneously in various countries different scientists undertook to solve one and the same problem, each attacking it differently — shows, first, that this problem actually was ripe and had become crucial for the growth of the science, and, second, that for solving it effectively there existed not just a single, strictly determined psychological route (for example, imagining musical-acoustical or spatial-visual associations, or any other, such as associations with playing cards). Under the influence of specific conditions it could be solved by techniques quite various from a psychological viewpoint, if only each of them brought the possibility in the given case of a form that would embody and reveal the sought-for necessity.

* * *

In conclusion we touch on the question of how sometimes there arise afterwards various hypotheses and legends about how a discovery was made, not corresponding to the actual history. Earlier, the account of Inostrantzev was mentioned, according to which Mendeleev revealed that he had discovered the periodic system in his sleep! Checking this account, which came to us from the testimony of an eyewitness, showed that much in Inostrantzev's account was exaggerated — more than that, distorted and confused.

Partly the sources of legends about scientific discoveries arise out of attempts to extrapolate a simple after-the-fact logical interpretation of the accomplished discovery, in other words, by explaining the results of the discovery to represent them as the route of the discovery itself. From a psychological standpoint this is as though the conclusion and the premises exchanged places, and the premises were subsequently entirely forgotten.

We can find numerous examples in the history of science. In 1803 Dalton discovered the law of simple proportions, one of the most fundamental laws of atomic chemistry. In making this discovery, he proceeded from simple physical, and partly hypothetical, principles, assuming that atoms were surrounded by mythical energy-holding shells. In order to fix the dimensions of these spheres (and this was necessary in order to explain the theoretical law of partial pressures, discovered in 1801), Dalton simply speculatively and theoretically arrived at the idea that it was necessary to know the relative (i.e., atomic) weights of the different elements, and the number of atoms of the elements combining in a complex particle. But since the atoms were indivisible, then the number in a complex particle could only be an integer. For example, one atom of carbon or cerium could combine with only one, two, or three atoms of other elements, say oxygen, but not a half, or a third, or a quarter, or one and a half atoms, and so on. Reaching this conclusion, Dalton thereupon checked it against the facts of experimental chemical analysis as reported by other chemists and, shortly afterwards, against the results of his own laboratory investigations. In this manner, still not undertaking any experiments, simply on theoretical grounds Dalton arrived at the conclusion of the existence of the law of simple proportions.

When this law had been discovered, he still had to explain on a theoretical and logical basis the consequences that followed logically from it. A year after this discovery, in 1804, Dalton was visited by his friend, T. Thomson. Dalton recounted to his visitor the discovery he had made, giving him permission to publish it. In this he omitted all details of the route of the discovery and stated only the result, in the generalized form, purified from all happenstances, that is usual in science, where one sets forth logically and explains the truths that have been deduced. Dalton showed that in two compounds of carbon with hydrogen (we refer to ethylene and methane), which he had personally analyzed in the laboratory at his home, the amount of hydrogen combining with a given amount of carbon varied in the ratio of one to two. Further, he showed that this experimentally established fact could be explained by assuming that atoms are indivisible and can combine only in whole particles, so that if ethylene is the compound C+H, then methane is C+2H. Thus, the law follows logically. Thus Dalton gave his guest an explanation of the discovery he had made from a completely opposite starting point than that from which he himself had reached the discovery. If he had begun to talk about the energy-holding spheres, the partial pressures of gases in mixtures, or similar matters, having no direct relation to the essence of his discovery, then that essential core would have been shoved into the background by attendant circumstances of an accidental, psychological nature. Therefore Dalton, trying first of all to convince his guest of the truth of the law he had discovered, acted in this situation as a teacher: he presented first a fact (although actually this fact was only established after the discovery), and thereupon proposed to explain it theoretically with the help of the notion of indivisible atoms.

In explaining the matter thus, his goal was achieved: Thomson immediately understood Dalton's idea, and from that time became its ardent champion.

The account of Dalton set forth a logical, fully correct exposition of the already discovered law. As a matter of fact, if truth is the essence of any phenomena, then in explaining them it is necessary to begin with the empirical facts (with the directly observable phenomena), and thereupon proceed to explain their bases, that is, to explain them theoretically. This, as a rule, is the general path of all cognition, considered from the standpoint of dialectical logic.

In this manner, in order that the logic should clearly, and in an orderly way, give the result of the discovery, Dalton did not begin his account with the matters that were actually the path of development of his own scientific thinking, leading him to the discovery.

Therefore it is fully understandable that Thomson, and all chemists after him, perceived the history of the construction of Dalton's theory of chemical atomicity as though it began with the establishment of experimental facts, and that then for their explanation Dalton came to the theoretical notion of atoms, explaining with their help the law of simple proportions, discovered by this empirical route. In fact, as we have already said, the road to the discovery of this law was directly opposite: starting out with hypothetical assumptions and theoretical foresight, Dalton proceeded to experimental verification of the facts that derived from the theory. In other words, in the case before us, he went not from experience to theoretical conclusions, but from theoretical assumptions to experience. This example reveals very clearly the guiding role of theory, thanks to which hypotheses mold the actual form of the developing science, resting on theoretical notions. All of this was concealed by the diffusion, in the nineteenth century, of the accepted version of the law of simple proportions, as a mere empirical development. Only at the very end of the century Roscoe and Hardin discovered and published Dalton's professional diary, which allowed the actual path of discovery of chemical atomicity to be determined, including the path of discovery of the law of simple proportions as its essence. However, the great forces of habit substitute for the confusing, but real, path of scientific discovery, with all its psychological curves and zigzags, and its ideal, logically clear path, that is, one like that by which we apprehend the result of a given discovery. This force of habit is so great that even after the documentary disproof of the false and imaginary version of Dalton's discovery, this version still survives to our own time, is repeated in our literature, and is given out as genuine history.

A completely analogous situation holds for discovery of the periodic law. Earlier we described its specific course, which was restored from its errors on finding the archive materials. Meanwhile, from earlier times other versions have been disseminated in our literature, which thus appear to be logical extrapolations into the past of the presently accepted formulation of the periodic law, as were the versions of Dalton's discovery of chemical atomism. In fact, when the essence of the periodic law first began to be widely discussed, the following conception sprang up: let all the elements be arranged in a single series according to increasing atomic weight; then there will immediately come into view the periodic recursion of the properties of the elements. Mendeleev himself explains his law in this way in his Fundamentals of Chemistry. In his third edition (1877), he wrote: "Thus, the essence of the idea is arranging in order all of the elements according to atomic weight. But then one notices immediately that the properties of the elements repeat periodically" [3; 255].

But if, from the psychological standpoint, for the exposition of a new fact it is necessary to present it to the reader in this manner, then the idea naturally begins to thrust itself upon the reader that the introduction of this fact into science came along the same path. In other words, a person learning from a book a new fact, previously unknown to him but already established in the science, will be inclined to accept the path that he himself took as the path along which this fact was first discovered and

established generally in the science. Thus, since the periodic law can most easily be understood if one begins by arranging all the elements in a single series according to atomic weight, then divides this series into separate groups (periods) and writes down one series below the other, this then begins to offer itself as the path of discovery of the periodic law by Mendeleev. The author of the discovery himself was partly responsible for this. Giving the first account of his discovery (in his paper "Correlation of the Properties with the Atomic Weights of the Elements," presented in March 1869), he wrote: "I undertook to base the system on the magnitudes of the atomic weights of the elements. The first attempt, set forth in this memorandum, was the following: I selected those with the smaller atomic weights and arranged them in a series according to their atomic weights. In this way it became clear that there existed a period, as it were, in the properties of simple bodies" [3; 8]. Thus since also in the Fundamentals of Chemistry, again and again, from edition to edition, there is repeated the analogical explanation, set forth earlier, of the essence of the periodic law, this version of its discovery — through first setting up the general series of the elements arranged according to atomic weight — soon came into our literature. The force of habit to accept as the real process of the discovery this one, which fits the logic of its exposition to perfection, was from this time an extraordinary force. Even after the discovery and publication of the new archive materials, fully demonstrating the falsity of this version, and showing that the discovery was accomplished by way of comparisons between one and another natural group of elements, the hypothesis of the initial arrangement of the general series of elements continues still to find its adherents. The essence of this hypothesis is in opposition to the acknowledged fact that the scientific discovery occurred in a process of moving scientific understanding from "singularity" (separate elements) through "particularity" (by representation of their groups) to "generality" (to disclosure of the general relations among all the groups, and hence among all the elements). Oversimplifying the actual route of the whole scientific understanding, by adhering to the hypothesis of setting up the single series of all the elements, discards completely the moment of "particularity" as an essential intermediate level of understanding, and attempts to represent the discovery as a spontaneous and direct jump from the level of "singularity" to the level of "generality."

Thus, our investigation allows us to trace out not only the path of the discovery itself, but also the habitual, living legend concerning its history.

Footnote

1) "In general, I am very forgetful of small events" [2; 84].

References

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3) Mendeleev, D. I. Izbrannyye proizvedeniya, Vol. 2.

4) Mendeleev, D. I. Nauchnyi arkhiv, Vol. 1. Izd-vo Akad. Nauk SSSR, 1953.

5) Mendeleev, D. I. Novyye materialy po istorii otkrytiya periodicheskogo zakona. Izd-vo Akad. Nauk SSSR, 1950.

6) Mendeleev, D. I. Osnovy khimii (7th ed.). St. Petersburg, 1903.