SCIENCE

FRIDAY, SEPTEMBER 15, 1916

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MSS. intended for publication and books, etc., intended for review should be sent to Professor J. McKeen Cattell, Garrison-on-Hudson, N. Y.

THE LIFE AND WORK OF CARL LUDWIG[1]

WE are gathered together as teachers and investigators to commemorate the life of a teacher of teachers and an inspirer of investigators. We represent many phases of academic activities, most of which are far removed from the special branch of science to which Ludwig devoted his life. Therefore, only a greatly condensed account of his physiological discoveries will be given, and most of this paper will be devoted to his life, and an attempt to bring out from the testimony of his old pupils and friends, the traits of character which gave him his remarkable power as a scientist, and enabled him to win the reverence and, I may say, the love, of all those who had the good fortune to work with him as students and colleagues.

Carl Frederick Wilhelm Ludwig was born in Witzenhausen, a little town on the banks of the Weser, not far from Cassel, in the electorate of Hesse, December 29, 1816. His father, an officer in the Napoleonic wars, had been compelled by wounds to give up a military career, and being in favor with the elector, was appointed Rentmeister in Hanau. Ludwig came from a race of fighters, and a deep scar on his upper lip gave evidence of his participation in student duels. He was proud of his descent, and I recall an amusing reference which he made to the fact that the Hessians had played a part in the early history of our land.

He was the second of six children, who

[1] Read before the Research Club of the University of Michigan, at the "Memorial Meeting," April 19, 1916, by Warren P. Lombard.

were carefully trained at home by a wise and affectionate mother. At the close of his school days at the Gymnasium in Hanau, he was sent to the University of Marburg, where his student days were stormy. Indeed, as a result of conflicts with the disciplinary authorities, some say because of political activities, he was forced to leave for a time. He studied at Erlangen, and spent one year at the surgical school at Bamburg, finally returning to Marburg, where he took his doctor's degree in 1839. Continuing his studies, he was appointed, in 1841, second prosector of anatomy under Ludwig Fick. The following year he was formally admitted to the faculty of the university.

Ludwig has often been incorrectly numbered one of the pupils of Johannes Müller, but Tigerstedt states that he was a finished physiologist when he first visited Berlin, and that the one of the older scientists who exerted the greatest influence on Ludwig was Ernst Heinrich Weber. Even in his old age Ludwig spoke with the greatest admiration of his predecessor in Leipzig, and could not say enough of the tremendous importance of the part played by Weber in the development of science.

In 1846 he was appointed ausserordentlich professor of comparative anatomy at Marburg, and in 1849 professor of anatomy and physiology at Zurich. It was in this year that he married Christine Endemann, who with loving care watched over him, guarding with affectionate solicitude his somewhat frail health, making possible his life-long devotion to science.

In 1855 Ludwig was called to Vienna as professor of physiology and zoology at the academy for army physicians—the Josephinum—and in 1865 he succeeded Ernst Heinrich Weber in Leipzig, receiving the title of professor of physiology and director of the physiological institute, which was about to be constructed.

A list of the honors which have been conferred upon a man is of interest as an indication of the way he was regarded by his contemporaries. Ludwig's titles in the register of the University of Leipzig read as follows: Ehrendoctor der Philosophie der Universität Leipzig, Königlich sächsischer Geheimer Rath, Comthur I Klasse des Königl. sächsischen Albrechtsordens mit dem Stern, Comthur 2. Klasse des Königl. sachsischen Verdienstordens, Ritter des Königl. preussischen Ordens pour le mérite unde des Königl. bayerischen Maximilianordens für Wissenschaft und Kunst, Inhaber der Copley Medal of the London Royal Society, Commandeur I Klasse des Königl. schwedischen Nordsternordens, und Ehrenbürger der Stadt Leipzig (this last honor being given on the occasion of the celebration of his fiftieth Doctor's jubilee). In addition he was a member of the Akademien der Wissenschaften in Berlin, Wien, München, Paris, Petersburg, Rome, Turin, Stockholm, Upsala, et cetera.

The period when Ludwig was entering upon his physiological work was one of unrest in medical as well as political thought. Modern biological conceptions can be said to date from that time. The greatest physiologists of the day in Germany, Johannes Müller and Liebig, while recognizing that living beings are influenced by the physical and chemical forces which govern inorganic things, assumed the existence of some mysterious force within the bodies of animals and men, which caused life processes to take a different course from those occurring in inanimate objects. Only death released the atoms from this mysterious influence and permitted them to act as they did outside of living organisms.

This vitalistic doctrine was combated and for a time at least overthrown by the scientific work of the pupils of Johannes

Müller, Helmholtz, Du Bois-Reymond and Brücke and by Ludwig.

Helmholtz, recognizing the limitations set by the existing chemical and physical knowledge, devoted himself only to those branches of science which seemed capable of exact chemical and physical explanation; Du Bois-Reymond contented himself with the study of the narrow field of electrical phenomena of living organisms, and did more than any one else to show that physiological problems are capable of being handled with the same precision as the purely physical; Ludwig, with characteristic fearlessness and enthusiasm, attacked problem after problem, striving to find out how many of the subtle processes of life were susceptible of a mechanical explanation.

Ludwig's "Lehrbuch der Physiologie des Menschen," the first edition of which came out from 1852–1856, and the second, from 1858–1861, was dedicated to his friends, Brücke, in Vienna, Du Bois-Reymond, in Berlin, and Helmholtz, in Bonn. The writer's point of view was diametrically opposed to that of his predecessors. Throughout the book the explanation for vital processes is sought in pure mechanics, in the widest sense. He wrote in the introduction:

> The problem of scientific physiology is to determine the functions of the animal body and deduce them as a necessity from its elementary conditions.
>
> Whenever the body of an animal is subdivided to its ultimate parts, one always finally arrives at a limited number of chemical atoms, and upon phenomena which are explainable on the assumption of a light ether and electricity. One draws the conclusion in harmony with this observation, that all forms of activity arising in the animal body must be a result of the simple attractions and repulsions which would be observed on the coming together of those elementary objects. This conclusion would be unassailable, if it were possible to show with mathematical accuracy, that the elementary conditions were so arranged in the animal body with respect to direction, time and quantity, that all of the phenomena of living and dead organisms must necessarily flow from their interaction.
>
> This conception, as is well known, is not the traditional; it is the one among the newer, which, as especially opposed to the vitalistic, has been named the physical. The view, aside from all details, finds its justification in the irrefutable demand of logic, that a cause shall underlie every result, and further in the soundest rule of every experimental science, that one draws only on absolutely necessary grounds of explanation.

Du Bois-Reymond toward the end of the year 1848 said:

> The belief in a vital force, like the other dogmas, depends less on scientific conviction than the need of a soul to certain organizations; that is why this belief, like that of the dogmas, can not be rooted out.

The slowness with which the new view was accepted is demonstrated by the fact stated by Kronecker, that Claude Bernard, only towards the end of his life, 1876, made the definite statement:

> Que les conditions de manifestations de la vie sont purement physico-chemique et ne diffèrent par sous ce rapport des conditions de tous les autres phénomènes de la nature.

In 1895 Mosso wrote from Italy:

> After a short truce during which vitalism appeared to be abandoned, we see it born again under another form. Literature and art bear witness to the reaction which produces itself, and on all sides one detects the breath of mysticism which invades the mind. The school of the neo-vitalists has already conquered the pulpit, and many fear that it will stifle the spirit of true science, as it has done in the Catholic universities.

Tigerstedt, one of Ludwig's favorite pupils, who has become one of the best known of the physiologists of our time, and who, although a Finn, was unanimously chosen as president of the International Congress of Physiologists, which was to have met in Paris this autumn, gives perhaps the best expression of the attitude of the present-day physiologists:

In the newest physiology there is noticeable an undercurrent which offers as its conception with always less reservation that not even the simplest life processes, as for example respiratory gas exchange and lymph formation, can be explained wholly on a physico-chemical basis, but that they chiefly depend on vital processes in the cells. . . . But this new vitalism distinguishes itself in a very important point from the old. It does not assume the existence of a peculiar, mystic vital force, and does not break away from the fundamental view, which the last fifty years have made the unalterable possession of physiology, with the truth that the principle of the conservation of energy applies to living as well as to dead nature. This being so, it is of relatively secondary importance whether the complicated processes, which take place in living beings, can or can not be explained by the physics and chemistry of our time. In any case they follow definite laws, and are not called out by a whimsical power, which can at the one instant be indefinitely strong and at the next nul. So if we say that this or that process is attributable to cell activity, that signifies nothing else than that our present physical and chemical knowledge is still insufficient to completely explain these processes, and that the right explanation will possibly only be found if the forces working within the cell lie more clearly in the sight of the experimenter.

And if it were true that many theories which Ludwig expressed had lost some of the likelihood which they formerly seemed to have, what has that to do with their importance for our science? In all natural science we meet the observation that theories have only a limited life, that one theory after a shorter or a longer time must give place to another, which can indicate more completely or better than its predecessor the character of the phenomena which it should explain. A theory is then good, and has an importance in the development of science, if it is of such a kind that it leads to new investigations, based on direct observation of nature, through which science wins in breadth and depth. If through it such facts shall be discovered as are not in harmony with the theory, which they have, nevertheless, to thank for their discovery, then the theory falls. But it falls with honor, for it has led to the discovery of new truths, and has constructed an important link in the development of science. Whatever the fate of Ludwig's theoretical views, we can surely say that they have greatly enriched science, and so bear the stamp that is the sign of good theories.

It is interesting to read the estimation of Ludwig's character and his methods of work by another great investigator, Wilhelm His, the great Leipzig anatomist:

Ludwig's weapons of research were an uncommon sharpness of analysis of living processes under observation, an always clear formulation of the question, and an absolute reliability of the method of attack. It was of great importance for his career that he was a schooled anatomist and controlled microscopical technique to a remarkable degree. From his anatomical knowledge came his consummate and careful technique as an experimenter on living animals, in which only Magendie and Claude Bernard are to be compared with him. Moreover, he had at his command a shrewd intuition, without which the clearest thinker is often powerless in the investigation of living processes. Nature does not always allow herself to be conquered by logic, her ways are frequently hidden, and she reveals herself only to him who has sharpened his sight for insignificant traces, by persistent, faithful observation. Ludwig had to a high degree a love for personal observation, and a successful preparation or a striking experiment was for him an esthetic pleasure. He placed direct perception, in the study of living nature, far above working with abstract conceptions.

As has been said, when Ludwig was appointed to the chair of physiology in Leipzig his first task was the planning of a physiological institute. This institute was the seat of Ludwig's labors for nearly thirty years; it saw the development of many of the greatest physiologists of the past five decades; it was the birthplace of discoveries which have been of inestimable value to medical thought; and the remarkable success of the ideals and methods which he, as director, put into practise, caused it to become the model for many others. The plan is a witness of his breadth of view, and the recognition that the problems of physiology can be solved only through a knowledge of the structure of the parts involved, and a study of both the physical and chemical changes occurring within them, and that under ideal conditions, all of these forms of work should go

on side by side. The building had the form of a capital E. The main portion was arranged and equipped for the study of physiological processes from the physical side, one wing was devoted to histological work, the other, to physiological chemistry. The lecture room, closely connected to the main part of the building, occupied the space between the wings. Above the laboratories, but completely separated from them, were the dwelling rooms of the professor and his family.

Ludwig reserved a well-lighted corner room for his private office. The door which communicated with the main laboratory was, however, very rarely closed, and his room was the passageway to the small adjoining room which contained the library, to which those working with him had access at all times. The books, largely journals, were free to the use of all, and could be even taken home, the only restriction being that the borrower should enter the book and his name.

His says that Ludwig's customary greeting, when His entered his chamber was, "Was giebtes neues?" The news for which he thirsted was not the gossip of the day, but suggestion for a new scientific problem, a new method of attack, the recital of some successful piece of research work.

When the London Royal Society presented the Copley medal to Ludwig, it was given not so much because of the important investigations which had appeared under his name, as because of the vast number of researches which he had conducted with the aid of his pupils, but in which his name failed to appear, and the still greater number, which were the result of the inspiration which those who had worked with him carried away, often to distant lands, and in their turn imparted to others.

Ludwig was truly remarkable for his ability to utilize the work of the young and inexperienced. A great school of physiology developed under him at Leipzig, with an activity with which only Liebig's chemical laboratory in Giessen could be compared. As many as nine or ten men, from almost as many different countries, might be found working in his institute at the same time, and this international circle lived, as Kronecker said, under the influence of the refined, kindly knower of men, in perfect harmony.[2]

Why was Ludwig's laboratory always full when the other German physiological laboratories had only one or two workers? The instant one entered it, he felt that it was a place where things worth doing were being done. Ludwig's enthusiasm pervaded it, and it was an intense pleasure to work in the stimulating atmosphere. I can recall Ludwig's joyous shout, as he called all who could leave their work to come and witness some physiological process revealing itself in its true light for the first time, or some unusually suggestive histological or anatomical preparation. And then came one of those delightful talks, leading us forward to the border land of science, and giving us glimpses into that fascinating, mysterious land—the unknown. I must admit that at such times, Ludwig's active mind sometimes, leaping over lines of thought which were new to us, often out-

[2] The following Americans were pupils of Ludwig: Gerau, of New York, 1845–46; Bowditch, of Boston, the first and best known of American physiologists, for many years professor at the Harvard Medical School, 1869–71; Minot, of Boston, one of the foremost of American embryologists, also many years professor at the Harvard Medical School, 1873–74; Abel, now professor of pharmacology at Johns Hopkins and formerly filling the chair in this university, who has a very high reputation, 1884; Mall, one of our graduates, now professor at Johns Hopkins, and probably the strongest anatomist in this country, 1885; Lee, professor of physiology at the medical department of Columbia, New York, who has done excellent work, 1886.

stripped his listeners. I thought that, in my own case, it was my incomplete knowledge of the language that was at fault, but I remember that von Frey, who was then docent in physiology, said that frequently he could not follow Ludwig.

Another thing that drew men from distant lands to his laboratory was the fact that it was well known that he never made use of his students for his own immediate glory, and that the researches which he inspired, and even those in which he did the most difficult part of the experimentation, were at all times treated as the personal investigations of those who worked with him, and were published under their names. As evidence of his unheard-of self-denial, Tigerstedt offers his own case. Having carried through a piece of work at Ludwig's suggestion, he sent him the manuscript from Stockholm for his criticism. The only correction which he made was to strike out the words, "Stetiger Beihülfe vom Herrn professor Ludwig."

It has often been said that Ludwig was absolutely unselfish in the lavish way in which he gave his ideas to others. He had so many ideas that he could well afford to be generous; he loved his science and rejoiced in the scientific achievements of his pupils; he was, moreover, worldly wise, in the best sense.

> Oh, if we draw a circle premature,
> Heedless of far gain,
> Greedy for quick returns of profit, sure
> Bad is our bargain.

The wonderful richness of the uninterrupted series of papers, published from his laboratory during the 56 years of his activity, was only made possible by his skilful division of labor, and his capacity to estimate the abilities and tastes of those who worked with him. Each man had his own clearly defined problem, and the problems were as distinct as the men. It was remarkable how many different forms of research he could supervise at the same time and keep them all clearly in mind. When I was working with him there were Wooldrich, who was studying the effect of stimulating special parts of the heart of the dog; Stolnikow, the rate of flow of the blood; Tigerstedt, the latent period of muscle; von Frey and Grubler, metabolism of isolated muscle when at rest and in action; Bohr, the way gases enter and leave the blood in the lung; myself, the method of spread of reflex processes in the spinal cord; and Miss Smith, who was working on a histological subject with Gaule, and others, working under Drechsel, on problems in physiological chemistry, among whom was Abel, now professor of pharmacology at Johns Hopkins.

You might be interested to know his daily routine. Every morning he visited the tables of the different men and discussed with them the next step to be taken, often appointing the hour when he would take part in the research with them (and the appointment was always punctually kept); or he would take them into his private room and critically discuss the methods employed, making suggestions as to the direction in which new and more effective methods could be sought, carefully go over the curves and other data already obtained and the inferences to be drawn from them. This was not done offhand, for each night when he left the laboratory he carried to his rooms above, records and protocols of investigations in progress, for careful study.

An hour or more was devoted to the preparation of his lectures, which were given at four o'clock and were richly illustrated with experiments. In the preparation of the experiments he was assisted by the mechanic of the laboratory, Salfamoser, who had come with him from Vienna to Leipzig. No account of Ludwig and

his laboratory would be complete without mention of Salfamoser. He had worked with Ludwig so long that he was thoroughly familiar with the routine of the laboratory and even the most complicated experimental methods. He was the first instructor of many a pupil in the technique of the operations which he had to perform, as well as the use of the apparatus. When Ludwig himself took part in operative experiments, Salfamoser often acted as his assistant, and, not infrequently, to the disgust of Ludwig, as his adviser. I can recall seeing Ludwig draw himself up and say to Salfamoser, "Who is the professor here, you or I?" "Oh, you are Herr Professor; nevertheless, I am right." Salfamoser was devoted to Ludwig, and Ludwig, fully recognizing his faithfulness and his ability, depended on him as one depends on his hands.

Ludwig's lectures were addressed to the most advanced of his students, and were attended by all of those working in the laboratory. The beginner had a hard time, and almost all of the ordinary students attended the course twice before presenting themselves for examination. Ludwig entered into his lectures with the same earnestness and vigor that characterized all of his activities. I attended, if I recall rightly, his forty-seventh course, and I never saw him enter the lecture-room that he did not change color. He did not know what it was to be blasé.

After his lecture he frequently went for a walk unless he had to attend the examination of some student, a task which he loathed. There was no work done in the laboratory Saturday afternoon, when it was left to the mercy of the scrubwomen; and no work was done on Sunday.

His intense interest in the problems that he was studying was infectious; his enthusiasm imparted itself to his pupils, and aroused all of their ingenuity and their best powers of observation and thought. Ludwig's untiring energy in the hunt, inspired the pupil with an unknown constancy of effort, the problem possessed him day and night, and when he began to dream of it the light began to dawn.

My own case must have found its counterpart in that of many others. I entered his laboratory knowing physiology only as I had learned it in the lecture-room. He assigned my problem, started me upon the method which at the outset seemed the most promising, and followed each advance with close attention. When I reported that I had found something new, he would ask me to show my records and prove to him that I had really found what I supposed. Even when the facts reported had long been known, no cold water was thrown on my enthusiasm, and I was allowed to have the supreme pleasure of having made, as I truly had, a discovery. And so he led me on, often helping me with the experiments themselves, and when, at the end of a year and a half, I had brought my results together and written the first draft of my paper in English, he put it into German, practically rewriting it. I shall never forget my feeling of embarrassment, as I said to him that I felt that I had no right to let the paper appear under my name, for I had been only his hands; that it was really his work and not mine. "It is all right," he said, "it has been your work." Then he added, "But if you never do anything else, it will be thought that you did not do this."

Ludwig did not know how to fail: once started on a trail he would follow it for years. He once said to me, "Never let nature get the better of you; if you do, she will take advantage of you next time."

He would never permit slovenly work. I remember one day he asked me to make

an iron hook which we needed. I bent one which I thought would do, but without criticizing it directly, he proceeded, while discussing the work, to painstakingly rebend it, until it exactly fitted our need. I carried that hook in my pocket for years, and although I finally lost it, the lesson has clung.

He taught his students independence. On one occasion when I offered to help him tie a ligature in a difficult place, he said with a merry smile, "No, no; if I let you help me now, you will want me to come and help you the next time you have a knot to tie."

Kronecker said of him:

> He understood how to instil his ideas so that those working under him often thought them their own. But he wished to bring out his own characteristic methods of expression when it came to the publication of the work, and every expert was able to recognize in the papers coming from the Leipzig institute the hidden thoughtful exposition of the master.

Von Frey admirably described his characteristics when he wrote,

> The steadfastness with which Ludwig clung to the complete control of the direction of the work, might suggest a form of military discipline in the laboratory. This certainly did not apply to the personal relations which existed. Nevertheless, such a comparison is not without value for an understanding of the exceptional results of his teaching. Among other qualities Ludwig possessed those which could be described as marked military virtues: boldness of design, tenacious perseverance in execution, presence of mind and high personal courage, an unusual talent for organization bound up with a knowledge of men, which knew how to put every force in its right place, strict discipline, frankness and heartiness in personal relations, indefatigableness in work, together with exemplary orderliness and punctuality.

With the love which our master inspired, there developed in the laboratory an esprit de corps, so that to have worked with him was a password that gave free entrance to the laboratory and the friendship of every other who had been his pupil.

Ludwig's old students, in token of their esteem, on the occasion of his twenty-fifth anniversary as ordentlicher professor, presented him with a Festschrift. In this was a list of his pupils up to that time, which numbered 142. In the twenty years that followed, a hundred others worked with him.

Many of Ludwig's researches were purely anatomical, or the physiological problems were handled chiefly on an anatomical basis. One thinks of the structure of the heart and its relation to its change of form, and of his attempts to bring the structure and course of the blood vessels in various organs into the explanation of their function. The excellent methods of injection of blood vessels developed in his laboratory, made it possible for him to study the circulation in many organs as it had never been done before, *e. g.*, in the eye, ear drum, liver, lymph glands, corpora cavernosa, intestines, muscle, ear-labyrinth, larynx, skin. Especially worthy of mention is the natural injection of the lymph spaces, by means of which Schweiger-Seidel and Ludwig studied the lymphatics of the pleura, the central tendon of the diaphragm, the retina and the liver.

As far as is known, his first physiological research was his habilitationsschrift, "Beiträge zur Mechanismus der Harnsecretion," published in Marburg, 1842, when he was twenty-five years old. In this work on secretion by the kidney, he developed the first physical theory of secretion of a gland. He deduced the method of the secretion of the urine from the structure of the kidney, and the physical forces which he thought must necessarily control them.

This work made him desire to know more concerning the action of physical forces on the passage of fluids through animal membranes, and led to important researches on

diffusion and osmosis. The exactness of the results were recognized by Ostwald.

He never lost interest in the original problem and a number of his students were assigned various phases of it during the succeeding years. An evidence of his open-mindedness is the fact that he was not disturbed by results which seemed to oppose his original view.

How Ludwig would have reveled in the clever technique displayed in the models and drawings of the kidney tubules, which have been developed in this laboratory by Dr. Huber.

Although emphasizing the important part played by blood pressure in the secretion of the urine, he proved experimentally that the pressure of the blood does not explain the secretion of the saliva, and his epoch-making discoveries with regard to the activities of the salivary glands began a new era in our knowledge of secretion processes. He proved that gland cells, like muscles, are capable of being awakened to activity by nerves, and become the seat of chemical changes, accompanied with the liberation of heat and the giving off of materials differing from those found in the blood.

Not less important were Ludwig's investigations of the interchange of oxygen and carbon dioxide gas between the blood and the tissues, and the blood and the air in the lungs. The blood-gas-pump devised by Ludwig and Setchenow in 1859, a new application of the Torricelli vacuum, proved the key to unlock many difficult problems. There followed many investigations by his pupils Schöffer, Holmgren, Preyer, Alexander Schmidt, giving the first measurements of the tension of the gases of the blood, and by Worm-Muller and Donders on the conditions which determine the tension.

Ludwig opened up still another line of work, the chemical changes occurring within special organs, when he found that it was possible to separate organs from the general circulation, and to study their metabolism by keeping them alive by artificially circulating defibrinated blood through them; *e. g.*, the heart of the frog was thus kept alive and acting for many days, and the effect of temperature, foods and drugs upon its activity were examined.

His studies into the formation of lymph, and the cause of its movement in the lymphatics, were of great value. According to Ludwig the plasma of the blood filters through the walls of the blood vessels, and so food materials are supplied to the various tissues. It is also the pressure of the blood which is the principal cause of the movement of the lymph stream. Where this is not sufficient, as in the case of the large cavities of the body, there are special pumping arrangements provided: in the abdomen and in the pleural cavities it is the respiratory movements of the diaphragm and of the chest walls which are responsible for the flow.

The conditions which determine the circulation of the blood always aroused his keenest interest, and it was because of his desire to grasp their significance that he was led to what has proved the most fruitful of his discoveries, the graphic method of recording physiological movements. In 1846, while still in Marburg, he studied the relation which exists between the movements of respiration and the pressure of the blood. He connected a U-shaped manometer tube partly filled with mercury, with an artery, but the movements of the column of mercury were so rapid and complex that the eye failed to retain them. It was then that he conceived the idea of recording the changes in pressure, and devised the kymographion. Let me quote his own words in his paper, "Beiträgen zur Kent-

niss des Einflusses der Respirationsbewegungen auf den Blut lauf in Arteriensystems," published in *Müller's Archiv,* 1847. "To obtain reliable figures under all circumstances by means of it (referring to Poiseulle's mercury manometer), and at the same time, time determinations for the duration and course of the different pressures, one places a rod-like float on the mercury, puts on the upper end a writing-point, and lets it draw the variations in pressure on a surface, which moves by the pointer with a constant velocity. In this way one obtains curves, the height of which is a measure of the blood pressure, and the width an indication of the time." Ludwig recorded the movements of the respiration and the oscillations of the blood pressure on the same paper simultaneously, and thus obtained curves which made possible an accurate comparison of the two series of events.

Although the graphic method was known at the beginning of the century to meteorologists and physicists (especially through the work of Thomas Young), it had been neglected and was carried again into physics and meteorology after the discovery of the kymographion. It has become, with its many modifications, an indispensable aid to the physiologist, pharmacologist, pathologist, clinician, and to experimental biologists and botanists. His pupil Angelo Mosso, the celebrated Italian physiologist, showed me the original tracing when I visited his laboratory in Turin. There is inscribed upon it the date, December 12, 1846, and notes concerning the experiment. It was the first time that the heart and respiration had spoken in their own language, and Ludwig in presenting it to Mosso wrote on the back—"I give to my friend Mosso for his collection, this first stammering of the heart and of the chest."

This was followed by researches into the structure and changes in form of the beating heart, which served to explain the true significance of the apex beat. He also did much to increase our knowledge of the cause of the first sound of the heart. All of these studies on the mechanics of the circulation naturally led Ludwig to a consideration of the means by which it is regulated, and so to a study of the nerves which act on the circulatory system.

The Weber brothers had discovered the effect of the vagus nerve to inhibit the heart. Schmiederberg, under Ludwig's guidance, 1866, discovered the accelerator nerve of the heart of the frog and of the dog, and in 1883, Wooldrich found centrifugal fibers to the heart of the dog, which altered the blood pressure without changing the rate of the beat. Bowditch, the best known of American physiologists, Luciani and Stienon, studied the effects of electrical excitations on the heart muscle, and ascertained a number of facts of theoretical importance to heart and muscle physiology.

Henle had observed the muscles in the walls of the blood vessels and Claude Bernard the existence of nerves which cause the constriction of certain blood vessels. It was left for Ludwig and Thiery to point out, 1863, the importance of these nerves in maintaining the tonus of the blood vessels, and consequently the blood pressure. Cutting the spinal cord was found to cause a fall, and exciting it a rise of blood pressure, without any change in the rate of the heart. They saw the vessels of the abdomen contract, and thought that the nerves ran in the splanchnic, a fact which Ludwig and Cyon proved in 1866. Moreover, during these latter experiments a nerve was found which ran from the heart to the medulla, the depressor nerve, which acts reflexly from the heart to dilate the blood vessels, and which protects the heart

from too great arterial blood pressure. Later, Ludwig and his pupils established more definitely the seat of the vaso-motor centers, and showed that the veins as well as the arteries of the portal system are under the control of nerves. Mall, now at Johns Hopkins, who worked with Ludwig in 1885, established this last fact.

It was Ludwig who started Mosso on the development of the plethysmographic method, by which the volume changes of organs under the influence of the alterations of the blood supply have been studied by many investigators, *e. g.*, Edmunds has found it of great value in work which he has been doing in the past years.

Ludwig's cleverness in inventing instruments required for his investigations is to be seen in the Stromuhr, by the use of which he was able to succeed where others had failed, and to measure the rate of the flow of the blood stream. By means of this he measured the rate of the output from the heart under varying conditions, and the amount of blood flowing through special organs when at rest and in action.

He was always deeply interested in reflex processes, and many experiments were carried on in his laboratory on the paths taken by nervous impulses along the white matter of the cord, summation processes, and the effect of local excitations and poisons. In addition, he caused many researches to be made on the special senses, sight, hearing and taste.

Investigations of a chemical nature were also made at his instigation, and von Frey has pointed out the difficulties which he must have encountered in directing such work, lying as it did outside of the fields with which he was most conversant. From the time that Ludwig and Alexander Schmidt found that easily oxidizable substances pass from the tissues into the blood, many such intermediate products were discovered in the chemical side of the laboratory, and their distribution through the body followed. Cloetta discovered the presence of inosit, uric acid, etc., in the animal body; calcium and phosphoric acid in the blood were measured; the lessening of glycogen in the "uberlebender" liver was noted; and the origin of jaundice studied. The method by which fats are absorbed, the streaming of fat in the lymphatics, the constitution and the fate of the fats entering the blood, all received attention. The digestion and absorption of proteins and sugars, and the changes which they undergo after entering the body were investigated, the structure of albuminous bodies being made the subject of special study by Drechsel.

An interesting discovery was made while the method of absorption of the digestion products of protein was being studied, namely, that albumoses if introduced directly into the blood act as poisons and deprive the blood of its power to coagulate. This observation gave a new impulse to the study of coagulation, and of the formed elements of the blood.

I am conscious of the incompleteness of this hasty summary of the work of Ludwig and his pupils.

Ludwig, himself, was deeply impressed with what had been accomplished, and the wide field of knowledge which had been opened up to man. I remember that he said the last time that I saw him, "What a pity that one must die just as it begins to be so interesting."

I can not close this paper without a few words concerning Ludwig's private life. He was no lover of forms and ceremonies, and counted of little worth the honors conferred by the so-called "great." I chanced to be present when a student called in dress coat and white gloves at the formal noon hour, as was the custom, to ask his

permission to enrole in his course of lectures. When the student addressed him as Herr geheimer Rath, Ludwig straightened up and corrected him, "Ich bin Professor."

In spite of his simple, genial manner, he had an innate dignity which always inspired respect. I can not imagine any one taking a liberty with him, certainly not a second time, for he could be cuttingly severe when he chose.

He was not only thoughtful and considerate of others, but his tender heart made him, although of necessity a vivisector, always careful to avoid the infliction of unnecessary pain. He saw to it that all experimentation on animals in his laboratory was performed in such a way that the suffering incurred should be the least possible. He was president of the Leipzig Society for the Prevention of Cruelty to Animals for twenty years, and did much to develop in the community a recognition of man's duty towards the animals dependent on him. The fact that he held this position for so long, shows how thoroughly this side of his character was recognized by his fellow citizens.

In his young days he was an active polemiker, and in that connection could use right hard words, but one never noticed in his controversies anything that pointed to an overestimation of self; the contest was simply the expression of his inner conviction that the way that the new physiology had chosen was the right way, and that one must vigorously fight the methods of dilettanteism, which, without regarding the true content of the question at hand, would escape the difficulties, to reach results which at first glance were striking.

Every new advance which promised to open the doors of nature's secrets, regardless of where and by whom they were made, was greeted not merely with warmth, but with enthusiasm. M. Chauveau, when president of the Société de Biologie of Paris, referring at one of its meetings to the loss which science had suffered in Ludwig's death, said, "Ludwig, du rest, etait animé du sentiments de l'equité porté au plus haut dégré; il n'a jamais ménagé l'expression de son admiration à ceux de nos compatriotes qui en étaient dignes."

Ludwig's interests were not merely scientific. He possessed a remarkable fund of information on the greatest variety of subjects, and whether he spoke of music, art, industrial and political conditions in other lands, of science or philosophy, his point of view was always original and suggestive. He had a keen sense of humor, and in the midst of a conversation of grave interest he would introduce an amusing story which would illustrate the point under consideration without breaking the thread of thought. An admirable storyteller, he rarely told a story for the story's sake; gifted beyond most men as a speaker, he was a good listener; in short he had the ability, possessed by so few, of leading a conversation so as to bring out the best from others.

Much of his power over his pupils was based upon his unaffected regard for them as individuals. He entered into their lives as only a friend can do, and continued his interest in them and their work long after they had left the institute. He wrote a charming letter, and found the time to answer his old pupils when, working under unsympathetic conditions, they turned to him for advice and new inspiration. I hold in my hand a photograph which I value greatly, and which bears a characteristic inscription: "Could I but spring and swim like the third in our league, I would soon croak 'Good morning' to you and your dear wife in New York. Oh they were good days. Your former teacher." They were good days.

In February, 1895, two months before he

died, when he was seventy-eight years old, Professor Ludwig wrote to me to say that he would take into his laboratory a young American whom I had recommended. Beginning the letter with a charming, fanciful sketch of the way my new house must look and the wish that he might be there with us, he ran into a soberer vein and wrote:

Destiny has conferred on us professors the favor of helping the responsive heart of youth to find the right path. In the seemingly insignificant vocation of the schoolmaster there is enclosed a high, blessed calling. I know no higher. In its fulfilment you will be the happier the more you yourself grow in knowledge and power of thought, the more you endeavor to be suited to the profession. How glad I am of your present and future happiness.

Ludwig died in his seventy-ninth year, in Leipzig, April 27, 1895. His wife wrote us:

Our daughter had come to us to help care for her father, and we were both by him day and night. Seven weeks he lay sick, but his mind was always clear. Only a few days before his death his thoughts were busied with a paper which he wished to write on his dead friend Helmholtz. On the last evening he still asked us about many things in which he was interested, then complained of great fatigue and so softly slept. The hastily called physician could only tell us that a sudden heart failure had quickly and painlessly ended his life.

No better words can be spoken at the end of an account of Ludwig's life, than those which he used at the close of his Gedächtnissrede for Ernst Heinrich Weber:

Now that he has departed from us, he has left us a rich heritage, but inestimable good has sunk into the grave with him. The one on whom his soulful eyes rested, who listened to the flow of his thoughtful words, who felt the pressure of his hand, will always long for him. Yet not only the friend, each one who in life and in science came in contact with his power, will mourn the death of a man, in whom were mingled in complete harmony, a spirit as clear as his and a nature of such richness.

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ANIMAL LIFE AS AN ASSET OF NATIONAL PARKS[1]

THE argument most frequently urged in favor of national parks is that they provide on a large scale for the protection of forest areas, and thereby ensure the transmission of a maximum water supply from the wooded tracts to the needy lands below. Attention has also been called to their value as refuges for wild life—particularly where the animals to be conserved are useful for game or food. The strict protection they afford enables the birds and mammals within their boundaries to reproduce at a maximum rate, and the surplus thus created, spreading outwards into adjacent unprotected areas, helps to make up for the depletion caused there by excessive hunting. The points mentioned above are fairly obvious. But national parks have other less generally recognized advantages, and among these we consider their potential uses as places for recreation and for the study of natural history, especially worthy of notice. We will here lay particular emphasis on their recreative value because this phase seems to have hitherto been treated only in a cursory way, and with an air of hesitancy, as if it were hardly deserving of practical consideration.

The term recreation is currently applied to any temporary change of occupation that calls vigorously into play latent or seldom used faculties of the mind and body. It is the purpose of this change to restore to the human organs the normal balance which special or artificial conditions of life disturb. As physiologists have long recognized, the interdependence of the various bodily functions is such that the neglect of one is bound to have its effect on the others, and complete health can only be attained when every function is given its adequate share of exercise. In view of this fact

[1] Contribution from the Museum of Vertebrate Zoology of the University of California.