Ostwald Memorial Lecture.

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During the starlit spring night of April 4th, 1932, in the city of Leipzig where his greatest work in the cause of physical chemistry had been done, died quietly and peacefully Wilhelm Ostwald, in his seventy-ninth year.

It is no easy task to give, within moderate compass, an adequate account of the life and work of this very remarkable man. In the history of chemical science he will be known as the man who, by his personal scientific investigations, his teaching and inspiration of hundreds of disciples, his indefatigable and continuous writing of books and foundation and editing of scientific journals, and his pre-eminent organising abilities, so consolidated and developed the work of investigators in physical chemistry that he became the real founder and the first great exponent of this branch of science. Ostwald was destined, however, to enter and play a conspicuous part in many other fields. The special importance of thermodynamics in the development of what we now call classical physical chemistry, the science created by the work of Gibbs, Horstmann, Helmholtz, Le Chatelier, Ostwald, van 't Hoff, Arrhenius, and Nernst, led Ostwald finally to the conviction that energy was the fundamental reality, the underlying component, of the physico-chemical world. From the generalisation of this view as a *Weltanschauung* applicable to a wider domain of thought and action, he passed naturally to the concept that there must exist a general *Naturphilosophie*, a science of all sciences. Work in these wider fields of thought led Ostwald gradually to the vision of a world of men organised and led by science, a world from which the clear formulations and exact investigations of science would banish the evils of prejudice and superstition. During the period 1906—1914 he took an active part in many national and international movements directed towards the organisation of scientific and intellectual work. He was, as he said, a " practical idealist," deeply interested in the building up of a scientifically-planned and orderly civilisation.

The world war overwhelmed and swept away the results of these efforts, but not the creative activity of Ostwald's brain. During the war years and afterwards he applied himself with almost youthful vigour and delight to the working out of a system of measurement and standardisation of body colours. From this he passed in the last years of his life to a study of the laws of beauty in colour and form. The active mind that had sought successfully for harmony in the relations of the physico-chemical world, now looked for it objectively in the realm of aesthetics.

In the last days we see him taking delight in painting pictures of the flowers in his garden at *Energie* (the name he gave to his country house near the hamlet of Gross Bothen in Saxony). All his life he had been a devoted painter of landscape scenes. The active thinker, organiser and protagonist in many arenas—physical chemistry, " energetics," philosophy, scientific organisation of human work, the measurement of colour, the objective basis of aesthetics—now at the very end of his life was still active, studying practically the harmonious relations of colour and form as displayed by the flowers of his country garden.

Of his life's work, his thoughts and actions, his travels and the many men he met, Ostwald has left a remarkable record in the " Lebenslinien," an autobiography in three volumes written in the closing years of his life. In this extraordinarily interesting " Histoire d'un Esprit " we are given an open-hearted account of the workings of his mind in its continuous efforts to apply objective scientific analysis to the varied situations and problems of life.

Whatever one may think of Ostwald's philosophy, he was an honest man, determined to make the best use he could of the scientific concepts which he had formed. Two examples of this may be given. At a difficult and critical point of his career he resolved to work out the theory of happiness. The result was the equation $G = k(A - W)(A + W)$, where

Prof. Dr. Wilhelm Ostwald

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[*To face p.* 316.

G = happiness, A = energy expended usefully in the accomplishment of work, W = energy dissipated in the overcoming of resistances. This is a famous example of Ostwald's application of energy concepts to the objective analysis of feeling. Another example of his philosophy of energy was his "energy imperative," a parallel to Kant's categorical imperative. This was "*Vergeude keine Energie, verwerte sie,*" which means "Dissipate no energy, *i.e.*, degrade or run no energy down to a lower level of usefulness; on the contrary, strive to make use of it by converting it into a higher (more useful) form (*veredle sie*)." Ostwald was led to this injunction by his reflections on the Second Law of Thermodynamics.

These two examples will serve to illustrate the honest attempts which he made to apply his philosophy of energy to the solution of the doubts and difficulties of life. Many philosophers and psychologists may laugh at them. In what Professor Lancelot Hogben has called the "public world" of objective science, they contain many grains of good sense and sound advice.

Friedrich Wilhelm Ostwald (as he was christened) was born in Riga on September 2nd, 1853, the second child of Gottfried Wilhelm Ostwald and his wife, née Leukel. Both his parents came of pure German stock that had settled in the Baltic province of Livland, then under the sway of the Russian Tsar. His father was a cooper who by dint of skill and industry gradually arrived at a comfortable competence as a successful master cooper and employer of labour. The boy was sent to the Realgymnasium at Riga, where he spent eight happy years. He was not exactly a "model" boy in the sense of constant attention to the efforts of his teachers. His development lay considerably in his own hands, and his interests extended to fireworks, home experiments in chemistry, music, drawing and painting, and attempts at photography. At school he studied mathematics, physics, chemistry and modern languages, and although he may have been somewhat careless of his studies during part of these earlier years, he applied himself with vigour at the end and had no difficulty in passing the leaving examination which admitted him to the study of science at Dorpat University. His father at first intended him for a course of engineering at the Riga Polytechnicum, but young Wilhelm Ostwald was determined to study chemistry at the University. With the aid of his mother's influence (he was always the apple of her eye) he won his father's reluctant consent, and in January, 1872, he entered the University of Dorpat as a student of chemistry. The first half of the prescribed period of three years required for the *Candidat* examination was spent in anything but regular attendance at lectures. As a member of a student corporation, the *Fraternitas Rigensis*, he threw himself into the varied life of a University student, though he always had a strong distaste for the heavy beer drinking and revelling which were practised by many of his contemporaries. He was greatly drawn towards music and with some friends formed a string quartet party. Ostwald played the viola, as he did not consider he possessed a sufficiently accurate ear for the violin. They were lucky enough to discover a forgotten possession of the Riga Fraternity, namely, complete parts for all the 83 string quartets of Haydn! During his Dorpat days Ostwald learned to play the viola parts of all the 83. So with the playing of the chamber music of Haydn, Mozart and Beethoven, the social life of the students, country wanderings, and further progress in the art of landscape painting, the time passed pleasantly enough. But his father was distressed by his want of progress in his University studies. Suddenly the sound moral fibre of the young man's character showed itself. By aid of his wonderful power of teaching himself from books and his splendid memory, he soon made up for the lectures which he had "cut," and successfully passed the examination which admitted him to the practical study of chemistry in the laboratory. He now came under the direction and influence of Professor Karl Schmidt, the former pupil of Liebig, Wöhler, Heinrich Rose and the physiologist, R. Wagner. In his earlier days at Dorpat, Karl Schmidt had made a great reputation by his work in physiological chemistry, but when Ostwald came he had been engaged for many years in researches on the mineral components of natural waters. His assistant was Johann Lemberg, who pursued investigations on the chemical composition of rocks and minerals. Ostwald now applied himself with vigour and success to the work prescribed for him in analytical and preparative chemistry and in 1875 passed with ease the examinations in these and other subjects. The complete examination for "Candidat" required, however, the presentation of a short thesis embodying the results of an original investigation. Apparently he chose his own subject. The choice was characteristic of him, and prophetic of his future career as an investigator. The subject was "the mass action of water," and dealt with the gradually increasing hydrolysis of a concentrated acidified solution of bismuth chloride as increasing quantities of water are added to it. Ostwald took a series of glass vessels and placed in them equal volumes of the bismuth chloride solution. To one vessel he now added sufficient water to produce a cloudiness due to the formation of a slight quantity of solid bismuth oxychloride, whilst to the other vessels he added increasing, but known, quantities of water. After a sufficient time had elapsed to secure equilibrium he determined the concentrations of bismuth and chlorine remaining in solution. The results showed quantitatively the increasing conversion of the dissolved bismuth chloride into solid oxychloride and hydrochloric acid as the ratio of water to bismuth chloride increased.

Ostwald's parents were delighted with his success. It was now agreed that he might devote himself, as he desired, to a scientific career, and his father arranged that he should extend his studies in the Physical Department under Professor von Öttingen. Means were, however, slender, so it was fortunate for Ostwald that he very soon obtained the post of Assistant in Physics. A few years later he became an Assistant in the Chemical Laboratory under Karl Schmidt.

Ostwald now began his scientific career with a study of the problem of measuring and comparing chemical affinities. Bergmann in the 18th century had attacked this question, but without great success, as he did not give sufficient attention to the effect of *mass action*, that is to say, the part played by the *concentrations* of the reacting substances. Berthollet in his celebrated "Essai de statique chimique" had subsequently made a very great advance by demonstrating this effect of concentration, whilst in 1867 Guldberg and Waage in their "Études sur les Affinités chimiques" had shown that the "driving power" of the chemical reaction between two dissolved substances was proportional in the simplest case to the product of the concentrations of these substances and an *affinity-coefficient*, thus arriving at the simple law of chemical equilibrium.

Ostwald saw that the best way to study chemical equilibrium in a homogeneous solution, and thus to compare competing affinities, was to employ physical properties or effects, since it was important that the concentrations of the reacting substances should remain unaltered. By measuring the evolution of heat, Julius Thomsen in his "Thermochemische Untersuchungen" had recently succeeded in comparing the affinities of acids competing in aqueous solution for an amount of alkali insufficient to "satisfy" both. Ostwald resolved to follow up this work of Thomsen, but as he did not possess the equipment requisite for such delicate calorimetrical measurements, he made use of changes of volume (or density). So began Ostwald's series of "Volumchemische Studien." The general theory of measuring equilibria in a homogeneous medium by measurements of changes in physical properties or effects had been given many years previously by Steinheil, but Ostwald was not aware of this at first and followed essentially the procedure of Thomsen.

Let us suppose that we mix one litre of a solution of an acid A with one litre of an equivalent solution of a base B. If no physical or chemical interaction occurs, we may expect the volume of the mixture to be two litres. Suppose now that in this volume of two litres chemical action occurs, namely, the neutralisation of the acid by the base, and that the volume becomes (at the initial temperature) $2 + v$ litres, where v may either be positive or negative. If we neglect physical actions, we may ascribe the volume change v entirely to the chemical action of neutralisation. In the case of another acid A′ and the same base B (both taken at the same temperature and at the same equivalent concentrations) let the corresponding volume change be v'. If now we mix one litre of a solution of the salt (A,B) with one litre of an equivalent solution of the acid A′, then if no chemical action occurs (and if we neglect physical interactions as before) the volume of the mixture will be 2 litres. If the acid A′ completely displaces the acid A to form the salt (A′,B), the volume of the mixture will be $2 + v' - v$. Suppose now that this action of displacement is only *partial*, and that, expressed in equivalents, the final equilibrium state of the mixed solution is represented by the scheme

$$\begin{array}{cccc} (A,B) + & A' = & (A',B) + & A \\ 1 - x & 1 - x & x & x \end{array}$$

where x = fraction of the salt (A,B) converted, then the volume of the mixture will be $2 + xv' - (1 - x)v$. Let the *measured* volume of the mixture in an actual experiment be $2 + v_0$. This result gives the equation $v_0 = xv' - (1 - x)v$, from which x can be obtained. The ratio $x/(1 - x)$ is the ratio of the quantity of the base B chemically held by the acid A′ to that chemically held by the acid A. The stronger the affinity of A′ for B compared with that of A for B, the greater will be this ratio.

The Guldberg–Waage equation for this case of equilibrium is

$$k_1(1 - x)^2 = k_2x^2$$

where k_1 and k_2 are the "*affinity-coefficients*" of the opposed reactions. Hence the *relative* "affinity-coefficient," k_1/k_2, can be determined.

Besides measuring volume and density changes, Ostwald also employed changes of refractive index. His results agreed in the main with those obtained by Thomsen. It may be of interest to give the table of relative affinities of monobasic acids which he published in 1878.

Ostwald's Table of Relative Affinities of Acids (Monobasic).

Nitric acid (taken as standard)	100	Formic acid	3·9
Hydrochloric acid	98	Lactic acid	3·3
Trichloroacetic acid	80	Acetic acid	1·23
Dichloroacetic acid	33	Propionic acid	1·04
Monochloroacetic acid	7·0	Butyric acid	0·98
Glycollic acid	5·0	*iso*Butyric acid	0·92

These figures only hold good, of course, for the equivalent concentrations employed in his experiments.

The results obtained by Thomsen and Ostwald gave values for the relative affinities or *strengths* of acids in aqueous solution, as determined by their powers of competing for a soluble base. Not content with these results, Ostwald began to look for other methods of measuring and comparing the affinities or "strengths" of acids in aqueous solution, and soon embarked on a series of researches which he published under the title of "Chemische Affinitätsmessungen." The principle underlying this work was as follows.

When an excess of a slightly soluble salt S in *solid* form is shaken with an aqueous solution of an acid A which forms a soluble salt with the base of the former, Ostwald found that a definite state of heterogeneous chemical equilibrium is reached, in which some of the solid salt S is chemically dissolved. When he took equal volumes of equivalent concentrations of a series of acids A, A′, A″, etc., he found that the amounts of the salt S decomposed and dissolved varied in general from acid to acid. He expected that in the case of the acids A, A′, A″, etc., the amounts of the salt S dissolved by equal volumes of equivalent concentrations of these acids would increase with their *strengths*. These expectations were justified and gave rise to a very interesting series of investigations.

It is not generally known that these researches led him to the discovery of *neutral salt* action. He found that the dissolving effect of dibasic acids was diminished by the presence of their neutral alkali salts, but this result did not surprise him, as he ascribed the effect to the formation of acid salts. What did surprise him, and what he could not explain, was that the dissolving effect of "strong" monobasic acids was markedly *increased* by the presence of their neutral alkali salts. This was a remarkable discovery. When we reflect on the long history of later efforts to explain this phenomenon, it is no wonder that Ostwald in 1880 could find no satisfactory solution of the problem.

The sparingly soluble salts which he employed in this work were very varied, *e.g.*, zinc sulphide, zinc oxalate, calcium oxalate, barium chromate, barium sulphate, calcium sulphate, strontium sulphate, and acid potassium tartrate.

These various series of researches enabled Ostwald to obtain successively the degrees of

Master and Doctor of the University of Dorpat. He was now a *Privatdozent* and gave courses of lectures on physical chemistry. His reputation as a very able and promising investigator in his chosen field was established. He was known, moreover, to his students and colleagues as a remarkably skilful experimenter, one who had learnt the arts of glass-blowing and working in wood and metal, and was expert in the devising and making of apparatus well designed for the purposes in view.

Two events of Ostwald's ten years in Dorpat must now be related. The first of these, which we may call a " negative " event, was his application in 1879 for one of the University's travelling scholarships. The award went to Gustav Bunge. As Ostwald has related, if he had obtained the scholarship he would have gone to Germany and probably fallen under the spell of the reigning and highly flourishing school of organic chemistry in that country. So his failure to obtain the scholarship, whereby he was forced to remain in Dorpat and to steer his own course in the less charted seas of physical chemistry, probably exercised a great effect on the whole of his career.

The other event was positive and exercised a very profound and well-known effect on his whole life. Throughout his time at Dorpat Ostwald continued to play the viola in a string quartet party. He was deeply attached to music and had given much attention to the study of counterpoint, harmony, and other branches of the theory and art of music. His friend and teacher, A. von Öttingen, who had been in the custom of giving lectures on *Tonkunst*, on one occasion asked Ostwald if he would undertake these lectures for him. To this Ostwald readily consented. His audience consisted mostly of ladies, and one of them was a Fräulein Helene von Freyher. They fell in love and in 1879 became engaged. In the spring of 1880 the wedding took place. Although in their earliest years of married life they had to live in simple student rooms, this marriage of Ostwald to Fräulein von Freyher was the greatest good fortune of his life and a source of continuous happiness, interrupted only by his death fifty-two years later. In order to help with the house-keeping expenses, Ostwald began in 1880 to teach physics, chemistry and some branches of mathematics at a Dorpat school, besides, of course, continuing his teaching and research work at the University. He also planned and began the preliminary work for his famous " Lehrbuch der allgemeinen Chemie."

In 1881 the Professorship of Chemistry at the Riga Polytechnicum fell vacant. After Johann Lemberg and Gustav Bunge had declined, Ostwald received the call and accepted. His teacher, Karl Schmidt, had written a letter to the Director of the Polytechnicum giving Ostwald the warmest and heartiest recommendation that any disciple could desire or deserve. In his 28th year Ostwald now became a full Professor, with his own laboratory and pupils, and wider and better opportunities now opened out to him, of which he made the fullest use. His Riga period, 1882—1887, was one of intense and continuous research. Again looking for further methods of measuring and comparing the strengths or affinity properties of acids, he began a series of investigations entitled " Studien zur chemischen Dynamik," in which he departed from the statical or equilibrium methods employed at Dorpat and turned his attention to the measurement of reaction velocities. The first paper of this series dealt with the effect of acids on the hydrolysis of aqueous solutions of acetamide and described the construction of Ostwald's famous thermostat, in which the temperature was regulated by the thermal expansion of calcium chloride solution (later toluene) contained in a glass tube, and the stirring of the thermostat water was effected by a horizontal paddle connected with a vertical rod or axis carrying a number of sloping mica vanes, the whole being kept in gentle and constant rotation, day and night, by a vertical current of hot air from a small gas flame. How many hundreds of his research pupils and how many thousands of students have constructed and worked with this world-famous thermostat ! It was highly characteristic of Ostwald's pre-eminent experimental ability in designing very efficient apparatus with simple means. The second paper dealt with the effect of acids in accelerating the velocity of hydrolysis of methyl acetate in aqueous solution, whilst in the third and fourth papers Ostwald described his measurements of the effect of acids in accelerating the rate of inversion of aqueous solutions of cane sugar. The theoretical formulation of the velocity of a chemical reaction had already been laid down by Guldberg and Waage and in part also by Wilhelmy and others, and Ostwald took full advantage of this earlier work. His object was not, however, to verify the equations of reaction kinetics, but to use this weapon as a method of comparing the strengths or *affinity-coefficients* of acids in aqueous solution. Suffice it to say that he found a marked parallelism between the results of his statical and kinetic measurements. Ostwald became more and more convinced that the relative series of affinity-coefficients which he was obtaining by these different methods represented some great truth of Nature, some fundamental and characteristic property of the acids. In the fifth paper of the series he measured the velocity of " saponification " of ethyl acetate by a number of soluble bases, and thus began the comparison of the corresponding affinity-coefficients of these substances.

It is important to note that in this series of researches Ostwald greatly developed the concept of *catalytic or contact action*. The hydrolysis of methyl acetate or the inversion of cane sugar were *slow* reactions in which water molecules took part. The added acid which accelerated these reactions did not disappear as such and could be determined by titration at the end as much as at the beginning of the reaction. The affinity-coefficient or " strength " of the acid showed itself in its effect, for equivalent concentrations, on the velocity constant of the hydrolytic reaction—the greater the strength, the greater the velocity constant. In the last period of his active scientific life at Leipzig (1897—1905), Ostwald returned with vigour and enthusiasm to a study of the great problem of catalytic action, but the seeds of this harvest were sown during the years at Riga.

Recognising Ostwald's great abilities and the increasing number of his students, the ruling authorities decided to build a new laboratory for him. As his personal acquaintance with other laboratories was confined to the old-fashioned one at Dorpat, Ostwald wisely decided to pay a visit to the German centres of chemical teaching and research, and did so during the winter holidays, 1882—1883. This was a great and important experience for the young Riga Professor and the " Lebenslinien " contains a lively account of the famous men he met on his travels.

Ostwald relates in this autobiography that he will never forget a certain day in June of 1884. On that day he got three things, a very bad toothache, a little daughter, and the Doctor Dissertation of an unknown young man called Svante Arrhenius, entitled " Recherches sur la conductibilité galvanique des électrolytes." Already in Dorpat Ostwald had been struck by the parallelism between the equivalent electrical conductivities of the few acids measured by F. Kohlrausch (the inventor of the alternating current method of avoiding polarisation effects in the measurement of the conductivities of dissolved electrolytes), and the affinity-coefficients or strengths of the same acids as determined by his various chemical methods. But at the time he could not understand the meaning of this relationship, although before the appearance of Arrhenius' paper he had already done some preliminary work towards the elucidation of this matter. After a careful study of Arrhenius' work he saw that the ideas and measurements contained therein not only provided the required explanation but demanded a close relationship between the affinity-coefficients and the equivalent conductivities. The great concept of the dawning " Chemical Theory of Electrolytes " was flashed from the mind of Arrhenius in Upsala to the mind of Ostwald in Riga. How well one can imagine Ostwald's excitement ! Immediately he set himself to construct and assemble the necessary apparatus. Soon his experimental genius in effecting a desired purpose with the least possible elaboration of means enabled him to carry out the necessary measurements with the 33 organic acids which he had collected for his earlier work. With wildly beating heart, as figure after figure came out, he saw that the equivalent electrical conductivities were indeed very nearly proportional to his chemically determined affinity-coefficients. The degrees of ionisation of the acids as determined by the future method of Arrhenius were a measure of the affinity properties of these selfsame acids. That was the real, though not yet fully understood, meaning of the great discovery that he had made. The results of this work were contained in the first paper of his " Elektrochemische Studien." Faraday had made the first great step in the quantitative relationship between electrical and chemical actions. Another great step had now been taken by Ostwald and Arrhenius.

It was characteristic of his enthusiastic and generous nature that in the same year (August 1884) he travelled to Upsala to make the acquaintance of that remarkable young man, Svante Arrhenius. This visit was the beginning of a life-long friendship and co-partnership. The two young men (for Ostwald was only in his 31st year) planned out a great series of investigations. We can picture them walking together in the beautiful Scandinavian summer. Let us hope that Arrhenius induced the rather abstemious Ostwald to mix great science with at least a little good beer ! Of course the real theory of ionisation was not yet developed (this took place several years later), but Ostwald persuaded Arrhenius to join him in Riga, which he afterwards did (in 1886), and together they worked on different but closely related problems for several months.

On his return to Riga Ostwald continued his electrochemical studies with fiery and tenacious energy. He had found that the equivalent (or molecular) conductivities of strong acids did not vary much with dilution, whilst those of weak acids were markedly functions of this variable. In the second paper of the electrochemical studies he made a careful examination of these dilution effects and could represent them by means of a trigonometrical function. It was only when the full development of the ionisation theory came a few years later that he was able to arrive at the true form of the dilution function. In the third paper of the series he made an exhaustive study of the conductivities of 120 organic acids and traced important relationships between molecular structure and equivalent conductivity; whilst in the fourth paper of the series he measured the conductivities of 24 bases.

It has often been remarked that Ostwald founded the science of physical chemistry as much by his writing of books and creation of new Journals as by the scientific investigations of himself and those he inspired. Two important events during the Riga period marked the beginning of this very characteristic side of his work. The first was the appearance of his famous "Lehrbuch der allgemeinen Chemie," published in two volumes (1883—1887). In this work he collected, critically sifted and arranged in orderly fashion the material from an enormous number of scientific publications. The word *general* in the title indicated that he took a very broad view of the subject. The first volume, entitled "Stöchiometrie," dealt with a great variety of subjects, *e.g.*, the laws of chemical combination, atomic weights, the properties of solids, liquids, gases and solutions, whilst the second volume, entitled "Verwandtschaftslehre," treated of thermochemistry, electrochemistry, photochemistry, and chemical affinity. This book must have cost the author many years of hard and continuous labour. It is no exaggeration to say that it created the science of general and physical chemistry and acted as a source of knowledge and inspiration for the hundreds of young men who within a few years flocked to Ostwald's banner from all parts of the world.

The second important event was the foundation of the *Zeitschrift für physikalische Chemie*, published by W. Engelmann in Leipzig. The first number appeared in February, 1887. Ostwald and his publisher, Engelmann, wisely saw that the new science must have a special Journal for its future development. The editors were Ostwald and van 't Hoff, though by agreement between them the editorial work fell entirely on Ostwald. The names of a number of eminent collaborators appeared on the title page, including "W. Ramsay in Bristol," and "T. E. Thorpe in London." The frontispiece of the first volume was a portrait of Bunsen.

For many years Ostwald not only edited the *Zeitschrift* but did, single-handed, an enormous amount of work in connection with reviews of books and critical abstracts of scientific papers published elsewhere. The new Journal was a success from the very beginning and proved to be of fundamental importance for the development of physical chemistry.

The first volume contains several papers from the last phase of Ostwald's scientific work at Riga. Two of them dealt with the "Law of Kohlrausch." In these important papers it was shown how the maximum molecular conductivity, *i.e.*, at infinite dilution, of a weak acid, which could not be experimentally determined, could be calculated from the easily measured limiting conductivities of several strong electrolytes. The basis of this method was the discovery that the sodium salts of weak acids were, under similar conditions of molecular concentration, practically as highly conducting (ionised) as the sodium salts of strong acids. It was also shown how the basicities of acids could be determined by noting the change in their equivalent conductivities at 25° over a certain range of dilution ($v = 32$ and $v = 1024$ litres per equivalent).

Other papers in the first volume bear witness to the fact that already at Riga Ostwald was becoming deeply interested in the problem of the seat of the E.M.F. of galvanic cells. For him this meant the determination of the electrical potential differences between metals and solutions of electrolytes or between two different electrolytic solutions. In order to measure E.M.F.'s by the compensation method, he constructed simple potentiometers and a very neat form of " capillary electrometer " as an effective and inexpensive " null " instrument. This was based on the work of Lippmann concerning the change of the surface tension of mercury in contact with an aqueous solution, when the mercury surface, acting as an electrode, is suitably " polarised " by a small flow of electricity.

When one measures the E.M.F. of a galvanic combination, the value obtained always involves at least two of the " single " electrode potentials (single contact potential differences) which Ostwald was so anxious to determine. A paper in the first volume of the new Journal gives an account of Ostwald's first attempt to obtain an absolute measure of these single potential differences, by the employment of a " dropping mercury electrode " as one of the pair involved in the galvanic combination. Ostwald's underlying idea (based on the work of Helmholtz) was that the dropping electrode would bring the potential of the main mass of mercury to that of the solution, so that one of the two single potential differences involved in the circuit could be made to disappear and hence the other be easily determined.

In the sixth and very important paper of the series of Studies on Chemical Dynamics (which was published at the end of Ostwald's first year in Leipzig), he dealt with the effect of acids in accelerating the velocity of oxidation–reduction actions, in particular the reduction of bromic acid by hydriodic acid in aqueous solution. It begins with the following statement. " In a series of earlier papers I have shown that the most varied actions of acids are numerically determined by certain coefficients, which depend on the nature, dilution, and temperature of the acid, but not on the character of the action investigated. These values, which I have called the affinity-coefficients of the acids, are very nearly proportional to their electrical conductivities." The paper announced the important new result, that " All oxidation–reduction reactions are accelerated by the presence of free acids and in proportion to their affinity-coefficients."

The following excerpt from one of the tables of figures will be of interest. (The effect due to HCl is put equal to 100.)

Acid.	Accelerating effect.	Electrical conductivity.	Acid.	Accelerating effect.	Electrical conductivity.
HCl	100	100	H_2SO_4	69·4	74
HNO_3...............	98	99	H_3PO_4	36·3	40
$HClO_4$	94	101	$C_2H_4O_2$	1·3	2·4

In this paper we see Ostwald summing up the main results of all his previous work and ready for the ensuing development of Arrhenius' theory of electrolytic dissociation and the great days of the Leipzig period.

An event of fundamental importance for Ostwald's whole career now took place. In 1871 a Chair of Physical Chemistry had been founded in Leipzig University. The first occupant was Gustav Wiedemann. The Professor of Physics, Hankel, now retired and his post was given to Wiedemann, who was really a " pure " physicist both at heart and in his scientific work. Who was to succeed Wiedemann in the Chair of Physical Chemistry? H. Landolt, Cl. Winkler, and J. H. van 't Hoff were approached, but all refused. Ostwald's fâme had by this time spread throughout Germany, though the sovereign lords of organic chemistry had little taste for the new wine. However, during his Riga period he had paid three visits to Germany and was personally known to a great many German professors, including a number of his future scientific colleagues at Leipzig University. The upshot was that Ostwald received the next call and accepted (1887). The dream of his life was realised! He was now to become a full Professor at an important German University. Moreover he was anxious to leave Riga. The shadow of the oncoming "Russification" was beginning to make men of German stock and speech uneasy. Very few of the students had any inclination for pure scientific research. Ostwald has said that he had only one such—Paul Walden. However, this one became great enough to make good the deficiencies of a host of others.

The post at Leipzig was not entirely a bed of roses. The new Professor of Physical Chemistry had to share with the Professor of Agriculture and Husbandry the old and very poorly equipped Agricultural Institute at 34 Brüderstrasse. Besides the organising of teaching and research in physical chemistry, he had to deal with the practical instruction of beginners in chemistry, engaged in analytical and preparative work, and of pharmacists. Having his laboratory divided into three sections, Ostwald had the right to appoint three assistants. He was very fortunate in his choice. For physical chemistry he appointed the young physicist, Walther Nernst, whom Arrhenius had met at Graz and strongly recommended to him. Nernst had carried out a series of important researches in the Physical Laboratory of von Ettingshausen and had discovered the transverse thermomagnetic E.M.F. in certain metals (now known as the Nernst effect). For the beginners in chemistry Ostwald obtained Julius Wagner, who long remained one of his faithful helpers and in later years (in Ostwald's new Institute) took up the chemical training of school teachers. Finally, for the pharmacists he got Ernst Beckmann, who was later to render such signal service in the devising of convenient apparatus for determining the molecular weights of dissolved substances.

Ostwald was fortunate also in his later assistants and collaborators, amongst whom may be mentioned Svante Arrhenius, Theodor Paul, Max Le Blanc, Robert Luther, Georg Bredig, Max Bodenstein, Herbert Freundlich, Carl Drucker, and Wilhelm Böttger. All these men have made great names for themselves in chemical science and risen to high positions.

Ostwald lectured on inorganic chemistry in the winter semester and on physical chemistry in the summer one. With his Riga experience behind him he quickly organised excellent practical courses in physical chemistry. The fruits of this work were embodied later in his invaluable "Hand-und Hilfsbuch zur Ausführung physikochemischer Messungen," which with the aid of Luther and others was frequently expanded and ran into many editions. Within a few years Ostwald had made the old laboratory at 34 Brüderstrasse the world centre of physical chemistry. Eager students flocked to it from many parts of the globe. The majority were Americans and British, whilst, curiously enough, the Germans themselves generally formed a small minority. This was probably due to the very powerful and influential German school of organic chemistry. Many of the famous exponents of this branch of chemistry looked rather askance at the "Ionier," and did not regard Ostwald as a chemist because he had never discovered a new substance. Ostwald said jokingly of himself that from this point of view he was a "negative" chemist, since he had reduced the number of recorded substances by one. The explanation of this joke lay in the fact that many years previously a certain chemist thought he had isolated a new acid from a photographic silver bath solution. When Ostwald obtained a very small specimen of this substance he was able to show by determining its ionisation-constant that it was a well-known organic acid.

The famous school of Physical Chemistry which Ostwald rapidly built up at Leipzig was mainly based on the ionisation theory of Arrhenius, van 't Hoff's osmotic theory of solutions, and the application to solutions and chemical equilibria in solutions of the laws of thermodynamics, particularly in the simple form expounded by van 't Hoff by means of the concepts of osmotic pressure and osmotic work. These aspects of the new field were brilliantly illuminated by two papers published in the first volume of the new *Zeitschrift*, namely van 't Hoff's paper entitled "Die Rolle des osmotischen Druckes in der Analogie zwischen Losungen und Gasen," and the paper of Arrhenius, "Uber die Dissoziation der in Wasser gelösten Salze." Nothing, however, contributed more to the immediate advance and general recognition of the new branch of chemical science than

Ostwald's discovery of his celebrated ***Dilution Law.*** Shortly before leaving Riga he had made an extensive visit to German chemical centres for the purpose of collecting specimens of organic acids. Soon after he obtained the Leipzig Chair he made a thoroughgoing investigation of the conductivities of this collection of material. With the development of Arrhenius' theory it became possible for Ostwald to test whether the law of chemical equilibrium applied to the aqueous solutions of these acids. Let us suppose we are dealing with a monobasic acid. The following scheme exhibits Ostwald's reasoning:

$$HA = H^+ + A^- \quad (1)$$
$$(1 - \alpha)/v \quad \alpha/v \quad \alpha/v \quad (2)$$
$$k(1 - \alpha)/v = \alpha/v \,.\, \alpha/v \quad (3)$$
$$\alpha^2/(1 - \alpha)v = k \quad (4)$$
$$\alpha = \lambda_r/\lambda_\infty \quad (5)$$

The total concentration of the acid is 1 mol. per v litres. Line (1) represents the equilibrium between the un-ionised molecule and its ions, (2) the molar concentrations of the constituents of the solution if α is the degree of ionisation, (3) and (4) express the law of chemical equilibrium. The constancy of k for varying values of α and v (at constant temperature) could be tested, since α was known for every value of v by the equation of Arrhenius shown in line (5), where λ = the molar conductivity of the solution. The result was startling. For hundreds of the " weak " acids, *i.e.*, those whose degree of ionisation at moderate dilutions is relatively small, the law of chemical equilibrium held with striking accuracy. Those who scoffed at the ions, because they could not be seen and handled in the usual way, were now bound to admit that they were sufficiently real to obey the law of chemical equilibrium. Soon afterwards Ostwald showed that the same law held for aqueous solutions of weak bases, and this was confirmed on an extensive scale by Bredig. The existence of the hydrogen and hydroxyl ions in aqueous solution was firmly established. Ostwald was presently able to show that the very small degree of ionisation of pure water could be determined by several different methods. The explanation of the alkalinity or acidity of certain salts when dissolved in water became perfectly simple. In several important papers published in his own Journal Ostwald discussed in a masterly way the various applications of the ionic theory and the laws of chemical equilibrium. It is true that one dark shadow lay aslant this brilliant scene. The majority of salts and the strong acids and alkalis were certainly ionised in aqueous solution, in fact their ionisation at moderate solutions was very great. But when tested by the Dilution Law they broke down completely. Well, this was rather strange, but there was no need to grieve. There was plenty of work to do. Ostwald and his assistants and pupils could prove at all events that the ions were there. These ions accounted for most of the rapid reactions of analytical chemistry. When such reactions failed, the ions were either not present or, if present, were there in too small quantity.

The investigation of the electromotive forces of galvanic cells was pushed rapidly ahead, and the contact potential differences at metallic electrodes and between electrolytic solutions of different concentrations, which Ostwald had already begun to investigate at Riga, were explained by Ostwald and Nernst on the basis of ionisation and the osmotic theory of solutions. Le Blanc successfully investigated the E.M.F. required to decompose an aqueous solution of an electrolyte and developed the theory and practice of " decomposition potentials," whilst Luther made important advances in connection with ionic equilibrium between coexistent phases and reaction kinetics. Ostwald's extensive series of determinations of the ionisation constants of organic acids led him to trace many interesting relationships between molecular structure and ionising tendency in aqueous solution. This was the pioneer step in a direction which has led in recent years to the very important development of organic chemistry based on electronic (*i.e.*, electrical) concepts.

It was a consequence of the theory of ionisation that very dilute aqueous solutions of salts with a " colourless " cation and " coloured " anion should all exhibit the same colour, independently of the particular cation (*e.g.*, K, Na, Li, Ca, etc.). By a careful spectroscopic examination of aqueous solutions of various salts of permanganic acid, fluorescein, eosin, etc., Ostwald showed that, within the degree of accuracy of his measurements, the absorption spectra of equivalent very dilute solutions were in each case independent of the particular cation.

In a very interesting paper published in 1890, Ostwald pointed out that certain artificially produced " semipermeable " membranes were semipermeable with respect to (certain) ions, *i.e.*, not to salts as a whole, and was able in this way to indicate the nature and existence of various phenomena which in later years became the subject of many investigations.

The solid crystalline state attracted a good deal of his attention. A very original example of this is his paper entitled " Studien über die Bildung und Umwandlung fester Körper," in which he gives an account of his determinations of the smallest quantities of solid crystalline substances which will start crystallisation in supercooled melts or supersaturated solutions. In this paper Ostwald developed his concept of " metastable " as contrasted with " labile " states, and was led to his " law of successive changes "; an unstable (labile) system does not change at first into the most stable state, *i.e.*, that possessing the smallest free energy, but into the state which lies nearest to the original state (as regards its free energy). Yellow and red mercuric iodide present a good example of phenomena of this sort.

Another example of Ostwald's interest in the solid state was his work on the yellow and red forms of mercuric oxide. He convinced himself by various methods, *e.g.*, chemical equilibrium with a solution of potassium bromide, that the yellow form was simply the red form in a finer state of division and therefore possessing the higher solubility. This work led Ostwald to his equation for the variation of solubility of a solid substance as a function of average grain size, and thus to a method of determining the (average) " surface tension " between a solid and a solution.

It would be quite impossible within the compass of this lecture to give any detailed account of the work done by Ostwald and his collaborators during the ten years, 1887—1897. Those interested in the matter may be referred to the four volumes of the " Arbeiten des physikalisch-chemischen Instituts der Universität Leipzig aus den Jahren 1887—1897 " (Engelmann, Leipzig). Ostwald was an ever-bubbling spring of fresh ideas and inspiration. Picture to yourselves a friendly enthusiastic man, with penetrating eyes, fresh colour, and reddish hair, moustache and beard, going the round of the research laboratory every day. If you had a difficulty, Ostwald had a solution to offer. If you had no difficulties, you probably got some new ideas. If you had any views on music, painting, or philosophy, the Master was full of attention and would discuss them with you.

As time went on Ostwald worked more and more through his research students. They were given the fresh ideas and constant help; and they were always allowed to publish under their own names. The Professor was entirely devoid of scientific greed and jealousy.

Throughout all his time at Leipzig Ostwald was constantly engaged on scientific literary work. He had an amazing speed and facility in writing. Engaged as he was with the heavy work in connection with the new Journal, he nevertheless found time for a constant stream of new books and other publications. His deep sense for the necessity of scientific men making direct acquaintance with the great original masterpieces of science was shown in his " Elektrochemie, ihre Geschichte und Lehre," and in his inauguration and editing of the important " Klassiker der exakten Wissenschaften," many of which were annotated by himself. The " Grundriss der allgemeinen Chemie " supplied a handy textbook for the thousands of students who could not face the " Lehrbuch," whilst the " Grundriss der anorganischen Chemie " showed how physical chemistry could render this somewhat neglected subject more interesting, logical and rational. This book was a forerunner of Abegg's well-known " Handbuch." The " Wissenschaftliche Grundlagen der analytischen Chemie " threw a marvellous flood of light on the operations of analytical chemistry and strongly helped to raise this subject to the status of an important branch of chemical science. The " Schule der Chemie " brought good chemical thinking to the notice of very young people, whilst " Der Werdegang einer Wissenschaft " was a " chemistry without chemicals," in other words a sort of rapid historical sketch of the development of general concepts in chemical science.

By the publication of these books Ostwald carried his teaching and the new knowledge to a much wider public than he could ever hope to influence personally in the laboratory. Throughout his life his continuous work "*am Schreibtisch*" was an essential and important component of his mental activity and output. He divided great scientific men into two types, the *Klassiker*, or those who work best quietly and alone, and the *Romantiker*, whose best work is done amidst a crowd of disciples and in the heat and fray of personal intercourse and argument. Van 't Hoff said of Ostwald in 1903 that he was a man who, as soon as he knew or discovered something, was immediately possessed of a burning desire to communicate it to others. It was a true saying, for Ostwald was an ardent apostle of the light within him and the king of the Romantiker.

The title of his inaugural lecture when he came to Leipzig in 1887 was "Die Energie und ihre Umwandlungen." The subject was prophetic of much that was to follow. Already in Dorpat he was much interested in the science of thermodynamics. This was probably due to the influence of von Öttingen, who was a master of that subject, and even in those early days drew Ostwald's attention to the work of Willard Gibbs. The development of the school of physical chemistry at Leipzig was largely based on thermodynamics, and Ostwald, recollecting the advice of von Öttingen, translated Gibbs's famous paper into German and published it in book form under the title "Thermodynamische Studien." He relates in his autobiography that he was much struck by the fact that most of the terms in Gibbs's equations represented energy in different forms. Gradually he became more and more convinced that molecules, atoms and ions were only mathematical fictions and that the real underlying component of the Universe was energy in its various forms. The laws of happening were the laws governing the fluxes and transformations of energy. In this manner came into being Ostwald's "Energetik." Ostwald, the reasoner and rationalist, was, perhaps unknown to himself, an artist by temperament. There is a beautiful passage in the "Lebenslinien" in which he describes how suddenly one sunny morning in early summer, as he walked among the flowers and butterflies and hearkened to the singing of the birds and the movement of life all around him, there came to him such an outpouring of the spirit that he could never again doubt the reality of energy as the essence of all being and happening. It would seem that this experience was a veritable mystic exaltation.

At the Lübeck meeting in September, 1895, of the Society of German Scientific Investigators and Physicians, Ostwald delivered a lecture which created a great sensation. The title was "Die Überwindung des wissenschaftlichen Materialismus." He explained to his audience that the existing view of the world as consisting of something called matter, of material particles in constant motion, was an illusion and must be replaced by the view that reality consists in the interplay of energy in different forms. This was Ostwald's first great public declaration of faith in his *energetische Weltauffassung*. It was coldly received and unfavourably criticised by the majority of chemists and physicists. Although his conceptual scheme was too simple, it must be admitted that in certain respects his ideas were nearer to the theories of modern physics than those of his contemporaries. What he was really attacking were the "mechanical models" of the 19th century, the "engineer's universe" of a now almost forgotten age. Ostwald maintained that it was fruitless to attempt to reduce all phenomena to matter and the mechanical laws relating to motion of matter. The substitute he proposed—energy in various forms—was perhaps the best that the science of his day could suggest to him, but constituted in its turn an insufficient basis for a new development of physico-chemical science. In later years, owing to the work of Perrin and the newer developments of physics, Ostwald somewhat modified his views and admitted the existence of an apparently discontinuous "grainedness" in the physico-chemical world—in other words, atoms and molecules.

He soon began to apply his energy concept to a wider range of ideas. From this, as stated in the beginning of this lecture, he passed to the concept of a new general *Natur-*

philosophie, a philosophy of science which would be a " science of the sciences." This was something that he hoped would replace the efforts of Kant and his followers. Perhaps we might regard it as in some respects an extension and development of the ideas expounded by August Comte in the " Philosophie positive " many years earlier. Ostwald now began to give lectures on *Naturphilosophie*, embodied these in a book entitled " Vorlesungen über Naturphilosophie," and founded and edited yet another new Journal, the *Annalen der Naturphilosophie* (1901).

In spite of all these excursions into more general fields of thought, he continued his work as a Director of a Research Laboratory and a physical chemist. He brought out a new and greatly enlarged edition of the famous " Lehrbuch der allgemeinen Chemie," though he was never able to finish it, owing to the swelling tide of new material which he himself had done so much to encourage.

In 1894 Ostwald took a very important step, by the foundation, together with A. Wilke, of the Elektrochemische Gesellschaft. He played an important part also in the creation (in the same year) of a corresponding new Journal, the *Zeitschrift für Elektrochemie*, of which he acted as one of the chief collaborators. The new Electrochemical Society held annual scientific meetings and absorbed a great deal of Ostwald's time, since he was President until 1898. At his own suggestion the name was changed in that year to *Deutsche Bunsen-Gesellschaft für angewandte physikalische Chemie*, an indication that the scope of the Society's work extended much beyond electrochemistry. Since that time the annual meetings of the Society, the records of which are published in the *Zeitschrift für Elektrochemie und angewandte physikalische Chemie*, have exerted a powerful influence on the development of physical chemistry.

The increasing number of research students who came to work under Ostwald's guidance and inspiration made the old quarters in the Brüderstrasse entirely inadequate. At length the University authorities lent an ear to Ostwald's appeals for a new laboratory. A new Physico-chemical Institute was built, and in 1897 he and his students and collaborators moved into the new laboratory at 2 Linné Strasse. The second phase of Ostwald's scientific work and influence at Leipzig now began. He bethought himself of new fields to cultivate and decided on a study of catalytic actions. As we have seen, the seeds of this idea were sown at Riga. But Ostwald had already initiated and encouraged various researches on reaction kinetics. His " isolation " method for determining the exponents in the general reaction velocity equation

$$\text{Rate} = ka^m b^n c^p \; . \; . \; .$$

where a, b, c, . . . are the concentrations of the reacting components was well known. He had formed a general concept of catalysis as the effect of a present constituent in changing the velocity of a possible, though perhaps exceedingly slow, reaction, *i.e.*, a reaction which must not be thought of as *caused* by the catalyst (thermodynamically possible without it). The catalyst must be a substance which did not form a constituent of the final products. From the laws of thermodynamics Ostwald deduced that in reversible reactions the catalyst must increase in like measure the velocity constants of both reactions. A very valuable publication of this period was his " Ältere Geschichte der Lehre von den Berührungswirkungen " (Decanatschrift, 1898), whilst a very clear statement of the whole question was given by Ostwald in his lecture " Über Katalyse " (published as a brochure, Leipzig, 1902).

He realised very clearly that his " Energetik " left the question of the velocity of physical and chemical changes untouched. The " problem of time " did not enter into the thermodynamic laws. The action of a catalyst did not infringe these laws, but in altering the speed of a chemical reaction it opened up a new world of " time " phenomena, the investigation of which must be regarded as a necessary development and extension of the energy theory.

Many important researches in this field of work were carried out in the new Institute. We may note Bredig's work on the catalytic effects of his colloidal platinum sol, Bodenstein's work on the catalysed combination of gases, Senter's work on *Hamase*, a ferment discovered by him in blood, which accelerates the decomposition of hydrogen peroxide, Ostwald's discovery (with O. Gros) of the *Katatypie* process, and his study (with E. Brauer) of the catalytic oxidation of ammonia to nitric oxide. With the help of Dr. Brauer this was developed into a technical method for the conversion of ammonia into nitric acid. Ostwald's clear formulation of the concept of ferments as organic catalysts was of great value for biology. He was awarded the Nobel Prize for Chemistry in 1909, the stated reason being the importance of his work on catalysis.

In the later Leipzig period falls his interesting investigation on the periodic solution of metallic chromium in acids. The chromium had been produced by Goldschmidt's new thermit process. Although later specimens of chromium failed to show the phenomenon of periodic solution, the investigation was a very good example of Ostwald's ingenuity and resource in devising new and suitable apparatus.

In 1903 the Jubilee of Ostwald's promotion to the doctorate (Dorpat, 1878) was celebrated by his friends, pupils and admirers. As is the graceful German custom, Volume 46 of the *Zeitschrift für physikalische Chemie* was dedicated to him by his present and former research students. It contained 34 papers, occupying 878 pages, and an enthusiastic account of Ostwald's life and work by van 't Hoff. There was also a valuable bibliography of all Ostwald's publications up to 1903 (compiled by P. Walden).

In the later period of Ostwald's career at Leipzig signs were not wanting that his main interests were gradually extending to wider and more general fields than physical chemistry. The research work of the laboratory went on as successfully as ever, but he began to rely more and more on his excellent assistants for the initiation and direction of new researches. Robert Luther was appointed Sub-Director of the Laboratory and was a great source of strength. Moreover the enormous strain of the work accomplished by Ostwald in so many various fields was now beginning to tell. He had already had one breakdown in health (1896), from which, however, he had made a good recovery.

Some relief was afforded by visits to the United States. In 1903 he was invited to open the new Physiological Laboratory of Jacques Loeb at Berkeley, near San Francisco (University of California), whilst in 1904 he was invited to lecture on Philosophy at the St. Louis Exhibition. In 1905 Ostwald asked the University to relieve him of some of his routine lecturing work. This the Faculty refused to do. Ostwald sent in his resignation, but was requested by the Saxon Ministry of Education to defer it. As he had received another invitation to the United States to lecture there during the winter and spring of 1905—1906, he consented on his return to complete the summer semester of 1906 before retiring from his Professorship. In America he lectured at Harvard University, the Massachusetts Institute of Technology, and Columbia University, New York City, his subjects comprising both Philosophy and Chemistry. His visit was made as the first *Exchange Professor* between Germany and the United States, a new plan in which the German Kaiser took the liveliest interest. That the first choice fell on Ostwald was a high mark of the honour in which he was held.

In the summer of 1906 Ostwald left the University of Leipzig and retired to his country house " Energie." Some years previously he had bought this house, with its wild garden and grounds, as a summer holiday resort for his young family. It was now enlarged and made into a suitable permanent residence, whilst as the years went on he gradually bought more and more ground until he was the possessor of quite a considerable estate. Ostwald had made a good deal of money by his continuous literary production, so that this, together with his University pension, gave him a sufficiency of means.

In October 1906 he was invited to Liverpool as the chief foreign guest at the opening of the Muspratt Laboratory of Physical and Electro-Chemistry, the first special and independent University Laboratory of this sort in the British Empire. Ostwald stayed with the donor of the laboratory, Dr. Edmund Muspratt, at his beautiful home, Seaforth Hall, and was very interested to learn that both Dr. Muspratt and his brother Sheridan had studied under Liebig at Giessen, whilst Liebig himself had stayed at Seaforth Hall. In the summer of 1907 Ostwald returned to the University of Liverpool to receive the honorary degree of Doctor of Science.

To a man of his active temperament, broad interests, and widespread fame, retirement meant no peaceful period of leisure. With increasing frequency he was called upon to give lectures and take part in national and international movements directed towards the development and organisation of intellectual work. He became the "practical idealist" (as he described himself), who was anxious to devote his talent of organisation, his scientific knowledge and his philosophical outlook to the improvement of human civilisation. Only a brief reference can be made here to the manifold activities of this period (1906—1914). He made important contributions to what he called the " psychographic " study of genius and wrote his famous book " Grosse Manner: Studien zur Biologie des Genies," whilst the reform of school teaching attracted much of his attention. He was anxious that the best possible methods should be used in the development of human abilities. He continued to edit the *Annalen der Naturphilosophie* and to devote much of his spare time to the writing of papers and books dealing with the application of his *Naturphilosophie* to a wide variety of problems—the philosophy of values, the nature of good action, etc.

The value and practical possibility of an auxiliary artificial language appealed greatly to Ostwald, so he welcomed the opportunity of taking an active part in the international meetings and discussions at Paris which resulted in the establishment of Ido, a greatly reformed and improved variant of Esperanto.

About this time the German industrialists were becoming dissatisfied with the too highly specialised education of the University-trained chemist. Suggestions were made for the introduction of a State Examination, but Ostwald, foreseeing the danger of further extension of bureaucratic control, took a leading part in the formation of the " Association of Directors of University Chemical Laboratories " and the establishment under their auspices of the well-known *Verbandsexamen*.

Ernst Haeckel persuaded him to become President of the " League of Monists." Ostwald consented, as he regarded his philosophical scheme as a true monist philosophy. Scenes of great enthusiasm accompanied the meeting at Hamburg where Ostwald and others addressed large audiences. At the conclusion of the meeting a pilgrimage was made to Haeckel's home at Jena. As a fruit of this period there resulted Ostwald's " Monistic Sunday Sermons." Unfortunately he lost a considerable amount of money in the establishment of a colony of Monists. This was a failure, as might have been expected, since the consolations of philosophy have little effect on the greed, jealousy and ill temper of average mortals. He also lost money in connection with an enterprise called the *Brücke*, the object of which was to create a sort of central nervous system for the organisation and integration of intellectual and cultural work.

During all these efforts and strivings Ostwald did not forget his chemical interests. Thus he became a member of the International Commission for Atomic Weights, and took a very active part in the movement for the foundation of an international Association of Chemical Societies.

Then came the world war and the shipwreck of much work and many hopes. Ostwald asked the authorities to make use of his knowledge and experience, but nothing was done. He was now 61 and had led a life of strenuous activity. Thrown back on his own resources and living in his quiet country house amidst a world of raging war, what wonder if at last had come the long-deferred period of repose? Nothing of the kind happened. The philosopher and would-be world organiser returned to his old love, a voyage of experimental discovery. He had always been a skilful landscape painter and this had led him, as we know from his " Malerbriefe," to consider the scientific foundations of the art of painting. He now resolved to investigate the theory of body colour and to establish both methods of measurements and colour standards. His object was to enable Mr. X. in any part of the world to reproduce any definite and desired body colour, provided he knew its metrical specification and the selected standards.

Ostwald began with the greys, which he regarded as mixtures of black and white. He found that he could match any given grey by employing a standard white pigment and varying the amount of light falling on it by means of a half-shadow photometer which he constructed and affectionately called his *Hasch* (a contraction of *Halbschatten*). From the greys he passed on to colours in general, regarding each definite body colour as a mixture of a standard " full " colour, black and white.

As the war progressed and the shortage of fuel for the heating of his house got more and more acute, we can picture the valiant old investigator stalking about his laboratory on winter days with hot water bottles strapped to his feet (a precaution due no doubt to his wonderful wife, though the method savours of Ostwald's experimental genius). But what did cold and other inconveniences matter to a man whose soul was filled with delight as his ideas and methods took ever clearer shape? Was he not succeeding where Goethe and Helmholtz had failed?

Ostwald considered these researches and their results to be the greatest work of his life. He published an account of them in the " Farbenlehre " and other related works. His joy in this investigation was due, no doubt, to three causes: the working out of clear concepts and a new theory, the successful return to experimental research, and the satisfaction of the artistic side of his nature.

In the very last period of his life he passed on to the serene regions of aesthetics, the meaning of beauty in form as well as colour. He regarded beauty as harmonious relationship, and harmonious relationship as the embodiment of underlying law. So he drew inspiration from the work of Weber and Fechner and by making experiments with colours and forms persuaded himself that there was indeed a law of harmony, a *Schönheit des Gesetzes*.

In his progress upwards through various realms of thought and discovery, Ostwald probably felt that his career bore some resemblance to that of his hero, Goethe. It was meet therefore that his last work, published in the year in which he died, should bear the title " Goethe, der Prophete."

Ostwald was very happy in his family life. For fifty-two years his devoted wife managed his household (and himself?) with unfailing love and efficiency. At this time of writing she is still alive and well. Surviving Ostwald are two daughters, Grete, who is a skilful artist, and Elsbeth, who married Dr. E. Brauer; also three sons, Wolfgang, Professor in Leipzig University, the well-known investigator of colloid phenomena and the founder and editor of the *Kolloid Zeitschrift* and the *Kolloidgesellschaft*, Walter, who is a fuel chemist and writer, and Otto, who holds a Government post in Berlin. There are nine grandchildren, the sons and daughters of Dr. Brauer and Walter Ostwald.

It would be impossible to enumerate on this occasion all the honours which were showered on Ostwald. In a list given to the present writer by Mrs. Ostwald there are 67 items. He was the recipient of honorary degrees from the Universities of Halle, Toronto, Aberdeen, Cambridge, Liverpool, and Geneva, and the Technische Hochschule of Karlsruhe. He was elected an honorary member of the Chemical Society; the American Chemical Society; the Royal Institution; the Bunsen Society; the Prussian Academy of Sciences, Berlin; the National Academy of Sciences, Washington; the Royal Academy of Sciences, Copenhagen; the Swedish Academy of Sciences, Stockholm; the Royal Society of Sciences, Kristiania; the Imperial Academy of Sciences, Vienna; the Imperial Academy of Sciences, St. Petersburg; the Royal Hungarian Academy of Sciences.

He was the recipient of the Faraday, Guldberg, and Exner Medals, and a member of six Orders.

Ostwald visited many countries and gave important lectures and addresses. Of these may be noted the Faraday Lecture in London in 1904, where he endeavoured—*horribile dictu*—to explain the mass laws of chemical combination amongst the elements without the use of the atomic theory; various visits to the meetings of the British Association and especially the celebrated one at Leeds in 1890, when, together with van 't Hoff, he had to expound and defend the theory of ionic dissociation; the Ingersoll Lecture at Harvard University in 1906, when he explained his reasons for not believing in the immortality of individual personalities and shocked some Americans.

There can have been few moments in Ostwald's life when ideas were not fermenting in his brain, or his active pen not making speed to carry the truth as he saw it to those outside the circle of light. It was a rich, full and successful life, in which he endeavoured to make the best use of the abundant energy accorded to him. In science as much as in philosophy there is no attainment of absolute Truth, for the great current of thought, investigation and discovery flows ever on. We may say with deep sincerity and respect that Wilhelm Ostwald strove long and gallantly for the great cause.