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IN COMMEMORATION OF THE 100th BIRTHDAY OF P. N. LEBEDEV

IN MARCH 1966 the 100th birthday was celebrated of the famous Russian physicist Peter Nikolayevich Lebedev. He was born of a merchant's family. He received his secondary education at the Khainovsky technical school. Since he graduated from a technical school he could only enter one of the technical educational Institutes. According to the rules existing at that time graduates of technical Institutes were not admitted to the Universities.

Upon entering the High Technical School he soon found that he was not interested in technical sciences. In fact he was strongly attracted by the type of studies whose subject was the investigation of the physical phenomena of nature. For this reason, in 1887 Lebedev went to Strasburg where he became a student of the Strasburg University. At that time the name of the prominent physicist–experimentalist Professor A. Kundt was already famous there. This scientist made a tremendous impression on Lebedev and virtually kindled in him the flame of love for physics. Lebedev wrote to his friends "From day to day I am falling in love with physics more and more. It seems to me that soon I may lose my human appearance, as now I can hardly understand how it is possible to live without physics".

In 1888 Kundt was invited to Berlin University to take over the chair of Helmholtz who had just been appointed President of the State Physico-Technical Institute.

Lebedev followed Professor Kundt. The stay in Berlin was a great benefit to him. While he was working in Kundt's department he zealously attended Helmholtz's lectures on theoretical physics. The spiritual influence of such celebrities as Kundt and Helmholtz further determined Lebedev's views not only on science and its social significance but also gave him the possibility to work out the educational system for young scientists.

Lebedev's first research work was done at Kundt's suggestion and was presented as his doctor's thesis at the Physico-Mathematical Faculty of the Strasburg University.

It was an experimental confirmation of the well-known theoretical Clausius–Massoti relation between the dielectric constant of the liquid vapours to the space occupied by them. Lebedev's outstanding abilities as a physicist–experimentalist were revealed in this work in which he also demonstrated his ingenuity and extreme thoroughness in conducting experiments.

Every experiment carried out for checking certain theoretical considerations should be conducted in such a way that all the extraneous factors involved in it must be rigorously controlled since it is never possible to eliminate them all. Lebedev understood this very well; from this point of view his work is of interest even now. It may serve as an example how to conduct an experiment thoroughly and how, if necessary, to eliminate possible errors in observation.

Lebedev's physical imagination was exceptional, and at first its flights had to be restrained by that outstanding teacher–scientist Kundt.

The thorough attitude towards the work proposed was not without consequence for Lebedev for the whole complexity of his thoughts developed and widened further in the course of time.

To understand this, it is necessary to note that not long before the beginning of Lebedev's scientific activity the great German scientist Heinrich Hertz experimentally confirmed the idea proposed by the no less brilliant Englishman Maxwell that electromagnetic waves were identical with those of light. This means that there should exist certain similarity between the effect of light and electromagnetic waves upon a substance. In other words, with the help of electromagnetic waves as well as with light waves it is possible to study properties of molecules of a substance. For instance, if a molecule is an ideal conductor, whose sizes are small as compared with the intermolecular distance, then as Clausius showed, the dielectric constant of a medium may be easily calculated.

This unexpected good agreement of Lebedev's with Clausius' calculations filled Lebedev's mind with a flood of new ideas, one more brilliant than the other.

For about two years an idea was maturing in Lebedev's mind that if according to Maxwell electromagnetic radiation affects matter, i.e. if the ratio of the energy of a beam falling per unit time on an absorbing body to its speed produces a pressure force, then this force may be the cause for the existance of comet tails. Lebedev communicated this thought to the well-known German scientist Wiener who at first took it for ravings of a madman. Only after thorough meditation Wiener understood the essence and congratulated Lebedev on his fundamental discovery. On this occasion Lebedev wrote: "It seems to me that I have made a very important discovery in the theory of motion of heavenly bodies, especially, of comets . . . the law discovered may be extended to all celestial bodies. I informed Wiener about this but at first he told me I was mad, but on the next day, having understood the essence, he congratulated me. At first, I was terribly excited but now when the law is proved, I am not a bit nervous, partly because—and I shall not hide this—I am perplexed, even stunned by its generality which I did not foresee. The law I formulated is not a matter of a minute's inspiration; for about two years I have been nursing it. This problem, which I have been studying for a long time, I love with my whole heart, in a way I imagine parents love their children".

The study of comet tails in connection with the effect of electromagnetic radiation upon a substance, directed Lebedev onto one more important idea regarding the nature of intermolecular interaction. In his opinion, a molecule is some complex electromagnetic system which may be simulated to an electromagnetic resonator. Consequently, when one molecule is at a rather close distance from the other, there may occur electromagnetic interaction between them since an electromagnetic field of each molecule will, as we would say now, influence the electric shells of atoms containing molecules. Due to electric disturbances in each molecule, the interaction of electromagnetic nature should take place between these molecules. As we can see, these ideas are quite up to date.

In Lebedev's time the electronic theory of a structure of a substance was only at the stage of development and nothing was said about a planetary structure of atoms. However, Lebedev's extraordinary physical intuition showed him the path, along which he should proceed and along which science later developed.

Lebedev never liked suggesting ideas which could not be checked experimentally. He was adverse to solving mathematical exercises which would not lead to experiments capable of verifying a hypothesis.

The stated views on the effect of electromagnetic waves upon a substance served as the basis for carrying out a number of works on the ponderomotive influence of waves upon resonators. Lebedev saw the nature of molecular forces in these interactions, as he clearly expressed in his collected works. In one of his works he wrote: "In Hertz' investigation, in the interpretation of light oscillations as electromagnetic processes still one more unsolved problem is not solved, namely the problem of radiation sources, of those processes which occur in a molecular vibrator while it releases its light energy into the surrounding medium; on one hand, such a problem leads to a spectrum analysis and, on the other, unexpectedly to one of the most complex problems of modern physics, to a study of molecular forces", see [1] pp. 56–57.

In our opinion, the results obtained by Lebedev in the experiments with magnetic and electric resonators are also of fundamental importance for a modern study of intermolecular-interaction potentials. They show that between molecules there should exist forces which at a definite approach of molecules may convert from repulsive forces to attractive ones. Lebedev himself formulated the discovered laws as follows:

1. The laws of the ponderomotive effect of waves on magnetic and electric resonators are identical.
2. When the resonators are tuned to a higher-frequency, an incident wave rotates them so that their excitation may increase; when the resonators are tuned to a lower-frequency the rotation causes a decrease in excitation.
3. The greatest quantities of these opposite forces appear quite near resonance, see [1], p. 79.

Further, Lebedev added that all the attempts to study a phenomenon with gradual transition through resonance did not lead to the desired result.

If Lebedev's magnetic and electric resonators are electromagnetic systems not quite imitating molecular systems, nevertheless they distinctly show the nature of the ponderomotive interaction when molecules approach each other due to heat motion.

Lebedev did not study only the ponderomotive interaction between magnetic and electric resonators. To extend this problem, he began to investigate these effects on the hydrodynamic resonators. These works clearly reveal his methodical approach to scientific research. He understood the heuristic force of analogies which very often lead to great discoveries. For example, it is enough to recall the works by Jacobi and Hamilton who managed to discover the profound analogy between mechanics and geometric optics.

C. Bjerknes and F. Bjerknes's investigations into mechanical interaction in incompressible fluid of pulsating, relatively moving and oscillating spheres are well-known. The authors have shown that the above interaction has reverse analogies with respect to ponderomotive interactions with static electric and magnetic polarization (Coulomb's interactions).

Contrary to C. Bjerknes and F. Bjerknes, Lebedev managed to find out direct analogies, i.e. to show that the dependence of ponderomotive forces upon hydrodynamic resonance is identical to the laws for electromagnetic oscillations. Lebedev's works on this problem proved to be more complete than those by C. Bjerknes and F. Bjerknes; for he succeeded in obtaining a continuous transition from the repulsive region to the attractive one. The results of these investigations were formulated by Lebedev as follows:

1. The law of the ponderomotive effect of an oscillating sphere on the appropriate resonator is identical both for longitudinal and traverse oscillations.
2. If the resonator is tuned in a higher-wave frequency, then attraction is observed; when it is tuned in a lower-frequency repulsion takes place.
3. The greatest quantities of these opposite ponderomotive forces appear in the vicinity of resonance and continuously convert into each other, see [1], p. 93.

If we take any modern monograph on molecular physics and look at a chart on a change in the interaction potential, depending on a distance of approaching molecules, it is easy to see that they are surprisingly like Lebedev's curves. The discrepancy is only at the reference points on the abscissa axis. In one case the distance of the approach is plotted and in the second, the natural frequency of a resonator. It is not difficult to understand that natural frequencies of oscillation of atomic cells depend upon a distance of the molecular approach. Therefore, there is no doubt that Lebedev's works on the ponderomotive effect of waves upon the resonators may still serve as guides for physical intuition even for a modern reader.

This is described in detail in the Appendix.

The persistant consistency of Lebedev's thinking was such that he was never satisfied with his discoveries, always attempting to generalize as far as possible. Having developed electromagnetic and hydrodynamic resonators he turned his interests to acoustic resonators, and here with the help of some most original devices he succeeded in discovering the same laws he established in his previous works. The investigations into the ponderomotive effect of waves upon acoustic resonators completed the series of his works which he himself appraised as follows: "The greatest interest in a study of wave motion lies in the principal possibility to extend the discovered laws to the region of light and thermal emissions of the individual molecules of a body and to predict the resulting intermolecular forces and their magnitude", see [1], p. 120.

The problem on molecular interactions stated by Lebedev is not yet finally solved up to now. The scientists all over the world are trying to solve this problem mainly in the direction anticipated by our famous countryman.

CONCLUSIONS

It is enough to note that the works of the famous English theorist London, effectively repeat Lebedev's ideas presented in terms of modern ideas on the structure of atoms and molecules.

The experimental investigations mentioned could bring glory to any physicist but Lebedev was not interested in achieving fame. His passion for knowledge was so great that he would not be stopped by any difficulties as long as the aim was clear and the advance of science would justify time and labour spent.

The survival of the electromagnetic theory of light proposed at that time by J. C. Maxwell considerably depended on the fact, to what degree its conclusions would be confirmed experimentally. One of the important consequences of this theory was the mechanical action of light waves.

If the beam of parallel rays falls normal to a flat surface, the value of the pressure of light p will depend upon the amount of energy E per second, the surface reflection coefficient r and the beam propagation velocity c. Mathematically the Maxwell law may be expressed as:

$$p = (E/c)(1 + r).$$

The absolute value of the light pressure is small. Nevertheless the fate of the Maxwell theory depended upon the experimental confirmation of the above formula. This confirmation involves great difficulties which could be foreseen by each experimentalist but not everyone could risk to sacrifice the labour and time required to overcome them. This work required not only resourcefulness and inventiveness but also great skill. Lebedev passionately liked difficult experiments, especially if they involved experimental confirmation of fundamentals of science. In this case nothing could stop him. He spent ten years of hard work to pass numerous obstacles and at last to wring out from nature its secret which it was carefully hiding and disguising. To measure the light pressure, it was necessary to make tiny mills, to place them in a high vacuum which at that time was difficult to achieve because suitable pumps were not available. Incomplete vacuum led on one hand to a convective gas flow, and on the other to radiometric forces, which were comparable in their magnitude to the light pressure. Lebedev thoroughly studied these phenomena and at last invented such a device which allowed the above mentioned auxiliary effects to be eliminated. In the end this work was crowned with success. He managed to prove the effect of light pressure upon solids in accordance with the electromagnetic Maxwell theory. From this very moment the question "to be or not to be" for this theory no longer arose. In 1901 the publication of the work by Lebedev was properly appreciated by the scientific world. For example, during the stay of K. A. Timiryazev in England

Lord Kelvin declared to him: "Perhaps you know that all my life I was fighting against Maxwell, not acknowledging his light pressure but your Lebedev forced me to surrender to the evidence of his experiments". Lebedev was awarded the prize for the works on light pressure on solids by the Academy of Sciences.

After studying light pressure on solids Lebedev at once began to make experiments with the pressure of light on gases.

The method used by Lebedev consisted on the fact that light passing through a gas contained in a closed vessel should cause the circulation of the gas. If the motion caused by non-uniform heating of a gas is eliminated from the circulation motion, then the whole effect should be determined by the light pressure which may be measured by a piston placed on the path of the moving gas. All the gases are bad heat conductors and in this respect only hydrogen occupies a special place as its heat conduction is relatively great. If it is added to the gases investigated, it is possible to achieve such conditions when the effect of convective currents will be very small and the gas motion will be caused entirely by the light pressure. Lebedev brilliantly carried out these experiments. About these experiments the well-known astrophysicist Schwartzshield wrote in his letter of February 9, 1910 to Lebedev: "I remember very well, with what doubt I learned in 1902 of your suggestion to measure the pressure of light on a gas and I was extremely surprised at hearing that you obviated all the obstacles", see [1], p. 19.

Lebedev was elected as an Honorary Member of the British Royal Society for his investigations of the light pressure on solids and gases.

At present the scientists all over the world are so accustomed to the Maxwell concept expressed in his well-known differential equations that nobody has doubts about them. Therefore, when looking into the past not everybody can perceive the importance and necessity of Lebedev's experiments to provide the experimental grounds to the Maxwell theory. Everything seems very simple and quite natural, it appears that there is no need at all to spend time and energy to check the laws which are clear and grounded theoretically. Such is the psychology of our contemporaries. It was quite different in Lebedev's time. There were doubts and distrust of the new concepts and representations alien to usual thinking. Thus, just the same occurred when the energy conservation law was discovered. Now everyone who will try to have doubts in the correctness of the energy conservation law will be considered mad. In Mayer and Helmholtz' time the contrary opinion prevailed.

The human habit is the enemy of all that is new and frequently kills in people the respect to the past, making them forget the fact that the present arises from the past.

Lebedev is an outstanding scientist because he understood the necessity to fight for the recognition of the Maxwell theory and he and Hertz share the great historic merit of consolidating the triumph of the Faraday–Maxwell theory in our century.

Lebedev carried out a series of outstanding and original investigations, the aim of which was to support experimentally the Faraday–Maxwell concept.

It is known that light waves refract, reflect, interferate and are subjected to diffraction from a sharp edge and a small hole, possess binary refraction in crystal bodies, etc.

Lebedev proposed to show that in accordance with the Maxwell ideas electromagnetic waves also had all these properties. He invented the devices which generated 6-mm electromagnetic waves and designed prisms and diffraction gratings to study their optical properties.

Lebedev's experimental results completely confirmed his expectations and he finishes his treatise with the following words: "If the number of the experiments described is not large, nevertheless it is quite sufficient to illustrate Maxwell's views on the propagation of electric oscillations in crystals which he published in 1862 and also to show once more the identity of the phenomena of the electric and light oscillations in a more complex case", see [1], pp. 44, 159.

Lebedev was a physicist of wide scope. He was interested almost in all the problems relating in any way to physics. For example, he was interested in the passage of light through interplanetary space, and towards the end of his life he worked a great deal on the origin of the earth magnetism.

Belopolsky's spectroscopic investigations of the binary star-β-Aurige and the discovery of some photometric peculiarities of variable stars made by Nordmann abroad and by Tikhov in Russia raised the problem of the possible dispersed properties of interplanetary space. Lebedev attached major importance to this problem; however, he did not see enough evidence for this statement in the observations of Belopolsky, Tikhov and Nordmann. He thoroughly analyzed the above observations and showed that the Nordmann and Tikhov methods were not sufficient to separate the interplanatary space dispersion, if such exists, from the collateral factors which were, in his opinion, the thermal effects, tide phenomena in atmospheres of the central bodies and satellites, etc. In general, Lebedev has come to the conclusion that it is quite impossible to prove dispersion of interplanetary space; to his mind "space absolutely lacks any light dispersion that could possibly be measured".

From our point of view, such a categoric judgement of the famous Russian scientist is perhaps premature although his conclusions based on some particular observations are quite convincing. The problem of light dispersion in interplanetary space is so fundamental that it requires a much broader analysis of the accumulated data.

We have already mentioned that Lebedev was particularly fond of solving difficult experimental problems if they were of significance to science. Following Hel's discovery of strong magnetic fields accompanying vortex motion of a photosphere around the sun spots the thought occurred to Lebedev of a possible parallelism of magnetic phenomena on the sun and the earth. To confirm this idea he decided to reproduce this cosmic phenomenon in the laboratory and to determine directly magnetometrically and to measure the magnetic phenomena caused by the rotation of bodies. In his opinion, when bodies rotate, due to contrifugal accelerations there should occur mutual motion of charges entering into the structure of atoms or molecules of a substance; and negative charges of atoms should be displaced normal to the axis of rotation. Lebedev's hypothesis is the well-known modified hypothesis of Sutherland who maintained that magnetism of the terrestrial globe results from the shift of charges under the influence of gravitational forces.

Undoubtedly, these well-planned experiments were very important but also extremely difficult. Probably only Lebedev could carry them out because half a century has elapsed since and nobody has so far dared to repeat them. He started these investigations at the beginning of 1911 but several months later he died in March 1912.

Lebedev brought fame to his homeland not only through his personal works; but as a true patriot he was the first of the Russian scientists who propagated the idea of team work in science. In one of his popular papers he wrote: "Large physical laboratories intended only for research have already existed for a long time in the West, England, Germany and America. By their continuous work on scientific problems, as practice has shown, they undoubtedly help technology. The Royal Institution in London established on private funds more than a hundred years ago, may be the striking example of such a laboratory. First of all, the greater number of persons taking part in the development of science is useful for the science itself, namely, for the development of its certain fields which are being studied at the laboratory and here I especially would like to point out such collective work . . .".

"If more arguments are required for the defence of a greater number of persons working in this field of science, then I should like to point out the importance of communication of each person working in this field with those who are interested in this very subject: such communication leads to a more interesting exchange of opinions and very often helps to overcome encountered difficulties following good advice and . . . ".

Lebedev's statement on cooperation in science was dictated not only by his enthusiasm for scientific work but he understood perfectly well that the future of any state considerably depends upon the fact, how rapidly the science is developing in the country. Now this truth has become an axiom.

Lebedev's activity at the Moscow University brightly underlines his above political credo as a scientist. Here he organized the laboratory which worked fruitfully up to 1911. That year a storm broke out over the Moscow University. More than a 100 professors and readers sent in their resignations as a protest against the encroachment of the Minister of Education Kasso upon the University autonomy. Lebedev was among those who left the University. Unfortunately, this catastrophy influenced him so that he became seriously ill and did not return to his young pupils who following him also left the University.

Lebedev's laboratory, situated in the basement of the old building of the Physical Institute at the Moscow University, was totally permeated by his ideas. Even now much work proposed by him is being developed. We shall emphasize the most important moments in Lebedev's activity in this period of his life.

After the publication of the works by Clausius, Maxwell and Boltzmann on the kinetic theory of a substance a number of concrete problems appeared. One such problem is heat and mass transfer in rarefied gases. This problem was studied by Smoluchowski who gave the first description of this phenomena.

Lebedev inspired his two intimate pupils Lazarev and Timiryazev to study this phenomenon experimentally.

According to the Smoluchowski theory, at the interface of a solid and a rarefied gas in the presence of a temperature difference between the gas and wall, a temperature jump should be observed and in the case of a moving gas also a gas slip should occur. The first problem was studied by Lazarev and the second, by Timiryazev. The experiments of both investigators completely confirmed the predictions of the theory. However, these experiments and the theory itself were limited to the case when the temperature and velocity gradients of the moving gas were sufficiently small at the distance comparable with the free path of the molecules.

It should be noted that the problem formulated by Smoluchowski and Lebedev acquired essential importance in our time due to the development of the rocket and space flight engineering. Modern space crafts and rockets move under such conditions that in calculating heat losses from their shells it is necessary to allow for the temperature jump and slip. However, in this case there appeared doubts in the validity of the application of Smoluchowski's approximate theory. Under the conditions of motion of space bodies in a rarefied gas, the temperature and velocity drops are such that temperature and velocity gradients over the free path of molecules are far beyond the limitations assumed in this first work. It was necessary to repeat Lazarev and Timiryazev's experiments. These experiments were repeated by Kulto in the U.S.A. and by Gribkova at the Department of Molecular Physics of the Moscow University in the Soviet Union. A quite unexpected result was obtained: Lazarev's conclusions on a temperature jump and Timiryazev's ones on slip were confirmed despite the fact that the conditions of the experiments were different. This contradictory circumstance is to be solved.

Lebedev continued his work of proving the identity between electromagnetic and light waves, and proposed to his pupils Kolli and Romanov to study dispersion of electromagnetic waves in different liquid media. These problems were developed after Lebedev's death. At present they are being investigated on a new basis of radiotechnical measurements. These investigations are of special interest in the study of the nature of fluids and for studying special states of gases which are now called plasma.

During the flourishing days of Lebedev's University laboratory the views on wave processes finally crystallized. Rayleigh's works appeared. It became clear that pressure is not only an inherent property of light and electromagnetic waves but also of acoustic ones. Naturally Lebedev together with his pupils began thoroughly to study the acoustic wave processes of the work carried out in this direction. We must mention specifically that by Neklepaev and Kasterin.

Neklepaev succeeded in discovering acoustic dispersion in gases which gave impetus to numerous investigations of the scientists all over the world. Later, these works were developed on a large scale at the Moscow University under the direction of L. I. Mandelshtam who together with his pupil M. A. Leontovich outlined the relaxation theory of acoustic dispersion. However, it should be noted that the mistake which was repeated in many investigations almost for forty years slipped into Neklepaev's investigations. Only the reader of the Moscow University, P. E. Krasnushkin, managed to notice, what role unparallelism of an acoustic beam may play in measuring the main dispersed gas properties.

Kasterin's work which was begun at the laboratory under the direction of Lebedev aimed at determining the interaction of the acoustic waves with acoustic resonators. The full theoretical solution of this problem was presented in his doctor's thesis which up to now is cited in the world literature. After the Great October Revolution P. N. Belikov, a pupil of Lebedev and Lazarev, repeated Kasterin's experiments under more perfect conditions.

We have mentioned only three directions of the works which were begun at Lebedev's laboratory. In reality, the range of the investigations conducted in that laboratory was much broader. It is quite clear that in any good team the ideas of the leader of the laboratory intermingled with the initiative of his young pupils. Lebedev appreciated and stimulated the scientific initiative of a beginner.

The comparatively short existence of Lebedev's laboratory nevertheless greatly influenced the development of science in Russia. The well-known Lebedev school of physicists was born, to which belonged such famous scientists as: P. P. Lazarev, A. K. Timiryazev, V. I. Romanov, A. P. Kolli, T. P. Kraverts, V. Ya. Albert, V. D. Zernov, V. K. Arkadiev, N. A. Kaptsov, A. B. Mlodzeevsky, P. S. Epstein, N. E. Uspensky, N. K. Shchodro, E. V. Bogoslovsky, N. P. Kasterin and many others. All these scientists held distinguished positions in Russia and P. E. Epstein is still a leading physicist in world science and is working in Pasadena in the U.S.A.

REFERENCE

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APPENDIX

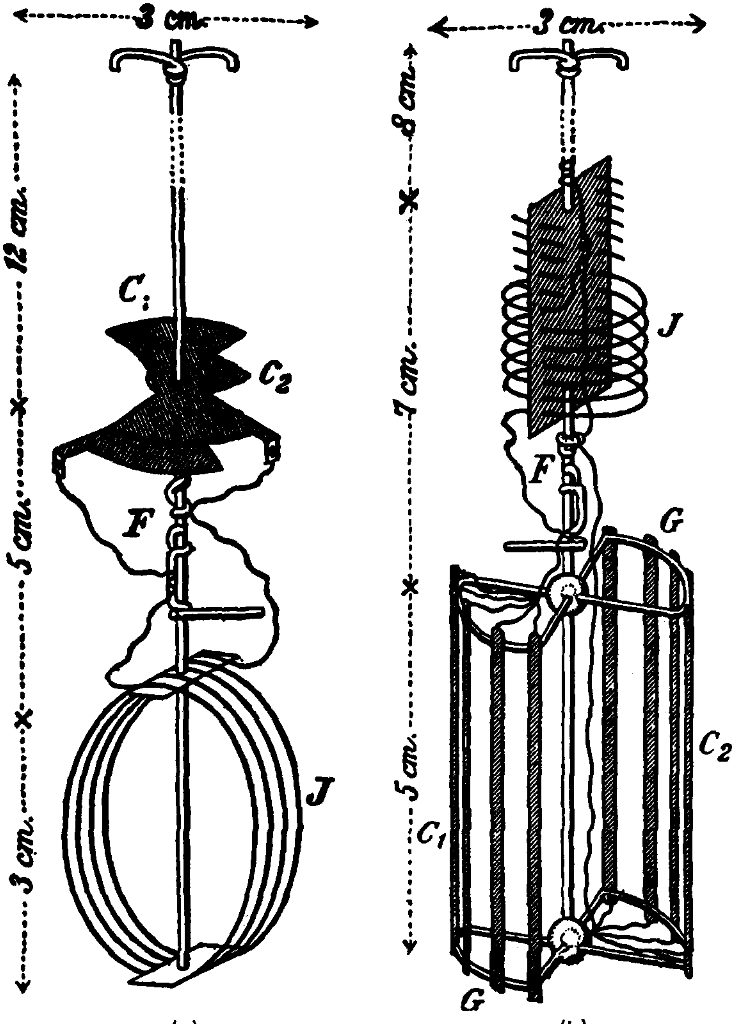
To illustrate, how profound were Lebedev's foresights on the nature of intermolecular interaction, we shall briefly describe his investigations.

In his work on the ponderomotive interaction of electromagnetic waves on resonators, Lebedev studied two types of resonators—magnetic and electric. The magnetic resonator is a self-induction circle with condenser plates similar to the pointers of the square Thomson electrometer [See Fig. A1(a)]. This resonator was so suspended in the electromagnetic field that the electric vector did not affect it. Only the magnetic forces acting upon the self-induction circle could turn the resonator. The proper length of the wave of the resonator λ_0 was 359 cm. The experimental results are given in Table 1. The first column of this table contains the lengths of waves of incoming radiation and the second column, the ponderomotive force in conventional units.

In this table the sign "+" corresponds to attraction and the sign "–", to repulsion.

The electric resonator is the self-induction circle connected with a cylindrical condenser. This condenser is shown in Fig. A1(b). It was so placed in the electromagnetic field that the magnetic vector could not produce forces that would rotate the winding thread. Only the electric vector acting on charges accumulated at the plates of a condenser could turn the resonator. The length of the resonator wave was 346 cm. The measured results for the electric resonator are given in Table 2.

If Lebedev's ideas are considered correct, i.e. forces of intermolecular interaction are of the resonance origin, then there appears the problem how to find the interaction potential according to the experimental resonance curve obtained. This problem turned out to be solvable. It is possible to show the model, with the help of which the interaction potential may be easily calculated according to Lebedev's resonance



(a) (b)

FIG. A1.

curve. We shall not dwell upon the ways which led to the development of the above model but consider only the main principles underlining this model.

Let any molecule in a condensed medium be a resonator possessing the inherent frequency of radiation ν_0. The action of all the surrounding molecules on this resonator may be replaced by some electromagnetic field. In such a representation of a liquid structure the interaction of one liquid molecule with another completely imitates Lebedev's experimental conditions.

Table 1

λ	K
301	+3·4
311	+3·8
331	+7·6
340	+14·8
351	+52·0
371	−18·8
389	−8·5
414	−4·5

Table 2

λ	K
283	+7·6
323	+14·6
333	+19·5
359	−22·6
376	−8·1
4118	−4·7

The described model of intermolecular interaction is equivalent to the Rayleigh–Jeans box where there is one resonator. All the molecules surrounding the resonator serve as the Rayleigh–Jeans box walls. The total energy of such a box consists of radiation energy I_0, energy of resonator thermal motion Q and molecular polarization energy W. Thus, we have

$$E = W + Q + I.$$

According to the laws of thermodynamics, transition from one steady state of a system to another is made in accordance with the relation:

$$E/\nu = \text{const} = h.$$

Here the constant of adiabatic constant h should not necessarily coincide with the Planck constant.

In our model polarization energy W is also simply accounted for. Assume that the gap δ between the resonator surface and the walls of the Rayleigh–Jeans box is a binary electric or magnetic layer. Designate the total charge of this binary layer by e and let the condenser itself be spheric. Then the polarization energy is expressed by the formula

$$W = e^2\delta/R^2.$$

Here R is the radius of the volume where the resonator was placed.

Now it is possible to write down such an obvious relation

$$\frac{e^2\delta}{R^2\nu_0} + \frac{Q}{\nu_0} + \frac{I}{\nu_0} = h\frac{\nu}{\nu_0}.$$

Here δ is the gap of a fictitious condenser.

From the relation obtained it follows that

$$\delta = \frac{R^2\nu_0}{e^2}\left(h\frac{\nu}{\nu_0} - \frac{I}{\nu_0}\right) - \frac{QR^2}{e^2}.$$

Up to now our considerations were of general character. Now we make some restrictions based on the following hypothesis. Let a constant h coincide with the Planck constant, and radiation energy I_0 be equal to $h\nu_0$. In this case the relation obtained assumes the form:

$$\delta = \frac{R^2\nu_0}{e^2}h\left(\frac{\nu}{\nu_0} - 1\right) - \frac{QR^2}{e^2}.$$

Designate the quantity $(v - v_0)/v$ by y, then we shall have:

$$\delta = \frac{R^2\nu_0 h}{e^2}y - \frac{QR^2}{e^2}. \qquad (1)$$

The quantity δ may be interpreted as the distance measured from the closest approach of molecules when attractive forces still take place;

the quantity y may be taken on the basis of Lebedev's experiments but the quantity $(\lambda_0/\lambda - 1) = y$ should be used as the abscissa rather than the wave length as used by Lebedev.

Thus, our model led to the formula allowing representation of Lebedev's resonance curve as a potential function of intermolecular interaction.

Proceeding from the aforesaid, we shall make an attempt to calculate the potential function for helium. Lebedev's resonance curve is given in Fig. A2 where the ordinate is the ponderomotive force in conventional units and y is the abscissa. Figure A3 gives the potential of interaction for helium calculated by the virial coefficients.

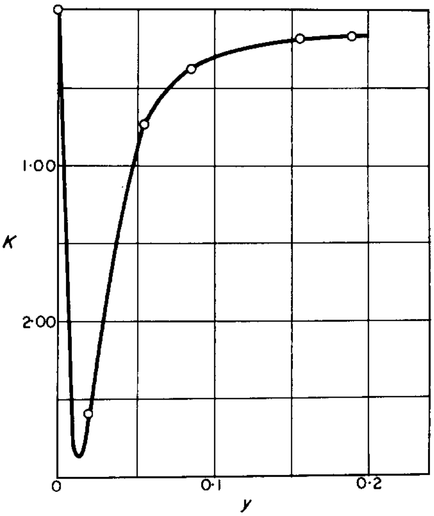


FIG. A2.

The values of the potential U in relative units are included in the ordinate and the values of δ, in the abscissa, i.e. the distance from the closest approach of molecules when the attraction potential changes into the repulsion one. In both figures the circles designate the data obtained experimentally. The calculations of the interaction potential by the virial coefficients are considered to be the experimental data although in these calculations the known theoretical conjectures were used.

To impose the Lebedev resonance curve (Fig. A2) upon the curve (Fig. A3) by means of formula (1) it is necessary to express the constant values in formula (1) by a number. It may be done on the basis of the following data: the quantity R is half the kinetic radius of helium. Following Keesom it is equal to $2{\cdot}54 \,.\, 10^{-8}$ cm. The proper resonator frequency may be found from optical data for helium. For ν_0 Kurbertson gives the value equal to $5{\cdot}9 \,.\, 10^{15}$. The total charge of a binary layer is assumed to be equal to one charge of electron. Thermal energy Q is obviously equal to the latent heat of evaporation calculated per one atom.

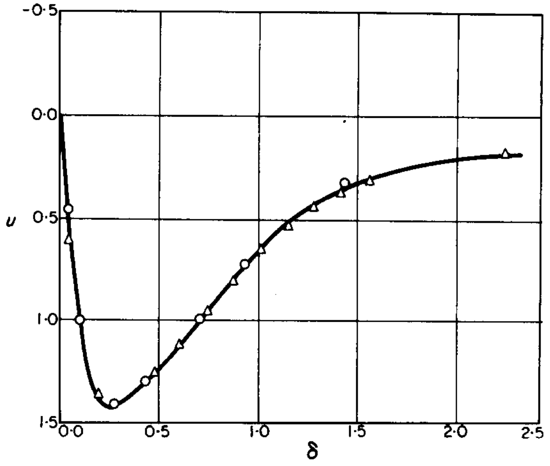


FIG. A3.

Taking into account the aforesaid, formula (1) may be reduced to the following form:

$$\delta = 2{\cdot}74 \,.\, 10^{-8}\, y - 0{\cdot}085 \,.\, 10^{-8}. \qquad \text{(1a)}$$

The ratio of the conventional unit of the ponderomotive interaction force to the unit of the potential interaction given in Fig. A3 is equal to 2·04. Using this condition and relation (1a) it is easy to impose Lebedev's resonance curve upon the attraction potential curve. The values of the interaction potential calculated by this method according to the Lebedev resonance curve are marked with triangles in Fig. A3. From the last figure it is seen that the imposition of one curve upon the other may be carried out with sufficient accuracy. This means that Lebedev's considerations of the nature of the intermolecular interaction are far from intuitive guess. They simply give a new method for solving a complex problem of a liquid state. These considerations also allow to understand why all the attempts to find out the mathematical form of a potential of interaction reach a deadlock. Formula (1) converts one resonance curve into such a large set which obviously cannot be represented only by the constants entering into the interaction potential, since they can reflect neither the polarization molecular effects, nor the optical qualities of the condensed media.

It seems to us that the above analysis of Lebedev's ideas gives new perspectives to the development of science.

Finally it should be noted that science is a great ocean of contributions by individual scientists most of whom are of but average value. Therefore, among the ocean of works it is very difficult for an ordinary mortal to find out without studying the history of science, the ideas of great scientific significance. Only great talents may do this without knowing the history, but nowadays there are only a few of them under the conditions of mass research work. Hence, one is drawn to the conclusion that when organizing research Institutions we should bear this in mind and following Lebedev's advice appoint highly talented scientists as leaders of the research groups and Institutions. Otherwise, science will be condemned to a slow development and may simply move backwards.

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