PHYSICS IN THE NEW AND THE OLD WORLD [1]

It is a great pleasure and an honour to me to give you this first lecture which may serve as a general introduction to what we may offer you in this second „American week'' of our University. We shall gladly avail ourselves of this opportunity to show you what has been done and is being done in this country, partly because we are anxious to make a good impression on our guests, but mainly because we know that you will be interested in it, and because we hope it may give you some pleasure. Indeed, scientific men all over the world ought to be, and fortunately are, to a great extent, like good comrades of whom each rejoices at what the others have achieved. They are struggling with the same problems and working at the same task; in fact, the advancement that has been made has been the outcome of the joint efforts of all civilized nations. This is what I should like to illustrate by some examples taken from the progress of physics in the new and the old world.

Three years ago I had the good fortune to spend a couple of months in Pasadena and to visit the observatory on Mount Wilson. It was formerly called the solar observatory, because its main object was the study of the phenomena observed in the sun, but from the beginning much attention was given to the multitude of suns that appear to us as stars. You know that Professor KAPTEYN of the University of Groningen, who was one of the pioneers of modern stellar astronomy, worked for many years in close connexion with the observatory and spent many summers on the mountain. Another countryman of mine, Dr. VAN MAANEN, has belonged to the staff of the observatory for a long time, devoting himself mainly to the accurate determination of the motion of heavenly bodies, stars and nebulae.

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[1] Inaugural address, delivered at the „American Week'' at Leiden, 1926.

What KAPTEYN told me about the observatory, had made it particularly attractive to me. We reached it very comfortably in a large autocar, much more comfortably, I am sure, than Mr. HALE, when he first visited the mountain for the purpose of studying the conditions which it would afford for solar research, and when he installed himself in the wilderness with a single working man for companion.

We were hospitably received in the Monastery, the abode of the astronomers when they are on duty on the mountain, and the afternoon and evening were spent in admiring the beauties of nature and those which science reveals to us. We had a glorious sunset and enjoyed the view on the plain stretching toward the Pacific with the thousands of lights of Pasadena and Los Angeles, and when night had wholly fallen, Mr. HUBBLE allowed us to see in one of the giant telescopes some of the marvellous nebulae which he is constantly examining in all their details. But the spectacle that, perhaps, impressed me most of all was the ZEEMAN effect in the sunspots.

I presume you all know what we understand by the ZEEMAN effect. It is a phenomenon that was first observed, in 1896, by Prof. ZEEMAN, then working here as Prof. KAMERLINGH ONNES' assistent. When you visit the laboratory you may notice a stained window pane commemorating the discovery.

A source of light giving sharp spectral lines is placed in a strong magnetic field. It is found that by this the period of the vibrations is a little changed, so that the spectral lines are shifted from their original positions, and there is even a decomposition of the lines. Whereas, outside the magnetic field, each line is characterized by one single period or frequency, the field calls forth, instead of this, a certain number of slightly different frequencies, each of which finds its own place in the spectrum.

In later years, when more powerful experimental means could be applied, the phenomenon has presented itself in many complicated forms, but we are now concerned with the simple form only, in which it was first discovered. If we examine the light that is emitted in the direction of the lines of force, we find two components lying to the right and the left of the original spectral line. On the other hand, the emission at right angles to the lines of force gives rise to three components. In addition to the two which

I mentioned just now, there is a third component midway between them and exactly occupying the place of the undisturbed line.

It is very important that the light which produces any one of these components is polarized, showing that it consists of vibrations of definite form and orientation. In the observation along the lines of force the components are circularly polarized, one being right handed and the other left handed (i.e. the light is such as could be produced by particles moving in circles about their position of equilibrium), the motion being in the direction of that of the hands of a watch for one component and in the opposite direction for the other.

In the other of the two cases which I distinguished, when there are three components, they are all rectilinearly polarized, the vibrations being along the lines of force for the inner component and perpendicular to it for the outer ones.

Professor HALE had carefully studied for many years the appearance of the sun, that is the distribution of great and small luminosity over its surface, using for this purpose the beautiful instrument that is known as the spectroheliograph. In this country the University of Utrecht possesses an instrument of this kind, designed by the late Professor W. H. JULIUS.

The spectroheliograph allows us to obtain a photographic picture of the sun, not using all its light but exclusively light of one single frequency, corresponding to one definite place in the spectrum. Choosing the red light that is emitted by hydrogen, HALE obtained peculiarly sharp pictures and in these, in and near a spot, a spiral structure could be seen; this suggested the idea of a whirling or revolving motion in the sun's atmosphere.

Now, it was known already that many causes, some of which may be expected to exist on the sun, may lead to the production of electrically charged particles, ions or electrons, and that under proper circumstances the positive and the negative particles may be more or less separated. If the gases revolving in the sun spot have an excess of either positive or negative charge, the whirl will be equivalent to a system of circular electric currents and the spot becomes comparable to a coil carrying a current and having its axis perpendicular to the sun's surface. It occurred therefore to Prof. HALE that in the sun spots there might be a magnetic field and that this might have on the spectral lines the influence that had been found by Prof. ZEEMAN. He was soon able to confirm this expectation. Many of the lines of the spot light were found to be double and the two components were really circularly polarized, the polarization being right handed for the one and left handed for the other. As we know of no other way in which this phenomenon could be produced, we may safely conclude to the existence of the magnetic field in question.

I cannot, of course, dwell for a long time on any special subject, but in recalling to you this beautiful discovery I should like to add a few further remarks. In the first place Prof. HALE found just what can be seen in ZEEMAN's experiment when one observes along the lines of force. This type of the effect would show itself exactly in a spot situated at the centre of the sun's disk, for then the axis of the whirl would be directed towards the observer. On the other hand, if a spot were situated near the border of the disk, we should see nearly the second type of which I spoke, three components with linear polarization, and in a spot having an intermediate position we should see phenomena that may be called a transition from the first to the second type. All this has been verified by HALE's further observations.

In the second place, two spots, whose spiral structure indicates whirling motions of opposite directions, often seem to belong together. Most probably they form the ends of a semi circular vortex, extending through the sun's body, such as you can easily imitate while drinking a cup of tea. If, holding your spoon in a vertical position, you dip it into the fluid to such an extent that half the spoon, say half a circle, is immersed, and if then you move the spoon in a horizontal direction, perpendicular to itself, you will observe two small dimples, moving along in the direction of the spoon's motion, and in each of which the fluid circulates about the centre, the deepening at this point being an effect of centrifugal force. The two hollows are simply the ends of a semi circular vortex ring that has been formed along the rim of the spoon and you can easily understand how it is that the rotation is in opposite direction in the two hollows.

Now, if the magnetic field in the sun spots is really due to the whirling motion, it must have opposite directions in the two associated spots. HALE was able to verify this. It is proved by the fact that, when we pass from one of the spots to the other, the component of the double line, say the one with the greater frequency, that had a right handed circular polarization becomes left handed, and conversely.

You will have noticed that my reasoning, or rather Prof. HALE's was based on the assumption that the motion of a body carrying an electric charge produced a magnetic field. This was shown fifty years ago by a young American physicist, working in the laboratory of HELMHOLTZ in Berlin, HENRY ROWLAND, afterwards professor in the Johns Hopkins University in Baltimore. He found that a charged disk of ebonite, rapidly rotating in its plane, exerts a force on a sensitive magnetic needle placed in a suitable position in its neighbourhood.

ROWLAND's experiment has been repeated many times, both by himself and by other physicists, and has become one of the foundation stones of the theory of electrons and in general of all theories in which phenomena are explained by the arrangement and the motion of small charged particles. Theories of this kind have made rapid advances during these last thirty or fifty years and have fundamentally altered our conceptions about the constitution of matter. As to the negative particles to which the name of electrons is more particularly applied, we now know that they exist in the β-rays of radio-active bodies and in the cathode-rays, flying along at high speeds, that they are emitted by hot bodies, thus giving rise to the phenomena that occur in triodes or audions, and that they belong to the constituents of all atoms, revolving about the positive nucleus like planets around the sun.

One of the first questions concerning these small particles was the measurement of their electric charge and their mass. The ratio between these two quantities has been found by different methods; in fact ZEEMAN was one of the first who assigned a value to it, using for this purpose the distance between the components into which a spectral line is split by a magnetic field of known strength. As to the absolute value of the charge, this was determined very accurately by Prof. MILLIKAN.

In his experiments a small oil drop suspended in a gas was observed by means of a microscope placed in a horizontal position. If there is nothing to prevent it, the drop will fall and, since it is very small, it will soon acquire a constant velocity determined by the condition that its weight is exactly counterbalanced by the resistance due to the viscosity of the air. This motion can be wholly controlled when the drop has an electric charge, as may easily be the case, if the surrounding gas has been slightly ionized; the drop will then catch a charged particle from time to time. Suppose now that the two horizontal plates of a condensor limit the gas on both sides. A potential difference between the plates will then produce an electric field and thereby a force acting on the charged drop, either upward or downward. By regulating the difference of potential we can keep the drop in equilibrium, or we may make it rise or fall with any velocity we like; we thus have the means to keep it in the field of view for any length of time. Now watching a drop for many hours, MILLIKAN found that now and then there was a sudden change of the velocity. This was undoubtedly due to the capture of a particle, and gave the means to determine the charge carried by it, the quantities necessary for the calculation being the observed change of velocity, the strength of the electric field, the velocity of fall in the absence of a charge and the weight of the drop that could be deduced from its size and the specific gravity of the oil.

There are many difficult and unsolved questions in the theory of electrons, but instead of speaking of these I shall, with your permission, point out to you some of its triumphs. Among these we may reckon in the first place the beautiful experiment performed by TOLMAN and STEWART, in which an electric current was produced simply by changing the velocity of a conductor. A large coil of metal wire whose windings were in horizontal planes was suspended in such a way that it could rotate about its vertical axis, while its ends remained in connexion with a galvanometer. The coil was first put in rapid rotation and was then suddenly brought to rest by means of a brake. This produced a transient electric current, the explanation of which is that while the metal is brought to rest, the electrons continue their motion for a short time. The direction of the current was indeed the one that could be expected when the movable particles in the metal have negative charges, and from the deflection of the galvanometer and some constants of the apparatus the ratio between charge and mass of which we spoke already could be determined. The results agree fairly well with the numbers found by other methods.

The experiment is a delicate one and it would be much easier to observe the effect if, with the same charge, the mass of the particles were f.i. thousand times greater than it is now. Then it would be possible also to observe an other phenomenon that is so to say the counterpart of the one observed by TOLMAN and STEWART, and can be deduced from it by means of general dynamical principles. If a change in the velocity of rotation of the coil produces a motion of electricity, then, conversely, starting an electric current in the wire must have the tendency to make it rotate. As it is there is little hope of observing this phenomenon, but there is an experiment much like it that has been performed by EINSTEIN and DE HAAS and some other physicists, and which differs from it in so far as we are not concerned with currents in the windings of a coil, but with those which we suppose to circulate around the particles of a magnetized body. We knew since the days of AMPÈRE that the properties of magnets may all be explained by the hypothesis of these molecular currents and in the light of modern experience it was natural to suppose them to exist in a motion of negative electricity only, more exactly in a motion of negative electrons. Now, if this is the case, magnetization involves the existence of a certain moment of momentum, whose direction changes with that of the magnetization, and which disappears when the body is demagnetized. This will be true whatever be the way in which the demagnetization takes place. We can imagine f.i. that each individual molecule loses its magnetic moment; this would mean that the electrons cease to circulate around it, so that their moment of momentum disappears likewise. But we can also conceive that, though each molecule remains a small magnet, the parallelism between their axes is destroyed; in this case, though each particle conserves its moment of momentum, the resultant moment will again disappear, just as in the former case.

EINSTEIN and DE HAAS' experiment was based on the principle, well known in elementary mechanics, that in a system that is free from any external couple, i.e. from any influence tending to produce a rotation, the total resulting moment of momentum remains constant; if once it is zero, it will be so for ever. If by some means a part of the system acquires a moment, the other part must acquire one of the same magnitude but of opposite direction. Hence, if an iron cylinder be suspended in a vertical direction, so that it can freely turn about its geometrical axis, a magnetization of the rod in the direction of its length, which makes the electrons revolve in one direction, must be accompanied by a sudden jerk of the rod itself, the metal taking a rotation opposite to that of the electrons. There will be a jerk opposite to the first, when the cylinder is demagnetized, or when the magnetization is inverted, and, by properly timing continuous reversals of the magnetization, the angles over which the rod turns may be increased. All these phenomena could be observed and it could be shown that the direction in which the cylinder is set rotating always agrees with the assumption that the particles revolving about, the electrons, have negative charges.

With this effect observed by Einstein and De Haas we may again associate another phenomenon that is the counterpart to it and may be deduced from it on general physical principles. It consists in this, that a rotation of a material body about an axis must produce the same effect as a magnetic force acting on the body in the direction of that axis and therefore gives rise to a magnetization when the body is made of a magnetic substance. Mr. and Mrs. Barnett in Washington have made the delicate experiment with great care and have actually succeeded in proving the magnetization excited in an iron rod by rapid rotation. The direction of the phenomenon again is all right but, and this is a great puzzle, the magnitude of the effect is not what was expected; it is nearly the half of it. The same discrepancy exists in the Einstein-De Haas effect and this is satisfactory in so far as the two phenomena belong together, so that the intensity of one can be deduced from that of the other.

The theory of electrons which amid all its troubles and failures finds some consolation in the experiments of which I have now spoken, is an offspring of Faraday's and Maxwell's great theory of electricity. It is based on the general principles laid down by Clerk Maxwell and it only tries to go somewhat further in forming a picture of the mechanism underlying the phenomena. Maxwell was very careful not to make any assumptions that were not sufficiently guaranteed by experience and he considers it as an open question whether in an electric current there really is something like a progressive motion. So he directed his attention rather to the charged bodies and the wires carrying the current than to the electricity itself.

There is one case in which his cautiousness led him to a statement that cannot be maintained. When a wire in which there is an electric current is placed in a magnetic field, it is acted on by a force at right angles both to the field and to the wire. This is the force that is used in Prof. EINTHOVEN's string galvanometer which you will see next Thursday. Now, MAXWELL explicitly says that this force must be understood to act upon the wire and not upon the electricity contained in it.

In 1880 EDWIN H. HALL, then working in ROWLAND's laboratory, had the courage to doubt this assertion and so became the discoverer of the remarkable effect that is named after him. I should like to say some words about this phenomenon but I think I had better in this case not trust entirely to words. I have therefore prepared this piece of cardboard which may represent on an enlarged scale the thin metal plate, a rectangle of gold foil in the first place, with which the experiment was made.

The plate is placed between the poles of a powerful electromagnet, so that it is perpendicular to the lines of force, but we shall begin by imagining that the electromagnet is not excited. An electric current is made to pass through the foil, and two points A and B on opposite sides of the rectangle are carefully chosen so that the electric potential is the same at the two places. Then, if A and B are connected with a galvanometer, there will be no deviation of the needle. After having made sure of this, we apply the magnetic field. The result will be a deflection of the galvanometer, showing that the electricity which moves in the direction of the arrow is acted on by a transverse force driving it from A towards B, or from B to A, as the case may be, and thus producing a current in the galvanometer circuit. This current takes the opposite

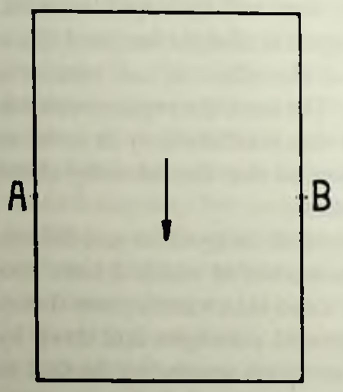

FIG. 1.

direction when we invert either the magnetic field or the principal current in the plate.

The HALL effect has been observed and measured by a great number of physicists. Some 16 years after its discovery Mr. LEBRET and Mr. VAN EVERDINGEN in the laboratory of Leiden carefully examined it in the case of bismuth, and one of the problems to which the late Prof. K. ONNES applied his for ever searching genius was the question whether there is a HALL effect in a supraconductor.

Unfortunately, or fortunately, the phenomena are extremely complicated, the sign of the effect being different in one substance and another. Moreover the HALL effect does not stand by itself; there are three other phenomena closely connected with it. In the first place, it has been found that, always under the influence of a magnetic field, the current through the metal plate produces not only a potential difference between the points A and B, but also a difference of temperature. Further, we can replace the current of electricity in the direction of the arrow by a current of heat, which we produce by maintaining at different temperatures the top and the bottom of the plate. This current of heat, like the electric current, gives rise to a potential difference between A and B and also to a difference of temperature between these same points.

You see that, well counted, there are really four effects and it is gratifying to see that, in these last years, Prof. HALL, resuming his work of old times, has been thoroughly examining them all.

Among the four effects there are two that are closely connected, namely the production of a transverse difference of temperature by an electric current and the production of a transverse potential difference by a current of heat. The relation between the two can be expressed by a mathematical formula that allows us to deduce the numerical coefficient of one of the two phenomena from that of the other. It was a curious coincidence that this problem was treated almost at the same time by Mr. BRIDGMAN of Harvard and myself. We were both preparing for the Solvay meeting in Brussels, and found nearly the same result, Mr. BRIDGMAN on the steamer and I in my room without any telegraphic or telepathic communication.

In this brief review I had, more than once, occasion to call your attention to the fact that physical phenomena often occur in pairs, perhaps I may say like our two sun spots. One may be deduced from the other by appropriate reasoning. The principles, which we have to use for this purpose, may be simply those of general dynamics, or, in other cases, those on which the science of thermodynamics is founded. So, in our case, Mr. BRIDGMAN and I had to apply the second law of thermodynamics. In fact, our reasoning was much like that by which the relation between the electromotive force of a thermo-electric current and the PELTIER effect is established.

I cannot speak of thermodynamics without recalling to you the memory of two great theoretical physicists who probably never saw each other, but worked much along the same lines, the late Prof. VAN DER WAALS of Amsterdam, whose investigations were at the base of much of the work that has been done in Leiden, and WILLARD GIBBS of Yale University. You know that the second law allows us to lay down important rules for the physical and chemical equilibrium between different substances, and no one has done so with greater mastery than GIBBS in his famous memoir published in 1876 on this equilibrium between heterogeneous substances. VAN DER WAALS highly admired this work and the principles developed by GIBBS have been most fruitful for the development of physical chemistry in this country. In the title of the great work in which BAKHUIS ROOZEBOOM collected the results of his researches, and of which my colleague SCHREINEMAKERS continues the publication: „Die heterogenen Gleichgewichte vom Standpunkte der Phasenlehre", the word „Phasenlehre" is to be expressly understood as meaning WILLARD GIBBS' theory of phases.

WILLARD GIBBS rendered another important service to science by his „Elementary principles of statistical mechanics", where the word „elementary" rather indicates the modesty of the author than the simplicity of the subject. Here he develops the principles which we may apply to all those cases in which we are concerned with the irregular motions depending on temperature of systems consisting of innumerable particles. In this field WILLARD GIBBS and BOLTZMANN are our great masters.

But I should like to revert again for some minutes to what I saw at Mount Wilson. Most important among it was the apparatus which had served Prof. MICHELSON of Chicago for measuring the diameter of some fixed stars, one of the many ingenious applications which he has made of the interference of light. There is a small beautiful book by Prof. MICHELSON on „Light waves and their uses" and the tale of what he has done with light waves forms one of the most fascinating chapters in the history of physical science. I need mention only the determination of the number of wavelengths in a standard metre, the observation of the tides produced by the action of the moon and the sun on the water contained in a long horizontal tube, and the proof that the time required for a beam of light to go around a large closed circuit on the surface of the earth is changed by the rotation of the earth to an amount that may be calculated on theoretical grounds. And above all, the famous MICHELSON-MORLEY experiment, that is almost known to the man in the street now that the theory of relativity has become so popular.

These last years the tranquillity and peace of mind of physicists has been more or less disturbed by the results obtained by Mr. D. MILLER in his many repetitions, made with the utmost patience, of the experiment. His observations really seemed to indicate the aetherdrift which, according to EINSTEIN's theory, it ought to be impossible to observe, and one has spoken already of a knock out, as I think sportsmen say, of the theory of relativity. The question is not wholly cleared up as yet, but we may expect that we shall be able in the near future to bring it to a decision. Plans for further repetitions are formed on different sides and it may interest you to hear that a fortnight ago Mr. PICCARD of Brussels went up in a balloon with his interferometer to an altitude of about 4000 metres. During his ascension which lasted for 16 hours or at least during a great part of this time, the balloon was made to rotate with a constant velocity, somewhat more than two revolutions per minute, and the interference fringes were continuously registered photographically. The films, however, were not yet developed when I saw Mr. PICCARD last week.

In the meantime Mr. D. MILLER is working out his last results. They indicate the existence of some unknown cause which it will be very important to discover, but all well considered I have good hopes and I think Mr. D. MILLER will agree with me that relativity will be quite safe.

In surveying the achievements that have been reached by the combined efforts of physicists, we naturally appreciate them in the first place according to what they have contributed to our insight into the hidden workings of nature. But we should not forget how much we owe to the genius and skill of those who design and manufacture instruments of observation. I saw in the workshop of the Ryerson Laboratory how large plane and spherical surfaces of glass are ground and polished with a precision of less than a wavelength and Mr. MICHELSON gave me some idea of the way in which large and, I may say, perfect gratings, such as were first made by ROWLAND, are obtained.

One can hardly exaggerate the importance which ROWLAND'S gratings have had for physical research work. Indeed, if we want to deal with really homogeneous rays, consisting in a succession of millions of waves, if we want to determine their wave numbers and to separate from each other rays with a small difference of wavelength, we need some material object, in which there is a great number of exactly equal parts, and which may therefore serve as a gauge which we apply to the rays of light. The greater the number of these parts, and the more exact their equality, the better shall we reach our purpose. Also, when we pass from longer to shorter waves, we shall need gauges with smaller and finer intervals.

In the case of light waves, ROWLAND'S gratings with their thousands of equidistant lines most admirably met all requirements, and when we came to X-rays, for which these gratings are too coarse, LAUE had the happy idea to use instead of them the gratings which nature offers us in crystals with the regular arrangements of particles. So the conditions were created for an unprecedented development of optics, including X-rays. This is perhaps the field, though the work in it is intimately connected with that in other parts of physics, where the labourers are most numerous and where the richest harvest is reaped; it is also the field where new ideas have sprung up and where the struggle between theories is liveliest.

Alas, but this word escapes me, things have turned out differently from what we could expect twenty years ago. While we drew the greatest profit from the teachings of classical optics and from the use of the instruments that are based on its principles, these foundations have now been shaken. With the notion of light quanta which it seems almost impossible to discard we are returning in a certain sense to NEWTON's corpuscular theory of light, and the explication of interference itself, with which we were so satisfied, again becomes a problem. We have always believed and considered it as evident that, apart from DOPPLER effects, light always conserves its frequency how as it may be reflected, refracted or scattered. And now, Mr. COMPTON of Princeton has shown that X-rays, when scattered by free or loosely bound electrons, have their frequency diminished. A beautiful theory of this phenomenon, attractive in its boldness, has been proposed by Mr. COMPTON himself and by DEBIJE. It is much like the theory of the impact of two elastic spheres, one sphere being replaced by an electron and the other by a quantum of light. Each of these „particles", if I may use the word, has its energy and its momentum, and the formula is obtained by applying the principles that the total momentum and the total energy of the system must remain unaltered. After having found the change of the energy, that of the frequency is deduced from it by the simple rule that the frequency of a light quantum is always proportional to the energy. The results agree with the experimental data, and as I said, the theory is very tempting and attractive. Yet we want to know how it can be that a quantum, that is treated here as a particle of extremely small size, shows in its reflexion by the grating of a crystal the properties which we find in long trains of waves.

So, after all, in our modern physics, there is much that is dark and mysterious. But light is dawning on many sides and we may confidently hope that, if not the older, at all events the younger among us may witness a new development of the nature of which we perhaps can have no idea.

It remains for me, Ladies and Gentlemen, to thank you for the attention with which you have listened to me.