Karl F. Lindman: The Last Hertzian, and a Harbinger of Electromagnetic Chirality

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Abstract

Karl F. Lindman has widely been referred to as being the first to demonstrate the effect of a chiral medium on electromagnetic waves, about 40 years ahead of the pack. But who was Karl F. Lindman? A study of his life and his work suggests that he was what may be called the last Hertzian physicist. During the first half of this century, he completed an extensive research career, using essentially the same methods as Heinrich Hertz did in his time.

1. Who was Karl F. Lindman?

Karl F. Lindman was born in the small, coastal town of Ekenäs, close to the southwestern corner of Finland, on June 7, 1874. He was the only son to Karl Gustav Lindman and his wife, Lovisa, born Lignell. Karl Gustav Lindman made it from humble origins to an independent farmer, and was honored later in his life by an appointment to a minor clerical function. As he had made good, he was able to put his son, Karl Ferdinand, into school. The rest is the usual story of a young man of great talent and prodigious energy: graduation from secondary school at the age of 18, and a university degree in physics at the age of 21, in 1895. Lindman took a long time to decide to major in physics. The alternative was history. Throughout Lindman's life, history remained a dear hobby to this physicist and extreme specialist in electromagnetic waves. Lindman got his PhD at the Helsinki University in 1901, with thesis work done in Leipzig.

For 20 years, Lindman served as an innovative secondary-school teacher in various towns in Finland. He was finally appointed Lecturer at Svenska Normallyceum, a national institute of a school in Helsinki. As early as 1909, Lindman introduced laboratory courses into the curriculum of Svenska Normallyceum. His various biographies also make one understand that Lindman was able to keep his classes under exemplary discipline. Lindman wrote a large number of textbooks on physics, astronomy, and chemistry, both in the Swedish and in the Finnish languages. These books were in use until the Second World War, and beyond. Lindman was also an active popularizer of science. He published a large number of articles in various newspapers and magazines, aimed at the public at large. In 1907, he spent half a year in England and Scotland, studying the methods of teaching used in English schools.

After his appointment to the Chair in Physics at Åbo Akademi, Lindman became deeply involved in university politics. He served for 24 years as the Dean of the Faculty of Mathematics and Natural Sciences. He was Vice Rector of the University from 1921 to 1929. Lindman was honored with two national prizes for his research, the Hallberg Prize in 1933, and the Homen Prize, also in 1933. It may be of interest to note that Lindman also took part in the discussion on Einstein's theory of relativity. Without ever publishing an original research article on the question, Lindman expressed severely-critical opinions of the theory in his textbooks. It appears that, the great experimentalist of electromagnetic waves that he was, he never came to believe that the transformation properties of the fundamental equations of his subject had changed physics for good.

Lindman never grew tired of his work. He continued teaching and doing research after his retirement, in 1942. He carried a full teaching load until 1945, and published his last paper as late as 1947. One may be struck by the absence of co-authors in the published work of Lindman. In his research he was a lone wolf. He trained only one PhD student, Hilding Slätis, who became his successor in the Chair of Physics for one year, before moving on to Sweden.

Karl F. Lindman died on February 14, 1952. He left behind one son, Sven Lindman, Professor of Political Science at Åbo Akademi.

2. Karl F. Lindman as a Hertzian Physicist

As already mentioned, Lindman was brought into electromagnetics at the University of Leipzig, in 1899–1901. The University of Leipzig had a tradition in electrodynamics founded by Wilhelm Weber, a student of C. F. Gauss and Professor of Physics in Leipzig, 1843–1849. Right before Lindman's stay, Paul Drude came to the Chair of theoretical physics, in 1894. Characterized as "mastering equally theory and experiment," he obviously had a

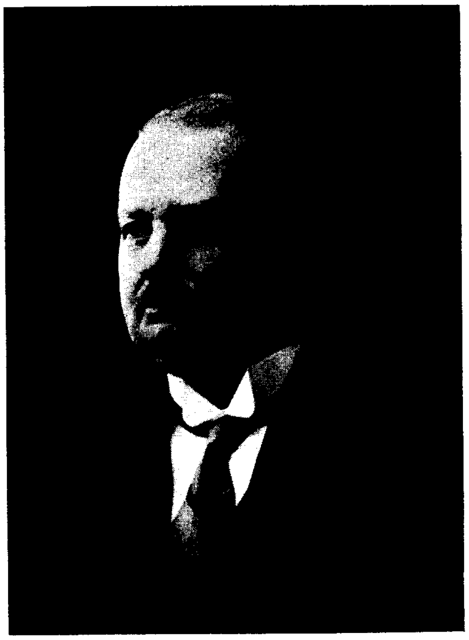

Figure 1. Karl Ferdinand Lindman (1874-1952).

strong influence on Lindman. In order to set things into perspective, it may be worth mentioning that people like Boltzmann, Debye, and Heisenberg also have held chairs at the University of Leipzig [1].

2.1 Experimental Equipment

Lindman returned to Finland in November, 1901, with a completed PhD thesis to be presented at the University of Helsinki. The title of the work was "On Stationary Electric Waves, An Experimental Study" (in German). He described an experiment on standing electromagnetic waves, from a Hertzian dipole with extendible arms and a spark gap ("oscillator O" in Figure 2). The dipole was fed with audio-frequency high voltage, generated by a Tesla coil (T), whose primary had a circuit containing a Leyden jar (K), a tunable spark gap (F), and a Ruhmkorff inductor (I). The inductor again was fed from a battery with a circuit breaker (not shown in Figure 2), producing 40 Hz current pulses. The spectrum of the radiated signal contained a peak with a main frequency between 0.6–7 GHz, determined by the arm lengths of the dipole, and a decaying band of higher and lower frequencies.

The receiving antenna ("resonator") was tuned to some frequency, and its current heated a load resistor connected to a thermocouple, whose weak current pulse created a deflection in a galvanometer. Since there was no detector for the signal level at the transmitter, Lindman made use of another antenna at a fixed position ("standard indicator"), coupled to a second galvanometer. He developed a technique of reading the two galvanometer deflections with one glance, to get the relative signal as the quotient of the two readings. The galvanometers were by far the most sensitive elements of the system. They were carefully shielded against external mechanical and magnetic effects. When Lindman became professor at Åbo Akademi, in 1918, he actually could not begin his measurements because the building was not steady enough. He had to wait until another building was found for his laboratory. Magnetic disturbances from electric streetcars forced him to do his measurements at nighttime.

This same method, developed and perfected at the turn of the century, was to be applied in Lindman's experiments for half a century, with only minor changes in the apparatus. A major disaster occurred in 1940. During the Winter War in Finland, the equipment was transferred to a shelter. In this process, one of the two galvanometers was damaged. The rest of Lindman's experiments were done with a single galvanometer and two consecutive readings, one for the measured quantity and another for the reference signal.

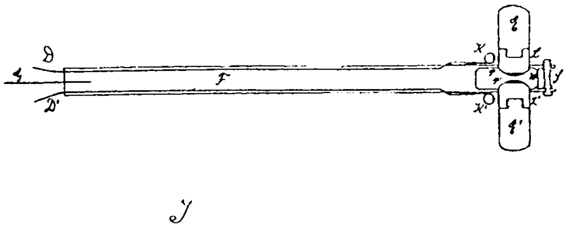

Figure 2. Transmitting spark-gap antenna ("oscillator") with adjustable dipole arms, together with its feeding circuit, as depicted in Lindman's PhD thesis from 1901. This wide-band Hertzian generator remained practically unchanged in his experiments for half a century, producing microwave, millimeter-wave and even infrared frequencies.

Lindman was always very careful in his work, and was satisfied only when repeated measurements showed no marked change in their readings.

2.2 Hertzian Studies of Electromagnetism

Lindman's PhD thesis was about a phenomenon he had encountered while observing standing waves in front of a conducting plate. Unlike the other peaks and valleys, the first maximum seemed shifted significantly, towards the plate, from its theoretical distance, $\lambda/4$. Lindman explained the effect as being due to the second-harmonic frequency, induced in the tuned receiving dipole because of the wide band of the transmitted signal.

After the thesis, Lindman continued his studies on electromagnetic wave problems. His last paper appeared in 1947. We will return to his work on chiral media in the next section. Apart from this major area, his work dealt with resonances of wire antennas, macroscopic models of different media, millimeter-wave and infrared-wave propagation in various media, diffraction grids, scattering problems, wave propagation in Sommerfeld single-wire transmission lines and metal-tube waveguides. All these experiments were carried out with the same equipment!

His aims were physical, in a purely Hertzian manner: to demonstrate an effect and increase knowledge of it, rather than to find practical applications. Measuring wavelengths on the Sommerfeld single-wire line, however, he could determine the permeabilities of many different materials with high accuracy from his thin-wire samples. His work on scattering (he called it reflection) from small particles led to a method which allowed the detection of bigger stones in a concrete wall. The steps from this to a practical radar could not have been completed with his limited skills in engineering.

A great deal of Lindman's work was done on finding resonances of different wire antennas ("resonators"). This was necessary for his experiments: in order to know which frequency in the wide spark-gap spectrum was being measured, the exact tuning of the receiving antenna was of prime interest. He developed numerical correction factors for dipoles depending on all conceivable parameters: length, thickness, material, and the end geometry of wires. One of his reports on wire antennas in Åbo Akademi (which always published his results first) consists of 201 printed pages. In addition to dipole and loop antennas, he studied the helical antenna, in 1933. Being interested only in the basic resonance, he failed to discover the axial radiation mode, found by John Kraus as late as after the Second World War.

In 1909–1910, Lindman investigated wave propagation through a grid of wire scatterers. He found that the distance between scatterers had a great effect on the propagation. Von Laue and Bragg had investigated the reflection of X rays from crystals, in 1912, and interpreted the results in terms of scattering from a grid. Lindman studied the electromagnetic wave reflection from a grid of wire loops, in 1921, and verified Bragg's law on a macroscopic scale. Later, he went on and studied various frequency-selective surfaces, with which he could separate different frequencies out of his broad-band transmitted signal, for further use. With a grid of small lead spheres, for example, he could obtain a peak of frequencies in the millimeter-wave region. He was also able to demonstrate that the spectrum from the spark-gap transmitter contained infrared waves. In one of his last papers, in 1945, Lindman exploited infrared waves thus produced in an investigation of the absorption of these waves in different materials.

Lindman was a full-blooded experimentalist. His papers contain few equations. The Maxwell equations can be found in them only once, in a footnote. Nevertheless, he regularly checked his experimental results against theoretical predictions obtained by others. He never reproduced derivations of the few formulas cited in his papers, nor did he make comments on them. Glancing through his papers from the 1920s and the 1930s, almost all of his references seem to go back to the turn of the century, either to the 1890s or the 1900s. We can easily feel sympathy for Lindman, the only twentieth-century physicist studying electromagnetism, while the mainstream of physics was following quantum and relativity paths. He does not seem to have had contacts with the electrical-engineering community either, which was not so well developed in Finland at the time. Perhaps the most dramatic contrast to the outside world is detected when looking at Lindman's paper on wave propagation in a circular metal tube, and between two metal plates, in 1942. At a time when there was a tremendous amount of worldwide effort devoted to problems of microwave propagation along metal waveguides for radar development, Lindman's problem was a shift in the principal frequency of a broad-band signal propagating through a tube. If the principal frequency from the generator was below a certain critical frequency, he found an output peak at a higher frequency, while higher, main peak frequencies did not change. A relation of the critical wavelength to the diameter of the tube was experimentally obtained. This reflects the pure physicist interested in one problem, among a multitude of others, in total ignorance of the fact that the problem happened to be among the hottest engineering topics of the day.

3. Pioneer in Chiral Studies

Why are today's electromagneticists so enthusiastic about Karl F. Lindman's results from almost a century ago? The explanation is that Lindman was focusing, as early as in the first and second decades of the century, on a field that was to evolve into the extremely hot topic that it is today. This topic is the electromagnetism of chiral media.

3.1 Chiral Media

Chiral materials are a subclass of bi-anisotropic media, more general than the normal isotropic media describable through the material parameters of permittivity, permeability, and conductivity. Chiral media, or "handed" media, display an intrinsic asymmetry with respect to the distinction between left and right. On the level of constitutive relations, this is visible in the magneto-electric coupling:

$$\mathbf{D} = \varepsilon\mathbf{E} - j\kappa\sqrt{\mu_0\varepsilon_0}\mathbf{H} \tag{1}$$

$$\mathbf{B} = \mu\mathbf{H} + j\kappa\sqrt{\mu_0\varepsilon_0}\mathbf{E} \tag{2}$$

Here, **E** is the electric and **H** is the magnetic field strength, and **D** is the electric and **B** is the magnetic flux density. The material parameters expressing the connection between these quantities are the permittivity, ε, and the permeability, μ, characterizing the electric and magnetic co-polarizability of the material. The third parameter, κ, stands for the magneto-electric coupling, and contains the (dimensionless) degree of chirality. ε_0 and μ_0 are the permittivity and permeability of vacuum. There are also other notations for the material parameters of chiral media: see, e.g., [2]. Because of the scalar nature of the material parameters, a medium with constitutive relations of the form (1), (2) is isotropic in the sense that its electromagnetic response does not depend on the field vector direction: it is bi-isotropic. Note, also, that the equations (1), (2) do not describe the most general bi-isotropic medium: for nonreciprocal chiral media, a fourth material parameter is needed.

The effect of chirality on electromagnetic wave propagation is a rotation of the plane of a linearly-polarized wave. In classical optics, this has been a well-known phenomenon since the early nineteenth century, from the studies by Biot, Arago, and Fresnel. It has been given the name *optical activity*. Somewhat later, Pasteur showed that the optical activity results from the handed structure of the material: a material that differs from its mirror image is capable of rotating the polarization plane of linearly-polarized light. Honoring his work, a chiral medium obeying the relations (1), (2) carries the name, "Pasteur medium."

The potential applications in microwave, millimeter wave and infrared frequencies gave the impetus to the "second wave" of chirality research which we are witnessing today. Among such applications are couplers, microstrip and lens antennas, wave-guiding structures, and antireflection coatings. The number of publications on electromagnetic waves in chiral media has increased tremendously: for references, see, e.g., [3]. A book has been published on chiro-electromagnetics [4], and an introductory article into the field can also be found [5]. The SPIE Optical Engineering Press has published a selection of treatises on optical activity and chiral electromagnetics [6].

3.2 Lindman's Role

These recent publications do not fail to recognize the work of Karl F. Lindman. His two pioneering papers on microwave chirality are cited and, sometimes, even reproduced. Lindman's papers appeared in the German language in the venerable journal *Annalen der Physik* in 1920 and 1922, with the titles

> "Über eine durch ein isotropes System von spiralförmigen Resonatoren erzeugte Rotationspolarization der elektromagnetischen Wellen" (**63**, 4, pp. 621-644, 1920),

and

> "Über die durch ein aktives Raumgitter erzeugte Rotationspolarisation der elektromagnetischen Wellen" (**69**, 4, pp. 270-284, 1922).

As a curiosity, let it be mentioned that today's scientists, in referring to these publications, obviously treat the experiments described there as having been performed in the '20s. Lindman, however writes in his 1920 paper,

> "die Versuche wurden im physikalischen Institut der Universität Helsingfors im Sommer 1914 aufgeführt,"

and, hence, his pioneering work is in fact six years older than normally recognized. The objection that Lindman did not publish his results until 1920 (with the implicit presumption that the date of publication is the date of discovery) does not hold water. Lindman did, indeed, publish his work in 1914, before the outbreak of the first World War [7].

Let us take a closer look into the contents of these two publications.

3.3 Lindman's Publication in 1920

Already, the nineteenth century had seen the proof that optical activity is a geometrical property, and arises from the dis-symmetric molecular structure of substances displaying such activity. Drude had presented a model for the wavelength dependence of the amount of rotation of the polarization plane, ϕ, in an optically-active material:

$$\phi = \sum_i \frac{k_i}{\lambda^2 - \lambda_i^2} \tag{3}$$

Here, λ is the wavelength of light, and the summation over i takes into account all the "characteristic vibrations of the electron groups," in the parlance of late-nineteenth-century physics: λ_i is the corresponding resonant wavelength, and k_i is the strength of this resonance.

All this was known to Lindman, and this was also his starting point. He was interested in testing the validity of Drude's model at lower frequencies, with radio waves, or, as he himself called them, "Hertzian waves." He noted that this means a situation similar to "ultraviolet electrons," i.e., in Drude's formula, the case where the wavelength is much longer than the characteristic wavelengths of the resonant modes:

$$\lambda >> \lambda_i \tag{4}$$

Hence, Drude's model gives

$$\phi \approx \frac{\kappa'}{\lambda^2}, \tag{5}$$

where κ' is now the strength of the lowest-order mode. Because of the strong inverse-wavelength dependence of ϕ, there is no measurable optical rotation to be expected of Hertzian waves. This formula (5) was known as Biot's first law.

Hence, what to do? Lindman's answer to this problem was scaling. If molecular dis-symmetry produced optical activity, radio-wave (or electromagnetic) activity should result from dis-symmetry that manifests itself on spatial scales of the order of centimeters. The artificial creation of this kind of a material was the next step.

Lindman synthesized a chiral medium by coiling small helices from copper wire, immersing these in cotton balls, and then positioning these in a cardboard box with random orientations. The length of the wire before coiling was 9 cm, and the thickness was 1.2 mm. The diameter of the spirals was 10 mm, and there were 2.5 turns in each spiral. The cardboard box had a linear dimension of 26 cm, and the total number of spirals in it was 700. Lindman made both left-handed and right-handed helices.

Lindman put his chiral box into his measurement system, shown in Figure 3. He directed linearly-polarized radio waves through the metal guide where the sample was located, and measured the linearly-polarized component of the intensity of the received signal as a function of the rotation angle of the linear receiving antenna. For a linearly-polarized wave, this function should be the square of the cosine. The polarization rotation could be read from the maximum of this curve.

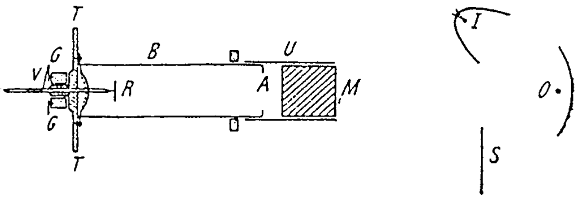

Figure 3. Lindman's measuring equipment. The transmitting oscillator, O, stands beside a reflector. I is the "standard indicator" discussed in the text. B and U are hollow metal tubes. The sensor dipole, R, can be turned with the stick, T, and the rotation angle is read in the display formed by V and G. M is the box containing the chiral sample.

His results are shown in Figure 4, at a frequency of 1.2 GHz. It can be clearly seen that the polarization plane has been rotated due to the cardboard box on the wave path: there is a clear shift in the peak of the curves. The figure also shows that Lindman's chiral sample is isotropic: three different orientations (Curves II, III, IV) lead to the same shift. Finally, he shows that the angle of rotation is directly proportional to the number of helices in the box: 300 helices produce a rotation of 11°, and 500 helices corresponded to 18°. This is in accord with the modern result that the polarization rotation can be given as the integral of the chirality parameter along the wave path [8]:

$$\phi = k_0 \int \kappa \, ds \tag{6}$$

where κ is the dimensionless chirality parameter, and k_0 is the wave number.

However, the basic aim of the study was to investigate the dispersion, i.e., the wavelength dependence. The polarization rotation was measured at wavelengths from 12 cm to 35 cm (frequencies of 1 to 3 GHz). Lindman then took Drude's model (3), with only one mode (one term in the summation), and compared the measured curve with the model. With eight frequencies and only two free parameters (λ_0 and k), the agreement is good, except at wavelengths close to the "resonant" wavelength of the model, λ_0.

Lindman was also able to show that equal amounts of left-handed or right-handed spirals bring about the same rotations, in opposite directions.

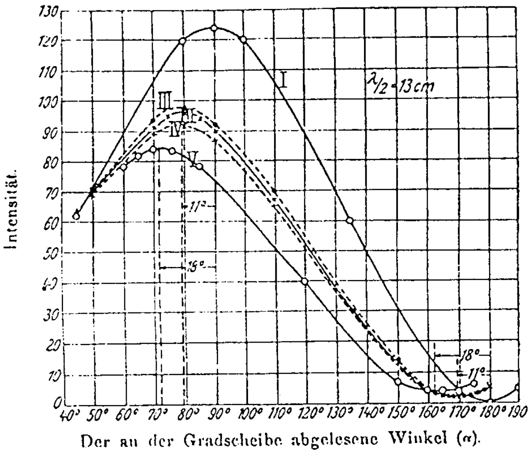

Figure 4. Measured intensity curves as functions of the rotation angle of the receiving antenna. Curve I is measured without a sample. It shows maximum polarization matching for a 90° angle. Curves II, III, and IV are for a chiral sample with 300 spirals on the propagation path of the wave. The three curves are for three different orientations of the same sample. Curve V represents a sample with 500 spirals, displaying the linear relationship between the number of chiral elements and the amount of the rotation of the polarization plane.

3.4 Lindman's Publication in 1922

It can be a refreshing experience to take a look at scientific publications of the good old times, such as those of Lindman. The personal tenor in the reporting, and the wordy descriptions about the background and motives for various assumptions in attacking problems, can sometimes convey deep insight into the way physical laws were conceived at those times. Lindman's paper of 1922 is a nice example of this.

Lindman begins his introduction by summarizing his 1920 paper, and briefly discussing absorption, a topic that was not touched upon too much in the earlier paper. Then he writes,

> "Durch eine briefliche Mitteilung hat Dr. Felix Stumpf in Berlin mich darauf aufmerksam gemacht, daß die Ergebnisse meiner Versuche sogar bedeutend besser als ich durch Vergleich mit der Drudeschen Formel zuerst fand, dem entsprechen, was man in dem vorliegenden Falle theoretisch erwarten kann."

In other words, a Berliner, Felix Stumpf, had carefully read Lindman's article, and noted the discrepancy between Drude's model for the wavelength dependence of the rotation and Lindman's measurements. The disagreement appeared only close to the resonant frequency, as observed above. Drude's model predicts infinite rotation at $\lambda=\lambda_0$, whereas Lindman's measurements showed no rotation at all! In his private letter to Lindman, Stumpf suggested that a slightly improved model, due to Natanson, would lead to extremely good agreement at all frequencies. Natanson had simply included a damping term in the model, and derived a somewhat more complicated formula for the polarization rotation. In a more modern fashion, Natanson's formula can be seen to arise from including an imaginary term in the Drude model, via a damping parameter λ_d:

$$\phi = \frac{k}{\lambda^2 - \lambda_0^2 + j\lambda\lambda_d} \qquad (7)$$

from which, by taking the real part,

$$\phi \sim \frac{\lambda^2 - \lambda_0^2}{\left(\lambda^2 - \lambda_0^2\right)^2 + \lambda^2\lambda_d^2} \qquad (8)$$

and, indeed, this expression vanishes at the resonant frequency $\lambda=\lambda_0$, which agrees with Lindman's measurements.

The 1922 publication reports testing the Natanson hypothesis. Extensive and careful measurements for this were carried out and repeated. The concluding sentence is affirmative:

> "Diese Versuche haben also die Natansonsche Formel innerhalb der Genauigkeitsgrenzen der Messungen bestätigt."

3.5 Later Publications About Chirality

Lindman continued studies on the rotation of the plane of a linearly polarized radio wave as it propagates through dis-symmetric media. In the mid-1920s, he published two articles in the Åbo Akademi report series, in Swedish. The titles were

> "Om en av en asymmetriskt tetraedrisk och av en spiralformig molekylkodell alstrad vridning av de elektromagnetiska vågornas polarisationsplan," (*Acta Academiae Aboensis, Mathematica et physica*, **III.4**, 1923)

and

> "Några nya försök rörande elektromagnetiska vågors genom tetraedriska molekylmodeller alstrade rotationspolarisation," (*ibid.*, **IV.1**, 1925).

In these publications, Lindman reported his experiments of a different type of synthetic chiral material. He was aware of the objection that the model of randomly-oriented helices is perhaps not the most realistic model conceivable for a molecular solid. Molecules in solids are arranged in crystalline structures. The large-scale model therefore should also mimic a lattice. Carbon compounds, in particular, were known to display optical activity. In order to model a carbon atom, Lindman simulated its stereo-chemical structure by a distorted tetrahedron. Discussion about the connection between lattice structure and optical activity was intense during those times: Oseen, Stark, and Born were known to raise questions on this subject.

In the first paper, Lindman reports on his new chiral objects made out of four identical copper spheres, each with a radius of 3.5 cm. He arranged these in the four corners of a distorted tetrahedron. The distances between the spheres were the slightly-different-length edges of the tetrahedron, 10.5, 10.5, 15, 15, 12.5, and 16 cm. The spheres were connected with each other by wooden rods. With one such "molecule," he was able to rotate the polarization plane of a 17.6 cm-wavelength wave by 2.5°.

In the latter publication, Lindman studied the effect of a composite, where several asymmetric tetrahedra were placed in a cylindrical wooden case, to constitute an isotropic chiral object. He was able to produce good agreement between his measurements and Biot's first law (5). The last chapter of the paper is interesting, because he there comes to a negative conclusion about the polarization rotation by an asymmetric object. He built a model molecule where, again, four spheres were located at the corners of a regular tetrahedron (of edge dimension 11 cm). This time the spheres were of different metals and sizes. One was made out of copper, with a radius of 3.5 cm. The remaining three were made out of brass, with radii 2.8, 2.5, and 2.2 cm. This clearly-chiral object lead to no measurable rotation of the plane of polarization of a 17.6 cm-wavelength wave!

3.6 Ahead of His Time

Lindman was the clear winner in the race to create synthetic microwave chiral materials. Forty-three years elapsed from Lindman's initial research on chirality until a similar (admittedly more extensive) measurement (9) was carried out in California. From that event, another thirty years were to pass before the technology of the manufacturing of chiral composite materials reached a sufficient level of sophistication to prepare samples with pre-designed chiroelectromagnetic parameters in the microwave and millimeter-wave ranges.

4. A Conference in Honor of Karl F. Lindman

Each year, a National Convention on Radio Science takes place in Finland, at some university, under the auspices of the URSI National Committee of Finland and the IEEE Finland Section. For the year 1991, Åbo Akademi, the university where Karl F. Lindman was Professor of Physics for 27 years, was picked as the venue of the meeting. Åbo Akademi is the university of the 6% Swedish-speaking minority in Finland, and it has its campus in the oldest city of Finland, whose Swedish name is Åbo and whose Finnish name is

Figure 5. Rector Stenlund opens the Convention by dedicating a Lecture Hall to Karl F. Lindman (photo by Anders Nordgren).

Turku. This Convention was largely in honor of Professor Karl F. Lindman. In a ceremonial Opening Session, a lecture hall was dedicated to Lindman by the Rector of Åbo Akademi, Professor Bengt Stenlund. The Conference Chairman and present occupant of Lindman's Chair, Professor Juhani Kurkijärvi, gave a review of the life and achievements of Karl F. Lindman.

A special session on chiral and bi-isotropic media was subsequently held in the Karl F. Lindman Auditorium, co-chaired by Professors Ismo Lindell, of the Helsinki University of Technology, and Gerhard Kristensson, of the Lund Institute of Technology, Sweden. Speakers and the audience, which included the present President of the international URSI organization, Professor Edward V. Jull, could feel the presence of professor Lindman in the auditorium. Actually, he was closely observing all the proceedings through his portrait on the wall, with a benevolent smile on his face: "I knew chirality would grow up to something big."

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Gravity Wave Update

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The article, "Will Gravity Wave Communication be Possible?" arrived at the tremendous loss factor of 680 dB for a hypothetical gravity-wave communication link [1]. The conversion of electrical or mechanical energy to a gravity wave at the transmitter, and the conversion of the gravity-wave energy back to an electrical or mechanical form at the receiver, is terribly inefficient.

The Laser Interferometer Gravitational-Wave Observatory (LIGO), for which Congress recently authorized $211 million, will be considered a success if it detects one feeble pulse from the explosion of a massive star or a collision between two black holes [2]. Such a pulse would provide the first direct evidence that gravity waves do exist.

To communicate with gravity waves is even tougher, making it clear that such communication is simply not feasible. In spite of this, studying the problem provides one with valuable insights into the similarities and differences of electromagnetic and gravity waves. How fortunate we are to have electromagnetic waves for communication!

I greatly appreciate the many stimulating discussions over the last two years with Professor Ulrich Gerlach and with Eric Braeden, both of the Ohio State University.

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