$$\rho = r \div 4\pi r^2 = \frac{1}{20\pi} = 0.016.$$

This is about 3×10^7 electrons per sq. cm. Now the number of atoms exposed in 1 sq. cm. of a copper surface is about 2×10^{15}. So, on a sphere of copper 5 cm. in radius, an excess of one electron for each 7×10^7 surface atoms will charge the sphere to a negative potential of about 300 volts.

Note: If the "ionization potential" is really considerably greater near the surface of a metal than at points deeper within, the degree of ionization,—that is, the number of free electrons and of positive ions per cu. cm.,—is probably less in the surface layer than in the interior. Accordingly, we should expect the specific conductivity of the surface layer to be smaller than that of interior layers, and the specific conductivity of thin films to be less than that of thicker pieces, which experiment shows to be the case. It seems doubtful, on the other hand, whether any practicable degree of surface charge would affect appreciably the conductivity of even a very thin piece of metal.

[1] *Physic. Rev.*, N. S., **14**, pp. 306–347, October, 1919.

[2] *The Emission of Electricity from Hot Bodies*, Longmans, Green & Co., 1916.

[3] *Physic. Rev.*, N. S., **7**, pp. 209–214, February, 1916.

[4] These PROCEEDINGS, **4**, January, 1918, and **5**, June, 1919.

[5] *Ibid.*, **7**, pp. 98–107, March 1921.

[6] *Proc. Amer. Acad. Arts Sci. Boston*, **53**, 269–386. March, 1918.

JOINING THE INFRA-RED AND ELECTRIC WAVE SPECTRA

By E. F. NICHOLS AND J. D. TEAR

NELA RESEARCH LABORATORIES, NATIONAL LAMP WORKS

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Historical.—In the first decade following Hertz's[1] discovery of electric waves in 1888 and his success in repeating a number of classical optical experiments with waves 60 cms. long, progress towards shorter and shorter electric waves went rapidly forward. Lebedew[2] obtained and experimented with waves which he estimated at 6 mms., and Lampa[3] worked with wave-lengths believed to be 4 mms. In 1918 Möbius[4] described some short wave experiments of his own and reviewed Lebedew's and Lampa's work, arriving at the conclusion that both had underestimated the wave-lengths with which they were dealing and gave 1 cm. as a more probable value for Lebedew's waves and 7 mms. for Lampa's. Möbius himself was unable to get waves shorter than 7 mms. He obtained evidence of ripples of shorter equivalent wave-lengths but no shorter regular waves. His paper gives a very fair idea of the difficulties he encountered.

Contemporaneous with this advance toward shorter electric waves, there was a corresponding progress in the infra-red spectrum toward longer waves. Following Langley's classical researches in the solar spectrum, Rubens[5] and Paschen[6] separately pushed the region of accurate wave-length determination to 9.4μ, sixteen times the wave-length of yellow light. In 1897 Rubens and Nichols[7] devised the method of multiple reflection or "reststrahlen" by which the known boundaries of the infra-red spectrum were extended tenfold. A further extension was obtained by Rubens' and Wood's[8] method of focal isolation. By the aid of this latest method and by using a quartz mercury arc as a source, Rubens and Von Baeyer[9] were able in 1911 to obtain and measure heat waves 0.320 mm. in length. Comparing the number of skilled experimenters, better instruments, and more rigorous methods of work in the infra-red spectrum with those previously employed in short electric wave experiments, it seemed that a systematic attack to bridge the gulf of missing wave-lengths between the two spectra had better chances of success if made from the less developed or electric wave side.

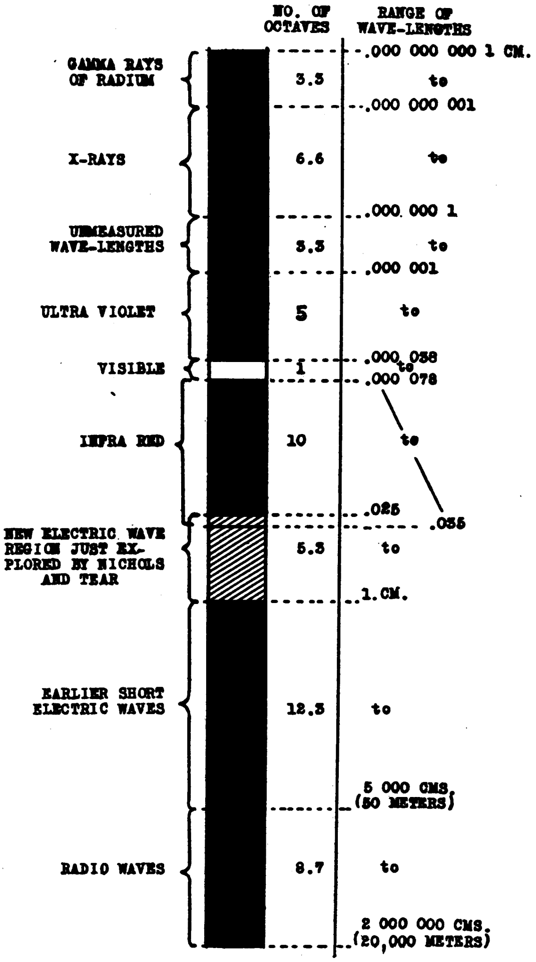

FIGURE 1
Chart of the complete electric wave spectrum

Instruments and Methods.—At the outset of our experiments it was plain that until instruments were devised of a different order of sensitiveness and efficiency from any heretofore used and until radical improvements in methods of experimentation were perfected, no certain advancement toward shorter electric waves could be hoped for. As the instruments and methods employed in the present experiments will be fully described in a series of two or more papers to appear later in the *Physical Review*, only the briefest reference is needed here.

(1) The electric wave receiver was a modified form of the Nichols radiometer.[10] When electric waves fall on a conductor they cause oscillating currents of the same frequency in its surface layers. Part of the energy of these oscillating currents is converted into heat by the electrical resistance of the conductor, and the conductor is in consequence very slightly warmed. To make use of this phenomenon in an electric wave receiver, the usual blackened vanes of the Nichols radiometer suspension were replaced by heater elements made of very thin deposits of bright metallic platinum on thin mica strips. These heater elements were shielded on one side and so disposed about the rotation axis of the suspension that when warmed by the action of electric waves the radiometric forces on the two vanes combined to produce rotation of the receiver system. This type of receiver proved to be a hundred or more times as sensitive as any quantitative receiver previously used for short electric waves.

(2) The oscillator was in principle the familiar Hertzian doublet with minute tungsten cylinders substituted for platinum. It also embodied a number of other improvements and accessories.

(3) In addition to a Boltzmann and a Fabry and Perot interferometer, a wholly new form of reflecting echelon analyzer was employed in wave-length measurements. The advantage of the new instrument was that in addition to accurate wave-length determinations, it gave the approximate wave form as well.

(4) One of the principal improvements in method was the use of a second identical receiver to which a fraction of the beam of radiation emitted by the oscillator was deflected. This second receiver served as a check on the performance of the oscillator, and errors due to irregularities of emission could thus be eliminated from the results.

Results.—By the patient development and use of the foregoing equipment and procedure, shorter and shorter electric waves were isolated and measured from Lampa's and Möbius' limit of 7 down to waves 0.220 mm. in length. We have thus found it possible to manufacture electric waves shorter than the longest known waves emitted by matter at high temperatures.

We further used our electric wave receiver in two different forms to remeasure Rubens' and Von Baeyer's 0.320 mm. heat waves obtaining results identical with those recorded by these earlier investigators.

The present methods and results throw open for intensive study practically the last unexplored region in the whole extent of the electric wave spectrum which spans the enormous interval from long radio waves to the shortest gamma rays of radium, a wave-length ratio of 20 million billion to one.

Discussion.—The more feasible method of charting the whole sweep of this comprehensive electric wave spectrum is by using geometric intervals such as the ascending powers of two used in laying off a piano keyboard on which the wave-lengths of two notes an octave apart are to each other as two to one. Such a spectral chart is shown in figure 1. On the left are the usual names given to the different main divisions of the spectrum. To these, braces are attached to show their extent on the black strip representing the spectrum. Beyond is shown the number of octaves embraced in each division and furthest to the right the actual wave-lengths roughly corresponding to these regional boundaries. Of the 55 octaves of the spectrum, shown in figure 1, only one octave contains wave-lengths visible to the eye, and there is but one remaining region of 3.3 octaves between the ultra violet and X-ray spectra in which wave-length measurements have not been made. Waves lying in this interval have been observed, and quantum relationships give a sound theoretical basis for calculating these wave-lengths, but no interference nor defraction measurements have thus far been carried out in this limited region.

Matter under the action of heat is capable of giving off radiations in the so-called infra-red, visible, and ultra violet spectra; gamma rays are the natural accompaniment of radioactive disintegration, and there are various static electric phenomena in the atmosphere giving rise to pulse-like disturbances resembling fragments of very long electric waves. But X-rays and the old and new short electric waves we may still regard as artificial or purely products of laboratory manufacture.

[1] Hertz, *Berline Berichte,* December 13, 1888.

[2] Lebedew, *Wied. Ann. Physik.,* **56,** 1895 (1).

[3] Lampa, *Wiener Ber.,* **105,** 1896 (587, 1049); 1895 (104, 1179).

[4] Möbius, *Ann. Physik.,* **62,** 1920 (293).

[5] Rubens, *Wied. Ann. Physik.,* **53,** 1894 (267).

[6] F. Paschen, *Ibid.,* **53,** 1894 (301).

[7] H. Rubens and E. F. Nichols, *Physic Rev., Ithaca,* **4,** (1897) (314); **5,** 1897 (98, 152); *Ann. Physik Chem.,* **60,** 1897 (418).

[8] H. Rubens and R. W. Wood, *London, Phil. Mag.,* **21,** 1911 (249).

[9] H. Rubens and O. Von Baeyer, *Ibid.,* **21,** 1911 (689).

[10] E. F. Nichols, *Physic Rev.,* **4,** 1896–7 (297).