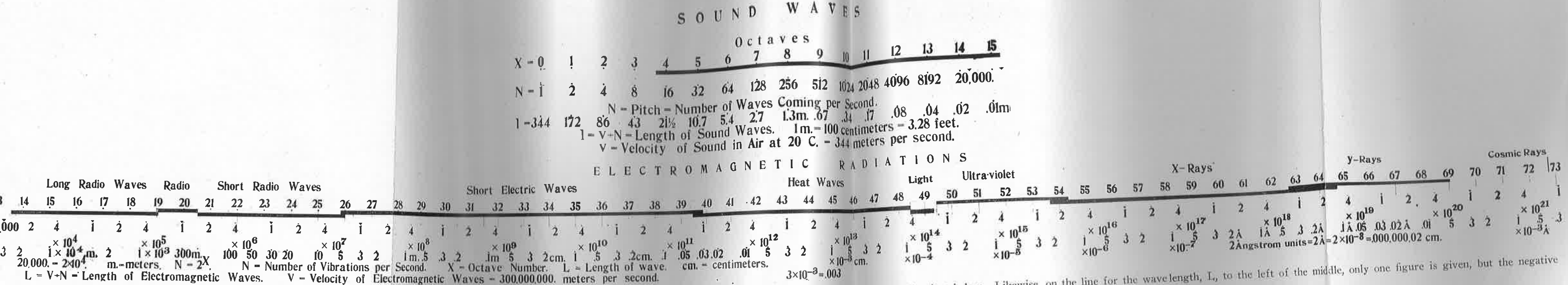

On the line for the frequencies, N, there was room for only one figure at each place, but the number of ciphers belonging to the right of each is shown by the powers of 10 on the line just below. Likewise, on the line for the wave length, L, to the left of the middle, only one figure is given, but the negative ponent on the 10 just below indicates the number of times that number is to be divided by 10.

SOUND WAVES AND ELECTROMAGNETIC RADIATIONS

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All waves are due to periodic or alternating stresses in some kind of medium. Since most people are more or less familiar with certain features of sound waves, the various characteristics of all waves will be illustrated first in connection with sound waves. These waves travel with an easily perceptible speed of about 1,129 feet per second at 20°C. That is, a flash of lightning one mile away is seen instantly, yet the clap of thunder sound wave leaving at the same time arrives nearly 5 seconds later. A body vibrating back and forth 100 times a second will send out 100 sound waves in one second, the first one being 1,129 feet away by the time the 100th one gets started. The 100 waves are thus stretched out a distance of 1,129 feet. Each wave crest is, therefore, 11.29 ft. ahead of the succeeding one. The wave-length, L, (from crest to crest) is thus equal to the velocity, v, divided by the frequency or number of vibrations per second, N. That is, for this case,

$$L = \frac{v}{N} = \frac{1129 \text{ ft. per sec.}}{100 \text{ vib. per sec.}} = 11.29 \text{ ft.}$$

The following forms of this equation are equally useful:

$$v = NL \text{ and } N = v \div L$$

The average human ear can detect, as sound waves, frequencies from about 12 per second to nearly 40,000 per second. Such a wide range in frequencies would be very difficult to plot on a direct linear scale. However, the most fundamental musical interval, the octave, supplies a very convenient means of showing graphically the whole range of sound frequencies. (In this article all frequencies or pitches mentioned will refer to the number of vibrations per second. That is, a pitch of 1000 means a frequency of 1000 complete oscillations per second. Expressed in kilocycles, N = 1000 = 1 kc.) An octave in music represents a range in frequencies of 2 to 1, that is, the frequency or pitch doubles for each octave. The plate accompanying this article shows the octave numbers, X, and the corresponding frequencies, N, for the entire range of 73 octaves. The corresponding frequencies extend from 1 to 9, 445, 765, 979, 014, 023, 380, 992. Mathematically this relationship is expressed as,

$$N = 2^X \text{ or } \operatorname{Log} N = X \operatorname{Log} 2$$

The pitches, N, are plotted, therefore, according to the logarithms of their distances from the first number, 1, and appear directly below the corresponding octave numbers, X, which are spaced equal distances apart. The heavy line on the sound chart shows the range of a good human ear. When less than 12 vibrations per second reach the ear, most people can distinguish the individual pulses and so do not recognize the effect as a musical tone. In fact, strong sound waves pitched below 16 or 20 are felt through the body nearly as much as through the ears. The telephone and cheap radio loud speakers are not designed to respond to frequencies above 10,000. On account of this, certain voices and certain words are very difficult to recognize over the telephone. We often realize that many phonographs and some radios fail to reproduce certain violin harmonics (frequencies above 10,000) when we are listening to some well-known artist playing a familiar selection containing such harmonics. The lowest note on the piano has a pitch of 27 while its highest note is 4138, four octaves above middle C (259). Very few soprano voices can produce clearly notes above 1035 ("High C"). There is a great deal of variation as to the highest notes various people can hear. Young people can usually hear higher notes than older ones. Most people can hear 30,000 vibrations per second, but many young people can hear frequencies as high as 40,000 (the highest point shown on the sound chart), while a few can hear notes as high as 45,000. There is at least one record of a woman being able to hear a pitch of 60,000.

Sound waves are longitudinal vibrations (compressions and rarefactions in the air. There is no special limit to the number of such vibrations per second, but we do not recognize, as sounds, frequencies beyond those here listed. However, vibrations of this same type have been produced with frequencies as high as 1,000,000. These are the so-called "supersonic waves," and they travel with the same speed as sound waves, but they have no more effect on the ear than on other parts of the body. Some of their effects are very interesting, but they will not be discussed here because the primary object of this paper is to show the relationships of the various electromagnetic waves.

The main part of the chart here shown deals with electromagnetic waves, which are very different from sound waves in many respects. Sound waves travel through the air with a speed of about 1/5 mile per second, while these waves go through space (or a medium called the ether) with the enormous speed of 186,500 miles per second (V = 300,000,000 meters per second = 30,000,000,000 centimeters per second = 3×10^{10} cms./sec.). These radiations are transverse waves, alternations in electric and magnetic stresses, which travel out into space with the so-called "velocity of light." The tremendous range in frequencies of these radiations makes it necessary to adopt the same method of representing them graphically as that used with sound waves. The range for sound waves is less than 12 octaves, while the electromagnetic frequencies cover a range of nearly 60 octaves, all of them greater than the highest frequency transmitted by the modern telephone. The smallest frequency used in commercial radio telegraphy is 12,000, which corresponds to a wave-length of 25,000 meters. There is no physical reason why still longer waves could not be used except that nearby telephones and radios would respond to any lower frequency. The standard lighting and power circuits are operated at a frequency of 60 and maintained so accurately at that value that electric clocks running in synchronism with these oscillations keep more accurate time than most of the expensive pendulum clocks. At this frequency, such power lines radiate very little energy into the regions beyond the wires designed to carry the currents.

The line on the chart extending from X = 13.5 to 19 (N = 12 kc. to 550 kc.) and labeled "Long Radio Waves" shows the range in frequencies used in commercial radio telegraphy. The longest of these (N = 12 kc. to 30 kc. or L = 25,000 m. to 10,000 meters) are used almost exclusively for transoceanic service, while frequencies from 30 kc. to 100 kc. (L = 10,000 m. to 3,000 m.) are used for point to point code work over distances up to 2,000 miles. Frequencies from 100 kc. to 550 kc. (L = 3,000 m. to 545 m.) are used for ship to shore and ship to ship communications. The bands near 150 kc. are better for the longer distances, so the bands from 400 kc. to 550 kc. are used by the smaller ships and for shorter distances. The frequency 500 kc. (L = 600 m.) is reserved for distress calls (S-O-S). Ships and coastal radio stations of all kinds are required to keep at all times a received tuned to this 500 kc. frequency, and all passenger ships must be able to transmit on this frequency.

The range from 550 kc. to 1500 kc. (L = 545 m. to 200 m.) is reserved for the broadcasting of speech and music. In this range of only about one and a half octaves, there are in the United States alone more than four times as many broadcasting stations as there are available frequencies (146), spaced 10 kc. apart. Several small powered stations, widely separated geographically, are made to use the same frequency. Some nearby stations share the time for using a certain frequency. It is not practical to have high-powered stations in the same region operating on frequencies closer than 10 kc. apart, without each of them interfering with the reception of the other's programs.

The "Short Radio Waves" (N = 1500 kc. to 60,000 kc., L = 200 m. to 5 m.) have been assigned for a great variety of purposes, as shown in table 1.

Much research work is being done in this field by amateurs, by radio engineers and by other scientists. A great many more uses will be found for these waves, especially as aids for airplanes in "blind flying" and for ships making ports through dense fogs. Some recent applications of this nature have been made using waves as short as 3 meters (100,000 kc.).

The range in frequencies from 100,000 kc. to 1,000,000,000 kc., more than thirteen octaves, has been explored by only a few research workers, but the whole field has been covered. No practical use has been found for any of the waves whose wave-lengths extend from 300 cms. to .03 cms. (1.64 feet to .0118 inch). As far as known today the human body has no organs that are particularly sensitive to any of these waves. However, there are various scientific instruments capable of detecting and measuring any of them. Such waves can be reflected very easily into parallel beams, by parabolic mirrors

TABLE 1

Assignment of short radio waves

Frequency band, kilocycles = kc.	Services, WashingtonGeneral Regulations, Art. 5	Frequency band, kilocycles = kc.	Services, WashingtonGeneral Regulations, Art. 5
550 to 1,300	Broadcasting	9,600 to 11,000	Fixed
1,300 to 1,500	a. Broadcasting	11,000 to 11,400	Mobile
	b. Maritime mobile,	11,400 to 11,700	Fixed
	1365 kc. exclus.	11,700 to 11,900	Broadcasting
1,500 to 1,715	Mobile	11,900 to 12,300	Fixed
1,715 to 2,000	Mobile, fixed and	12,300 to 12,825	Mobile
	amateurs	12,825 to 13,350	Mobile and fixed
2,000 to 2,250	Mobile and fixed	13,350 to 14,000	Fixed
2,250 to 2,750	Mobile	14,000 to 14,400	Amateur
2,750 to 2,850	Fixed	14,400 to 15,100	Fixed
2,850 to 3,500	Mobile and fixed	15,100 to 15,350	Broadcasting
3,500 to 4,000	Mobile, fixed, and	15,350 to 16,400	Fixed
	amateurs	16,400 to 17,100	Mobile
4,000 to 5,500	Mobile and fixed	17,100 to 17,750	Mobile and fixed
5,500 to 5,700	Mobile	17,750 to 17,800	Broadcasting
5,700 to 6,000	Fixed	17,800 to 21,450	Fixed
6,000 to 6,150	Broadcasting	21,450 to 21,550	Broadcasting
6,150 to 6,675	Mobile	21,550 to 22,300	Mobile
6,675 to 7,000	Fixed	22,300 to 23,000	Mobile and fixed
7,000 to 7,300	Amateurs	23,000 to 28,000	Not reserved
7,300 to 8,200	Fixed	28,000 to 30,000	Amateurs and ex-
8,200 to 8,550	Mobile		perimental
8,550 to 8,900	Mobile and fixed	30,000 to 56,000	Not reserved
8,900 to 9,500	Fixed	56,000 to 60,000	Amateurs and ex-
9,500 to 9,600	Broadcasting		perimental
		Above 60,000	Not reserved

or special types of reflectors, so they are sure to be very effective in the transmission of electric energy over short distances in a great variety of cases not yet discovered. At present the most promising field for them seems to be in air navigation and in communications between points without large opaque bodies between.

The range of frequencies labeled on the chart as "Heat Waves," extending from the shortest electric waves to the longest light waves, covers about nine octaves. (L = .04 cms. to .00008 cms.). The sun and all hot bodies radiate considerable energy throughout this range, the hotter the body the larger the percentage of short waves contained in its radiations. Glass is opaque to most of these radiations. Light waves from the sun go through the glass of a "hot house" and are absorbed by the plants and earth inside. Part of the energy absorbed there is reradiated as heat rays which cannot go back through the glass. The energy, and therefore the temperature, inside the hot house increases until the added losses of heat equal the energy absorbed as light. In cold weather heat radiations are very soothing to the human body and doubtless have other healthful effects, especially in local applications to certain parts of the body which are under abnormal conditions. When the human body becomes infected with certain disease germs, its temperature is increased automatically so as to destroy the germs more rapidly. Sometimes the temperature of the whole body is raised, sometimes only the infected part becomes hotter. The artificial application of heat, either as heat rays or hot pads, to the infected parts will usually hasten the control and elimination of the infection.

The human eye is sensitive to only one octave of these radiations, (X = 48.5 to 49.5), extending from a frequency of about 375 to 750 millions of millions of vibrations per second. This corresponds to the range from deep red (L = .00008 cms.) through all the colors of the rainbow, red, orange, yellow, green, blue and violet, to the shortest violet (L = .00004 cms.). Recently photoelectric cells and photographic plates have been developed so as to be more sensitive to the long red rays than is the human eye. Such instruments have been, for a long time, more sensitive than the eye to the violet and shorter waves. Both types of instruments are extremely sensitive to the waves still shorter than the shortest violet the eye can detect.

The ultraviolet rays just mentioned are sometimes called chemical rays because they can initiate chemical reactions more easily than the longer waves. These rays extend nearly five octaves above the extreme violet, to a frequency as high as 2,500 million millions of vibrations per second. This frequency corresponds to a wave-length only slightly greater than one millionth of a centimeter. Part of this ultraviolet radiation comes to us direct from the sun, but most of the shorter waves are absorbed by the air and never reach the surface of the earth. Investigation with the short ultraviolet rays must, therefore, be carried out with their production and handling all done within a vacuum. Iron and mercury arcs are particularly rich in ultraviolet rays and so are used very widely in making the so-called "health lamps," or "ultraviolet lamps." Since the rays from these lamps need not go through glass or enough air to absorb much of the shorter and more powerful rays before reaching the skin of a person near them, their effects may be much greater than the direct rays of the sun. The part of the ultraviolet rays from the sun that can penetrate our atmosphere, if allowed to fall upon the skin may kill disease germs, stimulate chemical changes in the blood, increase metabolism and growth and thus aid in the development of healthy bodies. However, very serious injuries to the human skin, such as the wholesale destruction of the surface body cells, causing high fevers and even death, may be produced by continuous exposures of the skin, unprotected by clothing or by previous tanning, to the direct rays of the sun or the more dangerous rays from "ultraviolet lamps." Since glass is opaque to most of the ultraviolet rays the iron arc and the mercury vapor arc must not be entirely enclosed in glass if these radiations are to get outside. Many people have received serious injuries to their eyes while watching workmen weld iron rails by means of the electric arc. The workmen wore eye glasses and were not injured by the ultraviolet rays emitted. So far only a small part of the ultraviolet radiations, those nearest the frequencies called light, are being used in any practical way. The others are absorbed very rapidly by the air, but doubtless they will be used sometime to do some important function for man's health or happiness.

The range of frequencies known as X-rays covers as many octaves (eleven) as are represented by the entire scale of sound pitches. Few people realize that there are as many kinds of X-rays as there are kinds of musical sounds. The name X-rays applies to all those radiations produced when high speed electrons are stopped by bumping into heavy molecules. The heavier the atoms they bump into the quicker they are stopped and the shorter the X-ray wave produced. The longest X-ray waves are scarcely 2 millionths of a centimeter in length, while the shortest ones are so tiny that a thousand million of them lined up end to end would reach less than one centimeter. The recent advances in very high electrical pressures and electron velocities will mean a considerable increase in the extent to which the X-rays overlap the γ-rays (to be described in the next section). The larger X-ray machines usually throw out some of nearly all the radiations represented on the chart as X-rays, especially while being operated with high voltages for great penetrations. The smaller type of machine, made for dentists, has been fairly well standardized as to the quantity and penetrating power of its rays. The large machines, for hospitals, have only two types of adjustment. Changing the current in the filament of the Coolidge X-ray tube changes only the quantity of the X-rays produced. Varying the electrical pressure (plate voltage) on the tube changes the quality of the rays emitted. If the plate voltage is low (10,000 volts) the rays are "soft," mostly of the longer wave lengths, and will not penetrate very far through flesh, bones, etc. When the plate voltage is high (100,000 volts) a much larger percentage of the "harder" rays are produced, but the "soft" rays are also present and in greater quantity than when the voltage was low. When high voltages are necessary, aluminum plates, or other absorbing materials are used to filter out the softer rays which would cause serious X-ray burns if applied very often or for an extended time.

Since it is very difficult to separate out the various types of X-rays into a spectrum, as we do with light, very little research work has been done to learn the specific reactions of the different wave-lengths of X-rays on various germs, plant and animal cells, etc. Many important developments for man's health and comfort may be expected from researches in this field.

The electromagnetic radiations of higher frequencies than most of the X-rays have all been developed in connection with atomic nuclei. The most familiar are known as γ-rays and are sent out when B particles (electrons) are fired out of the nuclei of certain radioactive elements. The greater the speed of the expelled B particle the higher the frequency of the waves and therefore the greater the quantum of energy in the γ radiation. The range in frequencies of this type of rays is from about eight million millions of millions of vibrations per second, to about seventy-five times that many. Since the radiant energy per wave is directly proportional to the frequency of the waves emitted (Quantum of energy, = hμ where h = Planck's constant and μ = frequency) the γ-rays contain more concentrated energy and are more penetrating than the X-rays. Of course, in the region where the frequencies of the two types overlap they are identical in energy and all other respects except their origin. These very penetrating radiations may be used for producing ionization, especially where it is necessary for the rays to penetrate great thicknesses of matter before reaching the substance to be ionized. Like the X-rays these radiations may produce serious burns if allowed to act too long on the body cells. Such burns are not just on the surface, but cells are destroyed all the way through the body. The sources of these rays may be enclosed in very small metal tubes and inserted in various internal cavities of the body where the rays may act more directly upon diseased tissues and thus destroy the cause of the trouble without injuring too many of the normal body cells. The technique in administering these rays has only just begun to develop. Some remarkable cures have already been recorded in cases of internal cancer, but wonderful developments in the use of these rays in fields not now anticipated are sure to follow.

The very small conductivity of ordinary dry air, formerly attributed to "natural ionization" or to traces of radioactive elements in the vicinity, seems now to be caused in most cases by "Cosmic rays" or by secondary radiations produced by cosmic rays. These rays, the last type shown on the chart, are the subject of a great deal of discussion at the present time. The chief point in the argument is as to whether the cosmic rays are electromagnetic waves or high speed particles (electrons, protons, neutrons or positrons). The chief proponent for the wave theory is Dr. R. A. Millikan, while the corpuscular point of view is most strongly advocated by Dr. A. H. Compton. It is quite certain now that these rays have their origin beyond the highest limits of the earth's atmosphere, and that these rays produce secondary rays as they plunge into the upper air. Since some of these rays are able to penetrate, not only all of the earth's atmosphere, but also hundreds of feet of water at the bottom of this blanket of air, they must have a quantum of energy far greater than that of the most penetrating γ-rays. Some of the cosmic rays arriving at the upper limits of our atmosphere may be less penetrating (lower frequency) than the shortest γ-rays, but if so, they would be completely absorbed in the upper realms of the atmosphere. Dr. Millikan estimates the smallest cosmic ray frequency found so far as nearly three octaves above the highest frequency of the γ-rays. The highest frequencies of the cosmic rays must be greater than 2×10^{23} (L = .000015 A. = .000,000,000,000,15 cms.) since they can penetrate more than 800 feet of water. The line on the chart at the end of the words, cosmic rays, represents the position first established as the most probable frequency of the cosmic rays.

A large share, if not all, of the ionization produced by the primary cosmic rays is due to reactions within the nuclei of the atoms encountered. These reactions cause the expulsion of a proton, an electron or both (possibly a neutron) from the nucleus of an atom. These charged particles or secondary rays are expelled with enormous velocities and thus produce considerable ionization among the molecules through which they pass. Practically all of the observed ionization is due to these secondary radiations.

The main body of the cosmic ray energy (over 90% according to Millikan) seems to be due to waves whose wave lengths are approximately .001 Angstrom units, ($N = 3 \times 10^{21}$), yet very little of this energy reaches the surface of the earth at sea level. Not more than 20% of the total ionization at sea level is due to this kind of soft cosmic rays. Millikan suggests that this band of rays may be due to the wave energy released when helium or oxygen atoms are built up by hydrogen atoms bumping into each other or into other light atoms traveling toward them at high speeds.

Equal energy seems to be coming to the earth from all directions, so these cosmic rays must be produced in all parts of the universe. Since there is no appreciable increase in these rays from the "Milky Way," they must be formed in the nebulae or in the spaces between the stars rather than in the stars themselves. They do not seem to come from our sun. There are at least three other bands of cosmic rays, all much more penetrating than the main band already mentioned. Their wave-lengths are roughly .0002 A., .00006 A. and .000015 A. Each of these may signal the birth of some one of the heavier atoms.

Evidently all of these very penetrating rays must produce ionizations in the various plant and animal cells through which they pass. Their actions in the reproductive cells of both plants and animals, it seems, must cause variations from the normal growth of the body cells and they must cause occasionally variations in the type of development the reproductive cells will take. However, the number of these rays that pass through any one cubic centimeter of the human body is very few and the probability of any one reproductive cell being ionized at the critical time in its life cycle is extremely small. Yet it appears possible that such happenings may be the cause of certain biological variations in species.

After considering individually the various types of electromagnetic radiations, a survey of the chart should give one a better understanding of the enormous range in their frequencies and the great variety of uses to which these waves have been put in the short time most of them have been known. Of the sixty octaves of electromagnetic waves shown on this chart, less than two had been definitely measured fifty years ago, and even twenty-five years later few practical applications had been found for any of the other waves. Of course radiant heat had been known for centuries, but it was not known definitely forty-five years ago that this kind of heat was a form of electromagnetic wave. The bridge connecting the knowledge of the very short electric waves with the long heat waves was not completed until 1923.