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# UNITS USED TO EXPRESS THE WAVE LENGTHS OF ELECTROMAGNETIC WAVES

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# UNITS USED TO EXPRESS THE WAVE LENGTHS OF ELECTROMAGNETIC WAVES

By Henry D. Hubbard

ABSTRACT

The closing up of the gaps in the wave gamut of electromagnetic radiations makes it opportune to systematize the units and unit usages to cover the entire range. A well-selected series of units connected with the c. g. s. unit by the "powers-of-10 notation" will facilitate computation and conversion, and aid in visualizing, comparing, and correlating widely differing wave magnitudes. This paper aims to give the best existing usages including the trend toward the units which have a multiple or submultiple relation of 1,000 connected by the powers of 10 equivalents.

CONTENTS



## I. NEED FOR STANDARD USAGES

The established continuity [1] of the spectrum of electromagnetic radiation from the shortest experimentally measured wave lengths to beyond the 25-cycle, alternating-current waves (12,000 kilometers) brings the need for a unified system of units for measuring and expressing the wave lengths throughout a suggested gamut of more than 60 octaves. A well-chosen set of units will facilitate computation and conversion, and will aid in visualizing, comparing, and correlating widely differing wave magnitudes. The closing up of the gaps in the wave gamut makes it opportune to set forth a systematic series of units and usages to cover all ranges.

[1] Nichols and Tear, Astrophys. J., **61**, p. 17; 1925.

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## II. USE OF WAVE-LENGTH RECIPROCAL—FREQUENCY

### 1. RADIO

In radio communication the use of wave frequency (number of waves per second) is growing on account of distinct advantages in measurement and computation. As frequency is the reciprocal of a time period it is directly calculated if the oscillation period alone is known. The oscillation period is usually known for the standard circuit or may be computed approximately from the constants of the radio circuit. Bureau of Standards Miscellaneous Publication No. 67, Kilocycle-Meter Conversion Table,[2] gives a list of radio-frequencies from 10 to 10,000 kilocycles, with equivalents for interconverting frequencies (per second) and wave lengths (meters).

### 2. SPECTROSCOPY

In spectroscopy the frequency is usually computed from the wave length (in vacuum). Atomic physics, however, in some cases permits computing the true frequency by the formula $E=h\nu$, where $E$ = energy (in ergs), $h$ = Planck's unit quantum[3] of action ($6.554 \times 10^{-27}$ erg second), and $\nu$ is the number of waves per second. However, the "wave number"[4] (waves per centimeter, $1/\lambda_{cm}$) is much used in spectroscopy and atomic physics.

## III. USE OF WAVE LENGTHS

The use of wave lengths is essential, especially in using light waves as standards of length, in measuring the radial velocity of stars and other celestial objects, in measuring space lattices by the use of known Röntgen (or X-ray) waves, and elsewhere. For converting wave lengths in air from 2,000 to 10,000 angstroms into "wave numbers" in vacuum the best tables are those of H. Kayser, Tabelle der Schwingungszahlen." [5]

Since the wave lengths of the gamut involve in all some 24 significant figures (from $10^{-14}$ to $10^{+10}$ centimeters) the "powers-of-10 notation" is advocated for use wherever facile comparison or translation is desirable. Equivalents in this notation are given in this paper for the various units cited. The c. g. s. units are fundamental, and the specialized usages adopted for convenience are directly correlated to the c. g. s. units through the "powers-of-10 notation" which permits simple expression of all orders of wave magnitudes in terms of the basic c. g. s. units, the centimeter and the second.

## IV. USAGES FOR EXPRESSING WAVE LENGTHS

The formulation of practice herein presented is approved standard usage for the Bureau of Standards with respect to units, subdivisions, abbreviations, and equivalents for all ranges of wave lengths within the entire electromagnetic wave gamut.

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[2] This publication may be purchased for 5 cents by addressing the Superintendent of Documents, Washington, D. C.
[3] International Critical Tables, **1**, p. 17; 1926.
[4] Sometimes incorrectly designated "frequency." The true or absolute frequency $\nu$ is the ratio of the velocity of light $c$ to the wave length in vacuum. The wave number is therefore equal to the ratio $\nu/c$.
[5] Printed by S. Hirzel, Leipzig; 1925.

The "angstrom" is defined in terms of cadmium red wave length measurements by Benoit, Fabry, and Perot, the relation being that this wave length equals 6438.4696 angstroms (0.00064384696 millimeter) in dry air, at 15° C. on the international hydrogen scale of temperature, at a pressure of 760 millimeters of mercury at the value of gravity equal to 980.67 cm/sec $^2$ (45° north latitude).

This value is in essential agreement with the previous determination made (1892) by Michelson, when reduced to the same basis. It is the value adopted (1907) and thereafter used by the International Union for Cooperation in Solar Research (now the International Astronomical Union), and it is in world-wide use in spectroscopy and astrophysics.

The meter might thus be defined as equal to 1,553,164.13 wave lengths of the red radiation of cadmium under the above standard conditions.

### 1. SPECTROSCOPY

"Angstrom" (abbreviate A)
1 angstrom = 0.0000001 millimeter, or
= 1,000 milliangstroms.

### 2. RÖNTGEN OR X RAYS, AND GAMMA RAYS [6]

"Milliangstrom" (abbreviate mA)
1 milliangstrom = 0.0000000001 millimeter.[7]
= 0.001 angstrom.
"Microangstrom" (abbreviate $\mu$A)
1 microangstrom = 0.000001 angstrom.
= 0.0000000000001 millimeter.

### 3. RADIOMETRY

"Micron" (symbol $\mu$); or any of above-named units.
1 micron = 0.000001 meter.
= 0.001 millimeter.
= 1,000 millimicrons.
= 10,000 angstroms.

### 4. COLORIMETRY

"Millimicron" (symbol m$\mu$)
1 millimicron = 0.000000001 meter.
= 0.000001 millimeter
= 10 angstroms.

### 5. RADIOCOMMUNICATION

"Meter" (abbreviate m)
1 meter = fundamental unit of length
= 1,000 millimeters.
= 10,000,000,000 angstroms.
"Millimeter" (abbreviate mm) for waves under 1 meter
1 millimeter = 0.001 meter.
= 10,000,000 angstroms.

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[6] Wave lengths of ultra-penetrating rays notably shorter than gamma ray waves may be expressed in terms of the "microangstrom" (symbol $\mu$A).
[7] One X-unit = 1 milliangstrom.

### 6. MULTIPLES OF 1,000 AS RATIO OF UNITS

The units above defined conform to the growing practice of using units having multiple interrelations of 1,000 or 0.001; for example, $\mu$, mm, m, km; or mg, g, kg, metric ton. The entire range of electromagnetic waves may conveniently be expressed in the following units: Meter, millimeter; micron, millimicron; angstrom, milliangstrom, microangstrom.

### 7. POWERS-OF-10 NOTATION

In general, to facilitate the intercomparison of wide ranges of electromagnetic wave lengths and to simplify computation, the "powers-of-10 notation" may be used to great advantage. The numerical interrelation in this notation for the above-defined units are given in the following table:

| Units | | Powers-of-10 equivalent of units listed in column 1 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Name | Symbol | $\mu$ | m$\mu$ | A | mA | $\mu$A | c. g. s. unit cm | mm | m |
| Micron | $\mu$ | 1 | $10^{3}$ | $10^{4}$ | $10^{7}$ | $10^{10}$ | $10^{-4}$ | $10^{-3}$ | $10^{-6}$ |
| Millimicron | m$\mu$ | $10^{-3}$ | 1 | 10 | $10^{4}$ | $10^{7}$ | $10^{-7}$ | $10^{-6}$ | $10^{-9}$ |
| Angstrom | A | $10^{-4}$ | $10^{-1}$ | 1 | $10^{3}$ | $10^{6}$ | $10^{-8}$ | $10^{-7}$ | $10^{-10}$ |
| Milliangstrom | mA | $10^{-7}$ | $10^{-4}$ | $10^{-3}$ | 1 | $10^{3}$ | $10^{-11}$ | $10^{-10}$ | $10^{-13}$ |
| Microangstrom | $\mu$A | $10^{-10}$ | $10^{-7}$ | $10^{-6}$ | $10^{-3}$ | 1 | $10^{-14}$ | $10^{-13}$ | $10^{-16}$ |

WASHINGTON, October 7, 1930.

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