**Microwave**

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*This article is about the electromagnetic waves. For the kitchen appliance, see* [*microwave oven*](http://en.wikipedia.org/wiki/Microwave_oven)*. For the heating process used in microwave ovens, see* [*dielectric heating*](http://en.wikipedia.org/wiki/Dielectric_heating)*.*

A microwave telecommunications tower on Wrights Hill in [Wellington](http://en.wikipedia.org/wiki/Wellington), [New Zealand](http://en.wikipedia.org/wiki/New_Zealand)

**Microwaves** are [electromagnetic waves](http://en.wikipedia.org/wiki/Electromagnetic_radiation) with [wavelengths](http://en.wikipedia.org/wiki/Wavelength) ranging from as long as one meter to as short as one millimeter, or equivalently, with [frequencies](http://en.wikipedia.org/wiki/Frequency) between 300 MHz (0.3 [GHz](http://en.wikipedia.org/wiki/Hertz)) and 300 GHz. This broad definition includes both [UHF](http://en.wikipedia.org/wiki/UHF) and [EHF](http://en.wikipedia.org/wiki/EHF) ([millimeter waves](http://en.wikipedia.org/wiki/Millimeter_wave)), and various sources use different boundaries. In all cases, microwave includes the entire [SHF](http://en.wikipedia.org/wiki/SHF) band (3 to 30 GHz, or 10 to 1 cm) at minimum, with [RF engineering](http://en.wikipedia.org/wiki/RF_engineering) often putting the lower boundary at 1 GHz (30 cm), and the upper around 100 GHz (3mm).

Apparatus and techniques may be described qualitatively as "microwave" when the wavelengths of signals are roughly the same as the dimensions of the equipment, so that [lumped-element circuit theory](http://en.wikipedia.org/wiki/Lumped_element_model) is inaccurate. As a consequence, practical microwave technique tends to move away from the discrete [resistors](http://en.wikipedia.org/wiki/Resistor), [capacitors](http://en.wikipedia.org/wiki/Capacitor), and [inductors](http://en.wikipedia.org/wiki/Inductor) used with lower frequency [radio waves](http://en.wikipedia.org/wiki/Radio_waves). Instead, distributed circuit elements and transmission-line theory are more useful methods for design and analysis. Open-wire and coaxial [transmission lines](http://en.wikipedia.org/wiki/Transmission_line) give way to [waveguides](http://en.wikipedia.org/wiki/Waveguide) and [stripline](http://en.wikipedia.org/wiki/Stripline), and lumped-element tuned circuits are replaced by cavity [resonators](http://en.wikipedia.org/wiki/Resonator) or resonant lines. Effects of [reflection](http://en.wikipedia.org/wiki/Reflection_%28physics%29), [polarization](http://en.wikipedia.org/wiki/Polarization_%28waves%29), [scattering](http://en.wikipedia.org/wiki/Scattering), [diffraction](http://en.wikipedia.org/wiki/Diffraction) and atmospheric [absorption](http://en.wikipedia.org/wiki/Absorption_%28electromagnetic_radiation%29) usually associated with visible light are of practical significance in the study of microwave [propagation](http://en.wikipedia.org/wiki/Radio_propagation). The same [equations](http://en.wikipedia.org/wiki/Maxwell%27s_equations) of electromagnetic theory apply at all frequencies.

While the name may suggest a micrometer wavelength, it is better understood as indicating wavelengths very much smaller than those used in radio broadcasting. The boundaries between far [infrared](http://en.wikipedia.org/wiki/Infrared) light, [terahertz radiation](http://en.wikipedia.org/wiki/Terahertz_radiation), microwaves, and [ultra-high-frequency](http://en.wikipedia.org/wiki/Ultra-high-frequency) [radio](http://en.wikipedia.org/wiki/Radio) [waves](http://en.wikipedia.org/wiki/Wave) are fairly arbitrary and are used variously between different fields of study.

[Stripline](http://en.wikipedia.org/wiki/Stripline) techniques become increasingly necessary at higher frequencies

Electromagnetic waves longer (lower frequency) than microwaves are called "radio waves". Electromagnetic radiation with shorter wavelengths may be called "millimeter waves", [terahertz radiation](http://en.wikipedia.org/wiki/Terahertz_radiation) or even *T-rays*. Definitions differ for millimeter wave band, which the IEEE defines as 110 GHz to 300 GHz.

Above 300 GHz, the absorption of electromagnetic radiation by Earth's atmosphere is so great that it is effectively opaque, until the atmosphere becomes transparent again in the so-called infrared and [optical window](http://en.wikipedia.org/wiki/Optical_window) frequency ranges.

**Microwave sources**

[Vacuum tube](http://en.wikipedia.org/wiki/Vacuum_tube) devices operate on the ballistic motion of electrons in a vacuum under the influence of controlling electric or magnetic fields, and include the [magnetron](http://en.wikipedia.org/wiki/Magnetron), [klystron](http://en.wikipedia.org/wiki/Klystron), [traveling-wave tube](http://en.wikipedia.org/wiki/Traveling-wave_tube) (TWT), and [gyrotron](http://en.wikipedia.org/wiki/Gyrotron). These devices work in the [density](http://en.wikipedia.org/wiki/Density) modulated mode, rather than the current modulated mode. This means that they work on the basis of clumps of electrons flying ballistically through them, rather than using a continuous stream.

Cutaway view inside a [cavity magnetron](http://en.wikipedia.org/wiki/Cavity_magnetron) as used in a [microwave oven](http://en.wikipedia.org/wiki/Microwave_oven)

A [maser](http://en.wikipedia.org/wiki/Maser) is a device similar to a [laser](http://en.wikipedia.org/wiki/Laser), except that it works at microwave frequencies.

Solid-state sources include the [field-effect transistor](http://en.wikipedia.org/wiki/Field-effect_transistor) (at least at lower frequencies), [tunnel diodes](http://en.wikipedia.org/wiki/Tunnel_diode), [Gunn diodes](http://en.wikipedia.org/wiki/Gunn_diode), and [IMPATT diodes](http://en.wikipedia.org/wiki/IMPATT_diode).

**Uses**

**Communication**

Before the advent of [fiber-optic](http://en.wikipedia.org/wiki/Fiber-optic) transmission, most [long distance](http://en.wikipedia.org/wiki/Long_distance) [telephone calls](http://en.wikipedia.org/wiki/Telephone_call) were carried via microwave point-to-point links through sites like the [AT&T Long Lines](http://en.wikipedia.org/wiki/AT%26T_Long_Lines). Starting in the early 1950s, [frequency division multiplex](http://en.wikipedia.org/wiki/Frequency_division_multiplex) was used to send up to 5,400 telephone channels on each microwave radio channel, with as many as ten radio channels combined into one antenna for the *hop* to the next site, up to 70 km away.

[Wireless LAN](http://en.wikipedia.org/wiki/Wireless_LAN) [protocols](http://en.wikipedia.org/wiki/Protocol_%28computing%29), such as [Bluetooth](http://en.wikipedia.org/wiki/Bluetooth) and the [IEEE](http://en.wikipedia.org/wiki/IEEE) [802.11](http://en.wikipedia.org/wiki/802.11) specifications, also use microwaves in the 2.4 GHz [ISM band](http://en.wikipedia.org/wiki/ISM_band), although [802.11a](http://en.wikipedia.org/wiki/802.11a) uses [ISM band](http://en.wikipedia.org/wiki/ISM_band) and [U-NII](http://en.wikipedia.org/wiki/U-NII) frequencies in the 5 GHz range. Licensed long-range (up to about 25 km) Wireless Internet Access services have been used for almost a decade in many countries in the 3.5–4.0 GHz range. The FCC recently carved out spectrum for carriers that wish to offer services in this range in the U.S. — with emphasis on 3.65 GHz. Dozens of service providers across the country are securing or have already received licenses from the FCC to operate in this band. The WIMAX service offerings that can be carried on the 3.65 GHz band will give business customers another option for connectivity.

[Metropolitan-area networks](http://en.wikipedia.org/w/index.php?title=Metropolitan-area_network&action=edit&redlink=1): MAN protocols, such as [WiMAX](http://en.wikipedia.org/wiki/WiMAX) (Worldwide Interoperability for Microwave Access) based in the [IEEE](http://en.wikipedia.org/wiki/IEEE) [802.16](http://en.wikipedia.org/wiki/802.16) specification. The IEEE 802.16 specification was designed to operate between 2 to 11 GHz. The commercial implementations are in the 2.3 GHz, 2.5 GHz, 3.5 GHz and 5.8 GHz ranges.

Wide Area [Mobile Broadband](http://en.wikipedia.org/wiki/Mobile_Broadband) Wireless Access: MBWA protocols based on standards specifications such as [IEEE 802.20](http://en.wikipedia.org/wiki/IEEE_802.20) or ATIS/ANSI [HC-SDMA](http://en.wikipedia.org/wiki/HC-SDMA) (e.g. iBurst) are designed to operate between 1.6 and 2.3 GHz to give mobility and in-building penetration characteristics similar to mobile phones but with vastly greater spectral efficiency.

Some [mobile phone](http://en.wikipedia.org/wiki/Mobile_phone) networks, like [GSM](http://en.wikipedia.org/wiki/Global_System_for_Mobile_Communications#Radio_interface), use the low-microwave/high-UHF frequencies around 1.8 and 1.9 GHz in [the Americas](http://en.wikipedia.org/wiki/The_Americas) and elsewhere, respectively. [DVB-SH](http://en.wikipedia.org/wiki/DVB-SH) and [S-DMB](http://en.wikipedia.org/wiki/S-DMB) use 1.452 to 1.492 GHz, while proprietary/incompatible [satellite radio](http://en.wikipedia.org/wiki/Satellite_radio) in the [U.S.](http://en.wikipedia.org/wiki/U.S.) uses around 2.3 GHz for [DARS](http://en.wikipedia.org/wiki/DARS).

Microwave radio is used in [broadcasting](http://en.wikipedia.org/wiki/Broadcasting) and [telecommunication](http://en.wikipedia.org/wiki/Telecommunication) transmissions because, due to their short wavelength, highly [directional antennas](http://en.wikipedia.org/wiki/Directional_antenna) are smaller and therefore more practical than they would be at longer wavelengths (lower frequencies). There is also more [bandwidth](http://en.wikipedia.org/wiki/Bandwidth_%28signal_processing%29) in the microwave spectrum than in the rest of the radio spectrum; the usable bandwidth below 300 MHz is less than 300 MHz while many GHz can be used above 300 MHz. Typically, microwaves are used in [television news](http://en.wikipedia.org/wiki/Television_news) to transmit a signal from a remote location to a television station from a specially equipped van. See [broadcast auxiliary service](http://en.wikipedia.org/wiki/Broadcast_auxiliary_service) (BAS), [remote pickup unit](http://en.wikipedia.org/wiki/Remote_pickup_unit) (RPU), and [studio/transmitter link](http://en.wikipedia.org/wiki/Studio/transmitter_link) (STL).

Most [satellite communications](http://en.wikipedia.org/wiki/Satellite_communications) systems operate in the C, X, Ka, or Ku bands of the microwave spectrum. These frequencies allow large bandwidth while avoiding the crowded UHF frequencies and staying below the atmospheric absorption of EHF frequencies. [Satellite TV](http://en.wikipedia.org/wiki/Satellite_TV) either operates in the C band for the traditional [large dish](http://en.wikipedia.org/wiki/TVRO) [fixed satellite service](http://en.wikipedia.org/wiki/Fixed_satellite_service) or Ku band for [direct-broadcast satellite](http://en.wikipedia.org/wiki/Direct-broadcast_satellite). Military communications run primarily over X or Ku-band links, with Ka band being used for [Milstar](http://en.wikipedia.org/wiki/Milstar).

**Remote sensing**

[Radar](http://en.wikipedia.org/wiki/Radar) uses microwave radiation to detect the range, speed, and other characteristics of remote objects. Development of radar was accelerated during World War II due to its great military utility. Now radar is widely used for applications such as [air traffic control](http://en.wikipedia.org/wiki/Air_traffic_control), weather forecasting, navigation of ships, and [speed limit](http://en.wikipedia.org/wiki/Speed_limit) enforcement.

A [Gunn diode](http://en.wikipedia.org/wiki/Gunn_diode) oscillator and waveguide are used as a motion detector for [automatic door openers](http://en.wikipedia.org/wiki/Swing_door_operator) (although these are being replaced by ultrasonic devices).

Most [radio astronomy](http://en.wikipedia.org/wiki/Radio_astronomy) uses microwaves.

Galactic background radiation of the [Big Bang](http://en.wikipedia.org/wiki/Big_Bang) mapped with increasing resolution

**Navigation**

[Global Navigation Satellite Systems](http://en.wikipedia.org/wiki/Global_Navigation_Satellite_System) (GNSS) including the Chinese [Beidou](http://en.wikipedia.org/wiki/Beidou_navigation_system), the American [Global Positioning System](http://en.wikipedia.org/wiki/Global_Positioning_System) (GPS) and the Russian [GLONASS](http://en.wikipedia.org/wiki/GLONASS) broadcast navigational signals in various bands between about 1.2 GHz and 1.6 GHz.

**Power**

A [microwave oven](http://en.wikipedia.org/wiki/Microwave_oven) passes (non-ionizing) microwave radiation (at a frequency near 2.45 GHz) through food, causing [dielectric heating](http://en.wikipedia.org/wiki/Dielectric_heating) by absorption of energy in the water, fats and sugar contained in the food. Microwave ovens became common kitchen appliances in Western countries in the late 1970s, following development of inexpensive [cavity magnetrons](http://en.wikipedia.org/wiki/Cavity_magnetron). Water in the liquid state possesses many molecular interactions which broaden the absorption peak. In the vapor phase, isolated water molecules absorb at around 22 GHz, almost ten times the frequency of the microwave oven.

Microwave heating is used in industrial processes for drying and curing products.

Many [semiconductor processing](http://en.wikipedia.org/wiki/Fabrication_%28semiconductor%29) techniques use microwaves to generate [plasma](http://en.wikipedia.org/wiki/Plasma_physics) for such purposes as [reactive ion etching](http://en.wikipedia.org/wiki/Reactive_ion_etching) and plasma-enhanced [chemical vapor deposition](http://en.wikipedia.org/wiki/Chemical_vapor_deposition) (PECVD).

Microwaves can be used to [transmit power](http://en.wikipedia.org/wiki/Microwave_power_transmission) over long distances, and post-[World War II](http://en.wikipedia.org/wiki/World_War_II) research was done to examine possibilities. [NASA](http://en.wikipedia.org/wiki/NASA) worked in the 1970s and early 1980s to research the possibilities of using [Solar power satellite](http://en.wikipedia.org/wiki/Solar_power_satellite) (SPS) systems with large [solar arrays](http://en.wikipedia.org/wiki/Photovoltaic_module) that would beam power down to the Earth's surface via microwaves.

[Less-than-lethal](http://en.wikipedia.org/wiki/Less-than-lethal) weaponry exists that uses millimeter waves to heat a thin layer of human skin to an intolerable temperature so as to make the targeted person move away. A two-second burst of the 95 GHz focused beam heats the skin to a temperature of 130 °F (54 °C) at a depth of 1/64th of an inch (0.4 mm). The [United States Air Force](http://en.wikipedia.org/wiki/United_States_Air_Force) and [Marines](http://en.wikipedia.org/wiki/United_States_Marine_Corps) are currently using this type of [Active Denial System](http://en.wikipedia.org/wiki/Active_Denial_System).

**Spectroscopy**

Microwave radiation is used in [electron paramagnetic resonance](http://en.wikipedia.org/wiki/Electron_paramagnetic_resonance) ([EPR](http://en.wikipedia.org/wiki/EPR) or [ESR](http://en.wikipedia.org/wiki/ESR)) spectroscopy, typically in the X-band region (~9 GHz) in conjunction typically with [magnetic fields](http://en.wikipedia.org/wiki/Magnetic_field) of 0.3 T. This technique provides information on unpaired [electrons](http://en.wikipedia.org/wiki/Electron) in chemical systems, such as [free radicals](http://en.wikipedia.org/wiki/Free_radical) or [transition metal](http://en.wikipedia.org/wiki/Transition_metal) ions such as Cu(II).

**Microwave frequency bands**

The microwave spectrum is usually defined as electromagnetic energy ranging from approximately 1 GHz to 100 GHz in frequency, but older usage includes lower frequencies. Most common applications are within the 1 to 40 GHz range. Microwave frequency bands, as defined by the [Radio Society of Great Britain](http://en.wikipedia.org/wiki/Radio_Society_of_Great_Britain) (RSGB), are shown in the table below:

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| [**ITU Radio Band Numbers**](http://en.wikipedia.org/wiki/ITU_Radio_Bands) [4](http://en.wikipedia.org/wiki/Very_low_frequency) [5](http://en.wikipedia.org/wiki/Low_frequency) [6](http://en.wikipedia.org/wiki/Medium_frequency) [7](http://en.wikipedia.org/wiki/High_frequency) [8](http://en.wikipedia.org/wiki/Very_high_frequency) [9](http://en.wikipedia.org/wiki/Ultra_high_frequency) [10](http://en.wikipedia.org/wiki/Super_high_frequency) [11](http://en.wikipedia.org/wiki/Extremely_high_frequency)[**ITU Radio Band Symbols**](http://en.wikipedia.org/wiki/ITU_Radio_Bands)[ELF](http://en.wikipedia.org/wiki/Extremely_low_frequency) [SLF](http://en.wikipedia.org/wiki/Super_low_frequency) [ULF](http://en.wikipedia.org/wiki/Ultra_low_frequency) [VLF](http://en.wikipedia.org/wiki/Very_low_frequency) [LF](http://en.wikipedia.org/wiki/Low_frequency) [MF](http://en.wikipedia.org/wiki/Medium_frequency) [HF](http://en.wikipedia.org/wiki/High_frequency) [VHF](http://en.wikipedia.org/wiki/Very_high_frequency) [UHF](http://en.wikipedia.org/wiki/Ultra_high_frequency) [SHF](http://en.wikipedia.org/wiki/Super_high_frequency) [EHF](http://en.wikipedia.org/wiki/Extremely_high_frequency)[**NATO Radio bands**](http://en.wikipedia.org/wiki/Radio_waves#EU.2C_NATO.2C_US_ECM_frequency_designations)[A](http://en.wikipedia.org/wiki/A_band_%28radio%29) [B](http://en.wikipedia.org/wiki/B_band) [C](http://en.wikipedia.org/wiki/C_band) [D](http://en.wikipedia.org/wiki/D_band) [E](http://en.wikipedia.org/wiki/E_band) [F](http://en.wikipedia.org/wiki/F_band) [G](http://en.wikipedia.org/wiki/G_band) [H](http://en.wikipedia.org/wiki/H_band) [I](http://en.wikipedia.org/wiki/I_band) [J](http://en.wikipedia.org/wiki/J_band) [K](http://en.wikipedia.org/wiki/K_band) [L](http://en.wikipedia.org/wiki/L_band) [M](http://en.wikipedia.org/wiki/M_band)[**IEEE Radar bands**](http://en.wikipedia.org/wiki/Radio_waves#IEEE_US)[HF](http://en.wikipedia.org/wiki/High_frequency) [VHF](http://en.wikipedia.org/wiki/Very_high_frequency) [UHF](http://en.wikipedia.org/wiki/Ultra_high_frequency) [L](http://en.wikipedia.org/wiki/L_band) [S](http://en.wikipedia.org/wiki/S_band) [C](http://en.wikipedia.org/wiki/C_band) [X](http://en.wikipedia.org/wiki/X_band) [Ku](http://en.wikipedia.org/wiki/Ku_band) [K](http://en.wikipedia.org/wiki/K_band) [Ka](http://en.wikipedia.org/wiki/Ka_band) [Q](http://en.wikipedia.org/wiki/Q_band) [V](http://en.wikipedia.org/wiki/V_band) [W](http://en.wikipedia.org/wiki/W_band)[edit](http://en.wikipedia.org/w/index.php?title=Template:MWband&action=edit) |

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| **Microwave frequency bands** |
| **Letter Designation** | **Frequency range** |
| [L band](http://en.wikipedia.org/wiki/L_band) | 1 to 2 GHz |
| [S band](http://en.wikipedia.org/wiki/S_band) | 2 to 4 GHz |
| [C band](http://en.wikipedia.org/wiki/C_band) | 4 to 8 GHz |
| [X band](http://en.wikipedia.org/wiki/X_band) | 8 to 12 GHz |
| [Ku band](http://en.wikipedia.org/wiki/Ku_band) | 12 to 18 GHz |
| [K band](http://en.wikipedia.org/wiki/K_band) | 18 to 26.5 GHz |
| [Ka band](http://en.wikipedia.org/wiki/Ka_band) | 26.5 to 40 GHz |
| [Q band](http://en.wikipedia.org/wiki/Q_band) | 30 to 50 GHz |
| [U band](http://en.wikipedia.org/w/index.php?title=U_band&action=edit&redlink=1) | 40 to 60 GHz |
| [V band](http://en.wikipedia.org/wiki/V_band) | 50 to 75 GHz |
| [E band](http://en.wikipedia.org/wiki/E_band) | 60 to 90 GHz |
| [W band](http://en.wikipedia.org/wiki/W_band) | 75 to 110 GHz |
| [F band](http://en.wikipedia.org/wiki/F_band) | 90 to 140 GHz |
| [D band](http://en.wikipedia.org/wiki/D_band) | 110 to 170 GHz |

**Microwave frequency measurement**

Microwave frequency can be measured by either electronic or mechanical techniques.

[Frequency counters](http://en.wikipedia.org/wiki/Frequency_counter) or high frequency [heterodyne](http://en.wikipedia.org/wiki/Heterodyne) systems can be used. Here the unknown frequency is compared with harmonics of a known lower frequency by use of a low frequency generator, a harmonic generator and a mixer. Accuracy of the measurement is limited by the accuracy and stability of the reference source.

Mechanical methods require a tunable resonator such as an [absorption wavemeter](http://en.wikipedia.org/wiki/Absorption_wavemeter), which has a known relation between a physical dimension and frequency.

Wavemeter for measuring in the Ku band

In a laboratory setting, [Lecher lines](http://en.wikipedia.org/wiki/Lecher_lines) can be used to directly measure the wavelength on a transmission line made of parallel wires, the frequency can then be calculated. A similar technique is to use a slotted [waveguide](http://en.wikipedia.org/wiki/Waveguide) or slotted coaxial line to directly measure the wavelength. These devices consist of a probe introduced into the line through a longitudinal slot, so that the probe is free to travel up and down the line. Slotted lines are primarily intended for measurement of the [voltage standing wave ratio](http://en.wikipedia.org/wiki/Voltage_standing_wave_ratio) on the line. However, provided a [standing wave](http://en.wikipedia.org/wiki/Standing_wave) is present, they may also be used to measure the distance between the [nodes](http://en.wikipedia.org/wiki/Node_%28physics%29), which is equal to half the wavelength. Precision of this method is limited by the determination of the nodal locations.

**Health effects**

Main article: [Electromagnetic radiation and health](http://en.wikipedia.org/wiki/Electromagnetic_radiation_and_health)

Microwaves contain insufficient energy to directly chemically change substances by ionization, and so are an example of [nonionizing](http://en.wikipedia.org/wiki/Nonionizing) radiation. The word "radiation" refers to the fact that energy can radiate. The term in this context is not to be confused with [radioactivity](http://en.wikipedia.org/wiki/Radioactivity). It has not been shown conclusively that microwaves (or other [nonionizing](http://en.wikipedia.org/wiki/Nonionizing) electromagnetic radiation) have significant adverse biological effects at low levels. Some but not all studies suggest that long-term exposure may have a [carcinogenic](http://en.wikipedia.org/wiki/Carcinogen) effect. This is separate from the risks associated with very high intensity exposure, which can cause heating and burns like any heat source, and not a unique property of microwaves specifically.

During [World War II](http://en.wikipedia.org/wiki/World_War_II), it was observed that individuals in the radiation path of radar installations experienced clicks and buzzing sounds in response to the microwaves radiation. This [microwave auditory effect](http://en.wikipedia.org/wiki/Microwave_auditory_effect) was thought to be caused by the microwaves inducing an electric current in the hearing centers of the brain. Research by [NASA](http://en.wikipedia.org/wiki/NASA) in the 1970s has shown this to be caused by thermal expansion in parts of the inner ear.

When injury from exposure to microwaves occurs, it usually results from dielectric heating induced in the body. Exposure to microwave radiation can produce [cataracts](http://en.wikipedia.org/wiki/Cataract) by this mechanism, because the microwave heating denatures [proteins](http://en.wikipedia.org/wiki/Protein) in the [crystalline lens](http://en.wikipedia.org/wiki/Lens_%28anatomy%29) of the [eye](http://en.wikipedia.org/wiki/Human_eye) (in the same way that heat turns [egg whites](http://en.wikipedia.org/wiki/Egg_white) white and opaque) faster than the lens can be cooled by surrounding structures. The lens and [cornea](http://en.wikipedia.org/wiki/Cornea) of the eye are especially vulnerable because they contain no [blood vessels](http://en.wikipedia.org/wiki/Blood_vessel) that can carry away heat. Exposure to heavy doses of microwave radiation (as from an oven that has been tampered with to allow operation even with the door open) can produce heat damage in other tissues as well, up to and including serious [burns](http://en.wikipedia.org/wiki/Burn) which may not be immediately evident because of the tendency for microwaves to heat deeper tissues with higher moisture content.

**History and research**

The existence of electromagnetic waves was predicted by [James Clerk Maxwell](http://en.wikipedia.org/wiki/James_Clerk_Maxwell) in 1864 from his [equations](http://en.wikipedia.org/wiki/Maxwell%27s_equations). In 1888, [Heinrich Hertz](http://en.wikipedia.org/wiki/Heinrich_Hertz) was the first to demonstrate the existence of electromagnetic waves by building an apparatus that produced and detected microwaves in the UHF region. The design necessarily used horse-and-buggy materials, including a horse trough, a wrought iron point spark, [Leyden jars](http://en.wikipedia.org/wiki/Leyden_jar), and a length of zinc gutter whose parabolic cross-section worked as a reflection antenna. In 1894 [J. C. Bose](http://en.wikipedia.org/wiki/Jagdish_Chandra_Bose) publicly demonstrated radio control of a bell using millimeter wavelengths, and conducted research into the propagation of microwaves.

Perhaps the first, documented, formal use of the term *microwave* occurred in 1931:

"When trials with wavelengths as low as 18 cm were made known, there was undisguised surprise that the problem of the micro-wave had been solved so soon." *Telegraph & Telephone Journal* XVII. 179/1

In 1943: the Hungarian engineer [Zoltán Bay](http://en.wikipedia.org/wiki/Zolt%C3%A1n_Bay) sent ultra-short radio waves to the moon, which, reflected from there worked as a radar, and could be used to measure distance, as well as to study the moon.

Perhaps the first use of the word *microwave* in an astronomical context occurred in 1946 in an article "Microwave Radiation from the Sun and Moon" by [Robert Dicke](http://en.wikipedia.org/wiki/Robert_Dicke) and [Robert Beringer](http://en.wikipedia.org/w/index.php?title=Robert_Beringer&action=edit&redlink=1).

Some of the history in the development of electromagnetic theory applicable to modern microwave applications see the following figures:

* [Hans Christian Ørsted](http://en.wikipedia.org/wiki/Hans_Christian_%C3%98rsted)
* [Michael Faraday](http://en.wikipedia.org/wiki/Michael_Faraday)
* [James Clerk Maxwell](http://en.wikipedia.org/wiki/James_Clerk_Maxwell)
* [Heinrich Hertz](http://en.wikipedia.org/wiki/Heinrich_Hertz)
* [Nikola Tesla](http://en.wikipedia.org/wiki/Nikola_Tesla)
* [Guglielmo Marconi](http://en.wikipedia.org/wiki/Guglielmo_Marconi)
* [Samuel Morse](http://en.wikipedia.org/wiki/Samuel_F._B._Morse)
* Sir [William Thomson](http://en.wikipedia.org/wiki/William_Thomson%2C_1st_Baron_Kelvin), later Lord Kelvin
* [Oliver Heaviside](http://en.wikipedia.org/wiki/Oliver_Heaviside)
* [Lord Rayleigh](http://en.wikipedia.org/wiki/Lord_Rayleigh)
* [Oliver Lodge](http://en.wikipedia.org/wiki/Oliver_Lodge)
* [Jagadish Chandra Bose](http://en.wikipedia.org/wiki/Jagadish_Chandra_Bose)
* [Julius Lange](http://en.wikipedia.org/w/index.php?title=Julius_Lange&action=edit&redlink=1)

Specific significant areas of research and work developing microwaves and their applications:

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| **Specific work on microwaves** |
| **Work carried out by** | **Area of work** |
| [Barkhausen](http://en.wikipedia.org/wiki/Barkhausen) and Kurz | Positive grid [oscillators](http://en.wikipedia.org/wiki/Oscillator) |
| Hull | Smooth bore [magnetron](http://en.wikipedia.org/wiki/Magnetron) |
| Varian Brothers | Velocity modulated electron beam → [klystron](http://en.wikipedia.org/wiki/Klystron) tube |
| Randall and Boot | Cavity magnetron |

Electromagnetic spectrum with visible light highlighted

**See also**

* [Cosmic microwave background radiation](http://en.wikipedia.org/wiki/Cosmic_microwave_background_radiation)
* [Electron cyclotron resonance](http://en.wikipedia.org/wiki/Electron_cyclotron_resonance)
* [Microwave auditory effect](http://en.wikipedia.org/wiki/Microwave_auditory_effect)
* [Rain fade](http://en.wikipedia.org/wiki/Rain_fade)
* [Microwave chemistry](http://en.wikipedia.org/wiki/Microwave_chemistry)
* Microwave [plasma-enhanced chemical vapour deposition](http://en.wikipedia.org/wiki/Plasma-enhanced_chemical_vapour_deposition)
* [Microwave radio relay](http://en.wikipedia.org/wiki/Microwave_radio_relay)
* [Thing (listening device)](http://en.wikipedia.org/wiki/Thing_%28listening_device%29)
* [Tropospheric scatter](http://en.wikipedia.org/wiki/Tropospheric_scatter)
* [RF switch matrix](http://en.wikipedia.org/wiki/RF_switch_matrix)
* L.N.B. [Low Noise Block Down Converter](http://en.wikipedia.org/wiki/Low_Noise_Block_Converter)
* B.U.C. [Block Up Converter](http://en.wikipedia.org/wiki/Block_Up_Converter)
* O.M.T. [Orthogonal Mode Transducer](http://en.wikipedia.org/wiki/Orthomode_transducer)