# Electromagnetic Radiation: Characteristics

**tranversal waves, velocity** $c_0 \approx 3 \cdot 10^8$ m s$^{-1}$

1. **Energy** (eV, kJ mol$^{-1}$)

<table>
<thead>
<tr>
<th>Property</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>-frequency</td>
<td>$\nu = \frac{c_0}{\lambda};$ s$^{-1}$, Hz</td>
</tr>
<tr>
<td>-wavelength</td>
<td>$\lambda = \frac{c_0}{\nu};$ Å, nm, ..., m, ...</td>
</tr>
<tr>
<td>-wavenumber</td>
<td>$\tilde{\nu} = \frac{1}{\lambda} = \nu/c_0;$ cm$^{-1}$, Kaiser</td>
</tr>
</tbody>
</table>

Energy ~ frequency: $(E = h \cdot \nu)$  
~ wavenumber: $(E = h \cdot \tilde{\nu} \cdot c_0)$  
~ wavelength$^{-1}$: $(E = h \cdot c_0 / \lambda)$

2. **Intensity** cross-section  
$I \sim |\mathbf{S}|^2 = |\mathbf{E} \times \mathbf{H}|$

3. **Direction** wavevector $\mathbf{S}_0$

4. **Phase** phase $\phi$

Range of frequencies for structural analysis: $10^6$-$10^{20}$ Hz, $10^2$-$10^{-12}$m, $10^{-8}$-$10^6$ eV  
radio-, microwaves, infrared (IR), visible (VIS), ultraviolet (UV), X-ray, γ-ray$^1$
Electromagnetic radiation: Spectral ranges

Orders of magnitude in wavelength, frequency, energy, temperature
Electromagnetic radiation: Spectral ranges

1 eV = 1.602 \times 10^{-19} \text{ J} = 96,485 \text{ kJ mol}^{-1} = 8065,5 \text{ cm}^{-1}

Orders of magnitude in wavelength, frequency, energy, temperature
Electromagnetic radiation: Spectral ranges
Electromagnetic radiation: Spectral ranges

\begin{align*}
E &= h \nu \\
\mathbf{c} &= \nu \lambda
\end{align*}

\[ c = 2.998 \times 10^8 \text{ m/s} \]

\[ h = 6.626 \times 10^{-34} \text{ Js} \]
Electromagnetic radiation: Origins and techniques
Electromagnetic waves are produced (a.o.), when charges or charged or dipolar species are oscillating with frequencies in the respective range. For microwaves, the charges oscillate in a resonance or tank circuit, consisting of a capacitor with capacitance $C$ and a coil with self-inductance $L$.

\[ f = \frac{1}{2\pi} \sqrt{\frac{1}{LC}} \]
**Electromagnetic radiation: Sources**

**Microwave radiation**

Magnetrons and Gyrotrons are diode-type electron tubes (~ 1-10 kV) with a trapezoid anode (*resonant cavities*) surrounded by permanent magnets producing an axial magnetic field. Under the combined influence of the electric and the magnetic field, the electrons are forced in a circular motion of travel to the anode resulting in electromagnetic radiation of 0.3 - 300 GHz.

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Impulsmagnetron MI-189W (ca. 9 GHz)
Bordradar, Russia
Electromagnetic radiation: Sources
IR-Sources, Globar, Nernst lamp

Any heated material will produce infrared radiations

Globar (SiC, \( \sim 1.500 \) K)
Nernst lamp with Nernst rod, a \( \text{ZrO}_2/\text{Y}_2\text{O}_3 \) ion conductor \( 1.900 \) K

http://www.techniklexikon.net/d/ernst-brenner/ernst-brenner.htm
Electromagnetic radiation: Sources
UV and NIR radiation

Wave lengths of some lasers for UV, visible and Raman spectroscopy
Electromagnetic radiation: Sources
UV and NIR radiation

![Graph showing emission spectra of various lamps at different wavelengths.](image)
Sketch of a mercury (low pressure) lamp
Excitation/ionisation of Hg by fast electrons
(Important Hg lines are 313 nm, 365 nm (i line), 405 nm (h line), 434 nm (g line), 546 nm (e line) and 577/579 nm (orange double line)).
Electromagnetic radiation: Sources

X-rays

X-rax tube

X-rax tube: sketched and dashed
Electromagnetic radiation: Sources

Electromagnetic radiation: Synchrotron

Abb. 5: Die Leuchtdichte von DORIS im Vergleich zu einigen bekannten Strahlungsquellen. (Die Leuchtdichte ist die Zahl der Photonen, die pro Sekunde und Wellenlängenintervall in eine bestimmte Richtung abgestrahlt wird.)
Electromagnetic radiation: Sources

Synchrotron

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increase of brilliance over the years
Electromagnetic radiation: Sources
Synchrotron

Source of radiation
Synchrotron

Magnitude of wavelength
WELLENLÄNGE

Type of radiation
STRAHLUNG

Use of Synchrotron Radiation in materials science
Gamma rays can occur whenever charged particles pass through magnetic fields or pass within certain distances of each other or by nuclear reactions (e.g. fusion or decay processes).
Electromagnetic radiation: Sources

Gamma-rays

Gamma-rays: Sources

Gamma-ray: Radiation Source

Gamma-ray: Nuclear Decay Products

Penetrating Distances

Gamma-ray: Penetrating Distances

Gamma-ray: Alpha

Gamma-ray: Beta

Gamma-ray: Gamma and X-rays

Gamma-ray: Paper

Gamma-ray: Plastic

Gamma-ray: Lead

Gamma-ray: Concrete

Gamma-ray: Gamma-ray source

Gamma-ray: Nuclear decay products
Electromagnetic radiation: Sources
Neutrons

View into a nuclear reactor with Cherenkov radiation

Scetch of a nuclear power plant

De Broglie wave length: $\lambda = \frac{h}{(m \cdot v)}$

e.g. n with $v = 3,300 \text{ m/s} \rightarrow 0,05 \text{ eV} \rightarrow 1,2 \text{ Å} (0,12 \text{ nm})