
Electromagnetic Spectrum
Electromagnetic (EM) waves carry energy and comprise transverse vibrations in electric and magnetic fields, not vibrating particles. They can travel through empty space (vacuum), without requiring any material to carry them. In vacuum, all EM waves travel at 299 792 458 ms-1 (the fastest possible speed). When passing through matter (e.g. air or glass), speed is reduced, though seldom less than half that when moving in a vacuum. Wave speed, frequency and length are related by the equation: speed = frequency × wavelength
The higher the frequency, the higher the energy.
The graphic below shows how the spectrum has been divided into seven 'types' according to use.
SI
kg
m
s
A
K
mol
cd
MYTH BUSTER!
Cosmic rays are not EM radiation but high energy particles
EM Spectrum
USING IT
wavelength × frequency = 299 792 458 ms-1 = the speed of light
time: MSF signal sets UK radio-controlled clocks 60 kHz
Wi-Fi, mobile phones and Bluetooth are all microwave
Channel 4 on SKY UK
microwave oven
Cosmic Microwave Background from Big Bang
Solar IR absorbed by atmospheric CO2
IR TV remote control
human eyes 'see' this range
UV tanning booth
UV purifies water by killing bacteria
X-rays for medical/ mechanical/security imaging and determining crystal structure
gamma rays used in cancer treatment
wavelength (to 1 sig. fig.)
3 × 10⁸ m 300 000 km
3 × 10⁵ m 300 km
300 m
30 × 10⁻² m 30 cm
300 × 10⁻⁶ m 300 µm
300 × 10⁻⁹ m 300 nm
300 × 10⁻¹² m 300 pm
300 × 10⁻¹⁵ m 300 fm
radio waves
microwaves
infrared (IR)
ultraviolet (UV)
X-rays
gamma rays
non-ionising
ionising
gamma rays or X-rays?
< 1 EHz also called 'soft X-rays'
> 1 EHz also called:
• 'hard X-rays' if originating from electron
• gamma rays if originating from atomic nucleus
frequency
1 Hz
10³ Hz 1 kHz
10⁶ Hz 1 MHz
10⁹ Hz 1 GHz
10¹² Hz 1 THz
10¹⁵ Hz 1 PHz
10¹⁸ Hz 1 EHz
10²¹ Hz 1 ZHz
EM Spectrum
MEASURING WITH IT
0
10
100
1000
radar: first UK radar invented by NPL's Robert Watson-Watt 22-50 MHz
electrical current standard pumped by microwave 2 GHz
temperature: microwave volume measurements contribute to kelvin redefinition
length standard uses red laser 474 THz (red)
luminosity: candela definition
frequency standard in NPL's Yb+ ion optical clock 682 THz (blue)
mass: X-ray crystallography finds amount of substance in silicon weights
NPL uses EM spectrum in precision measurement
radio waves, microwave, IR and visible all used to measurement cauliflower ripeness
NPL anechoic chambers used for traceable measurement of EM wave properties radio waves, microwave, 20 Hz – 110 GHz
NPL portable DIAL instrument measures airborne pollutants like methane and NO2 using IR, visible and UV
temperature: thermal imagers measure IR
feet
explosion
electronics
heating system
heat loss
Did you know?
The National Physical Laboratory (NPL) evaluates the power of EM sources, the responsivity of EM detectors and uses many forms of the spectrum in high precision measurement.
NPL
npl.co.uk
The values used are correct at the time of going to press