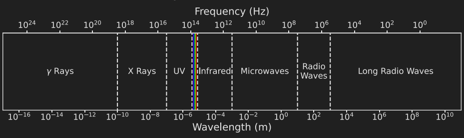
Colour Science Precis

for the CGI Artist

Electromagnetic Spectrum

The electromagnetic spectrum is the full range of all types of electromagnetic radiation, organised by frequency or wavelength.

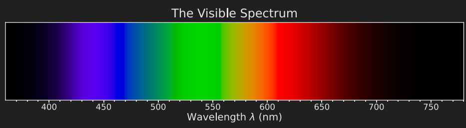
Wavelength (λ) is related to frequency (f) as follows: λ = C/f
Where C is the speed of light.



Light

Electromagnetic radiation that is considered from the point of view of its ability to excite the human visual system (HVS).

The visible spectrum approximately spans 360-780 nm in wavelength.



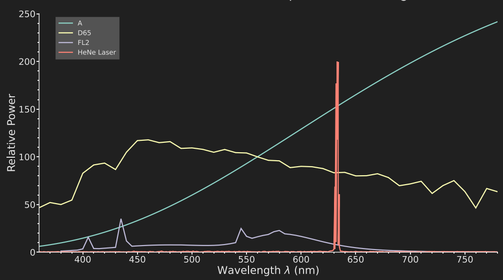
Colour

Characteristic of visual perception that can be described by attributes of hue, brightness (or lightness) and colourfulness (or saturation or chroma).

Even though colour is universally used to describe the stimuli that caused the sensation, *e.g.*, the red pen, colour is not an intrinsic physical property of objects but the interpretation our brains make about a specific characteristic of objects. This delineation, whilst not critical, is important to remember when modelling objects appearance with computer-generated imagery (CGI).

Spectral Distribution

The radiant power emitted by a light source (or illuminant, *i.e.*, **standardised table of values or mathematical function representing an ideal light source**) is characterised by a spectral distribution (SD) giving the power of the light per unit area per unit wavelength. The radiant power reflected, transmitted or absorbed by a surface is expressed by a SD giving the percentage of light reflected, or transmitted or absorbed per unit wavelength.



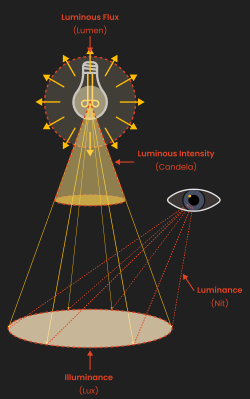
Radiometry & Photometry

Radiometry is **the measurement of quantities associated with electromagnetic radiation.**

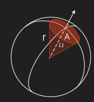
Photometry is **the measurement of electromagnetic radiation quantities relative to the HVS sensitivity to brightness, *e.g.*, V(λ).**

	Omni-Directional	Directional
Total	Radiant Flux Φ_e $(Watt, W)$ Luminous Flux Φ_v $(Lumen,\ lm = cd \cdot sr)$	Radiant Intensity $I_{e,\Omega}$ (W/sr) Luminous Intensity I_v $(Candela,\ cd = lm/sr)$
Per Unit Area	Irradiance E_e (W/m^2) Illuminance E_v $(Lux,\ lx = lm/m^2)$	Radiance $L_{e,\Omega}$ $(W/sr/m^2)$ Luminance L_v $(Nit,\ nt = cd/m^2)$

1 watt of 555nm green light has a luminous flux of 683 lumens.



Solid Angle Ω (Steradian, sr) : Three dimensional angle, ratio of subtended area A on a sphere to radius r squared.



$$\Omega = \frac{A}{r^2}$$

Luminous Flux : Luminous energy per unit time.
Luminous Intensity : Luminous flux per unit solid angle.
Illuminance : Luminous flux incident on a surface.
Luminance : Luminous flux per unit solid angle per unit projected source area.

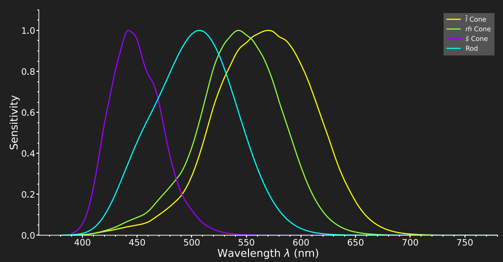
Human Visual System (HVS)

Photoreceptors

The HVS has two main classes of retinal photoreceptors:

Cone Cells : Responsible for photopic vision, *i.e.*, **vision under daytime illumination conditions**, and colour perception

Rod Cells : Responsible for scotopic vision, *i.e.*, **vision under dark illumination conditions**



Just-Noticeable Difference

The just-noticeable difference (JND) is the minimum change in stimulus intensity required to produce a detectable variation in sensory experience.

The Fechner principle, also known as Fechner's law, states that the intensity of a sensation increases proportionally to the logarithm of the stimulus intensity.

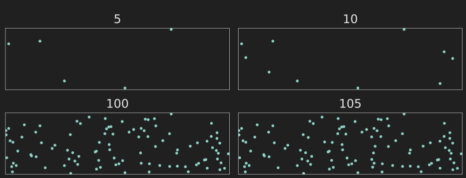


Illustration of Fechner's law principle: the change in stimulus intensity, i.e., the dots count increase by 5 for both rows, is perceptible on the top row but barely noticeable on the bottom row where the stimulus intensity was high to start with.

Dynamic Range

Dynamic range is the ratio between the maximum and minimum measurable light quantity in a scene.

In the context of motion pictures and games, dynamic range is expressed in photographic stops. Exposure value (EV) in stops is calculated as the log_2 of the test luminance (Y) relative to a reference luminance level (Y_r), *i.e.*, twice the luminance is a one stop difference; four times the luminance is two stops; and so forth:

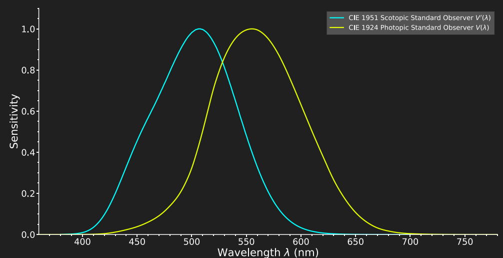
$$EV = log_2\left(\frac{Y}{Y_r}\right)$$

The HVS simultaneous or steady-state dynamic range spans over ~12 stops with an adaptation range of ~33 stops; the upper detection threshold rises with a brighter environment.

Object	Luminance (Nit)	Relative Exposure (EV)
Sun	1,600,000,000	23.9
Incandescent lamp (filament)	23,000,000	17.8
White paper in sunlight	10,000	6.6
Blue Sky	5000	5.6
Dolby Pulsar HDR reference monitor	4000	5.3
HDR reference monitor	1000	3.3
White paper in office lighting	160	0.7
Standard Television Reference Monitor	**100**	**0**
Preferred values for indoor lighting	50 - 500	-1.0 - 2.3
Digital Cinema Projector	48	-1.1
White paper in candlelight	1	-6.6
Night vision (rods in the retina)	0.01	-13.3

Luminous Efficiency Functions

The luminous efficiency function V′(λ) and V(λ) model the wavelength-dependent sensitivity of the HVS to light and are used to calculate the luminous flux of a light source (or illuminant).



Perceived Brightness

The HVS perceived brightness has a non-linear relationship with the physical intensity of light. It can better discriminate the brightness variation of light when its intensity is low.

CIE L characterises the perceptual response to relative luminance.*