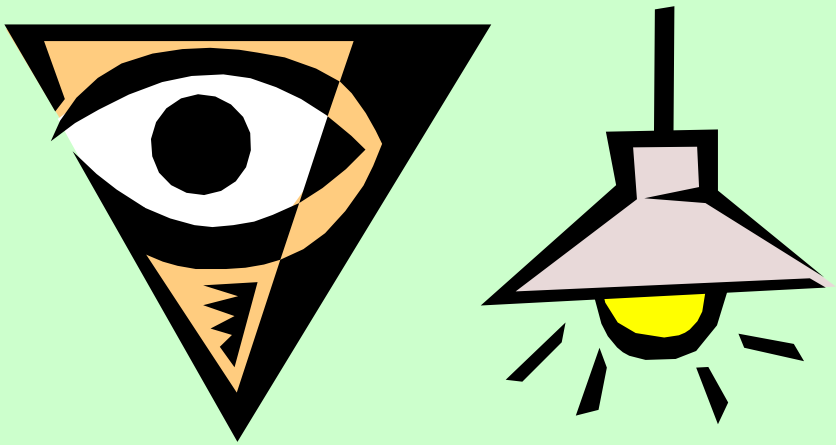
MEBS6004 Built Environment

http://ibse.hk/MEBS6004/



Visual environment: basic concepts and principles

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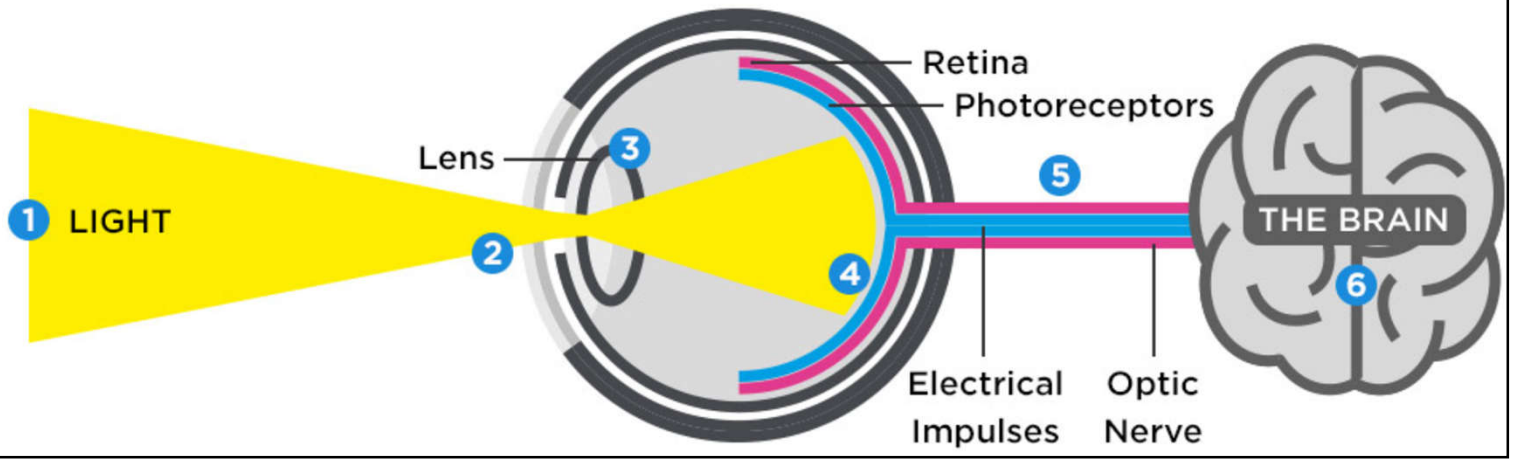
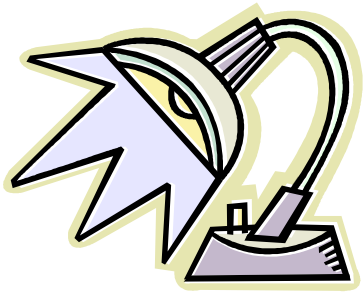
Sep 2022

Contents

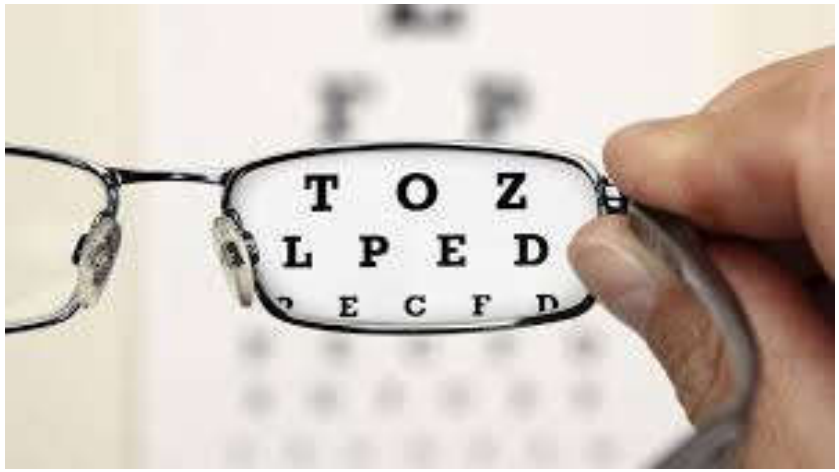
- What is light?
- How the human eye works?
- What lighting can do?
- Lighting quality
- Design considerations



What is light?



- The large majority of our impressions of the world come through our eyes, and light is necessary to vision
- Light is therefore the medium through which a majority of people perceive the world



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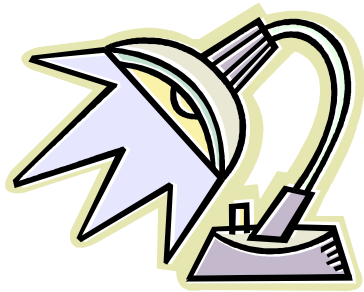
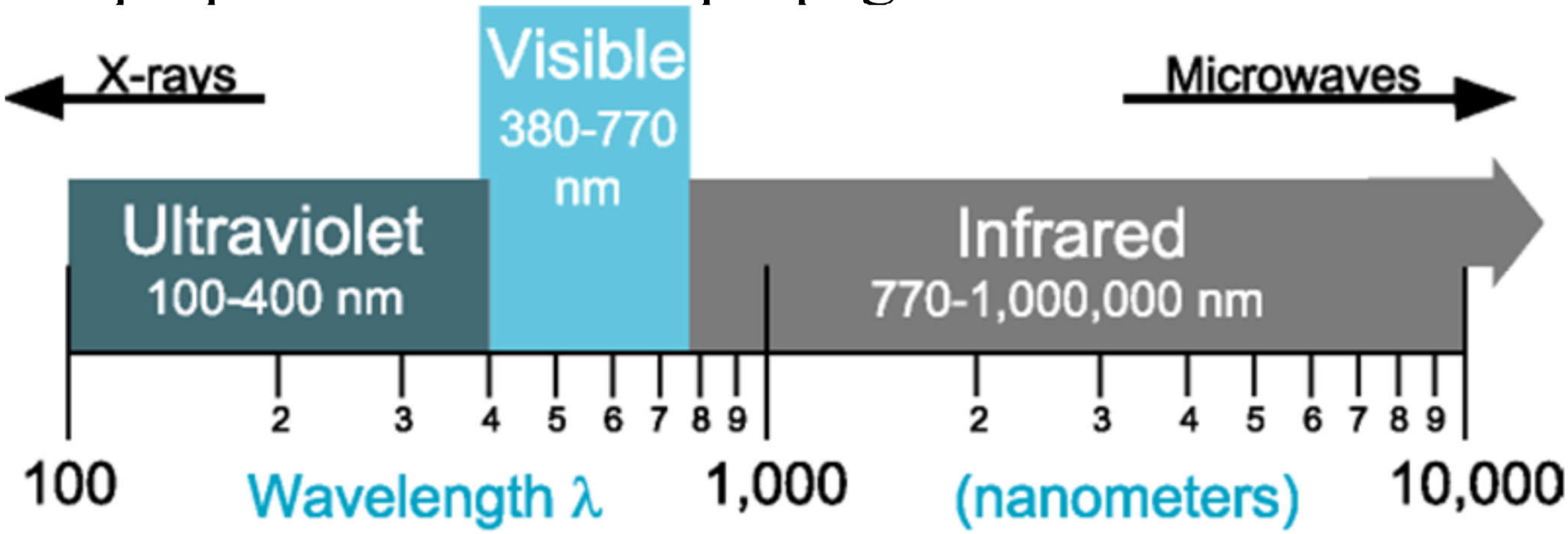
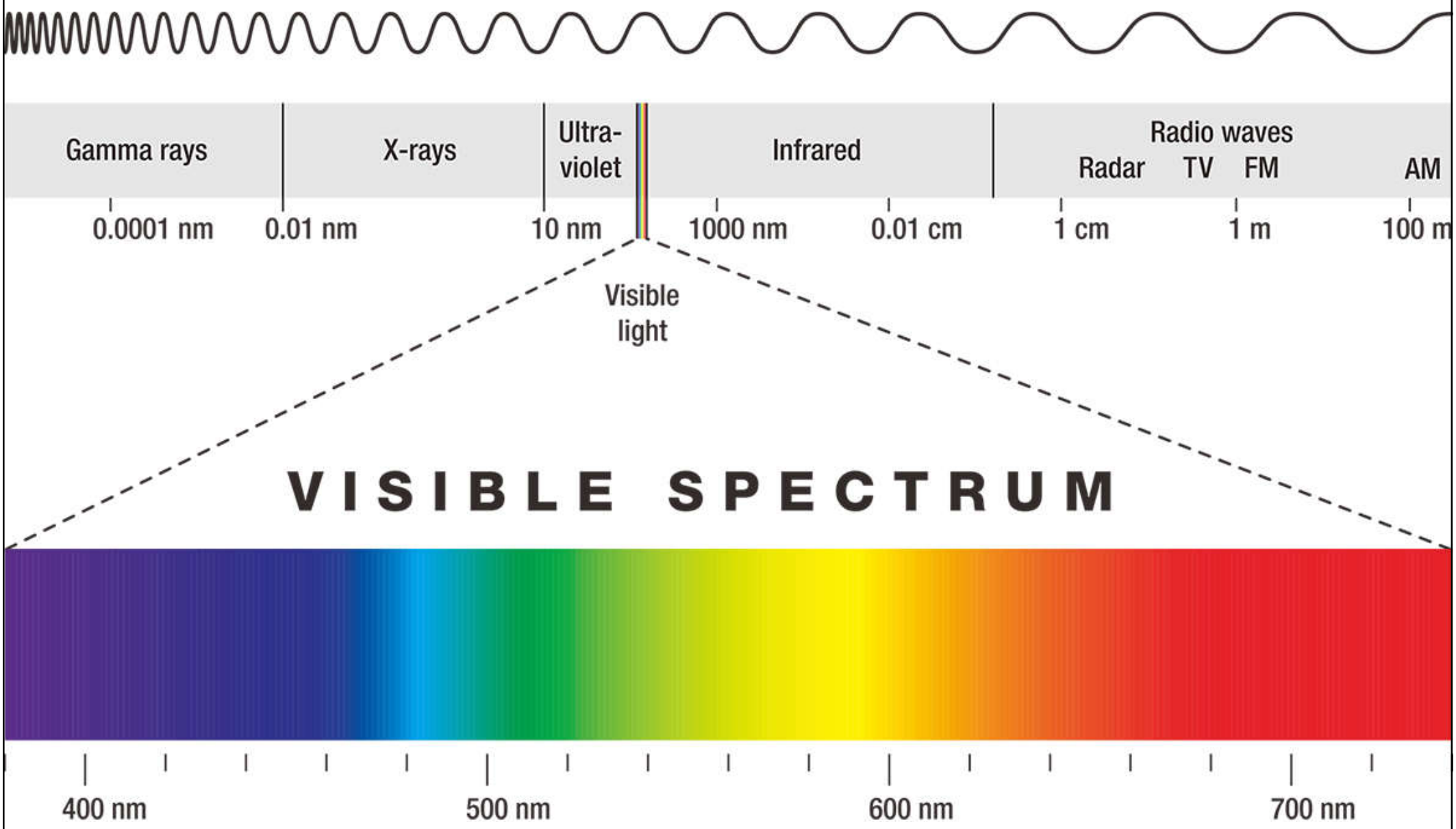


- What is *Light*?
  - Light is a form of electromagnetic radiation with an electric field & a magnetic field oriented at right angles and varies in magnitude in a direction perpendicular to the propagation direction

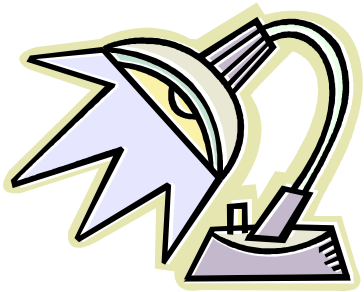


Visible spectrum of light

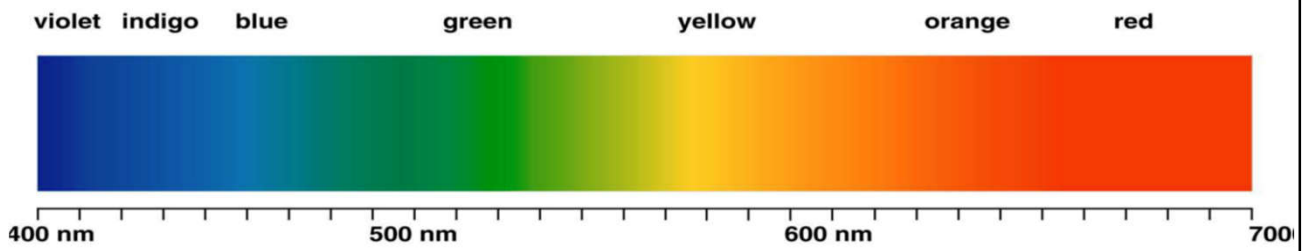


(Source: https://www.manufacturer.lighting/info/245/)

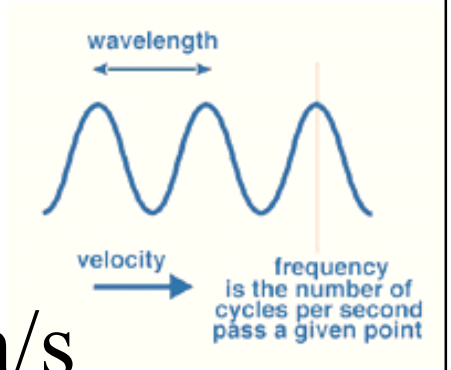
What is light?



- Electromagnetic spectrum
  - Visible light (380 to 760 nm)
    - Mr. ROY G. BIV (Red, Orange, Yellow, Green, Blue, Indigo, Violet)



  - Ultraviolet (100 to 380 nm)
  - Infrared (760 to 1,000,000 nm)
- Speed of light (in air) = 299 702 547 m/s
  - = (wavelength, metres) x (frequency, Hertz)



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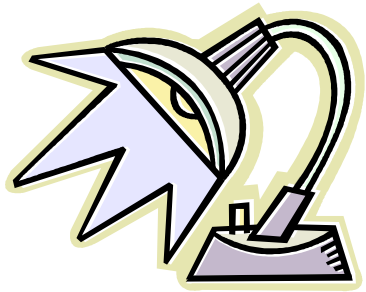
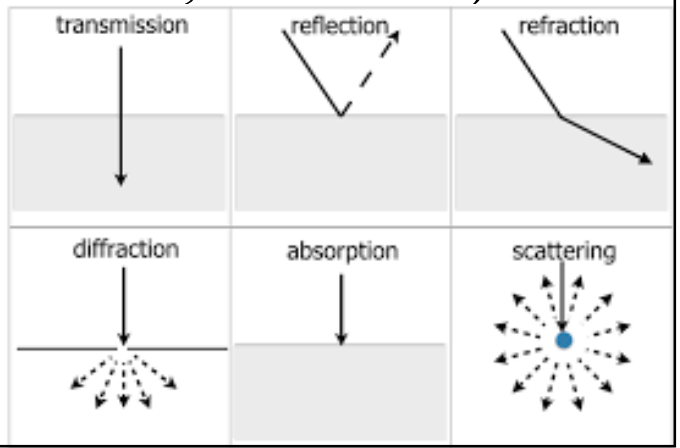
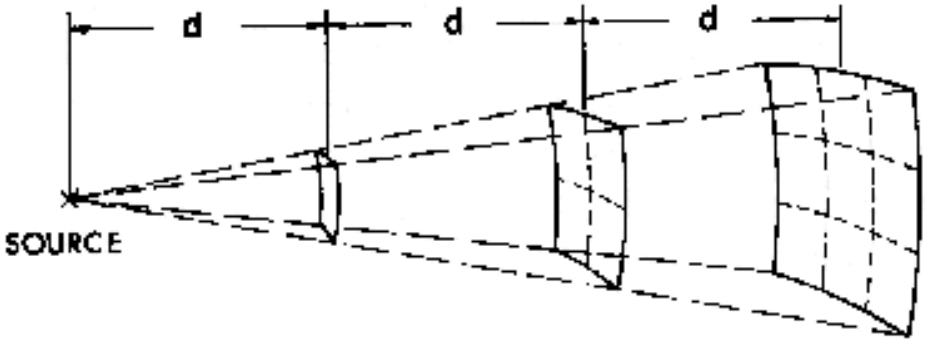


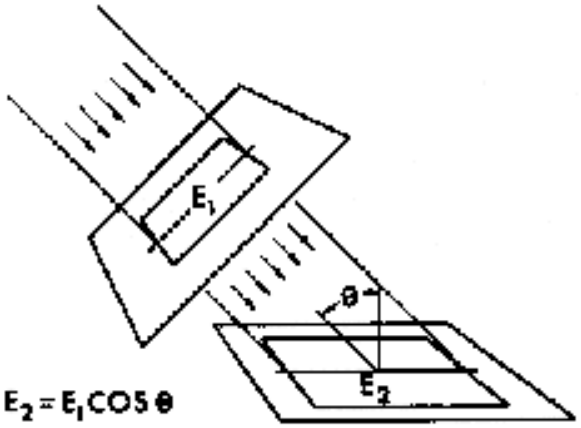
- The behaviour of light
  - Inverse square law $E = I / d^2$
  - Cosine law - the irradiance falling on any surface varies with the cosine of the incident angle
    - $E_\theta = E \cos \theta = (I / d^2) \cos \theta$
  - Optical properties
    - Reflection (specular, diffuse, spread, mixed, scattered)
    - Transmission and absorption
    - Refraction
    - Diffraction
    - Scattering and polarization

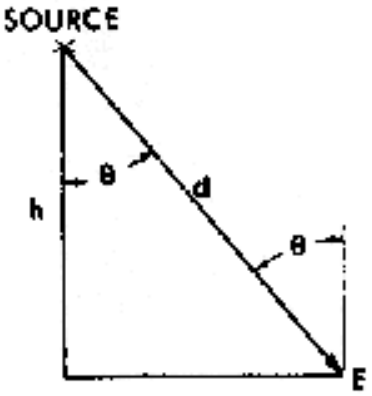


Inverse square law



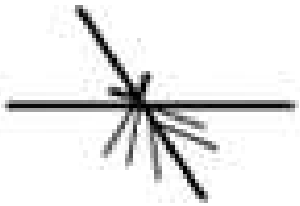
Cosine law



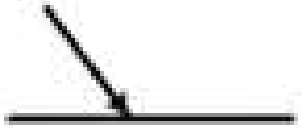


TYPES OF LIGHT MODIFICATION

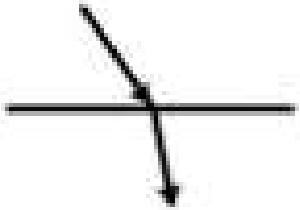
TRANSMISSION
(Diffuser)
Opal Glass
or Plastic



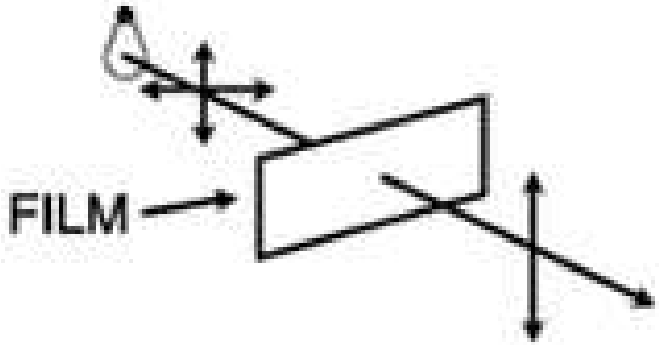
ABSORPTION
Matte Black
Paint



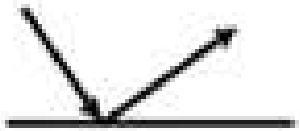
REFRACTION
Clear Glass



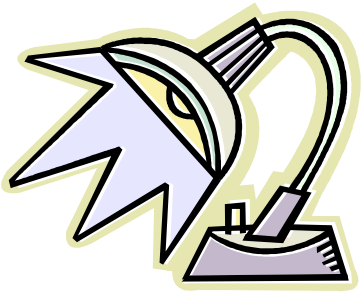
POLARIZATION



REFLECTION
Polished
Metal



What is light?



- Tools to measure light:
  - 1. Photometer (measures light intensity)

    - (a) Luminance meters - determine visible energy output of a light source
    - (b) Illuminance meters - measure visible energy falling on an object's surface
  - 2. Integrating sphere (measure luminous flux)
  - 3. Spectrometer (assess spectral components)
  - 4. Light/Lux meter (measure light levels)

Light measurement tools

Luminance meter

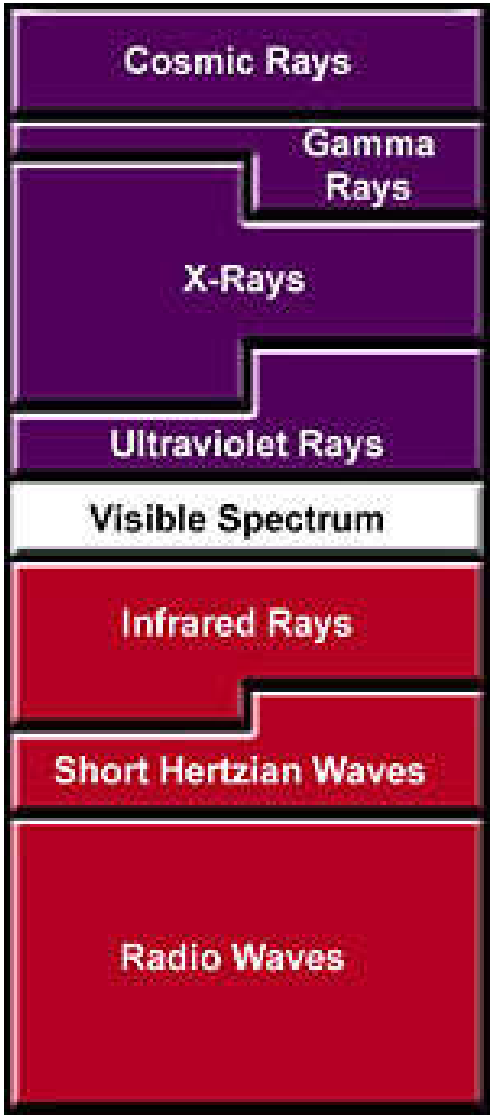
Illuminance meters

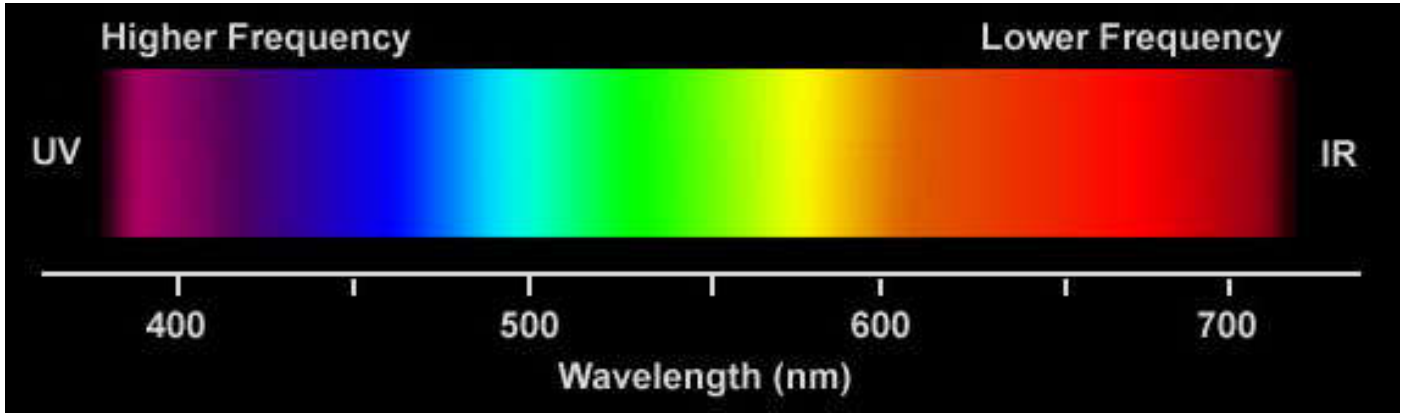
Integrating sphere

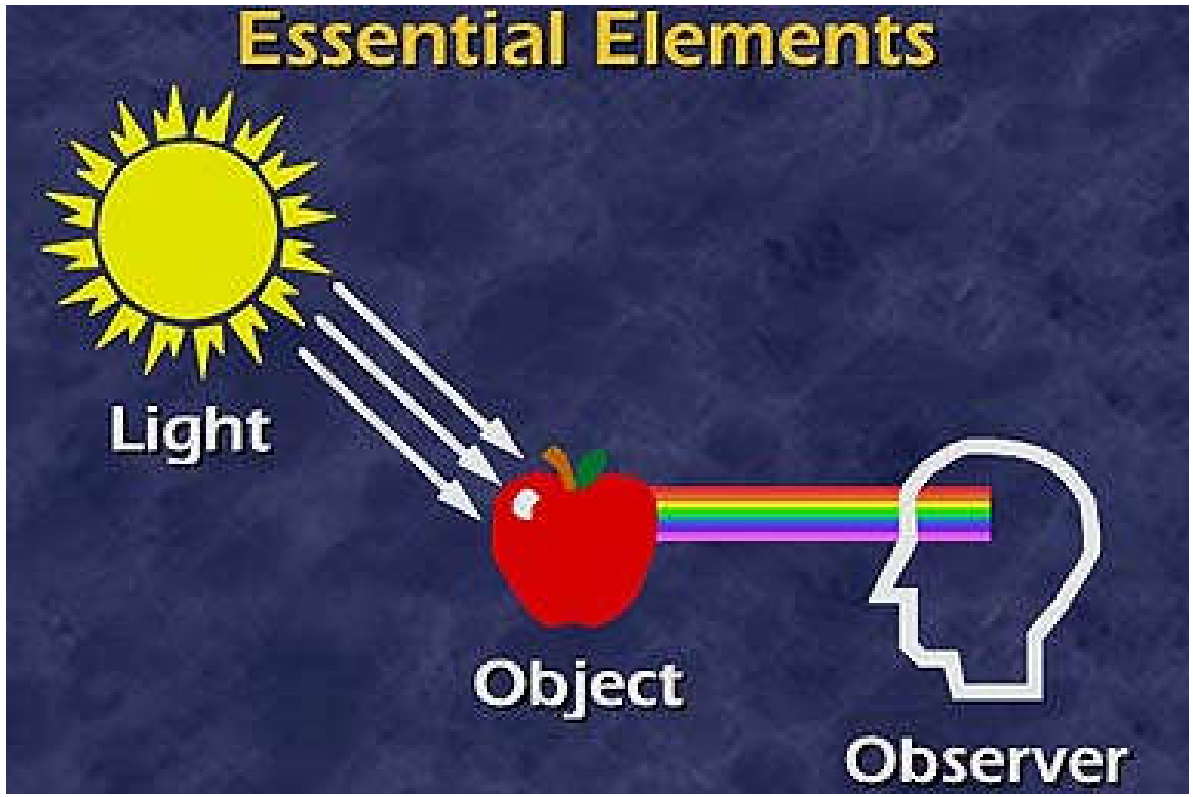
Spectrometer

Light/Lux meter

Essential elements of light and human vision

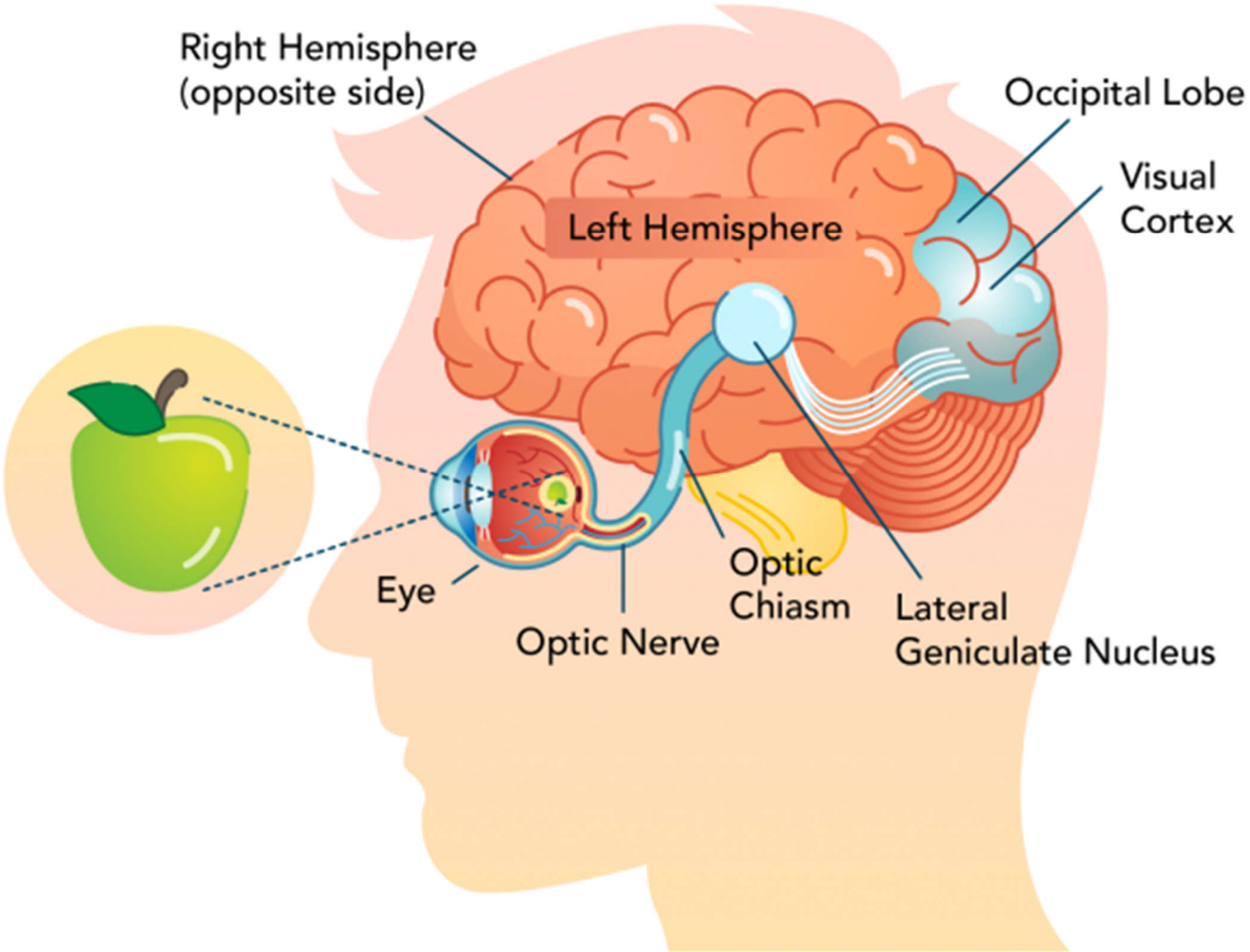






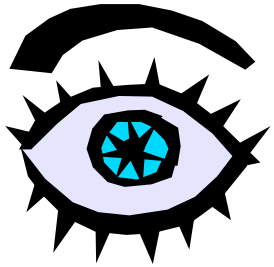
[Color Science, Texas A&M University http://www.isc.tamu.edu/%7Eastro/color.html]

Sight and brain pathway in human body

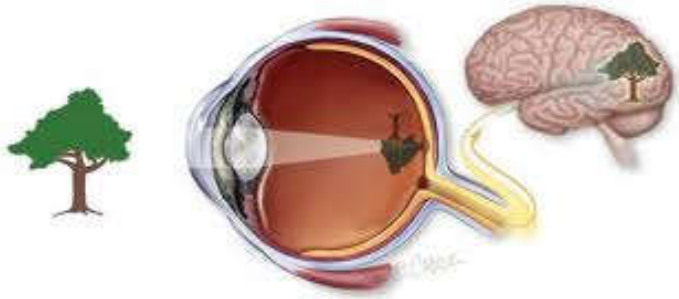


(Source: https://letstalkscience.ca/educational-resources/backgrounders/how-we-see)

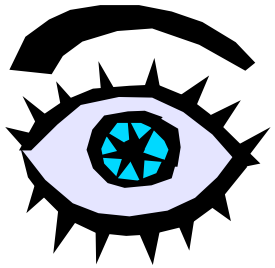
How the human eye works?



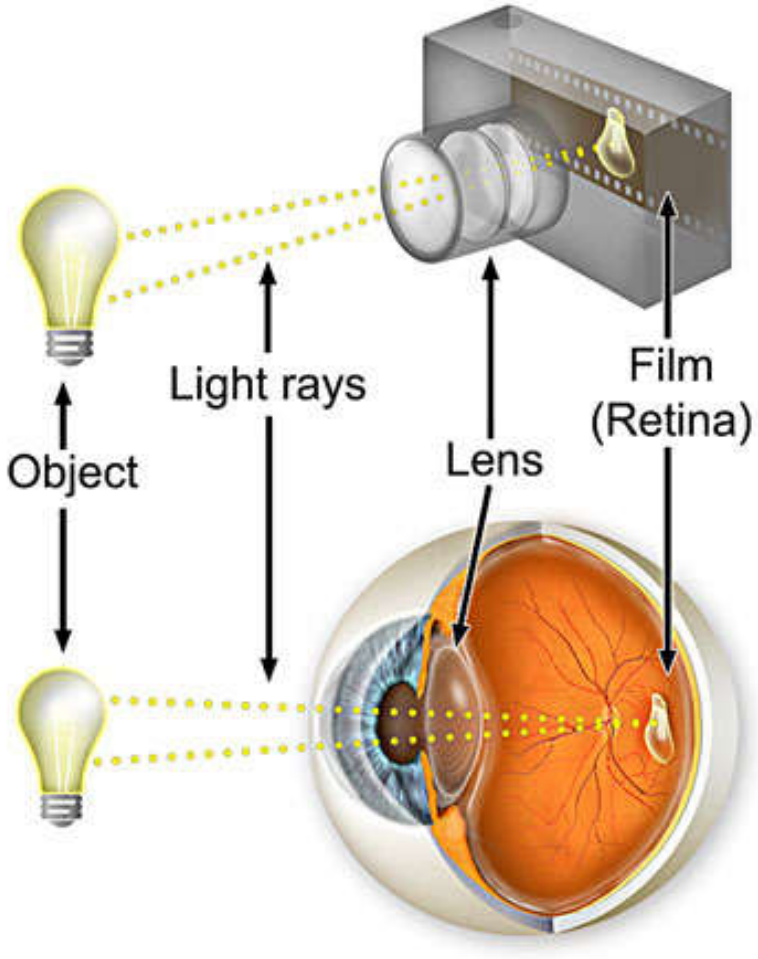
- Principle of VISION
  - Light energy → retina (photo-chemical) → optic nerve (electrical signal) → brain (sight centre)
  - Initial information: brightness + colour
  - *Stereoscopic effect* of two eyes (size & position)
  - The brain selects items in the *field of view*
  - The *sense of vision* depends on interpretations from previous experience

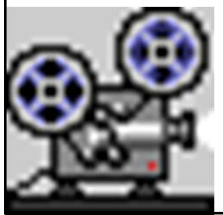


How the human eye works?



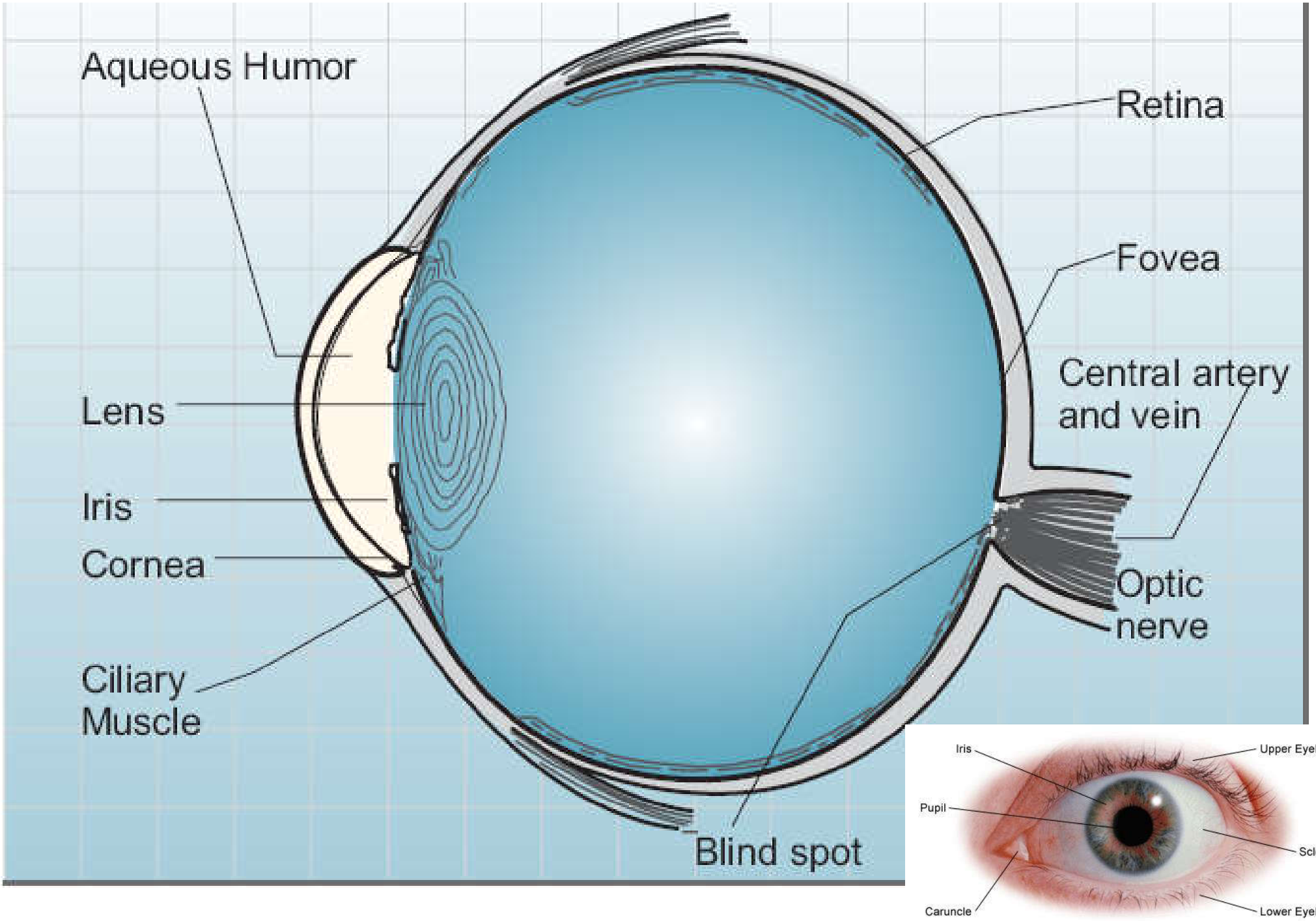
- The camera and the eye
  - Similar principles
- Structure of human eye
  - 1. Optical elements
  - 2. The retina
  - 3. Photoreceptors





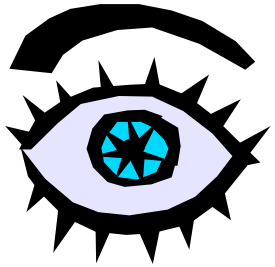
Video: A Journey Through the Human Eye: How We See (2:39) https://youtu.be/gvozcv8pS3c

Structure of the human eye



(Source: Source: Advanced Lighting Guidelines 2001, adapted from IESNA Lighting Handbook, 9th ed.)

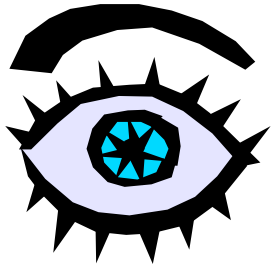
How the human eye works?



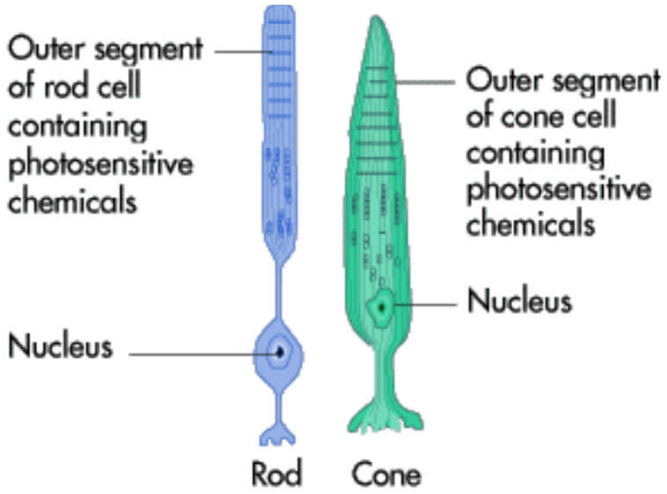
- 1. Optical elements
  - Cornea 角膜 – first “lens”, 70% of optical power
  - Sclera 鞏膜 – whites of the eye
  - Aqueous humour – liquid between cornea & iris
  - Iris 虹膜 – coloured muscular ring around pupil
  - Pupil 瞳孔 – hole into which light enters eye
  - Crystalline lens – 2nd lens, 30% of optical power
  - Vitreous humour – fluid filling the eye

(* See also http://hyperphysics.phy-astr.gsu.edu/hbase/vision/eye.html and http://en.wikipedia.org/wiki/Human_eye)

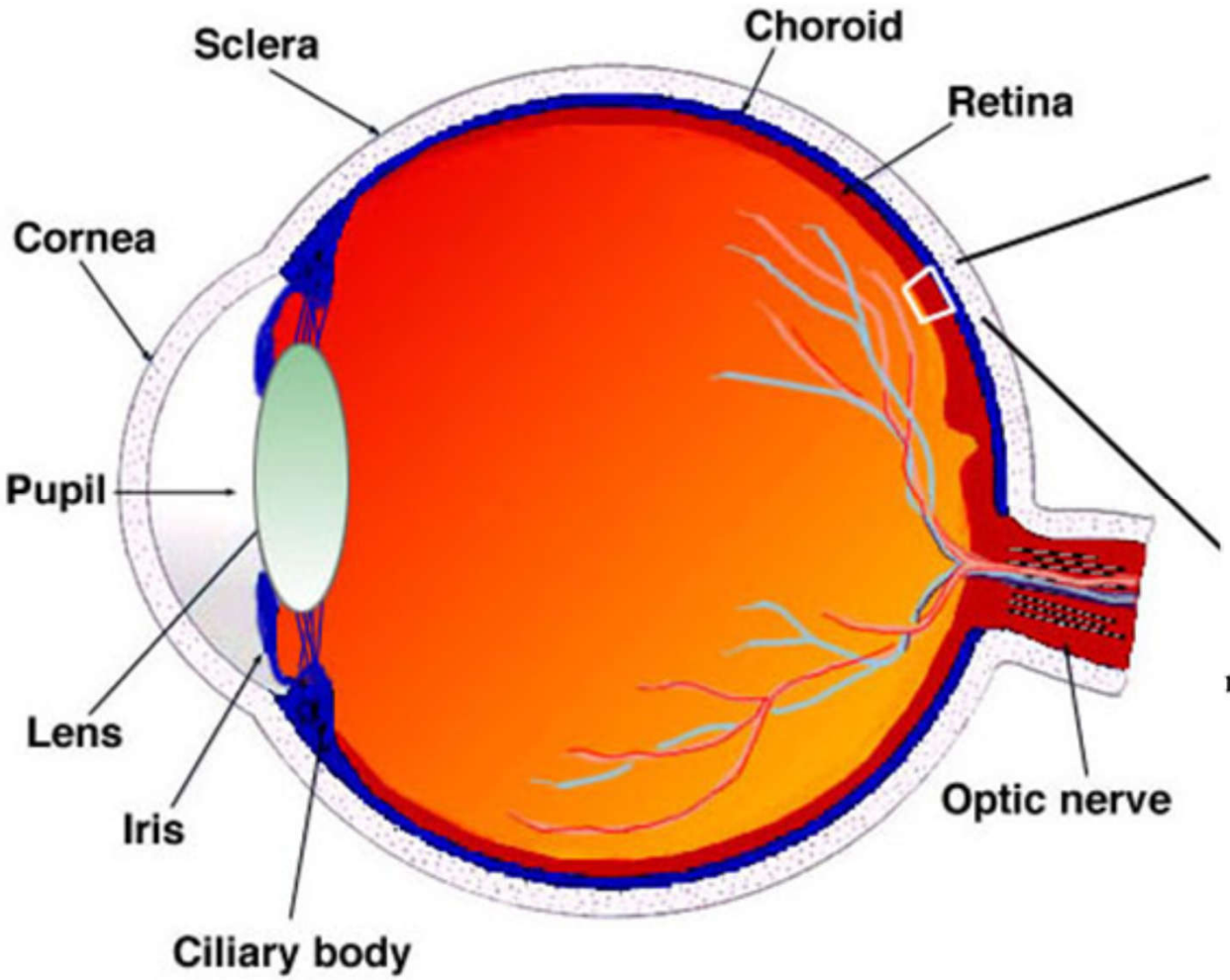
How the human eye works?

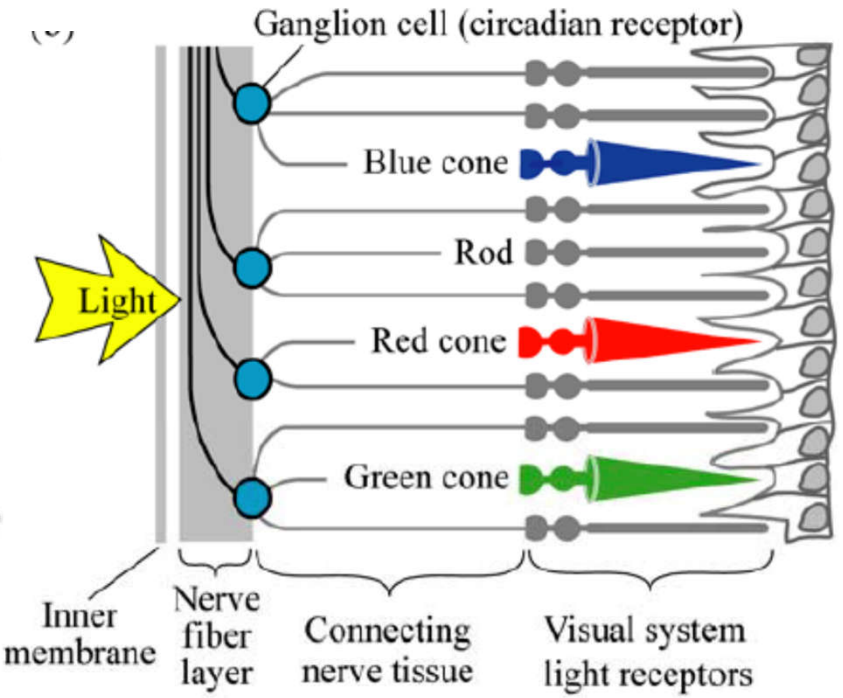


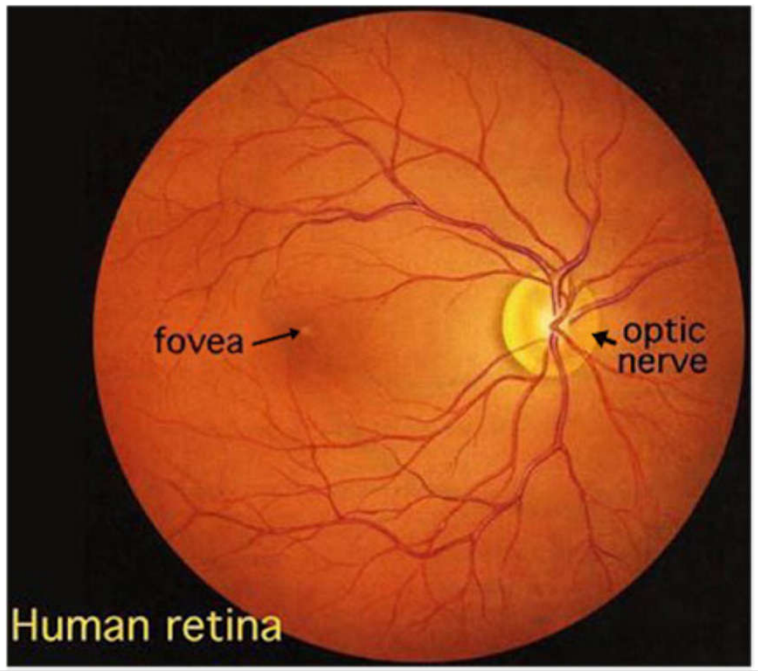
- 2. The retina 視網膜
  - Photoreceptors
  - Fovea – highly concentrated 2 degree field allowing colour and fine detail vision
  - Optic disk – "blind spot" pathway to end of the optic nerve (deficient in receptors)
- 3. Photoreceptors
  - Rods – 120 millions per eye
  - Cones – 8 millions per eye



Human eye and photoreceptors in the retina

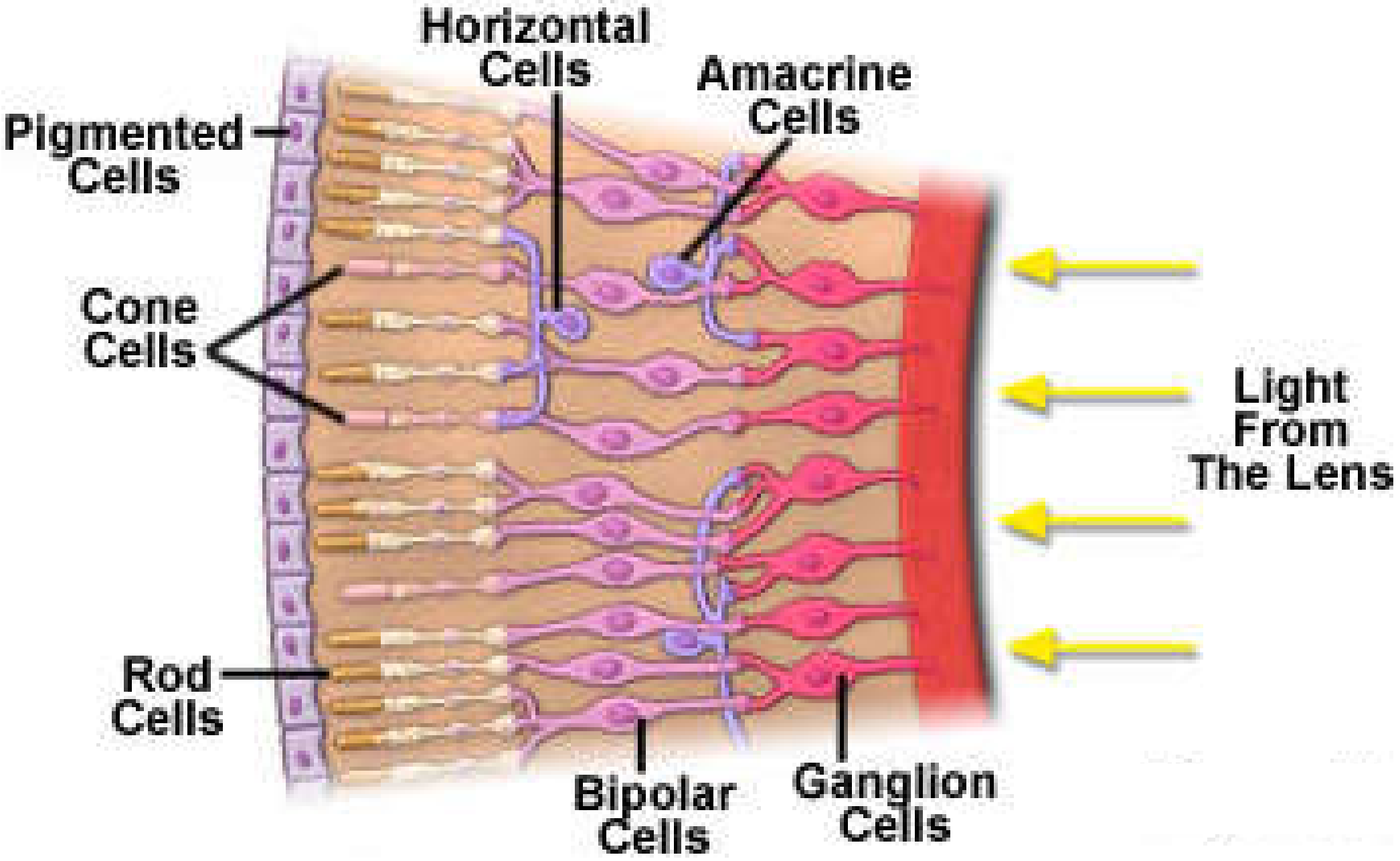






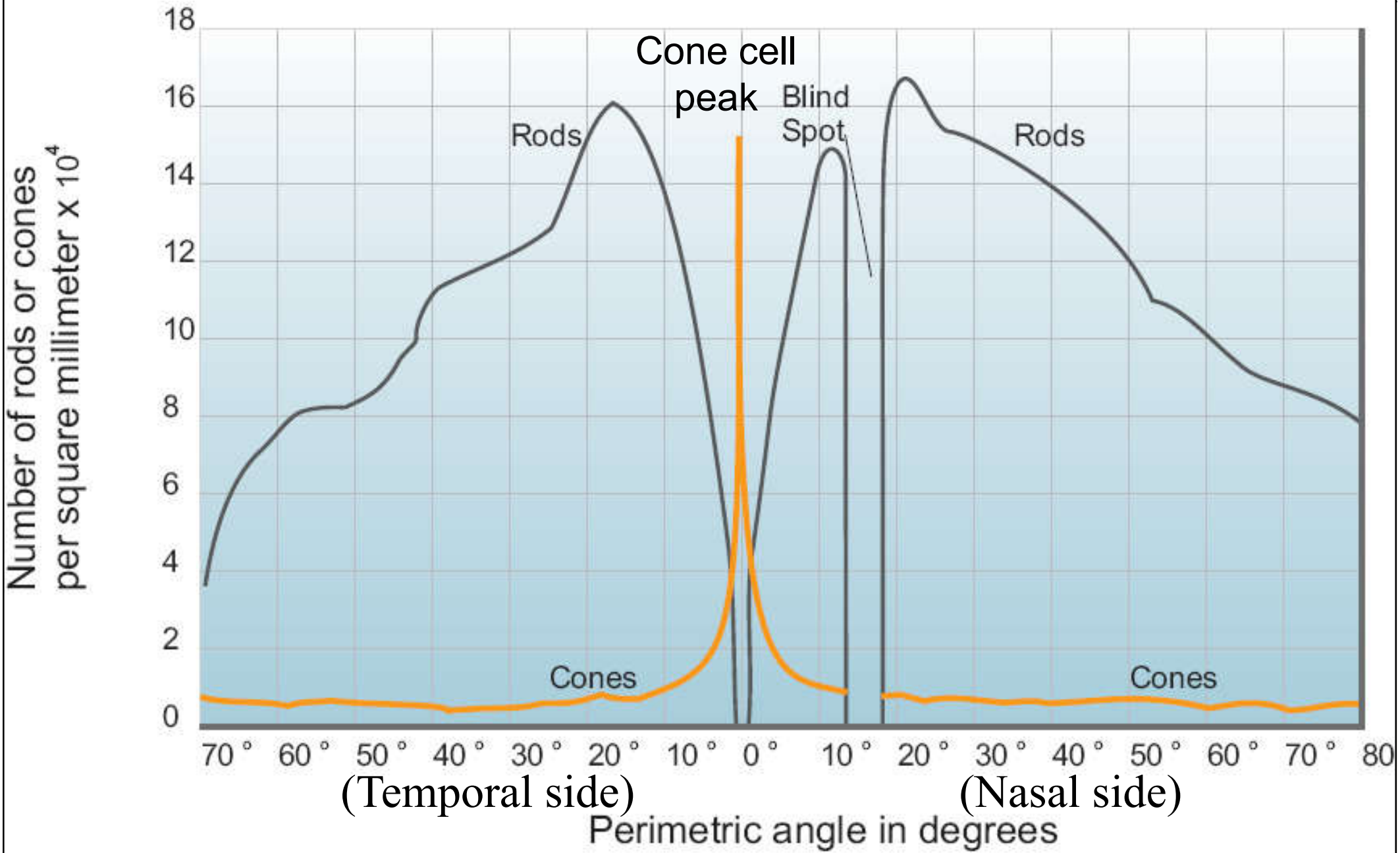
(Source: http://en.wikipedia.org/wiki/Photoreceptor_cell)

Microscopic anatomy of the retina



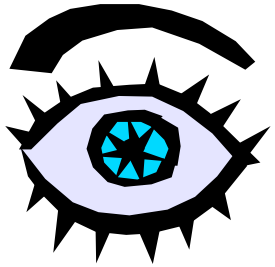
(Source: https://www.olympus-lifescience.com/en/microscope-resource/primer/lightandcolor/humanvisionintro/)

Distribution of rods and cones in the retina

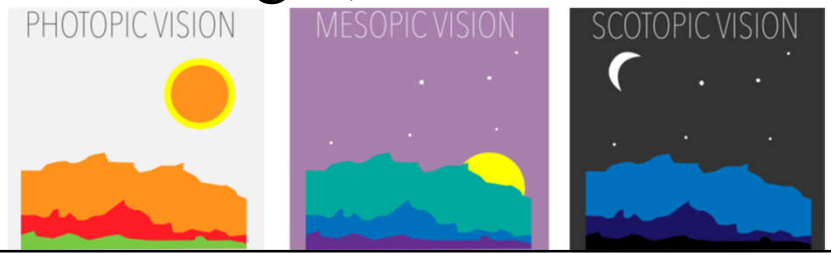


(Source: adapted from IESNA Lighting Handbook, 9th ed.)

How the human eye works?

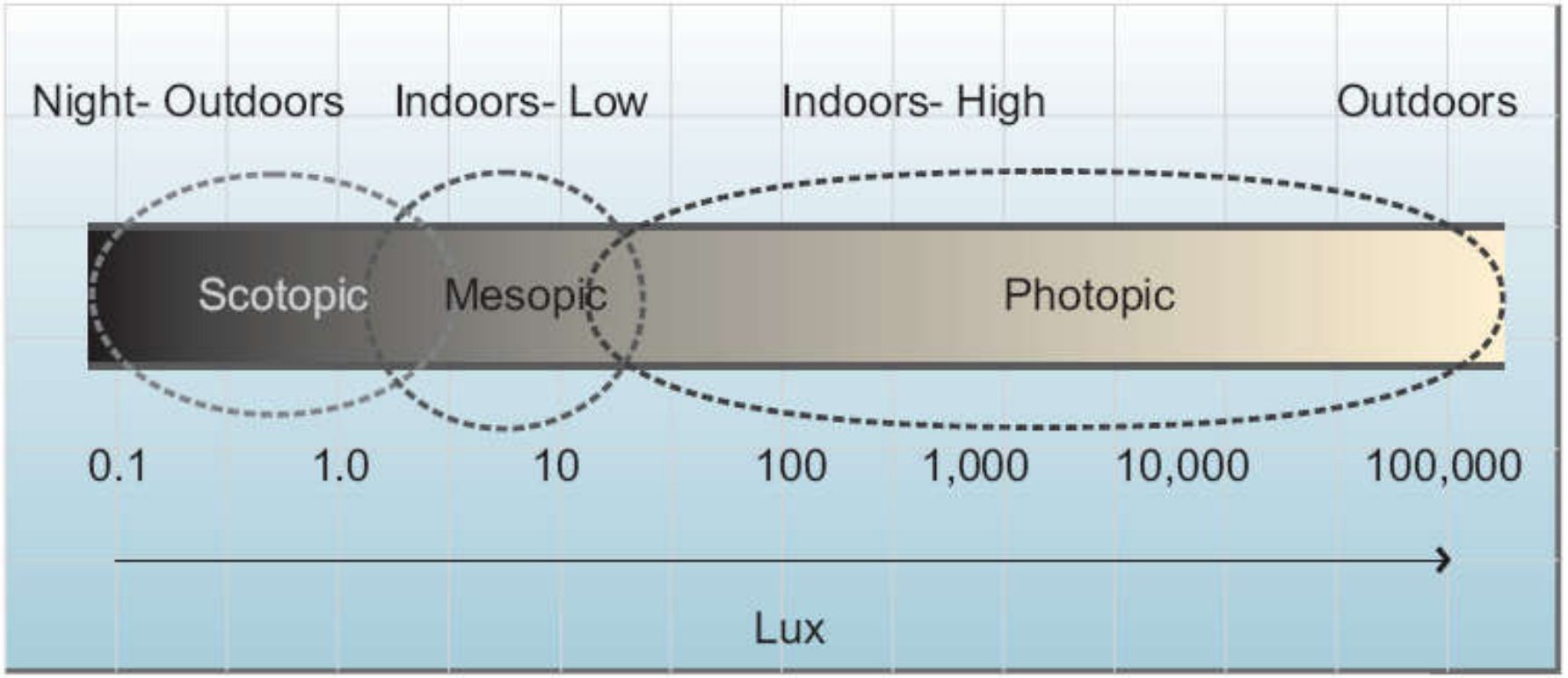


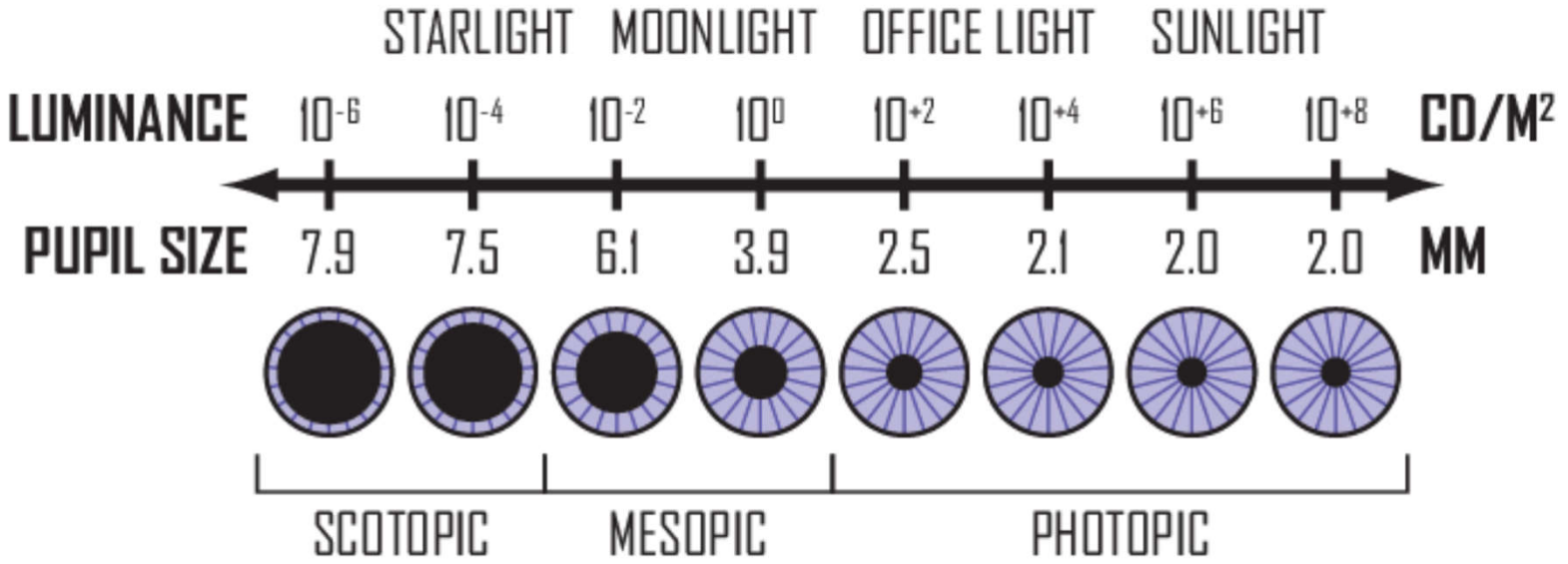
- Characteristics/Regimes of VISION
  - *Scotopic vision* 暗視 - in the dark by the rods
    - Luminance 10^{-6} to 10^{-2} cd/m^2 (dark adapted, by rods)
    - Low ambient light; only see in shades of grey
  - *Mesopic vision* 暮視 - between 10^{-2} and 10 cd/m^2
    - Sense of brightness & colour; foval detection
  - *Photopic vision* 適光 - above 10^{-2} cd/m^2
    - By cone mechanism (light adapted); in colour
    - High ambient light; enables details to be seen



Ranges of scotopic, mesopic and photopic visions

(Source: Advanced Lighting Guidelines 2001 and www.ecse.rpi.edu)

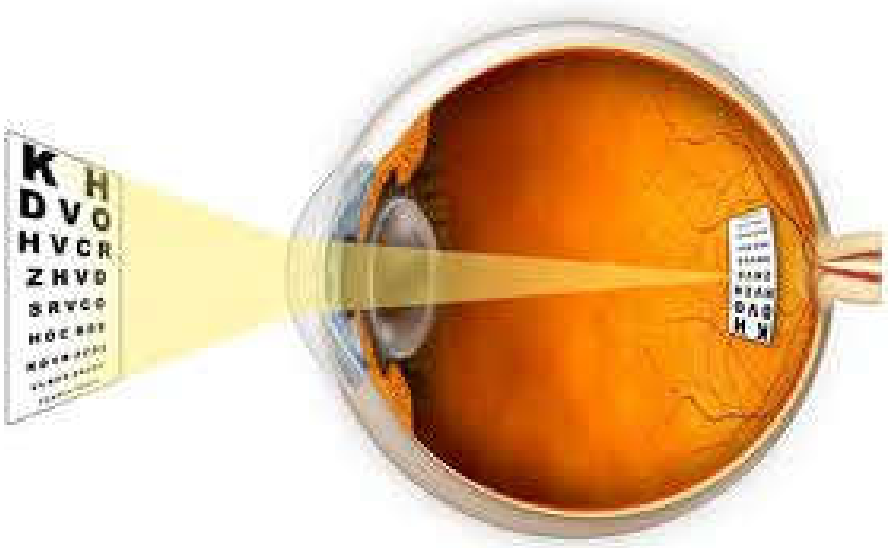


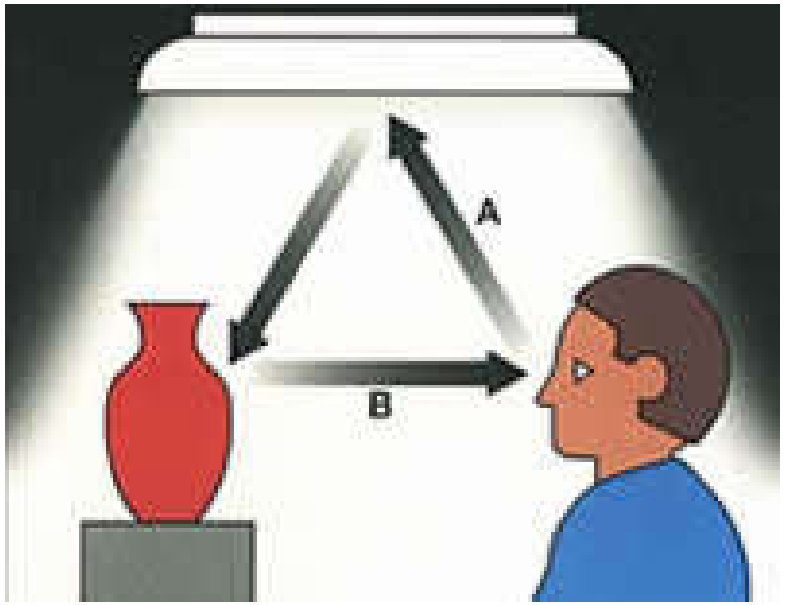


(Source: Advanced Lighting Guidelines 2001)

How the human eye works?

- Functions performed by the eye
  - 1. Adaptation
  - 2. Accommodation
  - 3. Eye movements





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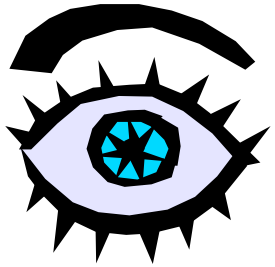
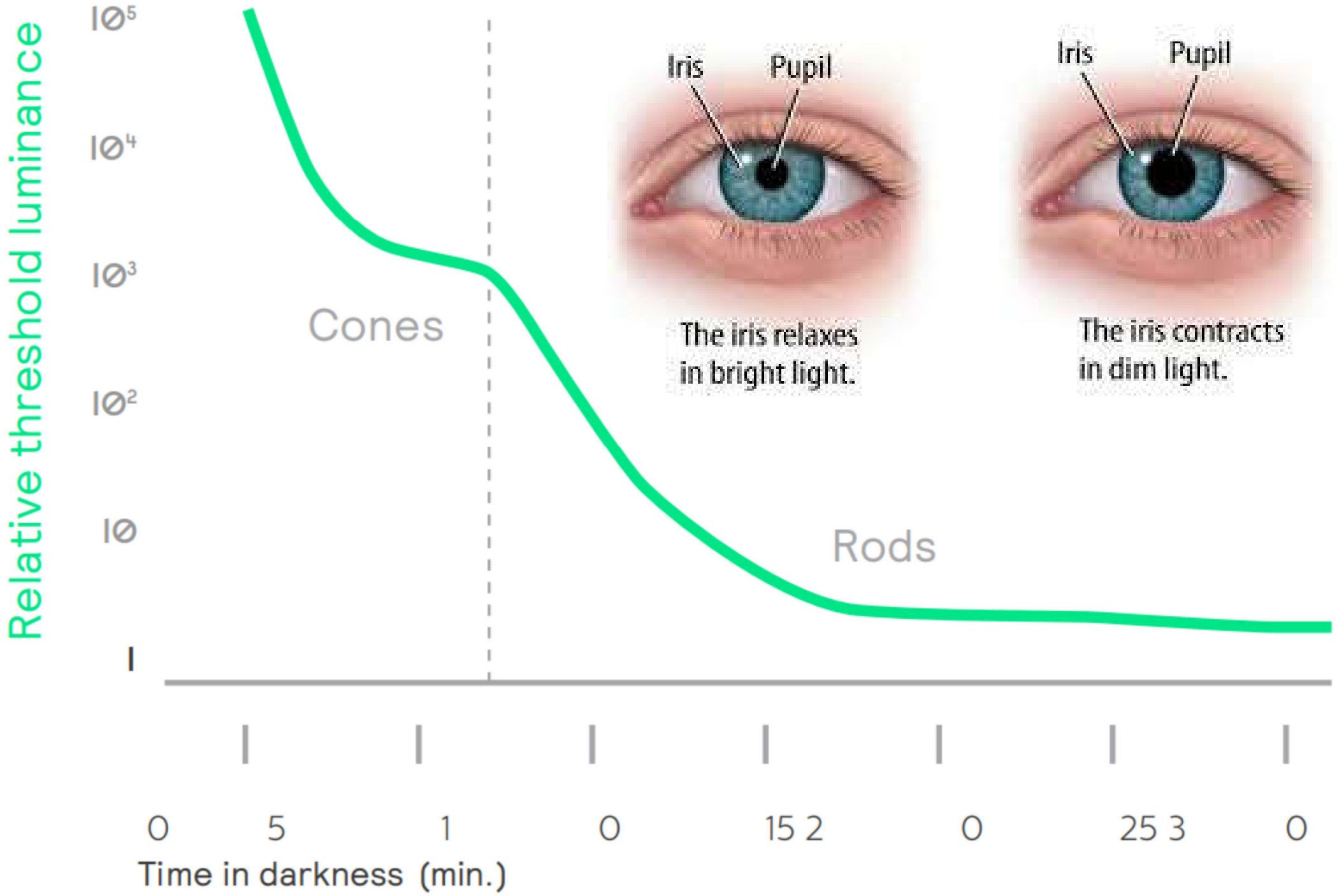


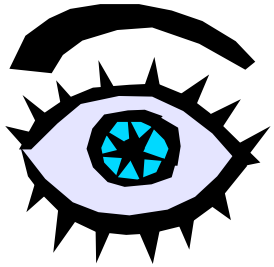
- 1. Adaptation
  - The process through which the eye changes its sensitivity to *respond* to different levels of light stimulation
    - Such as from dim “moonlight” to clear sky “daylight”
    - May take > 60 minutes for complete dark adaptation
  - Pupil size – 64 distinct magnitudes of control
    - Accounts for quantity of light entering eye and depth of field
  - Photochemical adaptation – over 1,000 levels

Adaptation time from light to dark

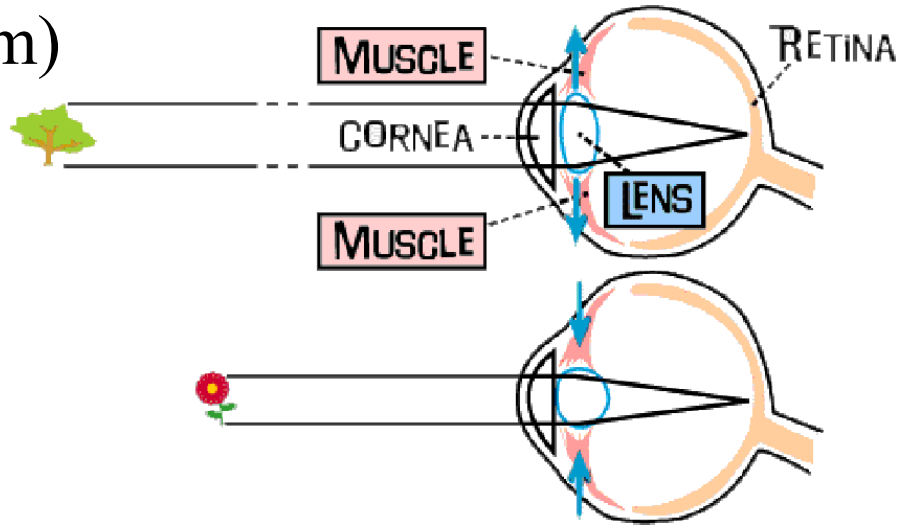


(Source: The Science of Lighting, Signify)

How the human eye works?

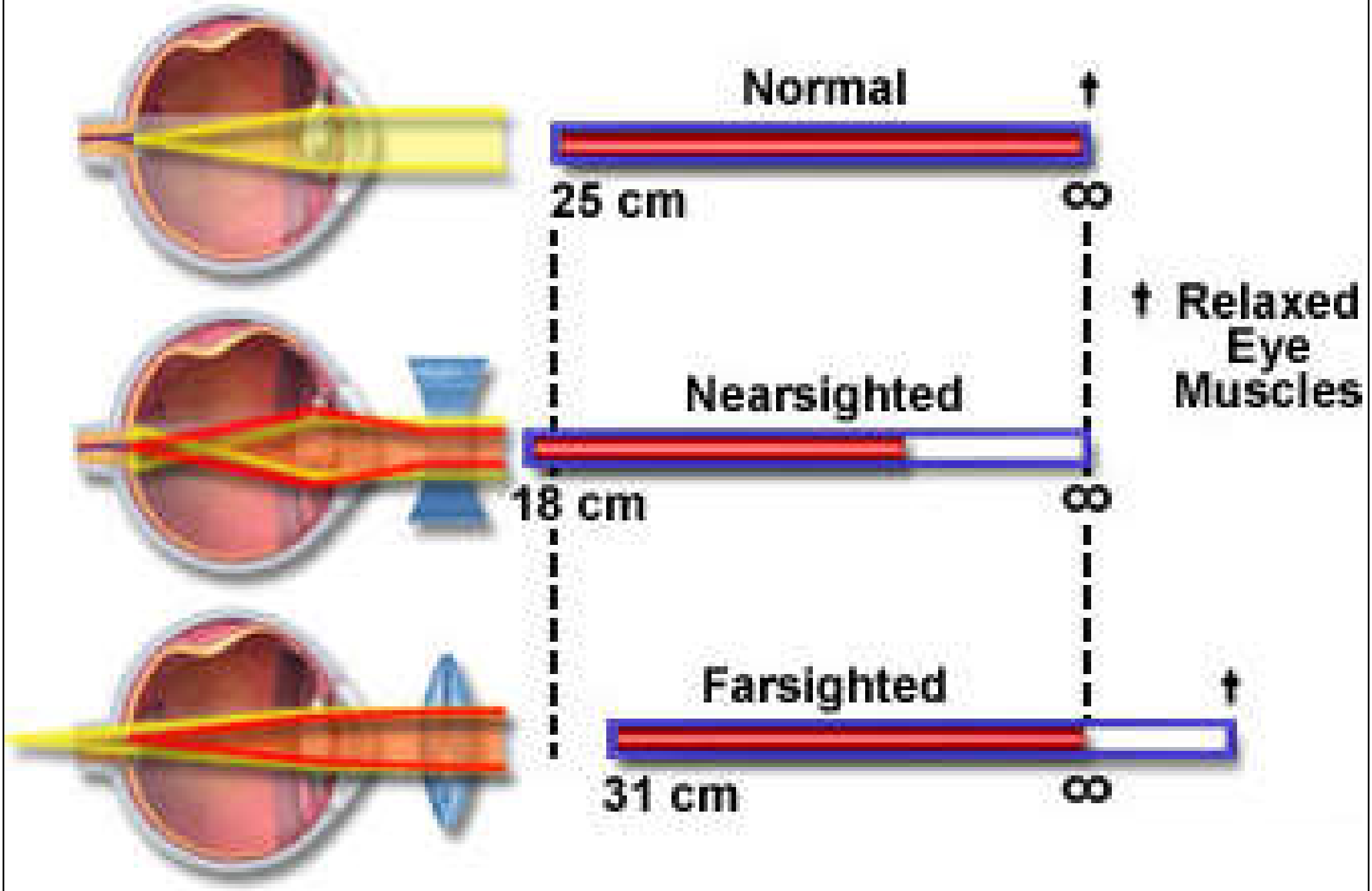


- 2. Accommodation
  - A process to focus images onto the retina by adjusting the curvature of the lens (by tightening the ciliary muscles)
    - *Near point* - closest distance at which objects can be focused (about 100-750 mm)



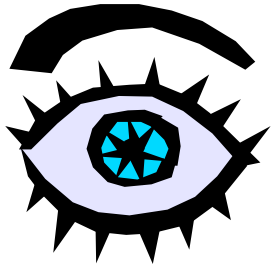
(* See also http://hyperphysics.phy-astr.gsu.edu/hbase/vision/accom.html)

Human eye accommodation range

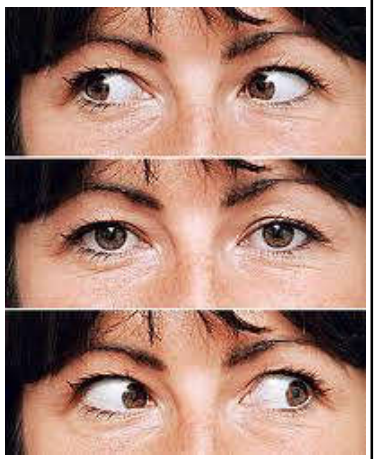


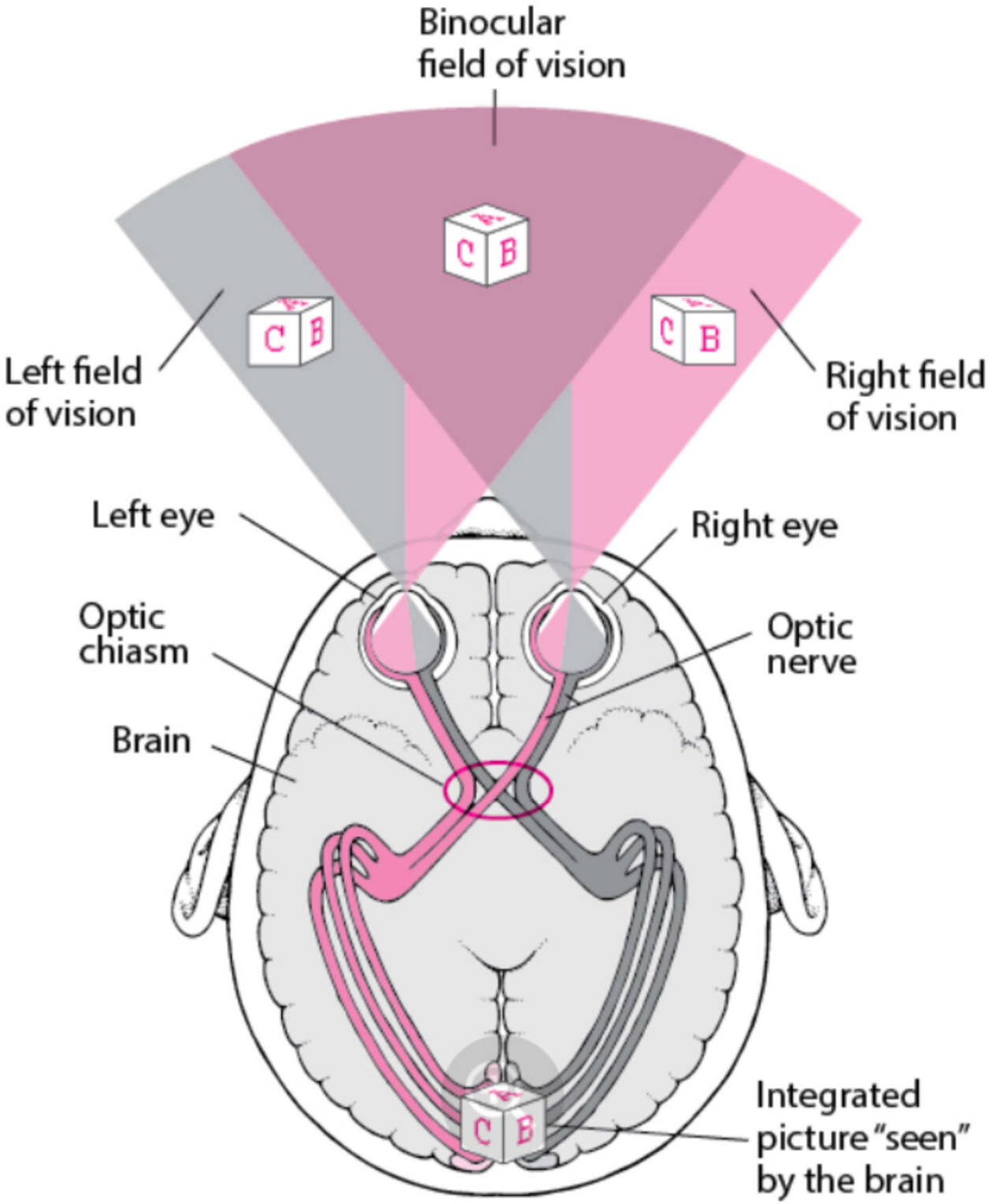
(Source: https://www.olympus-lifescience.com/en/microscope-resource/primer/java/humanvision/accommodation/)

How the human eye works?



- 3. Eye movements
  - Each eye has six muscles to control the movement of the eye
  - Smooth pursuit movement – binocular
  - Saccadic movement – "jumping" focus when scanning areas
  - Disjunctive eye movements – opposing eye movements for different distances

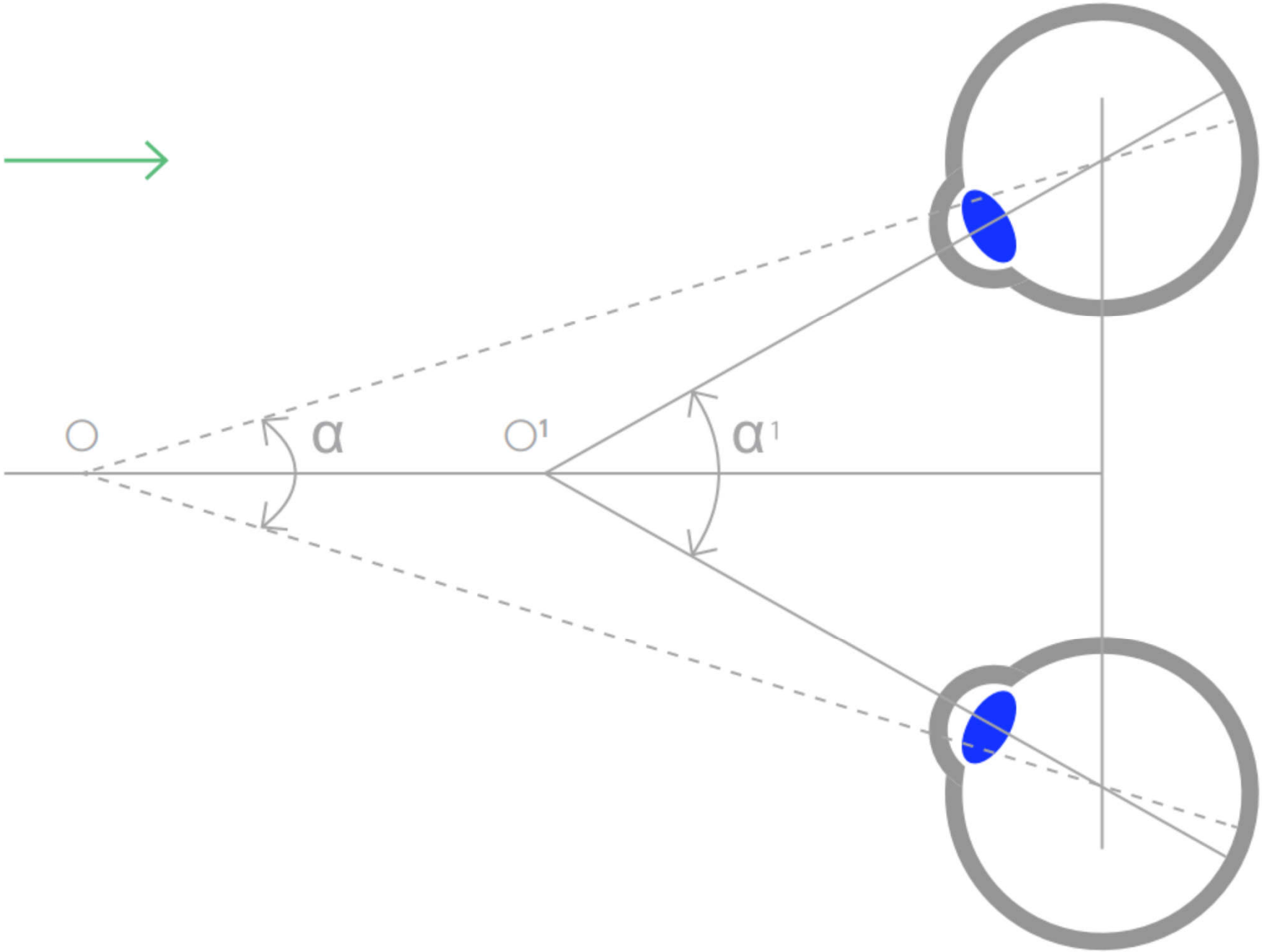




Binocular vision with two eyeballs

(Source: https://www.msdmanuals.com/home/eye-disorders/biology-of-the-eyes/structure-and-function-of-the-eyes)

With both eyes, different angles of convergence for objects at different distances help us to see depth



(Source: The Science of Lighting, Signify)

What lighting can do?

- "Lighting" is the application of light to spaces
  - Have a major impact not only on vision and visual comfort, but perception
  - Can impact satisfaction, visibility, task performance, safety, security, sales, mood and atmosphere, aesthetic judgment and social interaction
  - Also tells a story about the space, such as whether a restaurant is selling fast food or a fine dining experience

Examples of restaurant lighting design (fast food & fine dining)

(Source: https://www.luminancesys.com/pages/restaurant-lighting-design)

What lighting can do?

- Major visual effects of lighting
  - 1. Colour perception: For an object to be perceived a certain colour, that colour must be present both in the object & the content of the light striking it
  - 2. Focus: The human eye is naturally attracted to the brightest area in the field of view
  - 3. Space perception: The pattern of light in a space can stimulate a psychological response
  - 4. Modelling: The contrast of light & shadow can reveal texture & add depth to objects & surfaces

Lighting effect and psychological impact

Psychological impact	Lighting effect	Light distribution
TENSE	Intense direct light from above	Non-uniform
RELAXED	Lower overhead lighting with some lighting at room perimeter, warm color tones	Non-uniform
WORK/VISUAL CLARITY	Bright light on workplane with less light at the perimeter, wall lighting, cooler color tones	Uniform
SPACIOUSNESS	Bright light with lighting on walls and possibly ceiling	Uniform
PRIVACY/INTIMACY	Low light level at activity space with a little perimeter lighting and dark areas in rest of space	Non-uniform

(Source: https://www.lightnowblog.com/2016/03/introduction-to-lighting-design/)

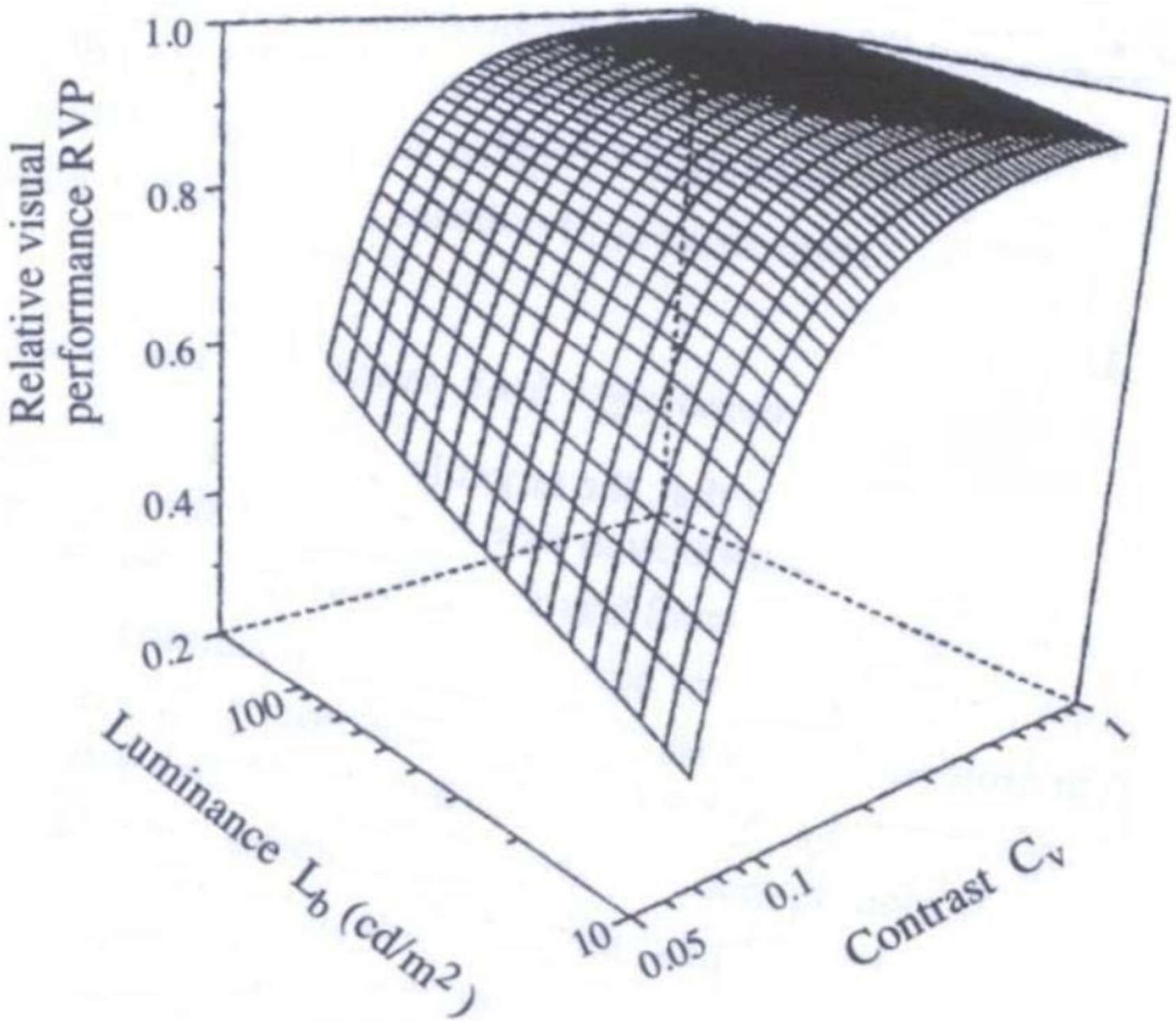
Modelling to reveal texture & add depth to faces, objects & surface

(Source: https://www.lightnowblog.com/2016/03/introduction-to-lighting-design/)

What lighting can do?

- Visual performance
  - Major aspect: Provide adequate lighting for people to carry out their visual tasks
    - Visibility is defined by our ability to detect objects or signs of given dimensions, at given distances & with given contrasts with the background
    - Visual performance is defined by the speed & accuracy of performing a visual task
  - Visual performance & consumption of electricity for lighting should be in balance in order to increase energy efficiency

Relative visual performance as a function of background luminance and target contrast



(Source: Halonen L.,1993. *Effects of Lighting and Task Parameters on Visual Acuity and Performance*, Thesis for the degree of Doctor of Technology, Helsinki University of Technology, Espoo.)

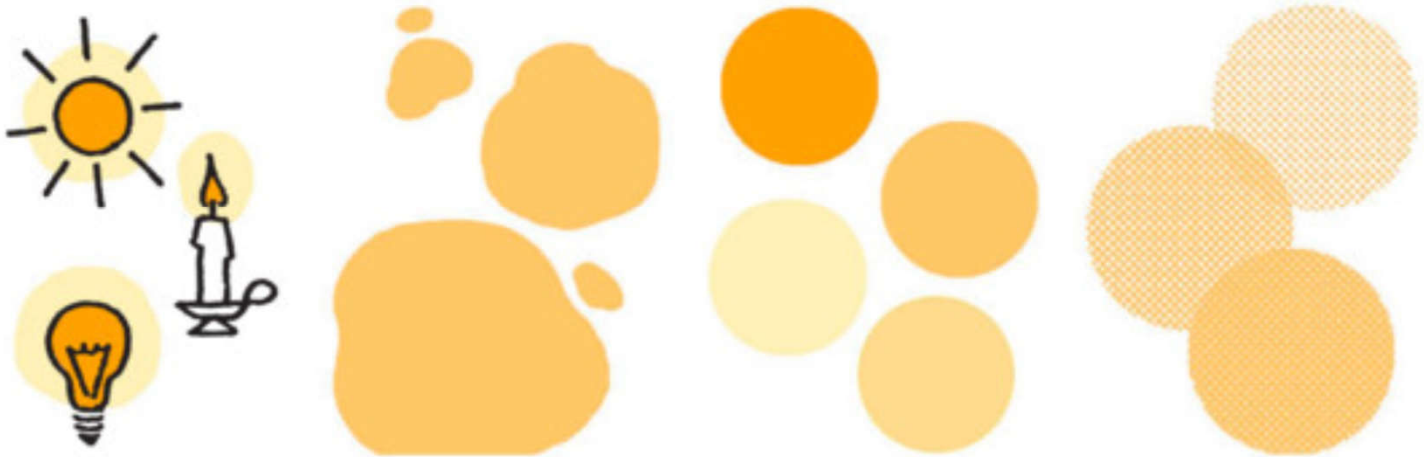
What lighting can do?

- Visual comfort
  - It is highly dependent on the application
    - Lighting that is considered comfortable in an entertainment setting may be disliked and regarded as uncomfortable in a working space
  - Pleasantness of the visual environment and its adaptation to the type of room & activity
- Many physical & physiological factors can influence the perception of lighting quality
- Also long term effects of light on our health

Considerations for visual comfort

To be able to fully describe light, one needs to discuss its many aspects:

its source, its distribution, its tone and color, its intensity…



Being able to control light levels is also key to visual comfort: both too little and too much light can be a source of discomfort.

Sharp constrast or major changes in light levels can cause stress and fatigue, as the human eye is permanently adapting to light levels.

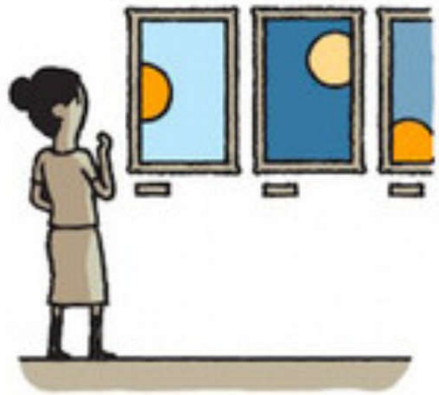
(Source: https://www.archdaily.com/911210/let-there-be-light-key-indicators-to-describe-and-design-visual-comfort)

The socio-psychological aspects of visual comfort

The SOCIO PSYCHOLOGICAL aspect of visual comfort

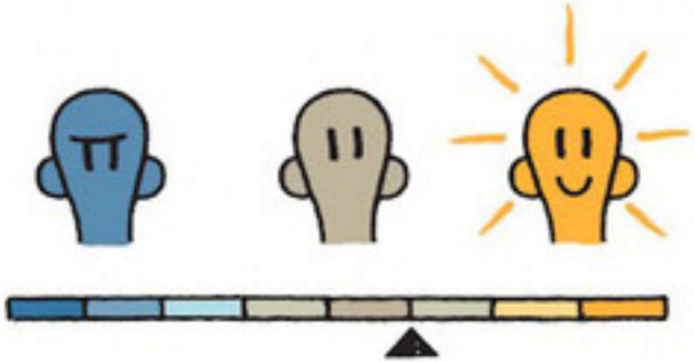
Light has a profound effect on the way we feel and experience time and space, both consciously and unconsciously.

Our personal history and culture also shapes the way we appreciate light and visual environments.



Extreme variations in preferred range of illuminances exist depending on age and culture.

But whatever the nationality, age or social category, light directly influences the mood and health of all humans.



Non-visual effects of light play an important role in this respect. Their discovery is fairly recent and they remain the subject of active scientific research.

(Source: https://www.archdaily.com/911210/let-there-be-light-key-indicators-to-describe-and-design-visual-comfort)

What lighting can do?

- Factors affecting visual comfort
  - Illuminance level
  - Uniformity & light distribution in a space
  - Glare & veiling reflections
  - Formation of shadows in the space
  - Flicker (fluctuation of light emitted by light source)
  - Light colour characteristics
- Psychological aspects of light
  - Light scenes judged w/ references & expectations

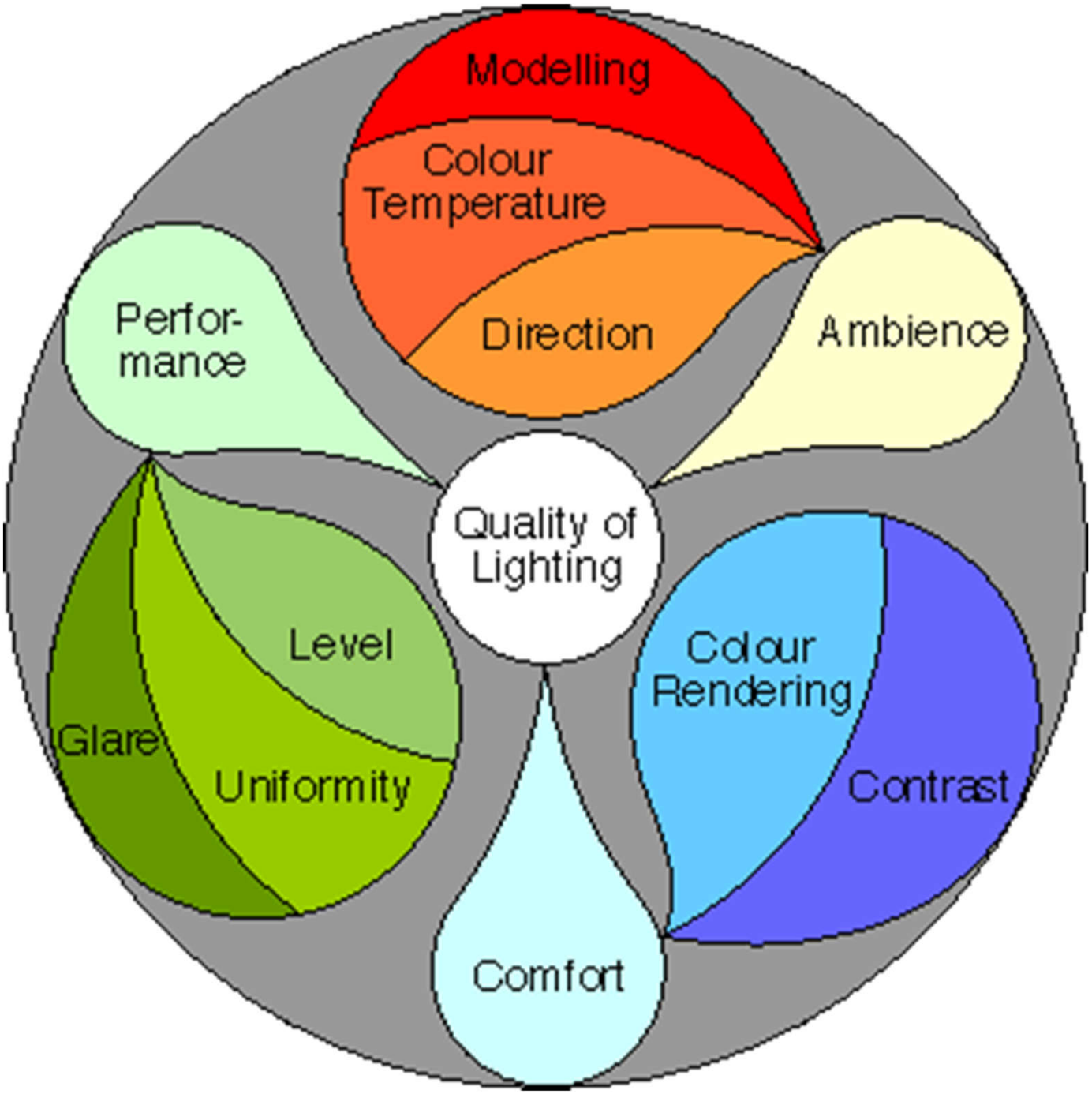
Colour mood chart for psychology emotion

(Source: https://www.spiritedexchanges.ca/thrive-in-2018/b5-colour-mood-chart/)

Lighting quality

- 1. Lighting level
  - To support visual performance for the tasks
- 2. Luminance contrast
  - Luminance distribution within the field of view
- 3. Glare restriction
  - Brightness levels within the visual field
- 4. Spatial distribution of the light
  - Determines the pattern of illuminances that will be created
- 5. Colour and colour rendering
  - Colour composition of the lighting & appearance

The quality of the lighting depends on a number of factors



(Source: http://www.new-learn.info/packages/mulcom/comfort/visual/quality/content.html)

Visual contrast – lack of contrast can reduce visibility

HIGH

Contrast is necessary for visibility

MEDIUM

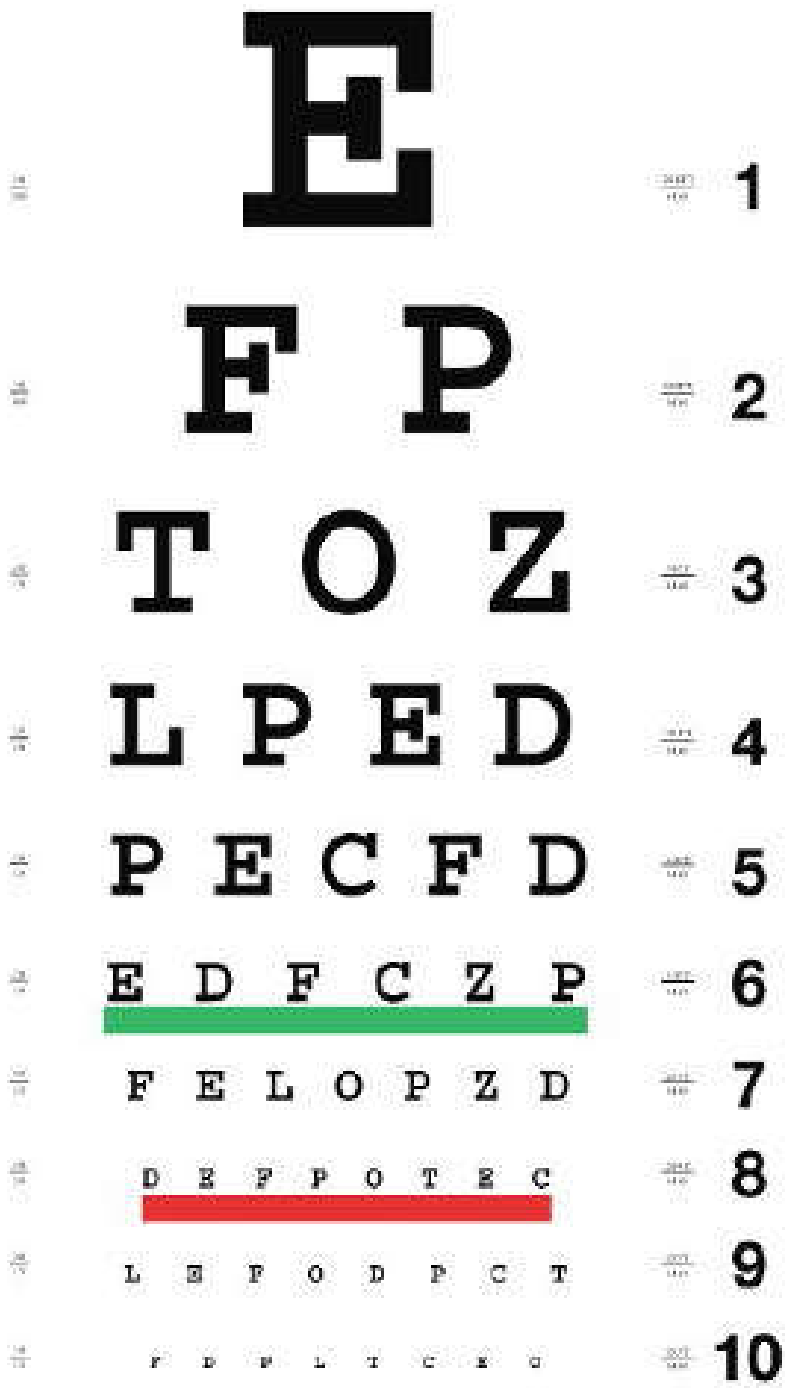
Contrast is necessary for visibility

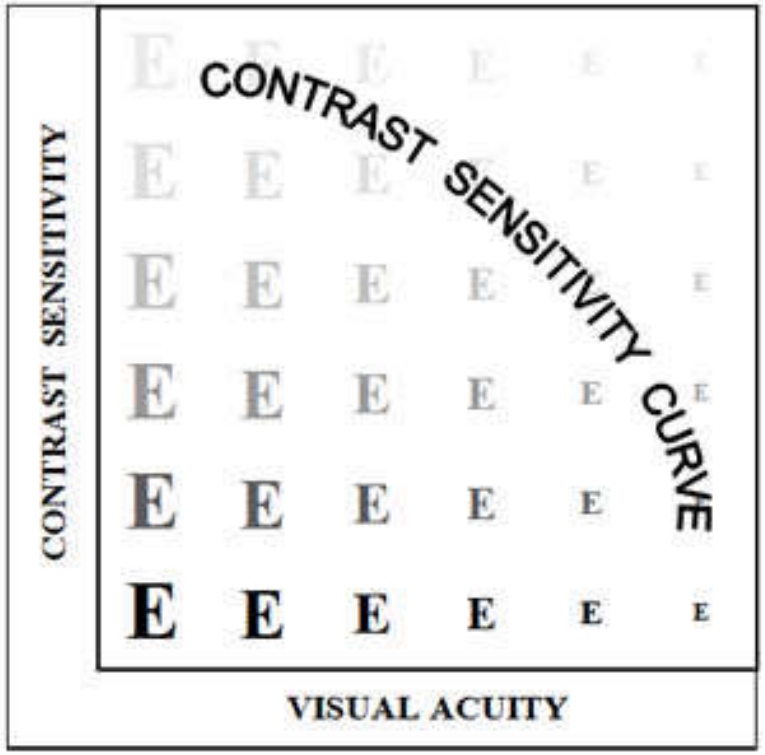
LOW

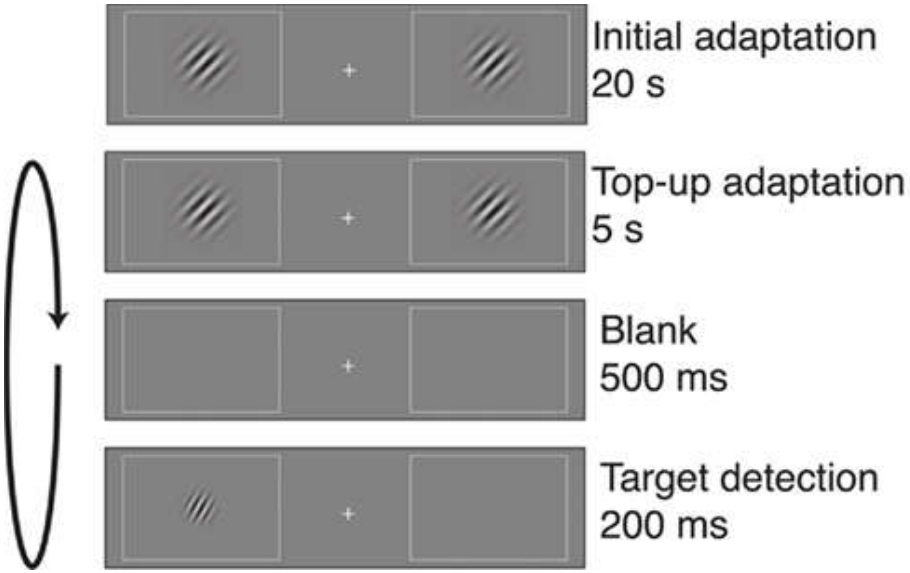
Contrast is necessary for visibility

(Source: Advanced Lighting Guidelines 2001)

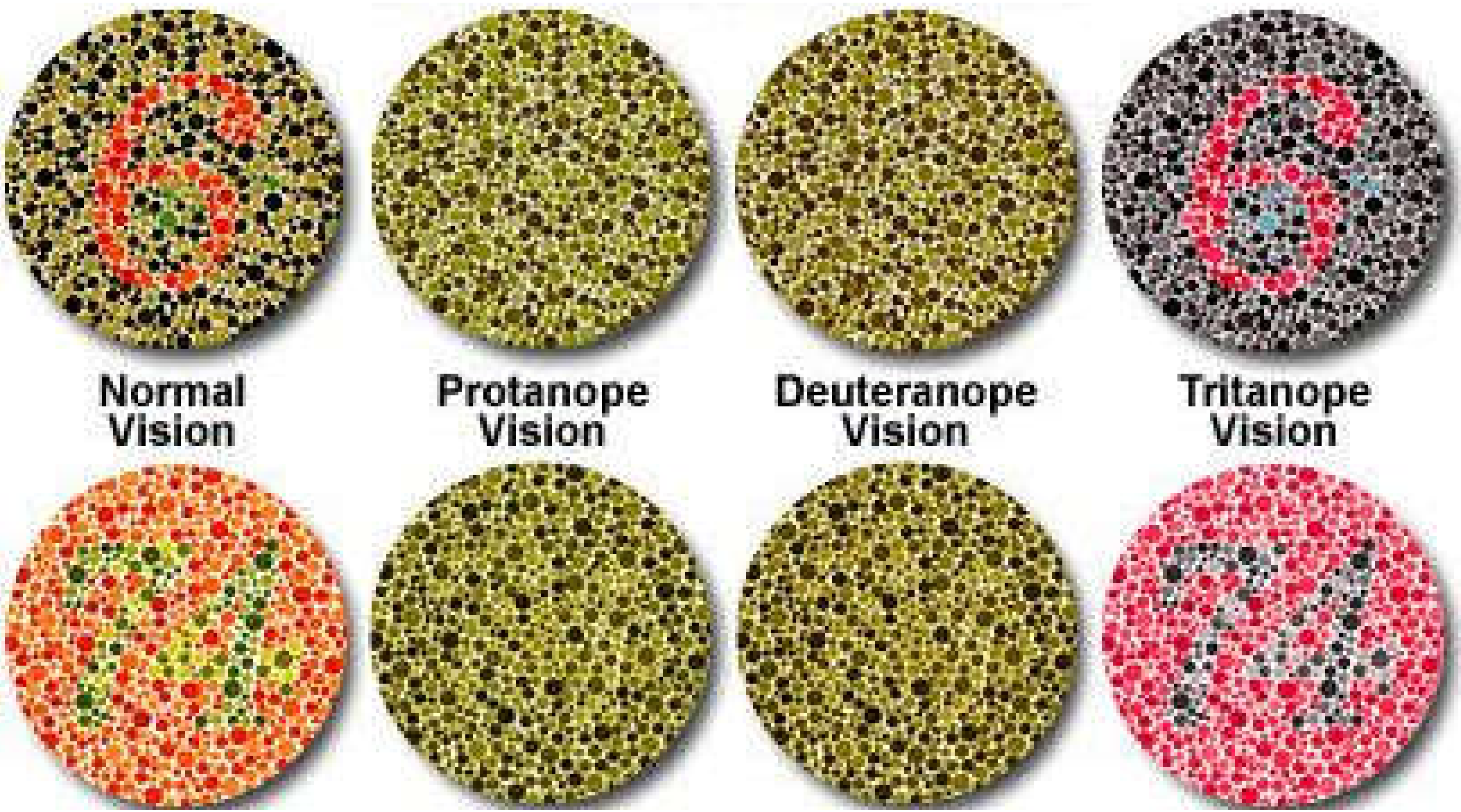
Methods for measuring vision







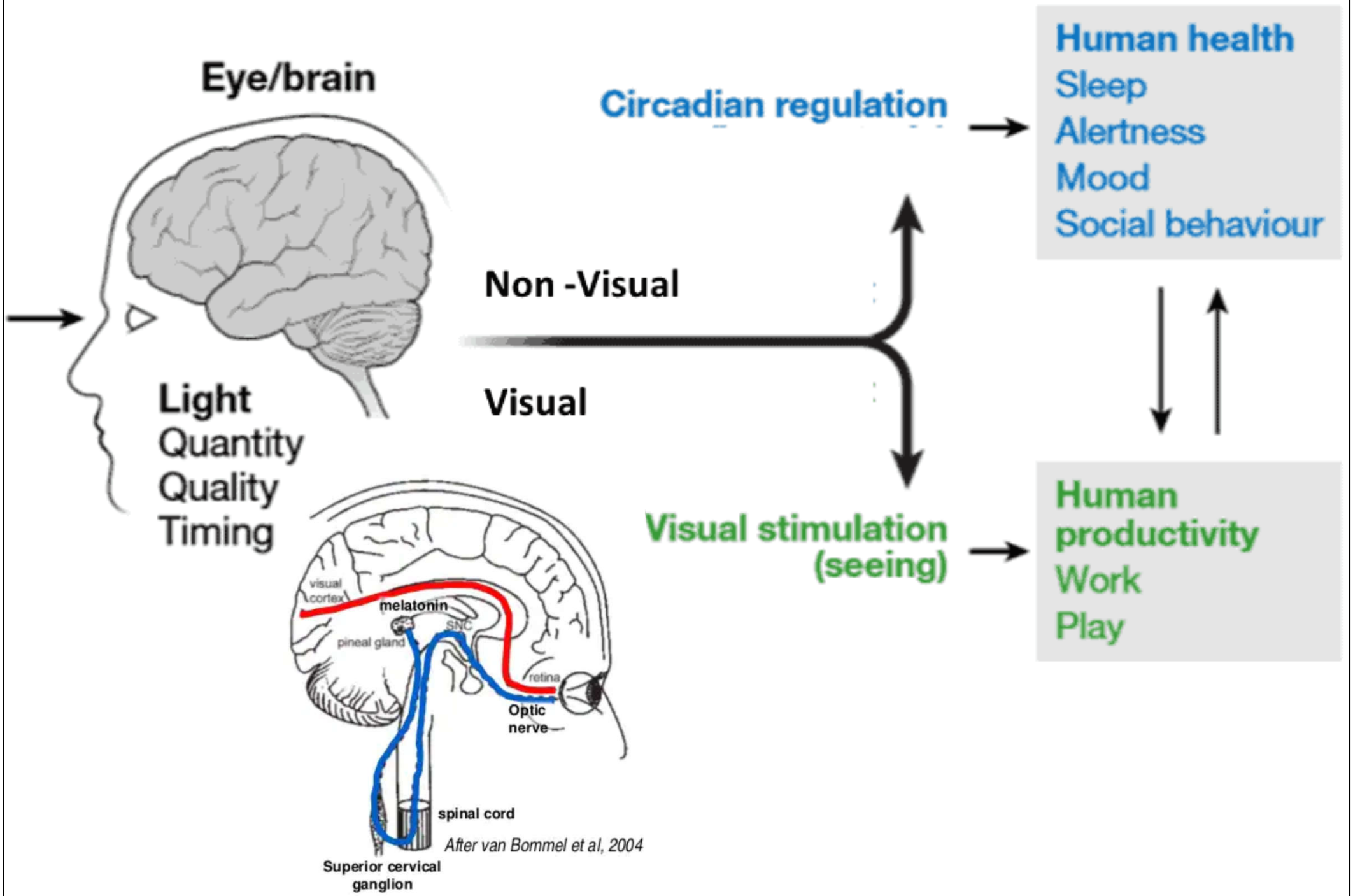
Ishihara colour blindness test



Ishihara Colorblindness Test:
https://www.colorlitelens.com/ishihara-test
https://www.olympus-lifescience.com/en/microscope-resource/primer/java/humanvision/colorblindness/

(Source: https://www.olympus-lifescience.com/en/microscope-resource/primer/lightandcolor/humanvisionintro/)

Visual and non-visual effects of light



(Source: https://www.oledworks.com/news/blog/from-lumen-centric-to-human-centric/)

Lighting quality

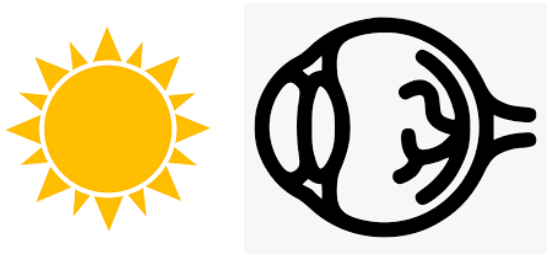
- Non-visual effect of light
  - Impact of lighting on human health, well-being & visual performance
  - Physiological mechanisms of the visual & non-visual effects of light on humans
  - Biological bases of photoreception & non-image-forming vision at the cellular level
- Circadian lighting & human centric lighting
  - Visual, emotional & biological effects

Light has both visual and non-visual responses acting through the different retinal photoreceptors and tracts in the nervous system

Light

Eye and retina

Rods
Cones



Intrinsically photosensitive retinal ganglion cells (ipRGC)

Nervous system

Primary optic tract

Occipital cortex

Retinohypothalamic tract

Synaptic outputs in the brain

Physiology

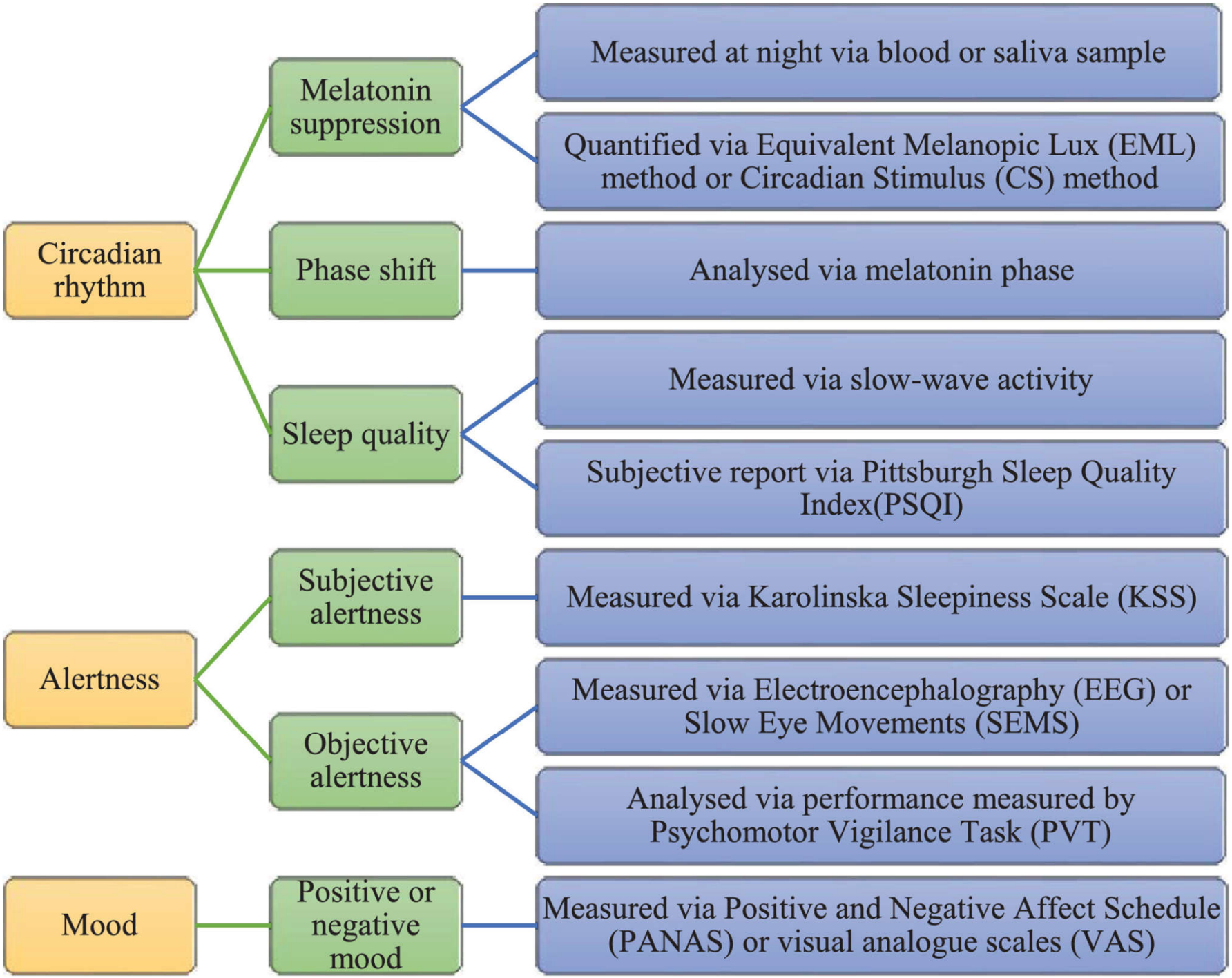
Vision

- Visual performance
- Figure recognition
- Movement perception
- Colour vision

Biological response

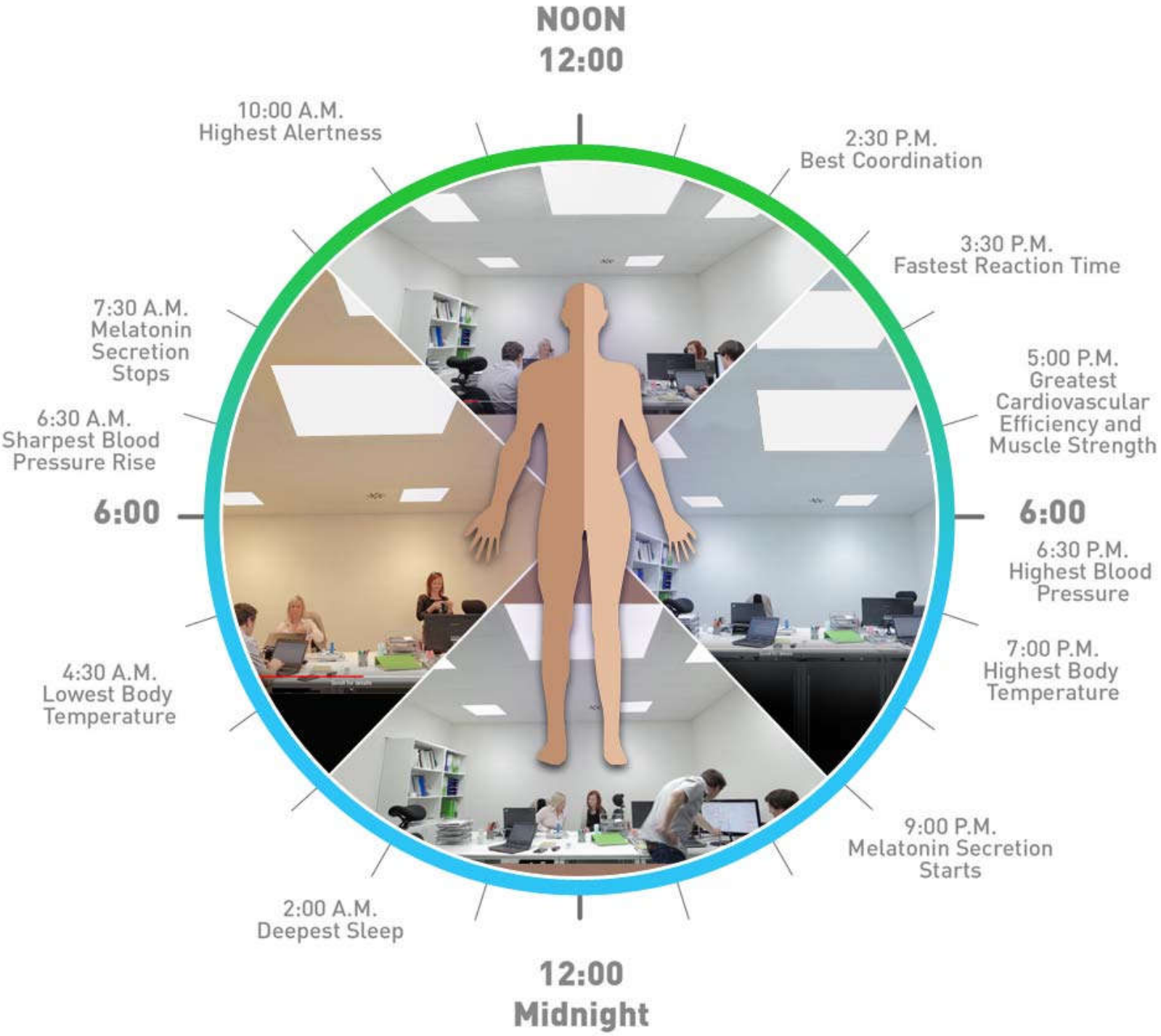
- Health & wellbeing
- Biological rhythms
- Hormonal action
- Cognitive performance
- Alertness
- Body temperature
- Blood pressure

Three aspects of non-visual effects of light*



(*Xiao X., Cai H. & Li X., 2021. Non-visual effects of indoor light environment on humans: A review, *Physiology & Behavior*, 228: 113195.)

Human Centric Lighting (HCL) based on the biological effects of light



(Source: https://www.actis.co.in/human-centric-lighting-hcl-why-is-it-a-buzzword-in-the-lighting-industry)

Design of different types of human centric lighting (HCL)

Circadian Lighting

The light is not static but changes throughout the day in terms of its colour and intensity. An installation of this type promotes the necessary sleep-wake rhythm.

Energising Lighting

Light with a high blue component (or cold white) and which energises the body, increasing performance as well as the ability to concentrate.

Relaxing Lighting

Light with a warm white tonality (with a high red component) has a relaxing effect on our body.

Emotive Lighting

Light that adapts to the chromatic intensity and tonality, depending on the emotional needs of the individual.

(Source: https://www.elt.es/en/human-centric-lighting)

Entertainment lighting to synchronise with movies, music & games

(Source: https://www.philips-hue.com/en-hk/explore-hue/philips-hue-benefits)

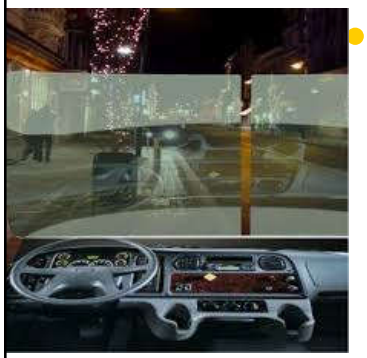
Design considerations

- Task parameters affecting visual performance
  - Contrast (C) – relationship between object and background luminances (L)
    - $C = (L_{task} - L_{background}) / L_{background}$
  - Size – visual angle subtended by an object from an observer
  - Luminance – quantity and quality of light reflected from an object
  - Time – viewing time necessary to process vision

Design considerations

- Building design considerations

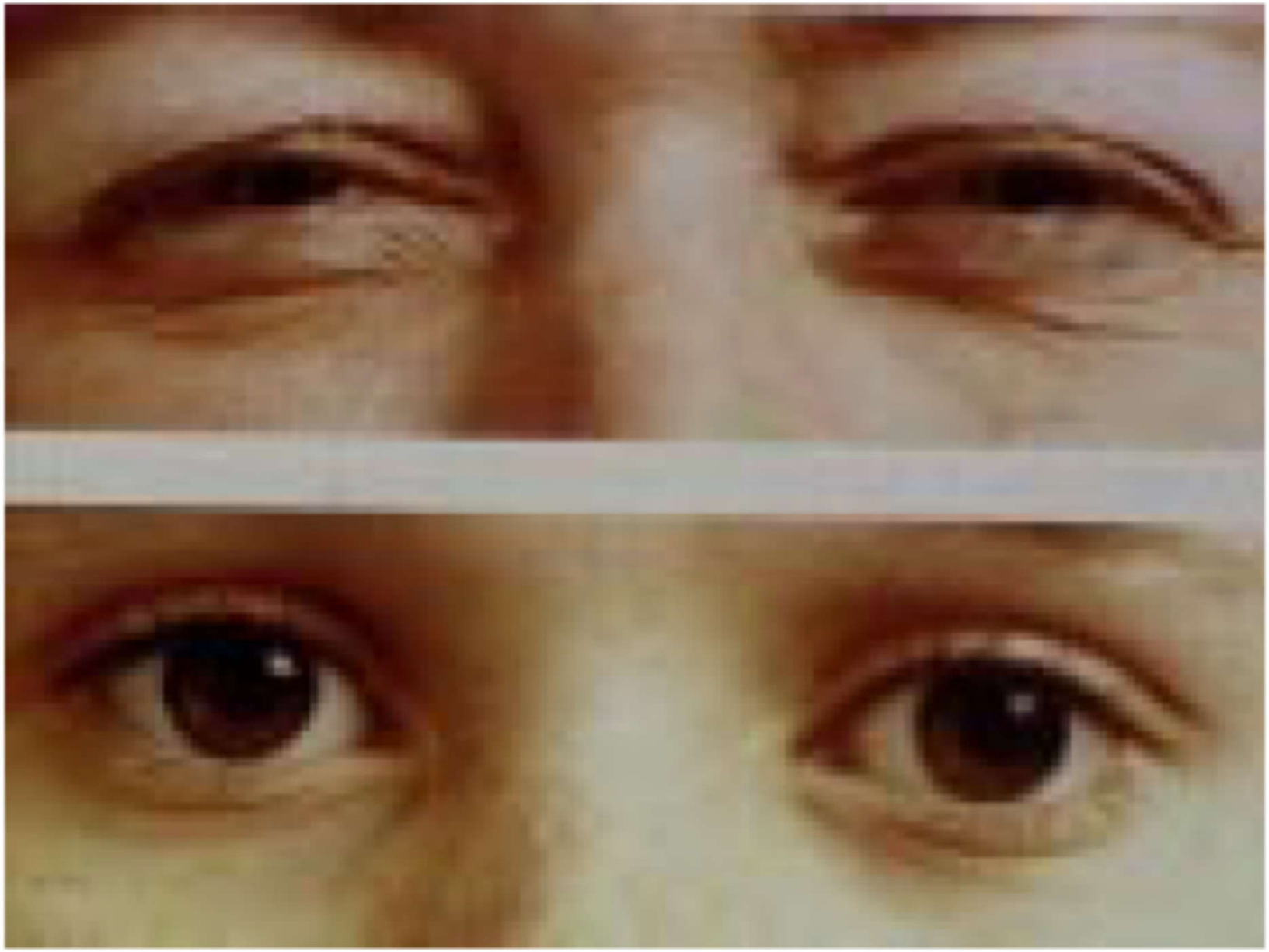
眩光
- Discomfort glare
  - Luminance which causes visual discomfort
    - Source luminance, position, size, number of sources, field luminance
- Disability glare
  - Luminance which adversely affects visual performance
- Veiling reflections
  - Reflected luminance which prevents visual performance
    - Tasks viewed at a mirror angle to a source



Examples of glare and veiling reflection

Bright light entering
from a window

Veiling reflection from
overhead light source



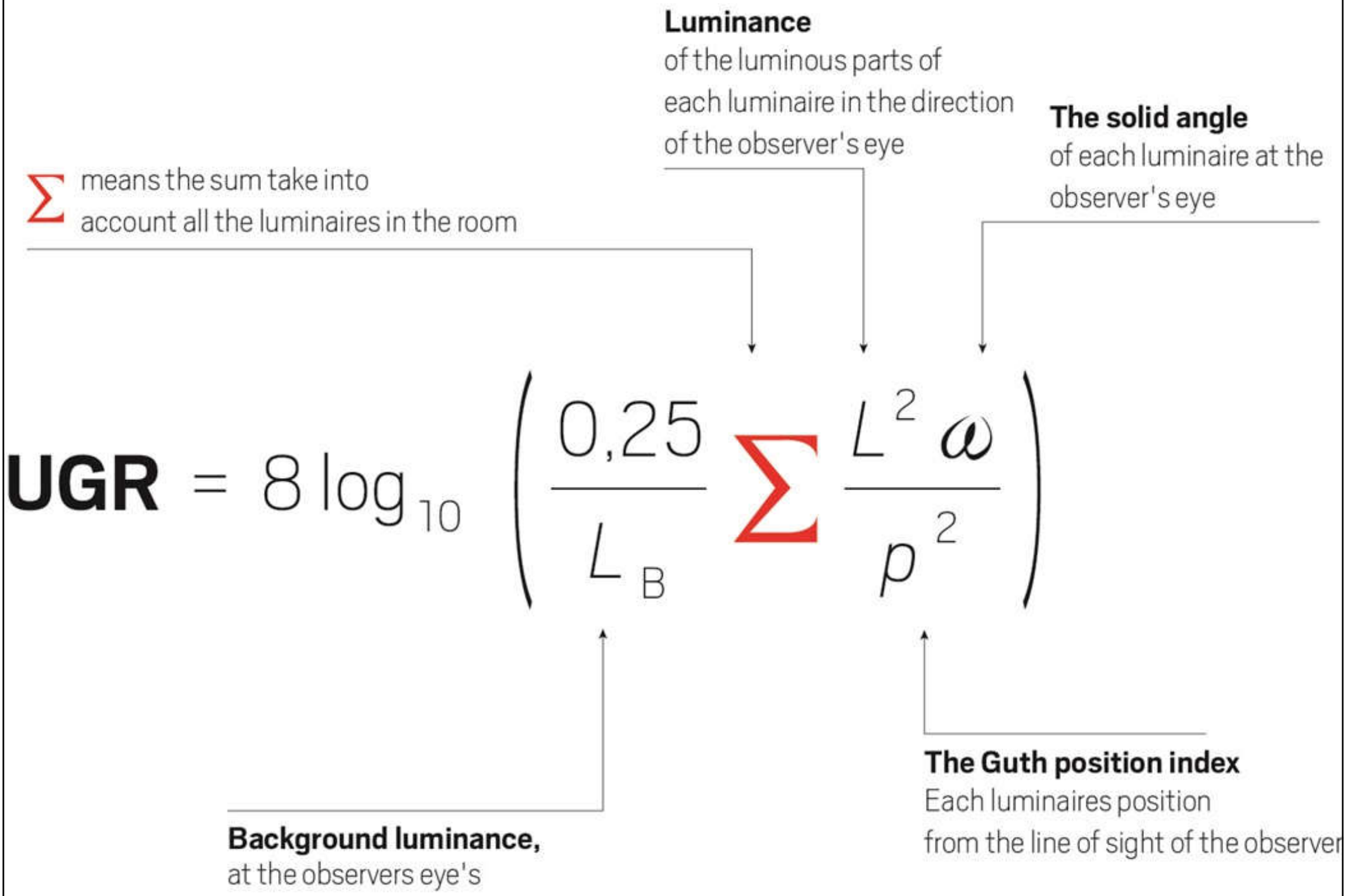
It is critical that lamps and luminaires be selected to mitigate the problem of discomfort glare.

Design considerations

- Unified glare rating (UGR) 統一眩光指數
  - A method of calculating glare from luminaires, light through windows & bright light sources
  - Helps to determine how likely a luminaire is to cause discomfort to those around it
  - UGR values range from 40 (extremely high glare) to 5 (very low glare)
  - International standards e.g. EN12464 recommend maximum UGRs for different situations
  - UGR < 19 is recommended for many office & classroom settings

(Source: What is UGR? https://www.nvcuk.com/technical/what-is-ugr/529.htm)

How to calculate unified glare rating (UGR)

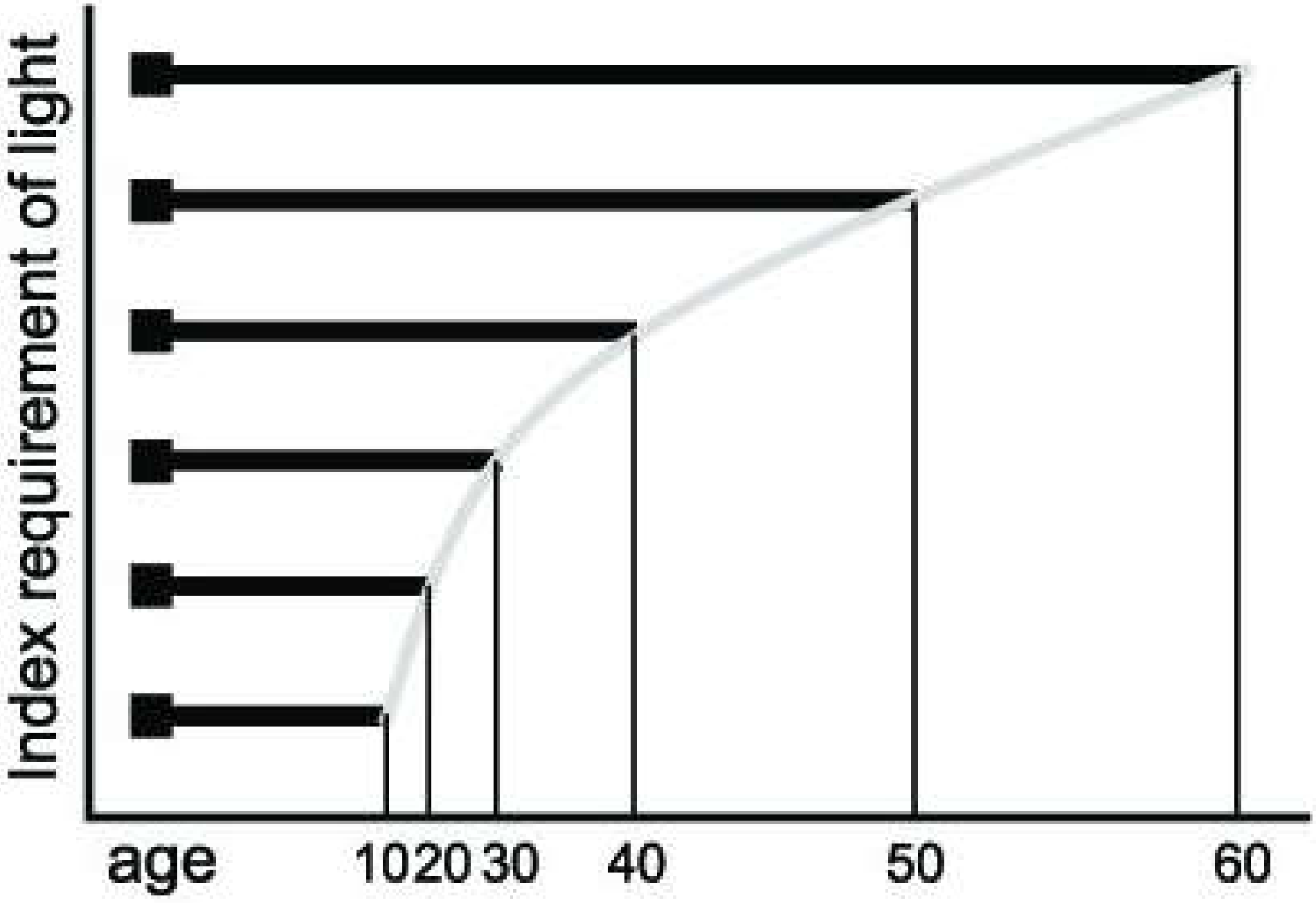


(Source: https://www.hidealite.com/en/knowledge/concept/ugr)

Design considerations

- Effects of aging
  - Increased lens opacity – light scattering within the eye flare
  - Crystalline lens yellowing – reduced blue vision
  - Presbyopia – loss of lens elasticity and near vision
  - Reduced pupil size – less light reaching retina – more light required
  - Increased visual processing and adaptation time – reduced performance
  - Decreased acuity and contrast sensitivity – due to decreased nerve function

Requirement of light in relation to human age



(Source: https://www.researchgate.net/publication/268326391_Visibility_Estimation_of_Textile_Warning_Materials_in_the_Pedestrian-Vehicle_Arrangement_n_Introduction/)

Design considerations

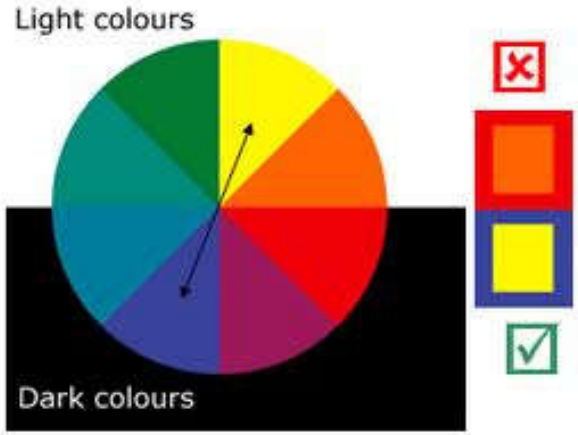
- Perceived colour of light source
  - Spectral content of emitted light determines source appearance
  - Two sources that appear to be the same colour may have different spectral compositions
  - Two sources that have the same colour appearance may have different colour rendering qualities

High CRI

Low CRI

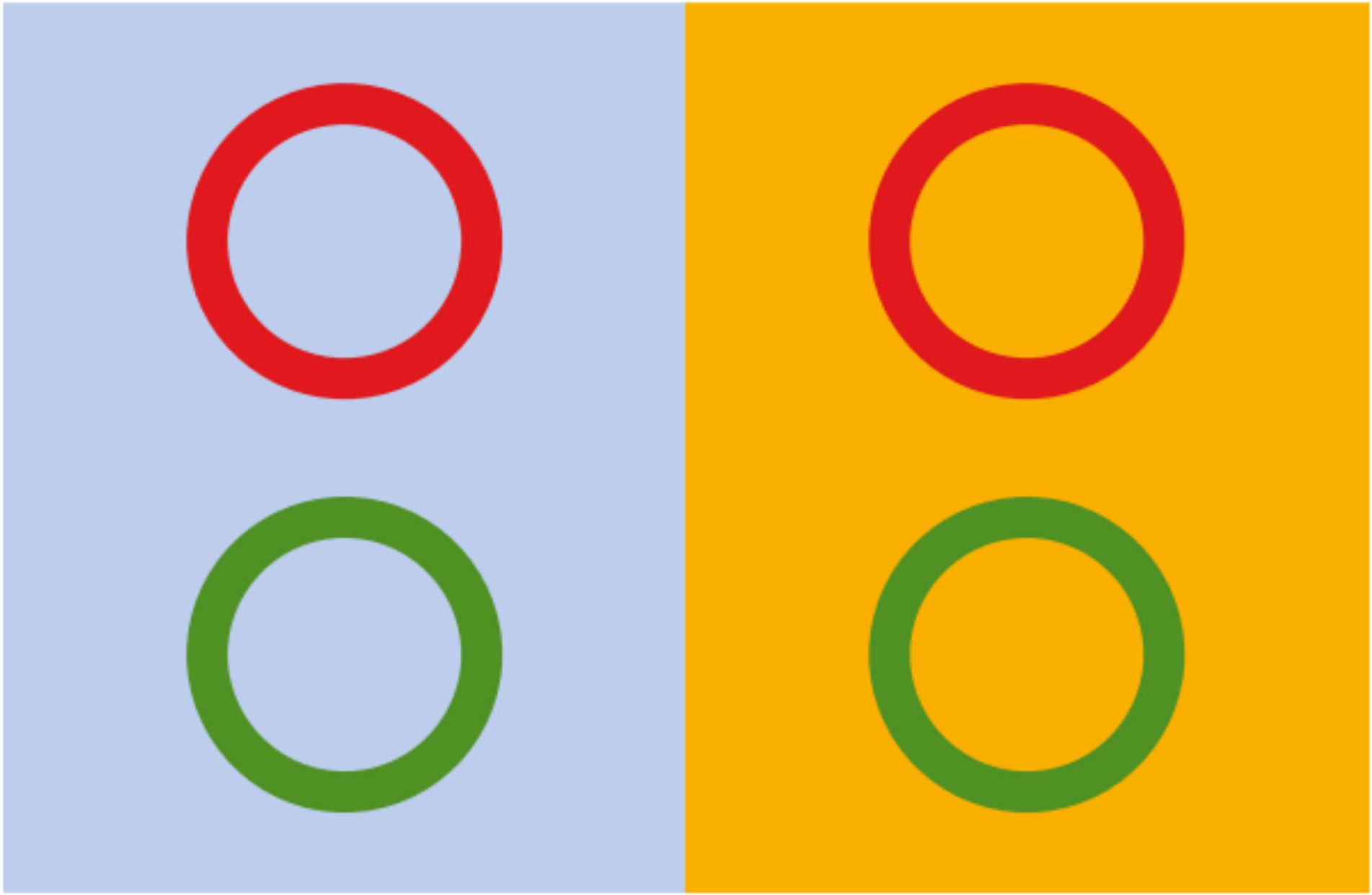
Design considerations

- Function of the surround
  - Simultaneous contrast
    - Appearance of a colour is affected by the colour against which it is viewed



  - Colour adaptation
    - An after image, the compliment of the colour to which the visual system was adapted, appears over the region of the visual field that was exposed to that colour
- Colour preference
  - Colour fidelity, saturation, naturalness & vividness

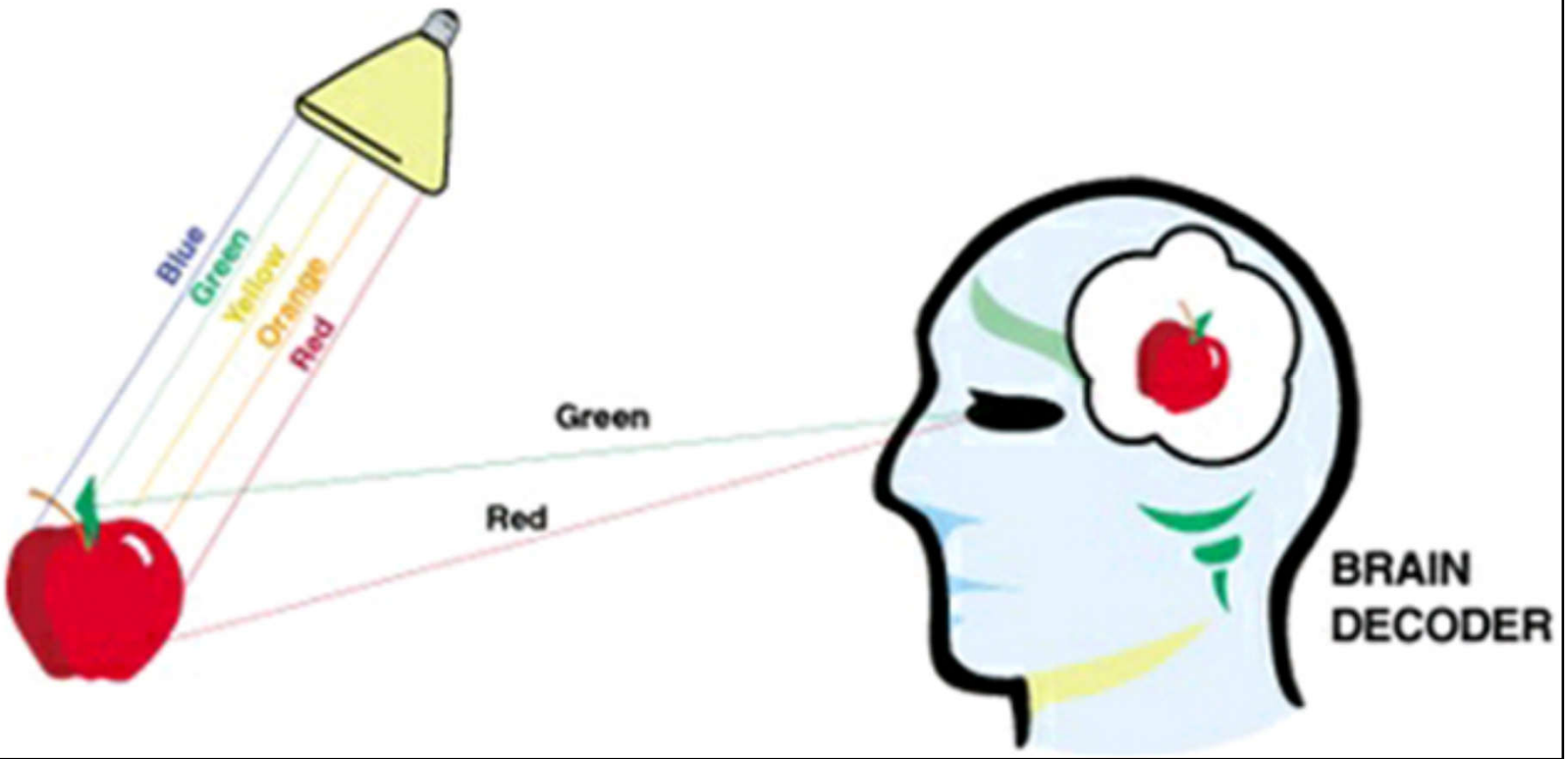
Colour contrast: the circles have a different apparent brightness with a different coloured background



(Source: The Science of Lighting, Signify)

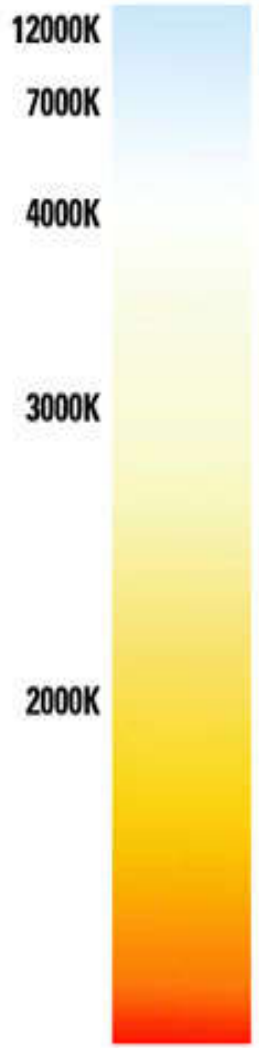
Design considerations

- Light source characteristics
  - Colour temperature
  - Colour rendering ability



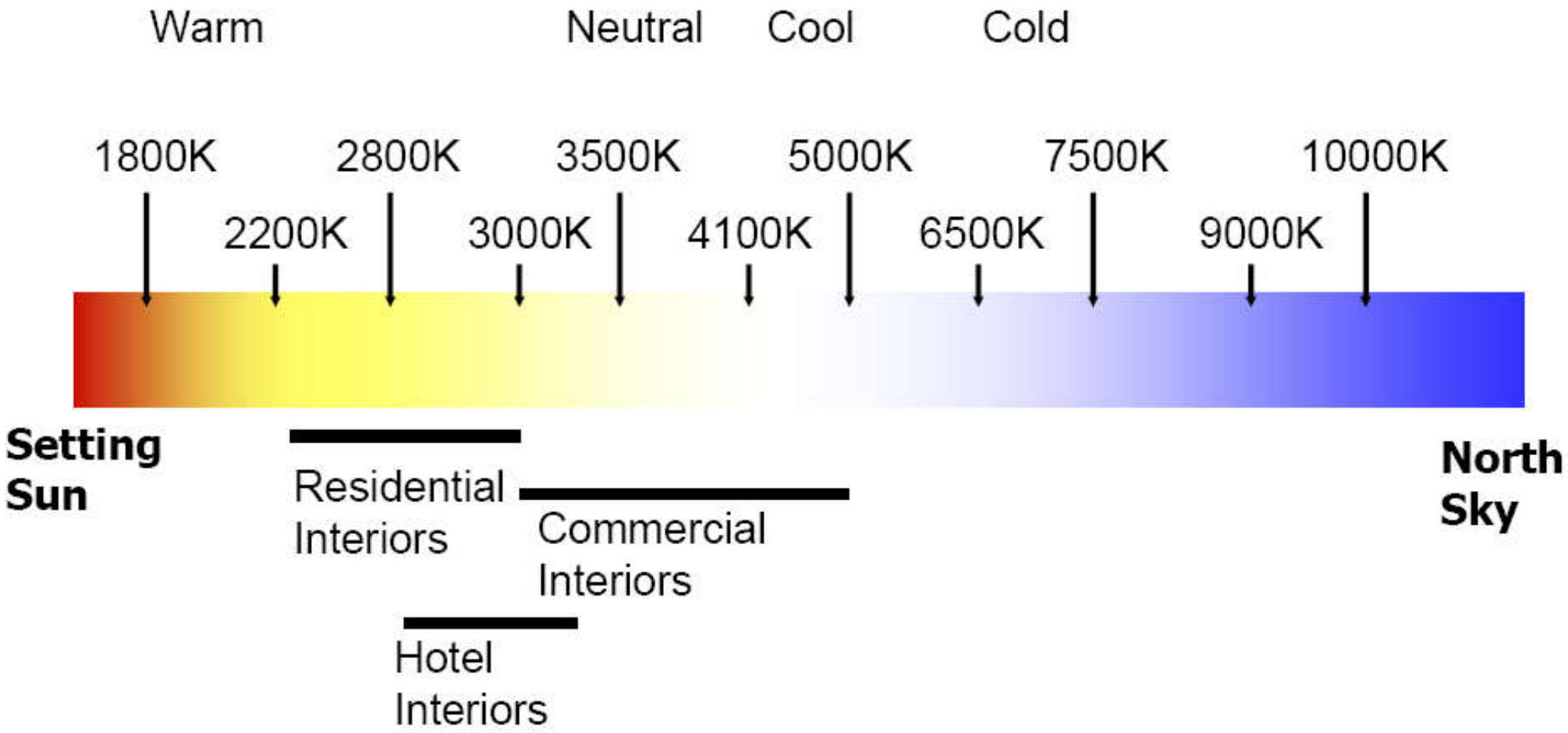
Design considerations

- Correlated colour temperature (CCT)
  - Used to specify source appearance
  - CCT equates the appearance of a source to a blackbody radiator operating at the same temp.
  - Expressed using Kelvin temp. scale
  - A lower CCT means longer wavelengths and warmer colour
  - Typical light source – 2,100 to 6,500 Kelvin



(* See also http://en.wikipedia.org/wiki/Color_temperature)

Correlated colour temperature (CCT) of lamps



[Source: www.benyalighting.com]

Design considerations

- Colour rendering index (CRI)
  - Used to evaluate light sources based on how well particular sample colours are rendered relative to a standard source at the same CCT
  - CRI index is a value from 0 to 100 that is a measure of the deviation in colour appearance that occurs when test colours are illuminated by the test source and the standard source
    - (A greater deviation results in a lower CRI value)

(* See also http://en.wikipedia.org/wiki/Color_rendering_index)

red-rich source

blue-rich source

Colour rendering index (CRI or Ra) of common lamp types

Lamp type	Ra
Incandescent	100
Fluorescent	
Colour / 33	65
Colour / 54	72
Colour / 82/ 83/ 84	86
Colour / 93/ 94/96	93
Low pressure sodium (SOX)	(- 44)
High pressure sodium (SON)	26
High pressure mercury (HPL – N)	45
Blended light (ML)	60
Metal Halide (HPI)	70

(Source: Philips Lighting, http://www.lighting.philips.co.in)

Further Reading

- IES Lighting Ready Reference App
  - https://www.ies.org/education/ies-lighting-ready-reference-app/
- Lighting theory essentials (Philips Lighting/Signify) https://www.signify.com/global/lighting-academy/browser/course/lighting-theory-essentials
- Principles of Vision https://www.ncbi.nlm.nih.gov/books/NBK11513/