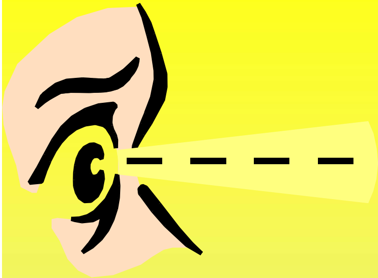


SEEING

3 lectures on the physics of sight

1) *Light and imaging*

2) *The retina and colour vision*

3) *Measuring light and seeing more*

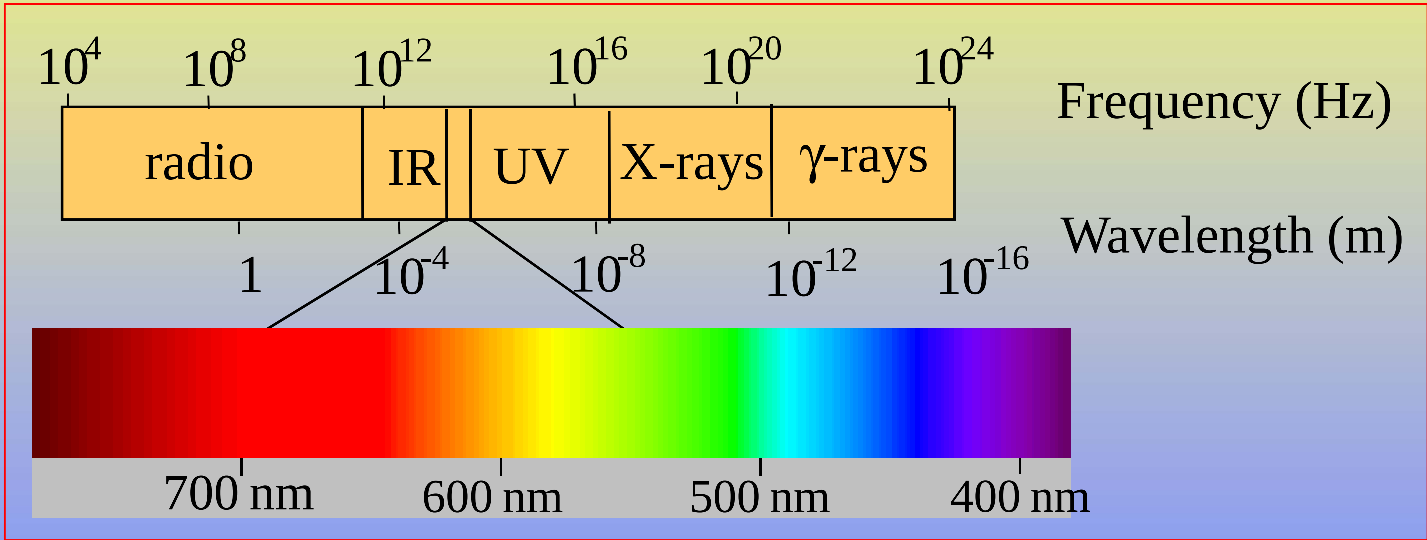
Dr John S. Reid

Department of Physics

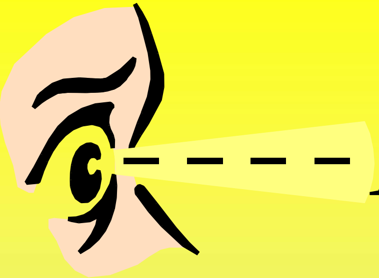
University of Aberdeen

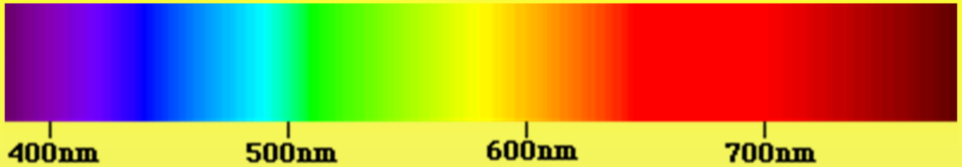
The Electromagnetic Spectrum

- Light is a tiny part of a huge spectrum of electromagnetic waves (section 24.2)



- Light in vacuum has **wavelengths** between ~400 nm and ~800 nm; 1 nm ≡ 10^{-9} m (a *nanometer*)
- 1μm ≡ 10^{-6} m (a *micron*)



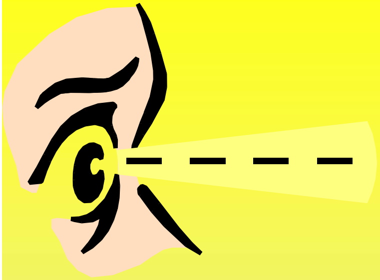
A 

of waves

Simple waves have 3 properties

- **Wavelength** (λ in **m**) - how far before they repeat
- **Frequency** (*f* in **Hz**) - the number of repetitions per second
- **Speed** (*v* in $\mathbf{ms^{-1}}$) - the speed of light in vacuum is always represented by the letter *c*
- The three quantities are simply related

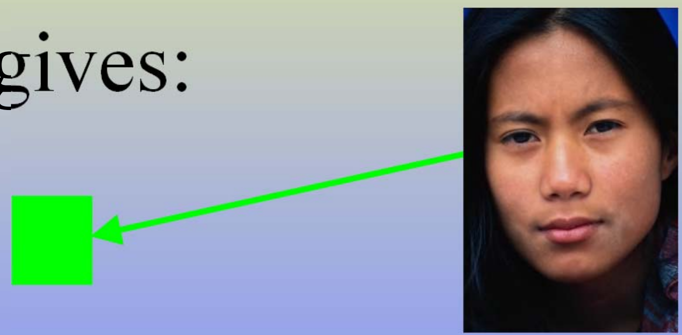
$$\lambda = \frac{v}{f}$$



Example

- The human eye sees different frequencies as different colours. What frequency corresponds to green light of wavelength 550 nm in vacuum?
- Rearranging the relationship gives:

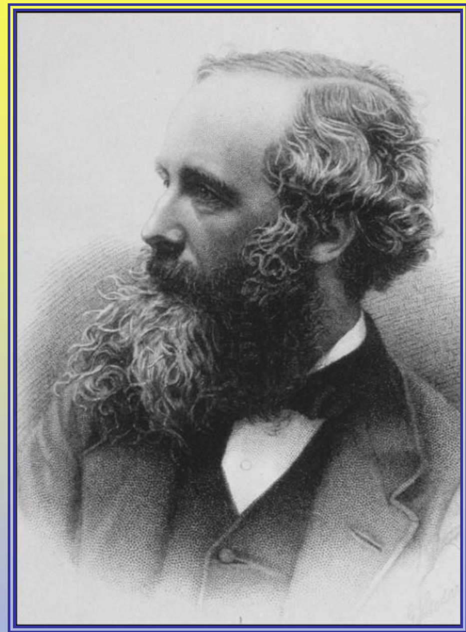
$$f = \frac{c}{\lambda}$$



- $c = 3.00\times10^{8}\ \mathrm{ms^{-1}}$; $550\ \mathrm{nm} \equiv 5.50\times10^{-7}\ \mathrm{m}$
- Therefore $f = 5.45\times10^{14}\ \mathrm{Hz}$

Electromagnetic?

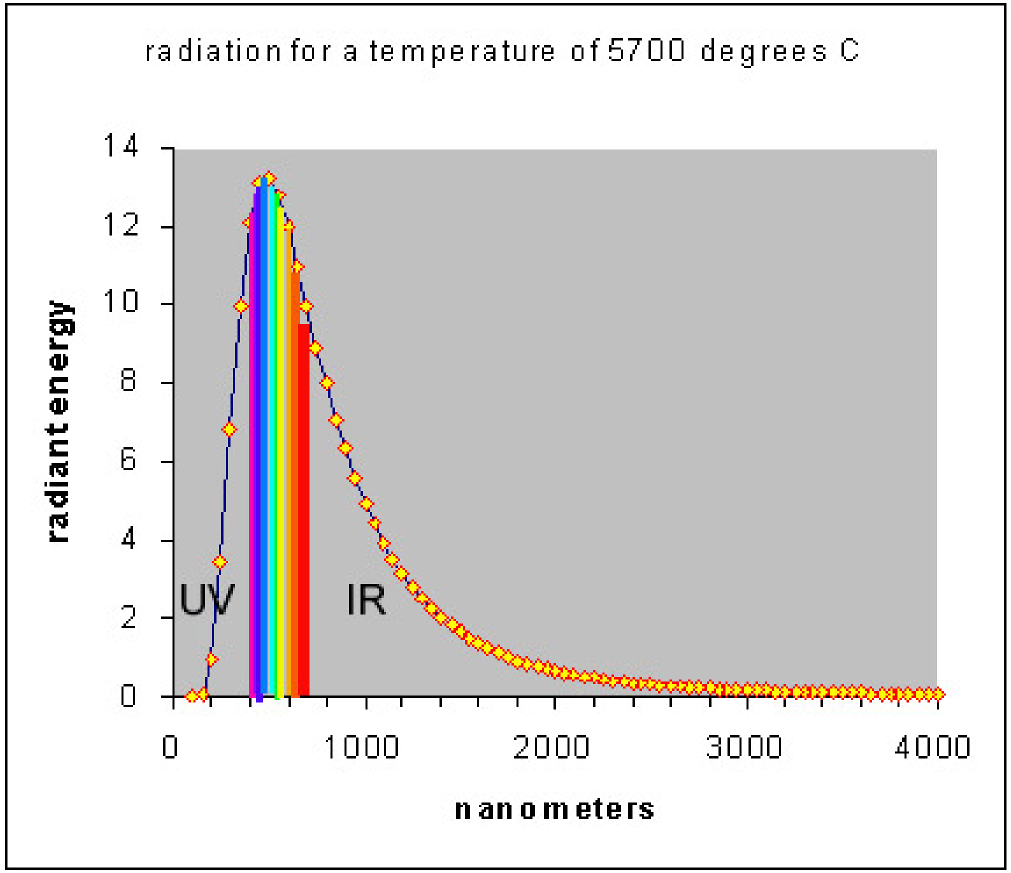
- James Clerk Maxwell, former professor at Marischal College, Aberdeen, established the mathematical equations that describe electricity and magnetism



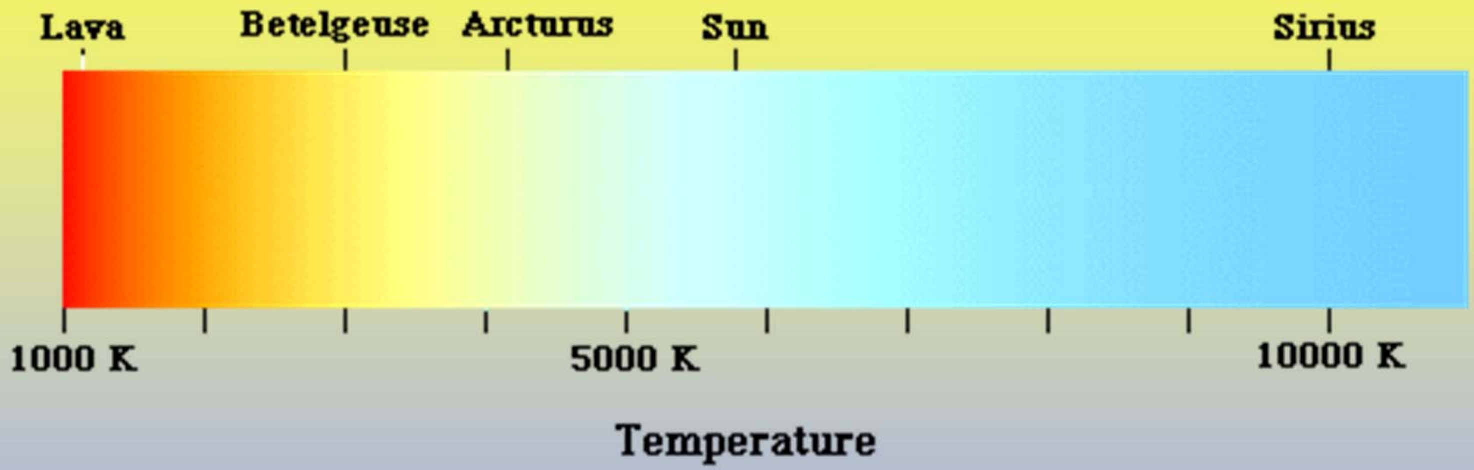
- He predicted that radiation would travel at speed *c* in vacuum and hence that light was an electromagnetic phenomenon

Hot body emission

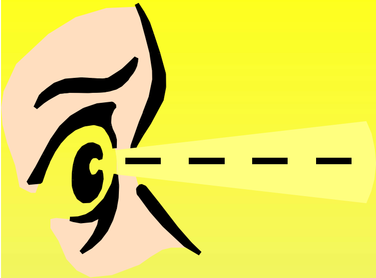
- **All bodies** emit electromagnetic radiation
- The spectral spread of this radiation is determined by the **temperature** of the body and a fundamental law of physics



Appearance of hot bodies

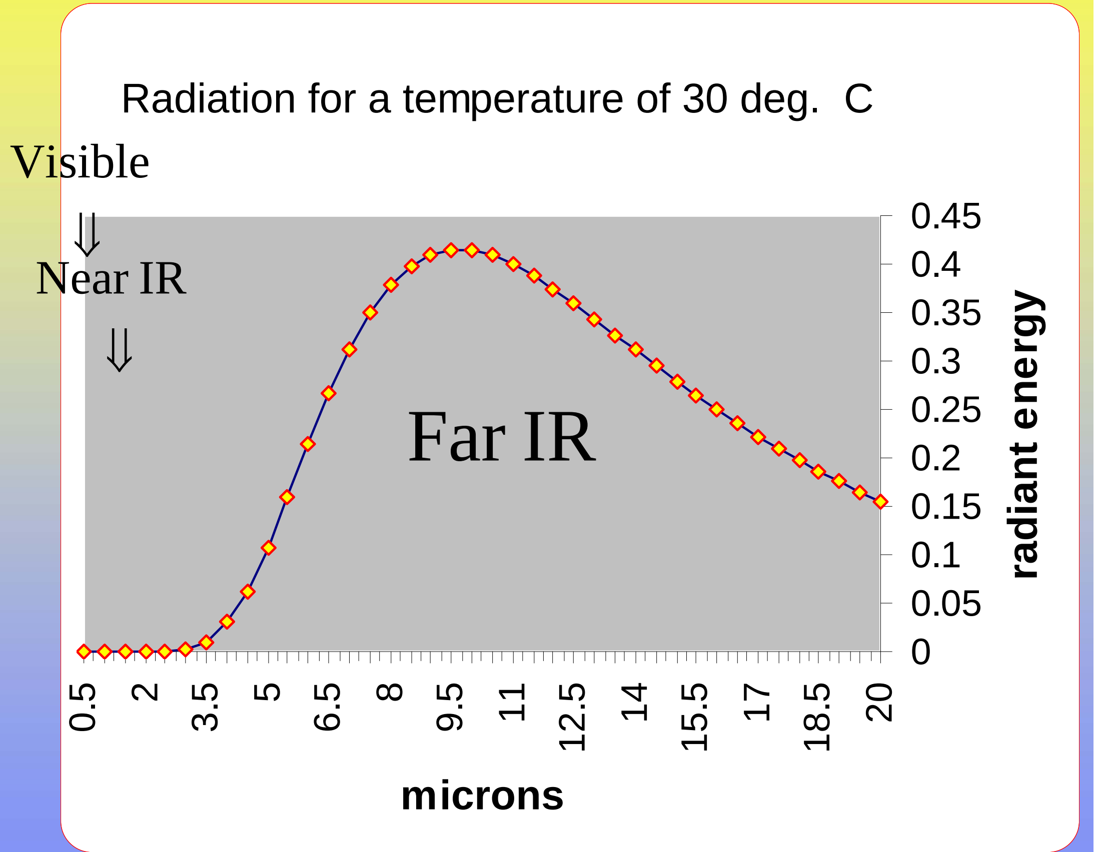


- Red is the colour of bodies that just glow; yellow, white and blue for really hot bodies
  - the concept of **colour temperature** is used by architects and others to label the spectrum of incident light they perceive

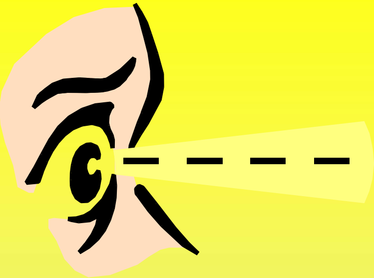


Emission from cooler bodies

- The spectrum of radiant energy was predicted by Planck
- Bodies at room temperature emit radiation in the far IR

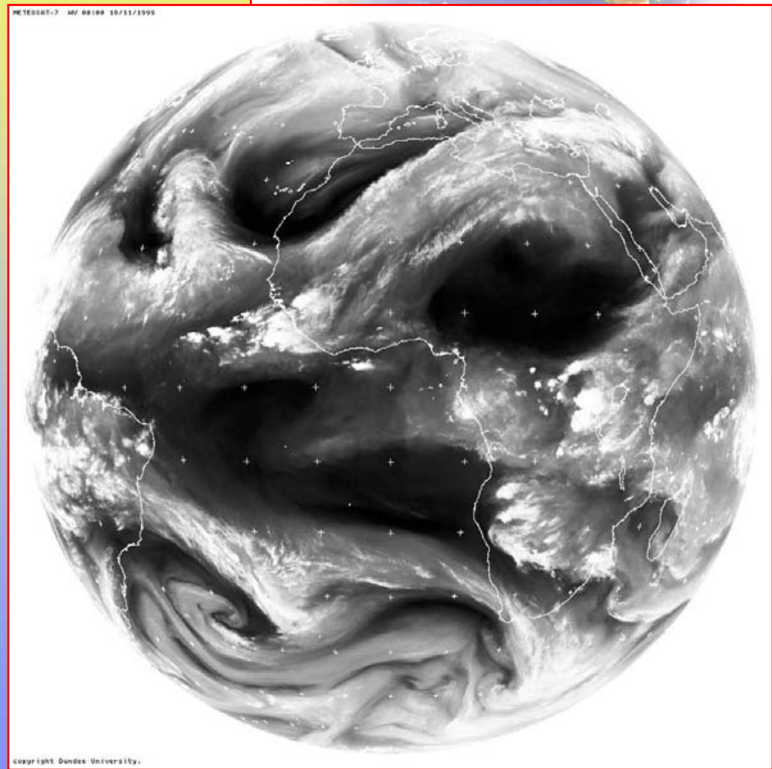


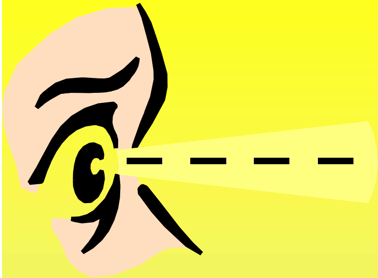
- Man-made detectors can ‘see’ at other wavelengths than visible light



Seeing in the IR

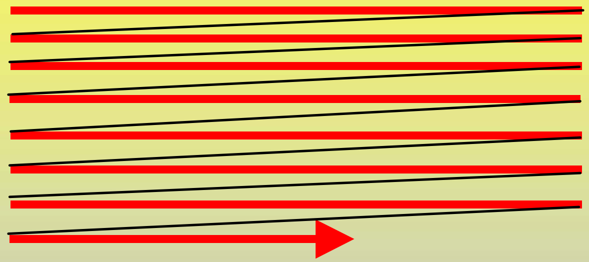
- Meteorological satellites take both visible light and IR pictures
- Each picture element is called a *pixel*. A geostationary satellite takes pictures of at least 5000 $\times$ 5000 pixels in about 15 minutes
- The picture here was taken at midnight at a wavelength of about 6.5 μm



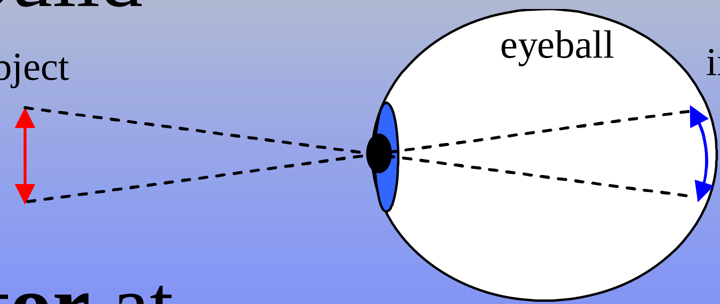


How a picture is built up

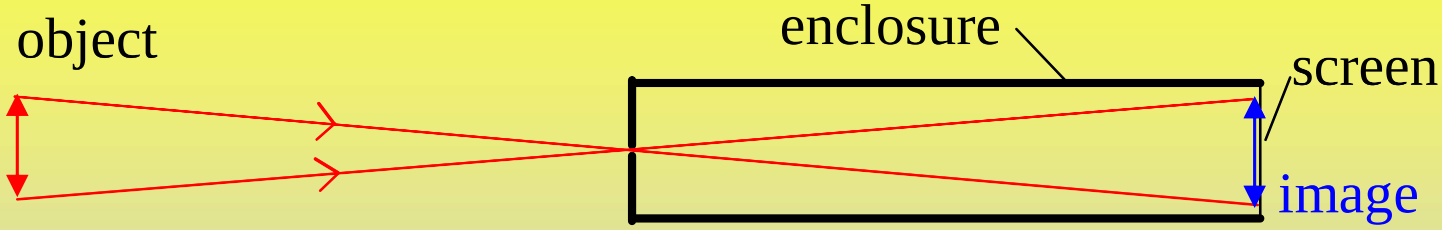
- Meteosat forms its images by scanning a ‘point detector’, line by line over the scene below
- TV pictures are built up in the same way. The lines that build up the picture are called *raster* lines
- Our eye has an **area detector** at the rear, called the *retina*



Building up a raster picture

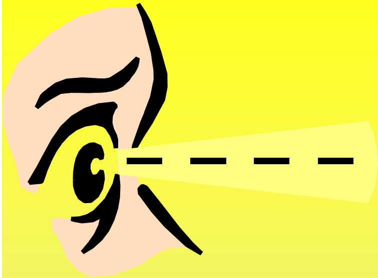


A pin-hole eye

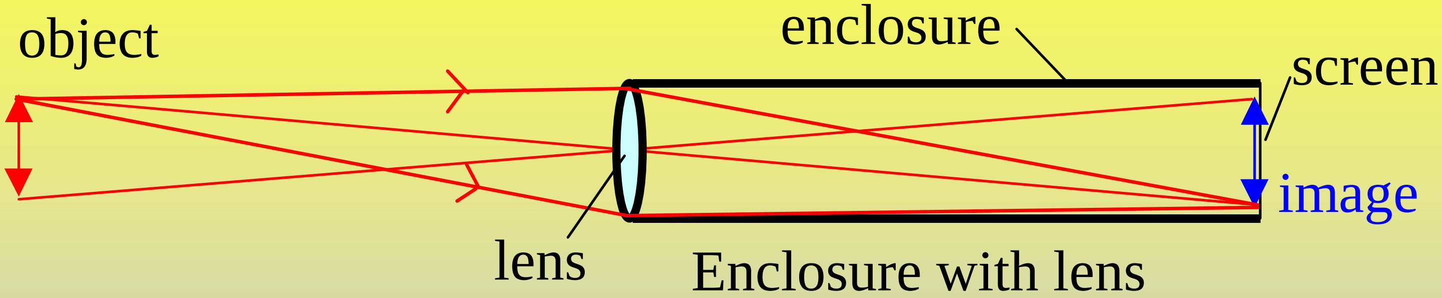


Pin-hole camera

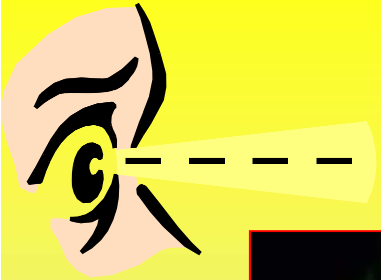
- Take an enclosure with a screen at the rear; make a tiny pin-hole and you have a *pin-hole camera*
- If the pin-hole is small (~0.3 mm) a very dim but respectable image appears on the screen
- The device relies on the property that **rays of light travel in straight lines**



An eye with a lens



- The lens collects a whole cone of light rays coming from each object point and focuses them down to one image point
- The function of the lens is to improve the illumination of the image
- If the lens fails to bring the image forming rays to a point, the image will be blurred

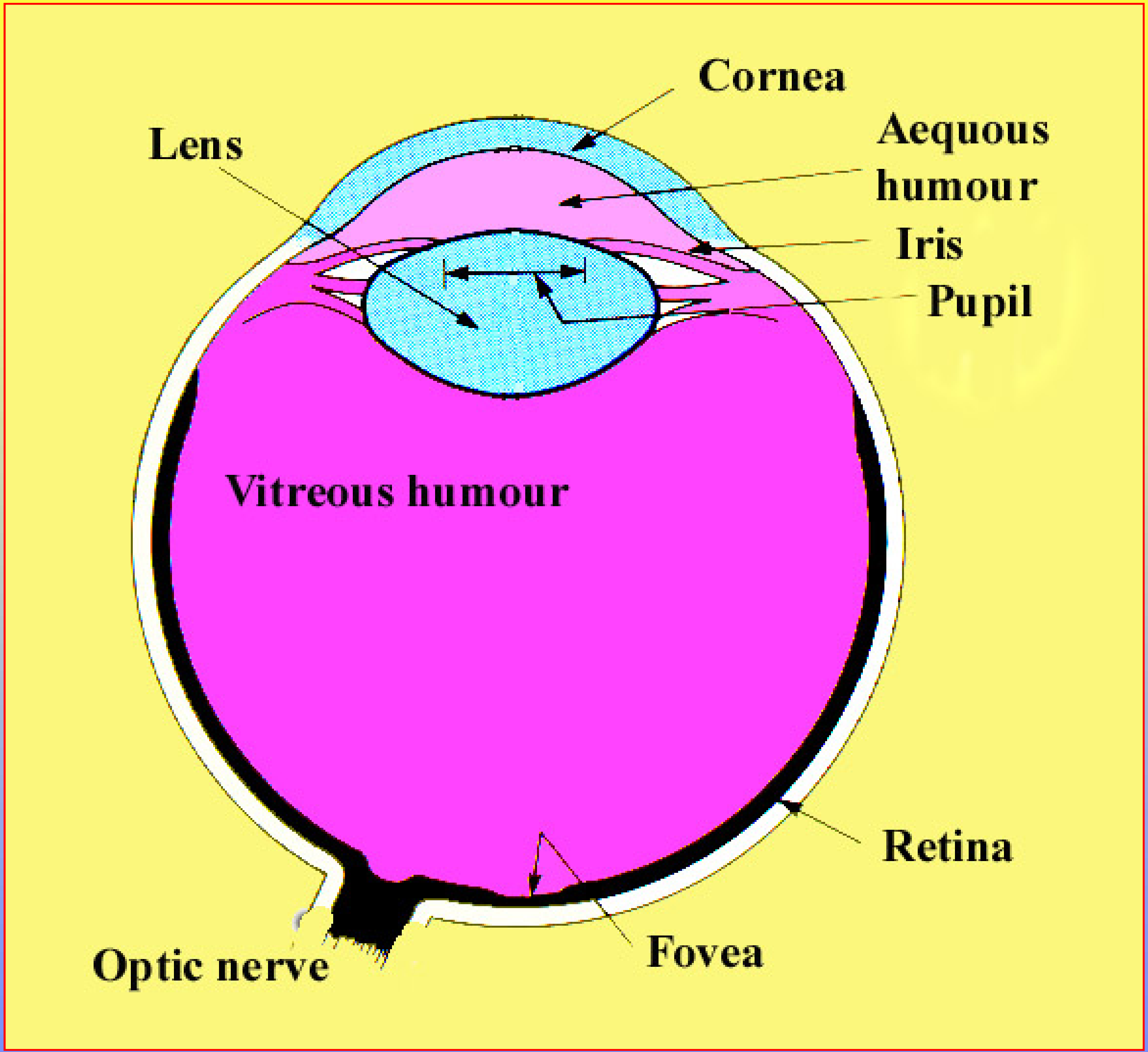


The iris

- The iris controls the aperture of the eye
- The smaller the aperture, the better quality the image
- The purpose of the iris is to give the eye the smallest aperture consistent with a bright enough image

Eye parts

- Cornea
- Lens
- Retina
- Optic nerve
- Humours
- Iris
- Pupil
- Fovea



Anatomy of the eye

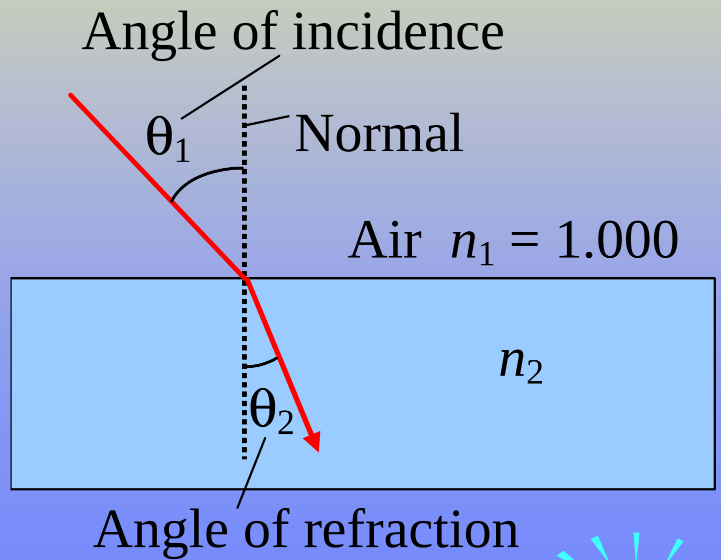
- What the scalpel reveals

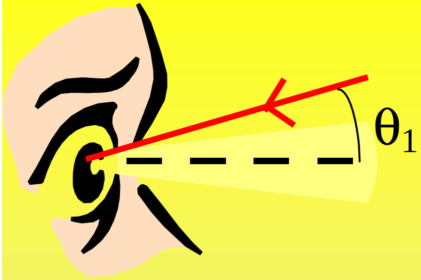
www.orlions.org/eyetour/fig24set.html

The bending of light

- To form an image, light rays must be bent
- The bending of light is known as **refraction**
- The law of refraction of light is *Snell's law*
- The ability of a medium to refract light is given by its *refractive index*, *n*

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$





Numerical example of bending

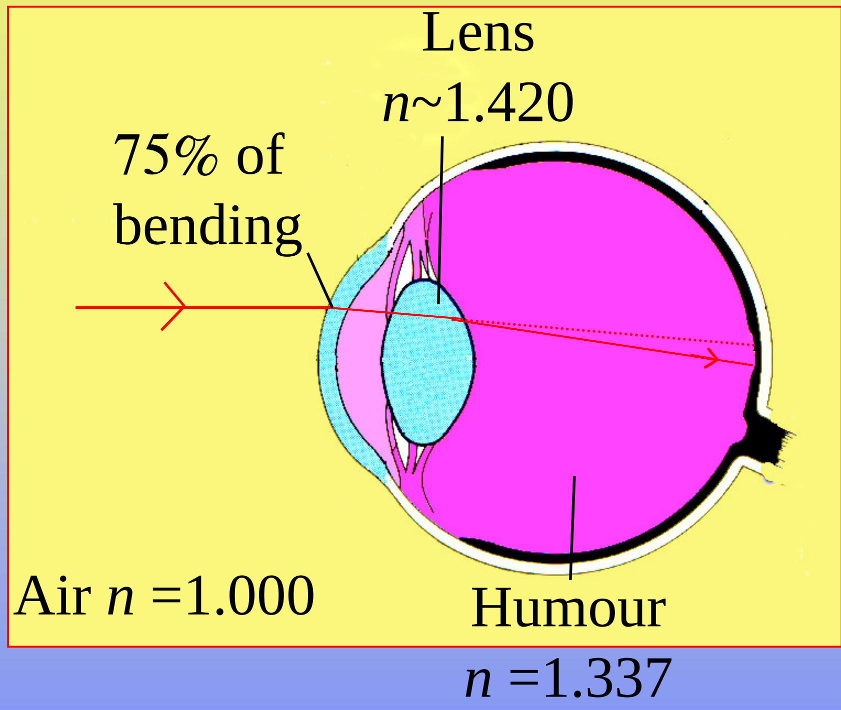
- Light strikes the cornea at an angle of incidence (θ_1) of 20°. The cornea has a refractive index of 1.376. What angle (θ_2) does the light leave the cornea surface?
- Take n_1 = 1.000

$$
\begin{aligned}
1.000\ \sin(20°) &= 1.376\ \sin\theta_2 \\
\therefore \quad \sin\theta_2 &= (0.342)/1.376 \\
&= 0.249 \\
\therefore \quad \theta_2 &= 14.4°
\end{aligned}
$$

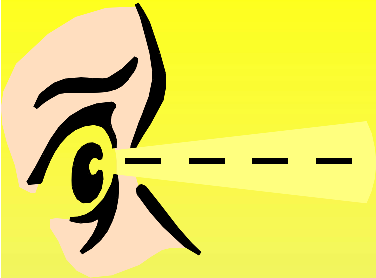
- The light leaves at 14.4° to the surface normal

Imaging by the eye

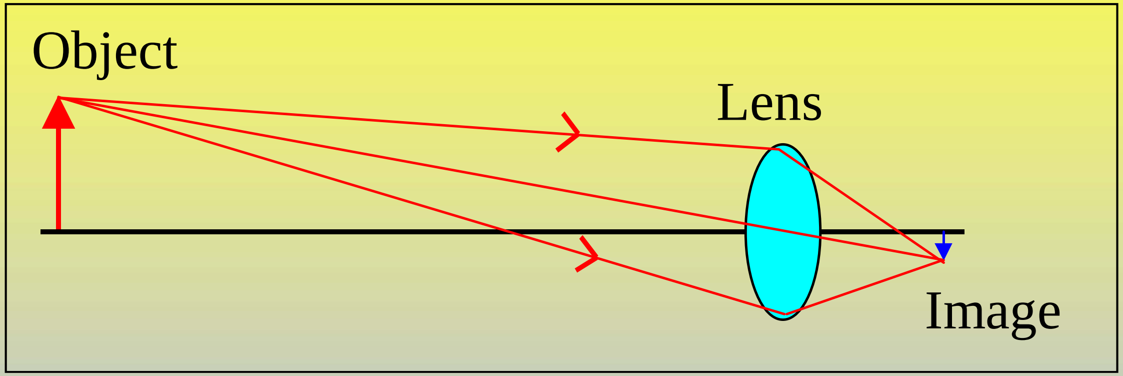
- 75% of the imaging power of your eye is at the front of the cornea. Look after it!
- The lens is an adjustable element for focusing objects at different distances



- The variable focusing of the eye is known as its *accommodation*



Imaging by a convex lens



- Broadly speaking, the eye images like a powerful convex lens
- The images of all objects we can see are small, inverted and form on the retina
- In the **next lecture**, we shall look at properties of the retina