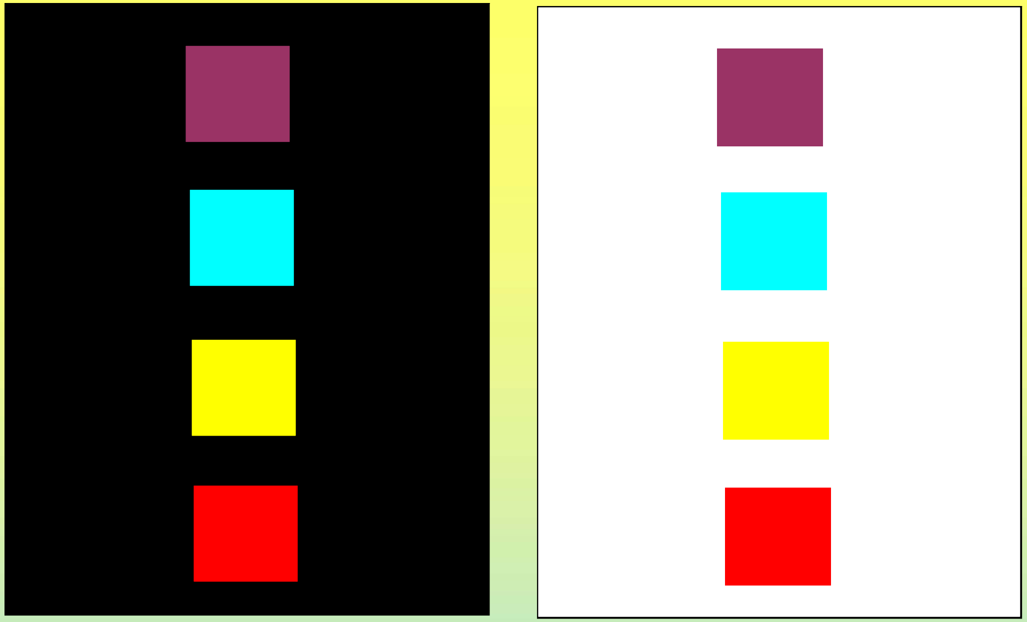
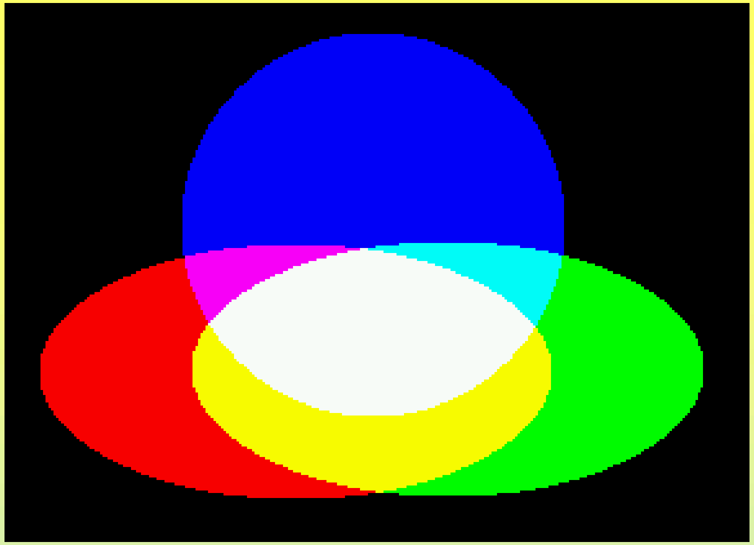
# Colour

- Topics not covered
  - psychological effects $\rightarrow$
- Topics covered
  - additive colour mixing
  - Maxwell colour triangle
  - CIE chromaticity diagram
  - subtractive colour mixing
  - the appearance of objects
  - colouring mechanisms



Isaac Newton 1643 - 1727

# Colour mixing

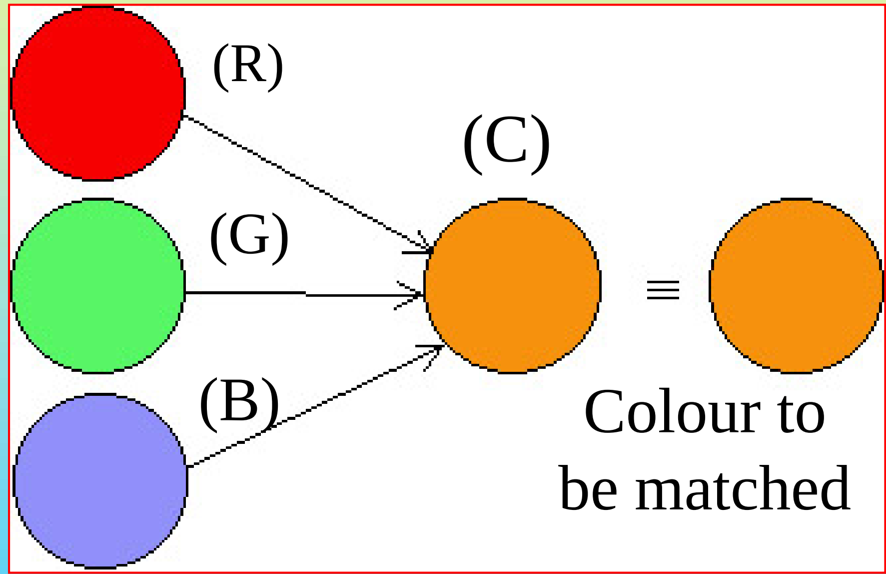


Activate ↑

- Most colours can be made by mixing 3 primary colours
- The diagram shows the effect of overlapping red, green and blue primary coloured lights on a wall
  - where all 3 colours fall, white is created when the relative amounts of each colour are right
  - where 2 colours fall, yellow, cyan and magenta are created

# 3-colour matching

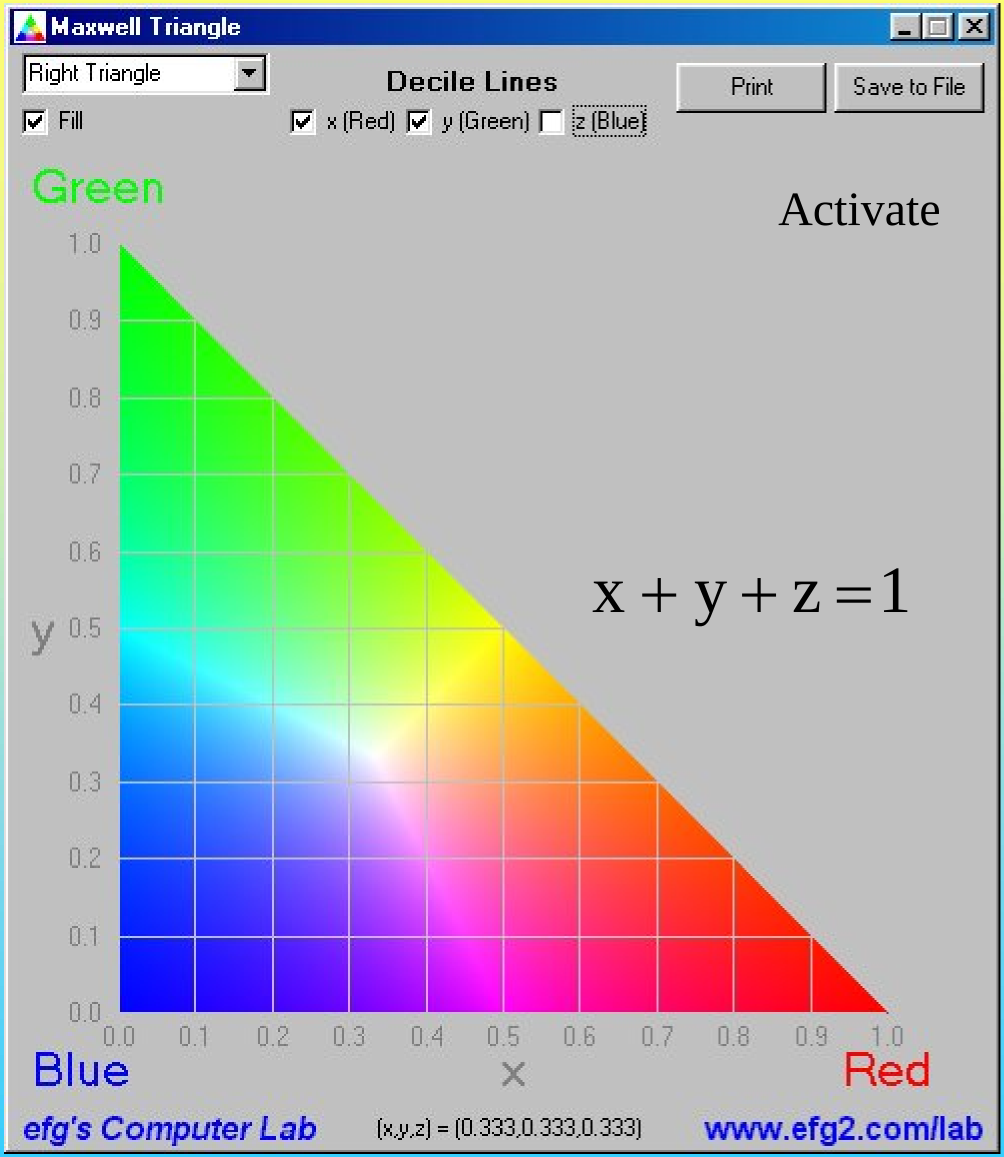
- **Metamerism** underlies 3-colour matching
- Superimposing variable amounts of 3 coloured primaries allows most colours to be produced
- Colour TV sets and monitors reproduce pictures using exactly this effect
  - it is called **additive colour mixing**



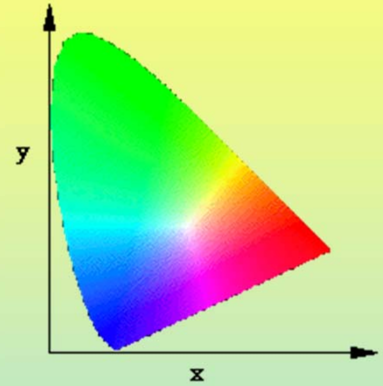

$$(C) \equiv x\,(R) + y\,(G) + z\,(B)$$

# Maxwell's colour triangle

- Maxwell realized that the 3-colour mixing relationship (which he investigated in detail in Aberdeen) allowed colours to be represented within a triangle
- Maxwell took the world's first colour photograph, in 1861



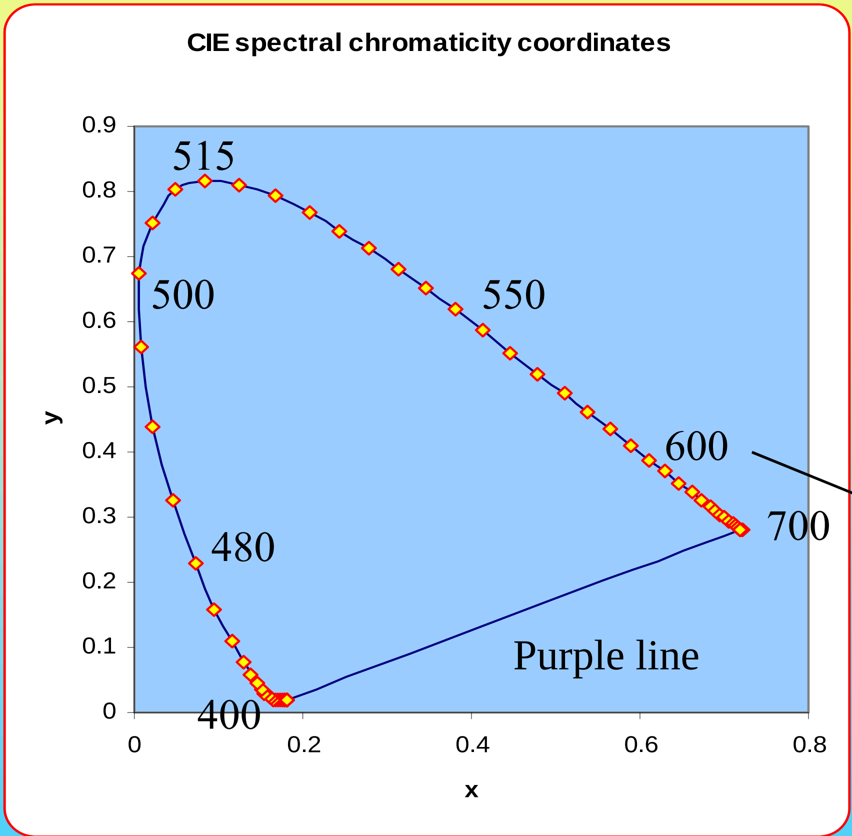
# CIE chromaticity diagram

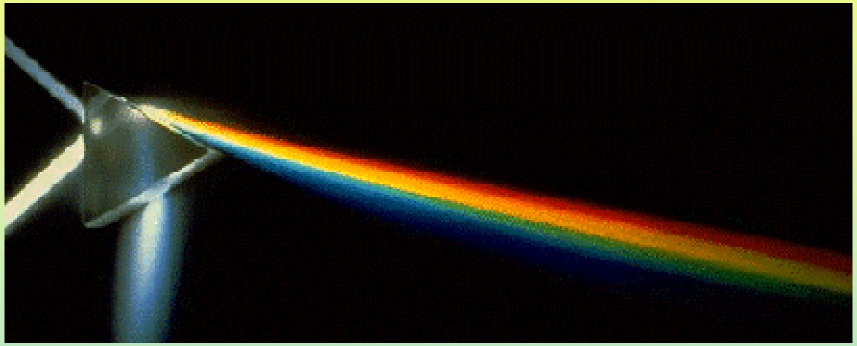



- Maxwell's triangle
  - changes when you make a new choice of primary colours (R) (G) (B)
  - cannot show all possible colours because some colours need -ve coefficients
- The Commission Internationale d'Eclairage (CIE) defined a new set of primaries (X) (Y) (Z) in terms of which all colour matches have +ve coefficients

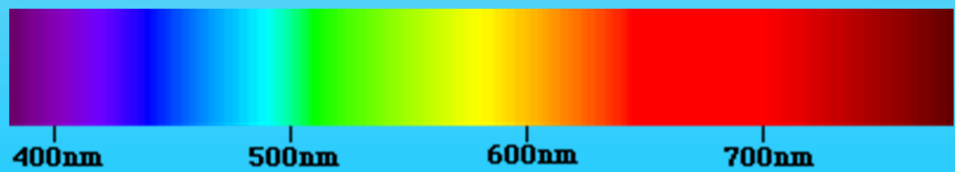
$$(C) \equiv x\,(X) + y\,(Y) + z\,(Z)$$

# Spectral wavelengths are the purest colours



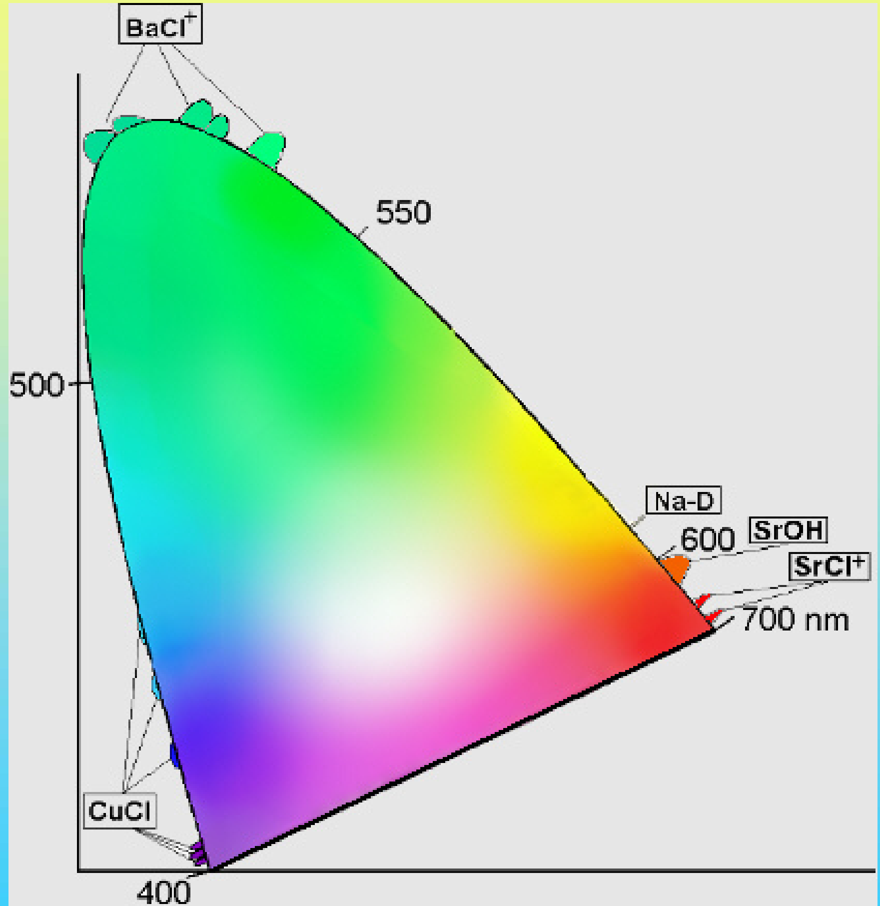



- Spectral wavelengths occur around the outside of the CIE diagram



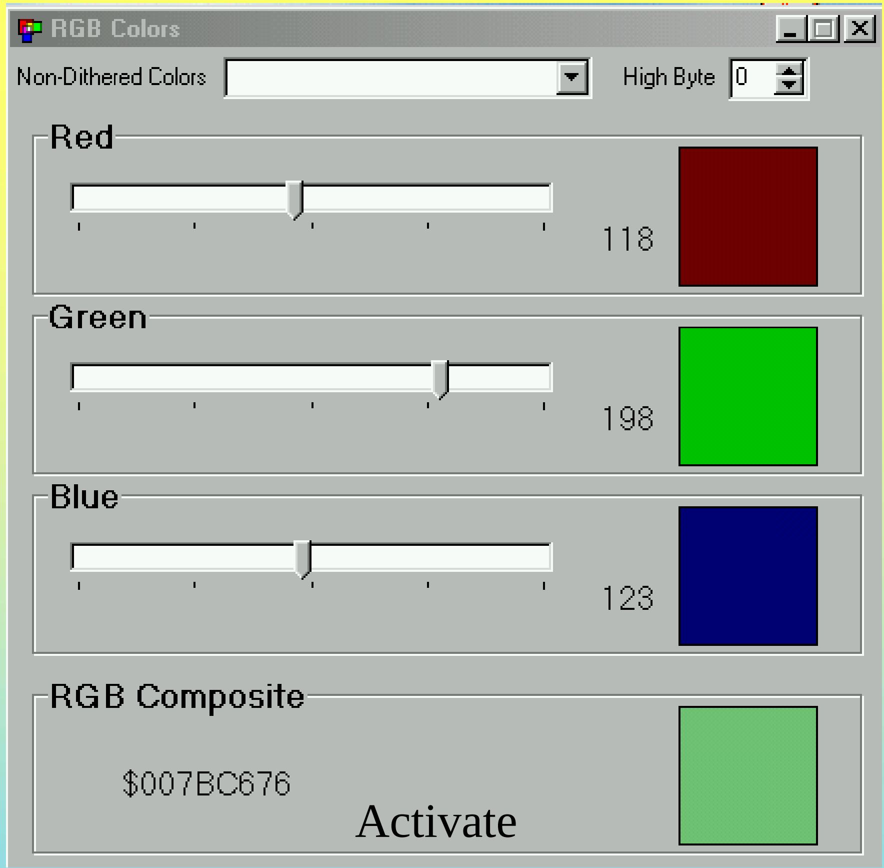
# An example of plotted colours

- Colours in fireworks are produced by the rapid burning of just a few compounds
- The chromaticity chart opposite shows the spectral colours produced by these compounds
- Other colours are synthesized by additive colour mixing



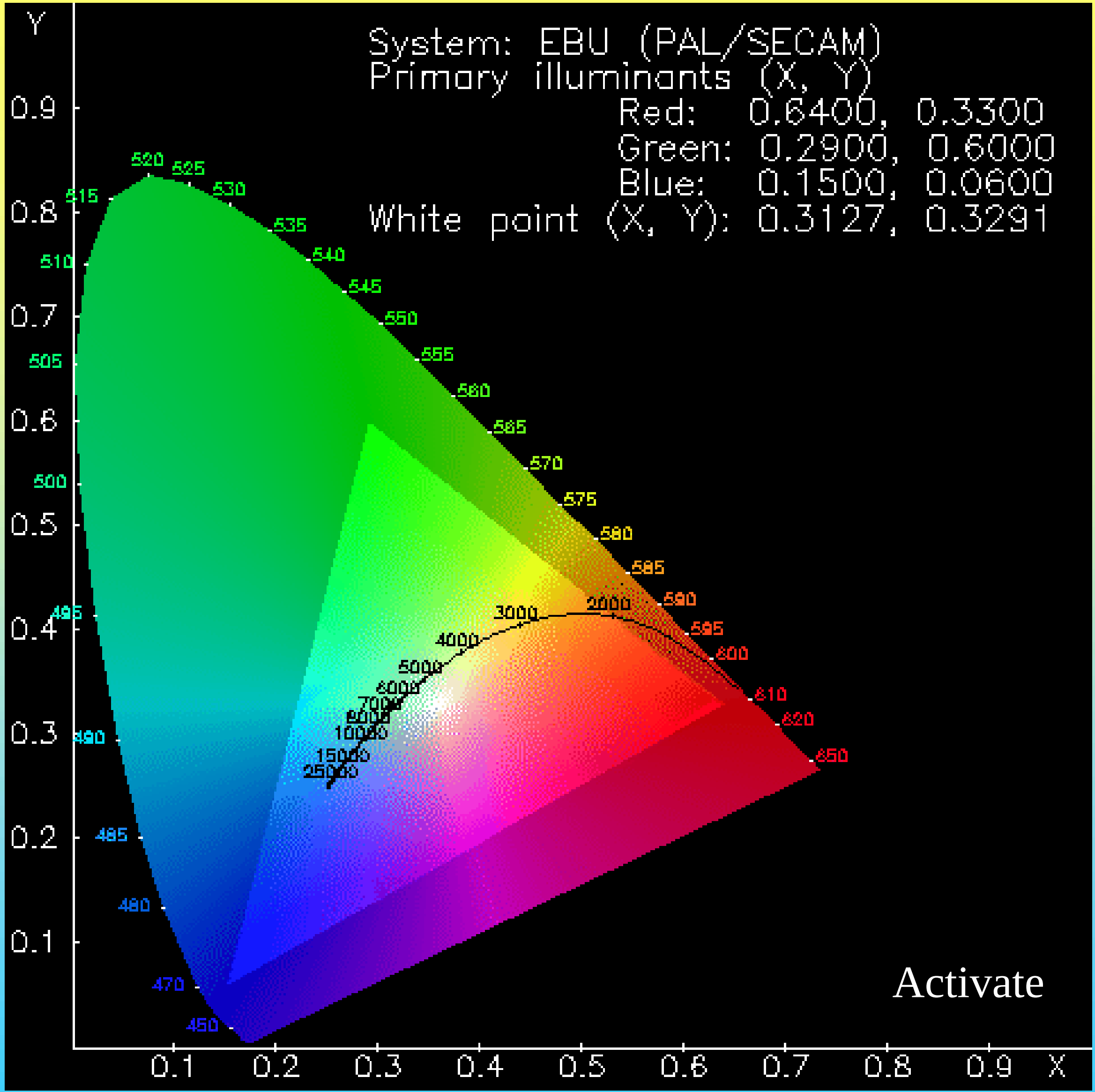
# The rgb colour system

- The rgb colour system specifies how much of each primary colour (r, g, b) is needed to make a given colour
  - r,g,b values are often represented in computers by 1-byte each, with values as integers 0 – 255
  - e.g. picture shows (r,g,b) = (118, 198, 123)



# Colour TV

- Colours reproduced by a colour TV are limited to the triangle shown within the CIE diagram
  - note Planck spectrum colours
- Run applet from www.efg2.com

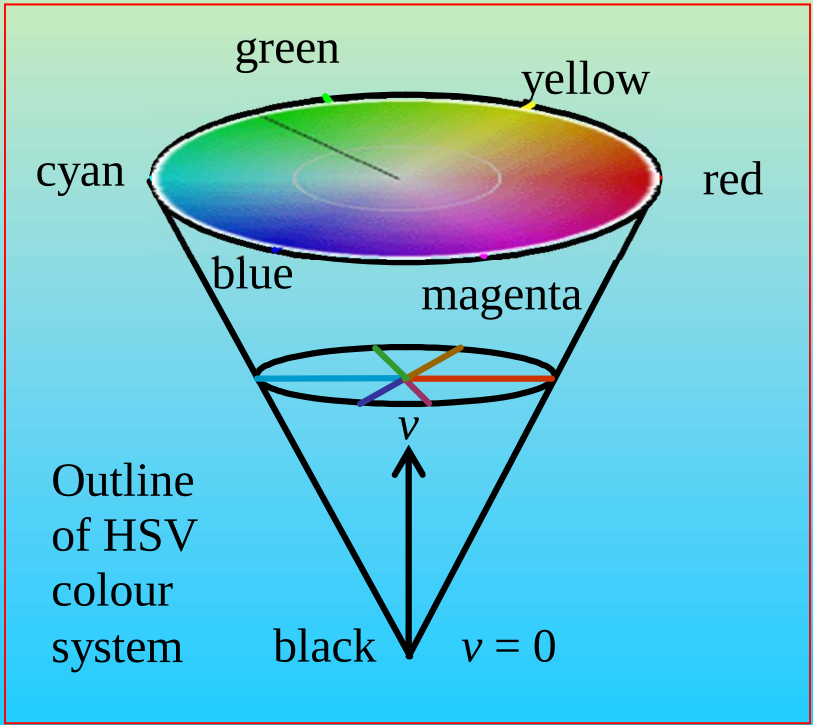


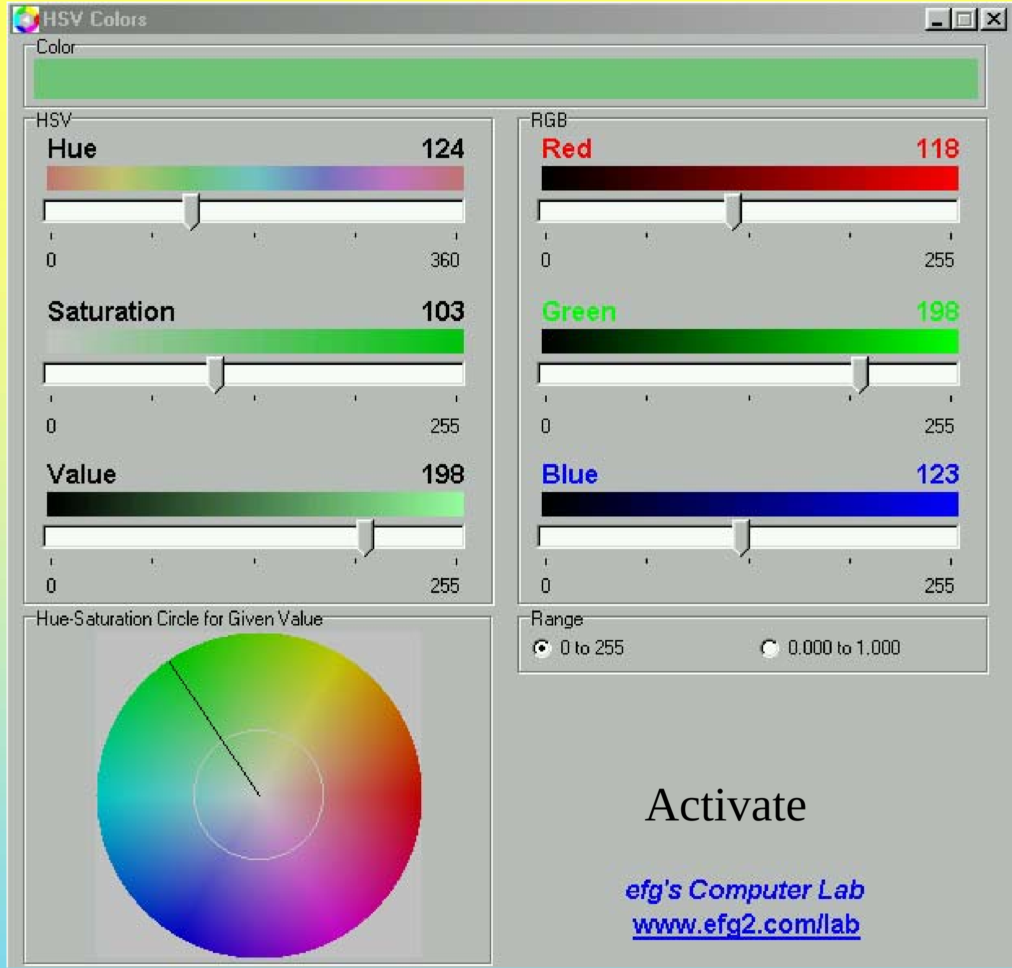
# White; dominant wavelength; purity

- ‘White’ point W depends on local illumination: e.g.
  - $S_E$ equal energy white
  - $S_A$ tungsten lamp white
  - $S_C$ overcast sky white
- Dominant wavelength of point P is the point $\lambda_D$ on the diagram, representing the **hue** of point P
- **Purity** % of colour at P is ratio $WP/W\lambda_D \times 100$

# The hsv system

- **hue**
- **saturation** ≡ purity
- **value** ≡ luminosity



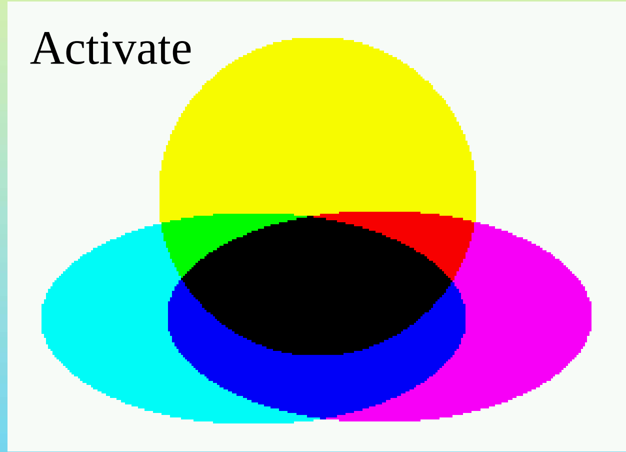
# Colouring by selective absorption

- Reflected or transmitted light is coloured because of a wavelength dependent absorption in the colouring medium
  - e.g. green leaves absorb in the blue and red ends of the spectrum making the dominant matt reflected light green

Bastide archway, Montreal, France

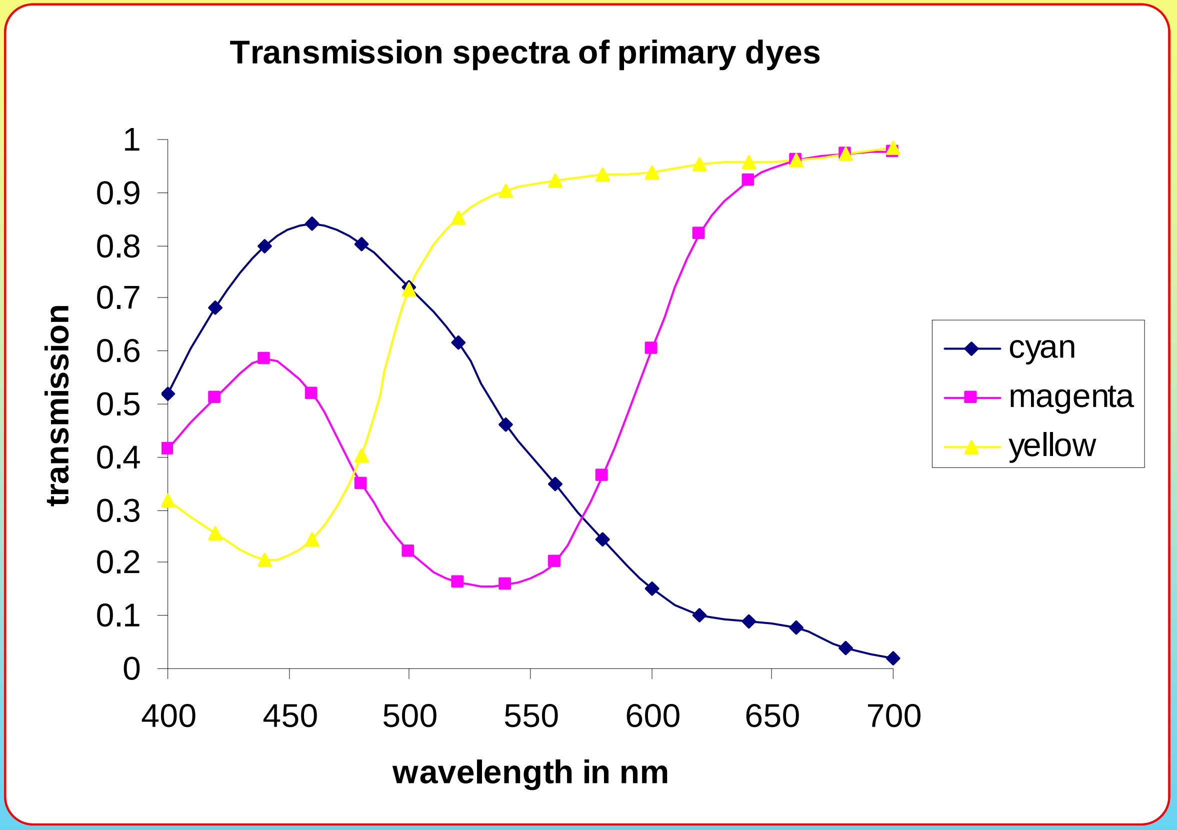
# Colour printing

- Ink put onto white paper reduces the spectral range reflected
- Colouring by inks, or paints, is usually a **subtractive process**
- Primary colours of inks are:
  - (white – red) = cyan
  - (white – green) = magenta
  - (white – blue) = yellow




- Most colour printing is done with the inks cyan, magenta, yellow and black
  - see example in class

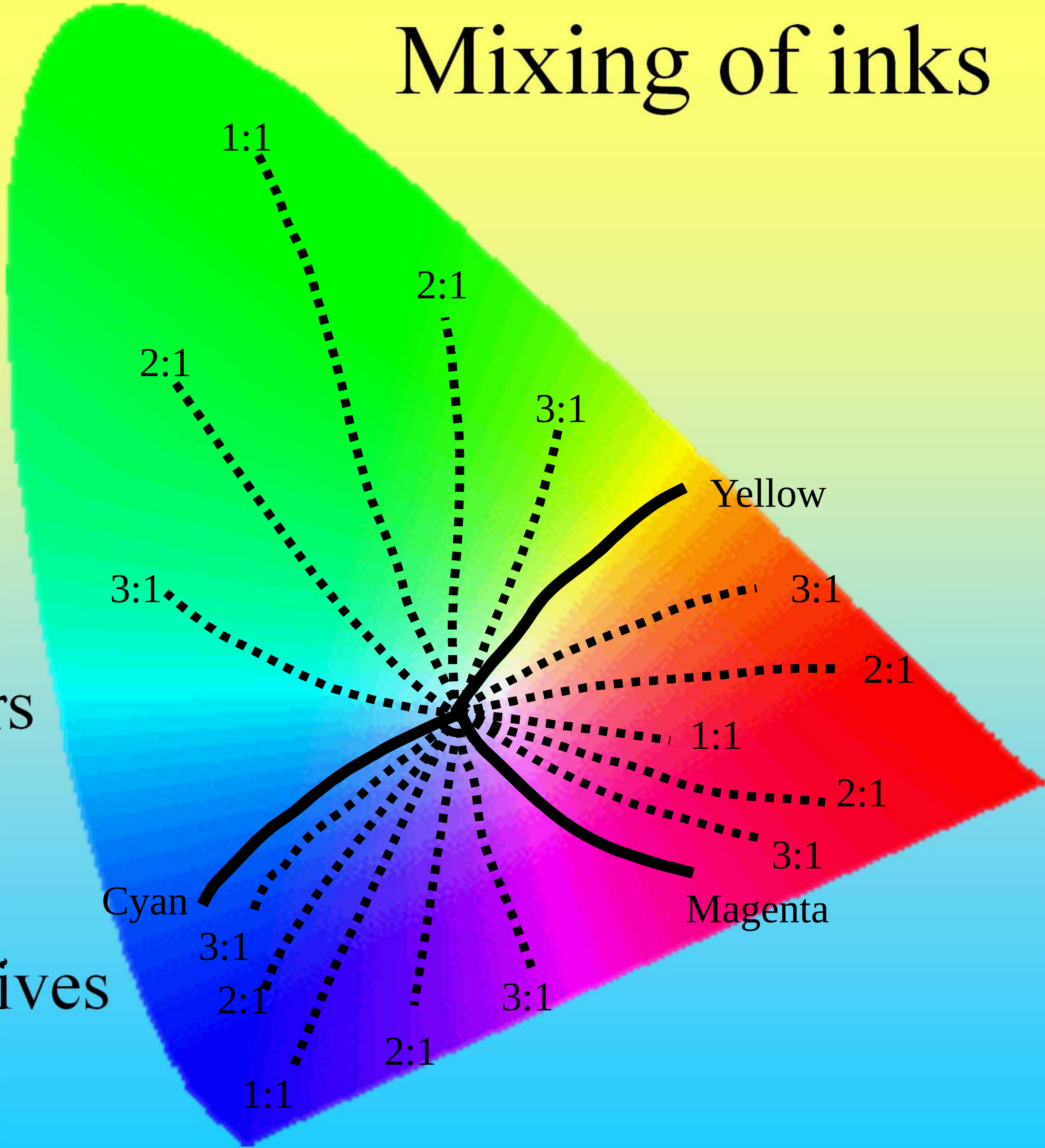
# Spectra of subtractive primaries




- Transmission spectra for a particular concentration of primary inks

# Mixing of inks

- Concentration of ink increases outward from the centre
- Chromaticity plots shown for different mixtures of pairs of inks
- Increasing concentration gives darker colours



# The appearance of things

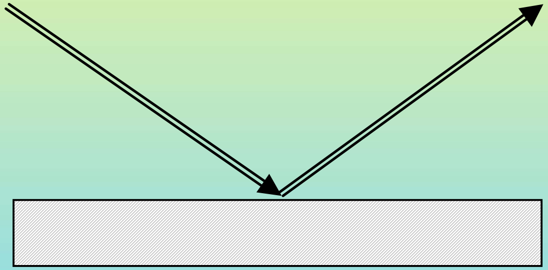
- Shiny
  or
  matt?
- White,
  coloured
  or
  black?
- Opaque,
  translucent
  or
  transparent?

Historic scientific instruments

Loch Spelvie

# Reflection - 1

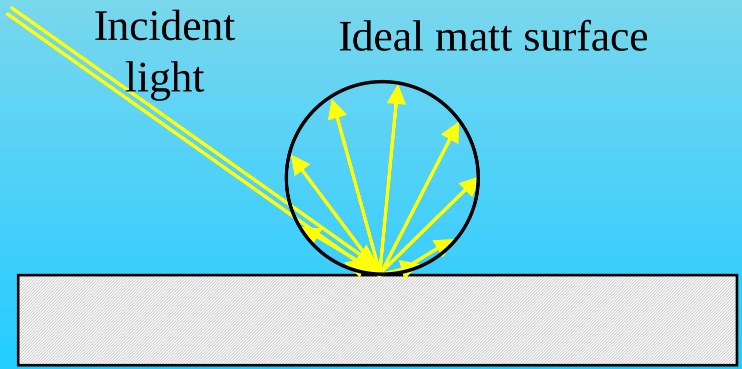
- Specular reflection
  - takes place at the surface with little penetration
  - optically smooth surface
  - the mirror laws
  - doesn't depend much on wavelength, hence reflection is similar in colour to incident light
  - reflection from gold, copper, etc. slightly wavelength dependent, giving their characteristic colour

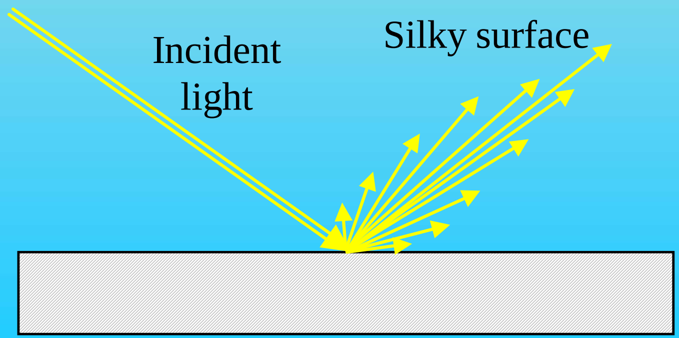


# Reflection - 2

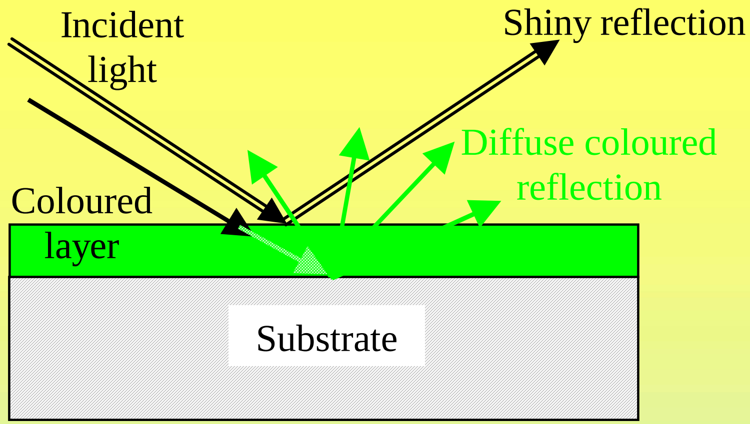
Loch Earn

- Diffuse reflection
  - takes place at the surface with little penetration
  - optically rough surface
  - 'polar diagram' describes roughness of surface
  - doesn't depend much on wavelength, hence reflection is similar in colour to incident light



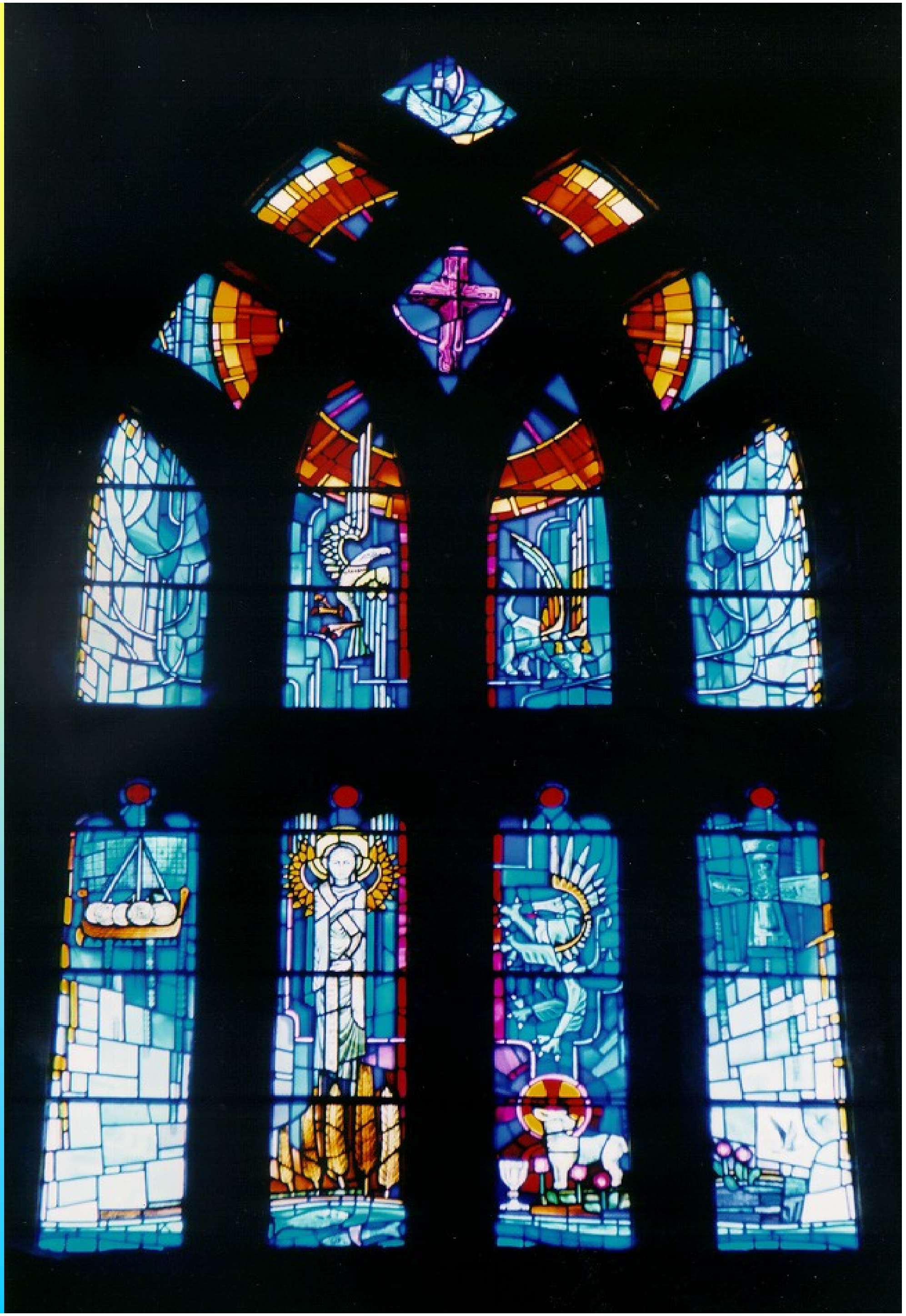
# Watercolours, inks, etc.



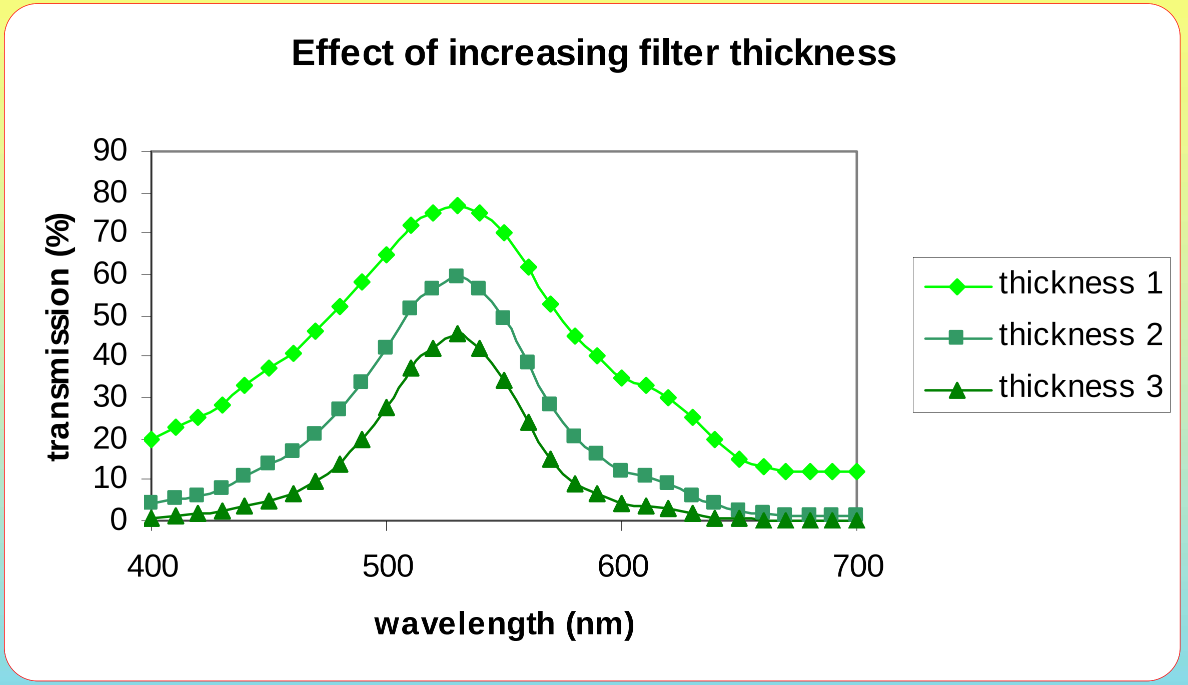

- Watercolours and inks behave like coloured filters
- The thicker the layer, the darker the colour
- Let $T_0$ be the fractional transmission through thickness $d_0$ at standard concentration. The transmission T through thickness d at concentration c% is $T_0^{(d/d_0)\times(c/100)}$
  - e.g. the transmission though 0.1 mm at standard concentration is 80%. What is the transmission through 1 mm when the concentration is 30%?
  - $T = (0.8)^{(1/0.1)\times(30/100)} \times 100 = 51.2\ \%$

St Peter

Stained glass window colours in St Magnus Cathedral, Orkney

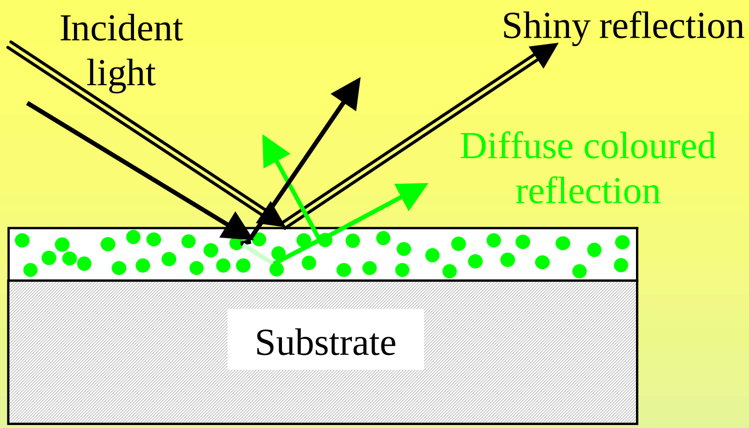


# Changing filter thickness




- Transmission curves for a green filter of single, double and triple thickness
  - the filter transmission becomes sharper but weaker with increasing thickness

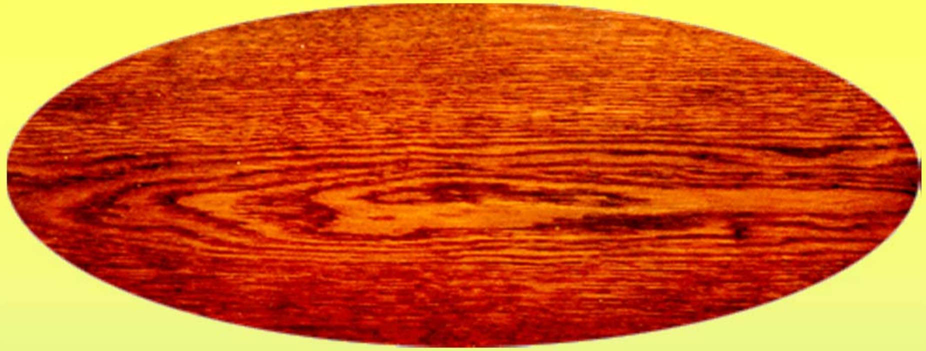
# Oil paints




- Colourant particles are embedded in a medium that is usually transparent
- The glossy reflection has the same colour as the incident light
- The matt reflection is coloured by preferential absorption by the embedded particles, and multiple scattering
- A matt top surface desaturates the pigment colouring

Early 19th century portrait in oils

# Wood varnish



Pine wood-grain

- Wood varnish smoothes the rough surface and allows light to penetrate the wood and be coloured by the natural wood pigment variations
  - note the superficial reflection of the incident light near the top right in the picture

Bookcase in figured walnut

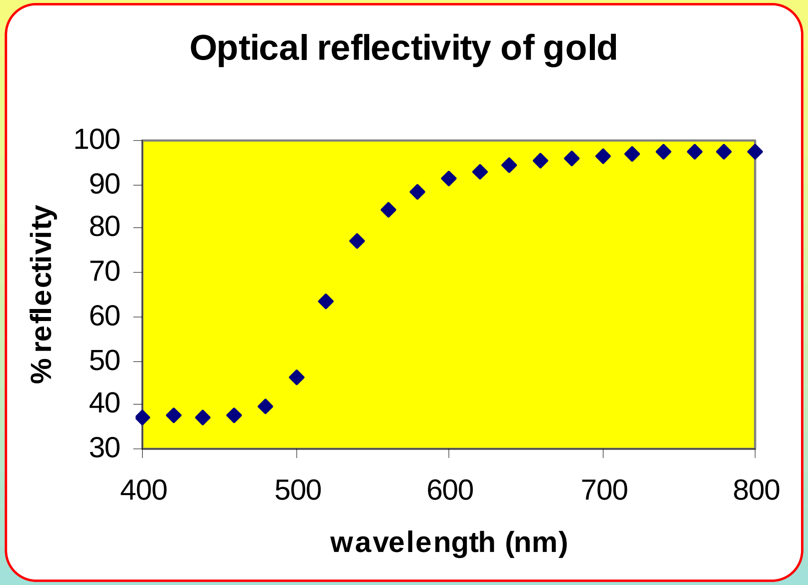
# Whiteness

- Whiteness is achieved by strong multiple reflections at the surface without preferential absorption
  - ▶white paper has cellulose fibres coated with a highly reflective oxide
  - ▶white bubbles form on coloured liquids
  - ▶white powders form when coloured solids are very finely ground



# Metallic reflection

- The colours of gold, copper, bronze and other metallic objects is caused by wavelength dependent reflectivity




Items from the Marischal Museum

Tibetan statuette

Maxwell's dynamical top

Bronze-age razor ~1100 BC