UNIVERSITY OF CAMBRIDGE

Liquid crystals
Lecture 11

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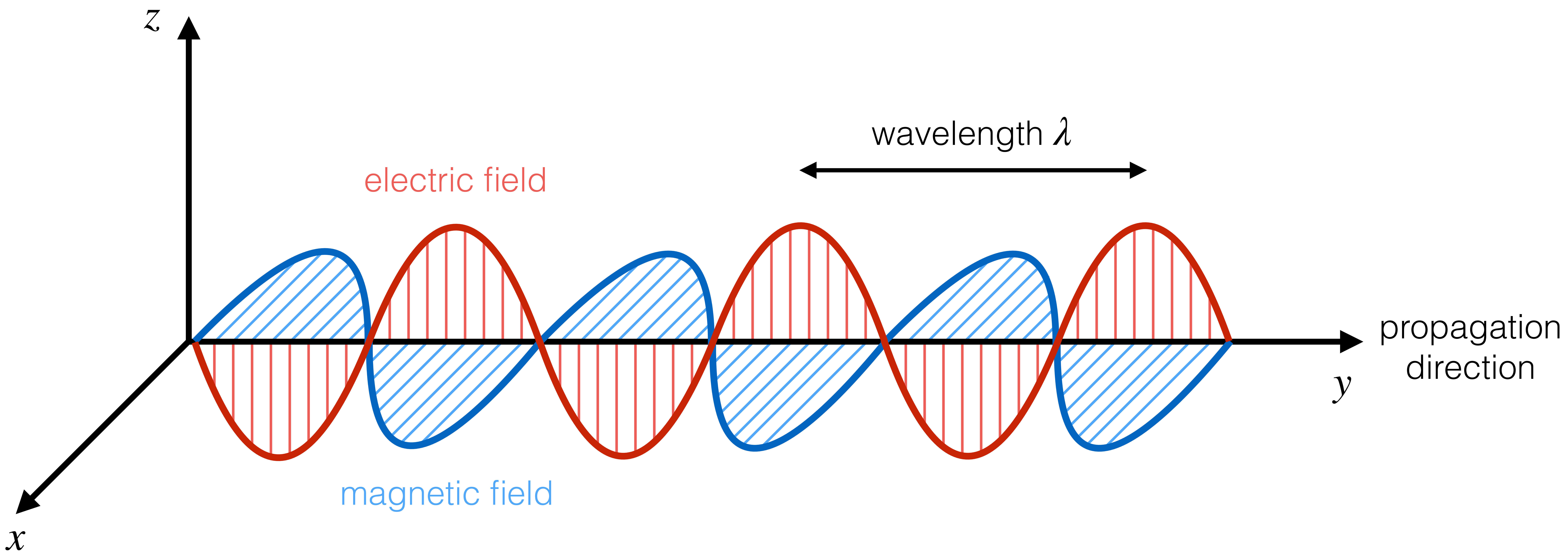
Course B: Materials for Devices

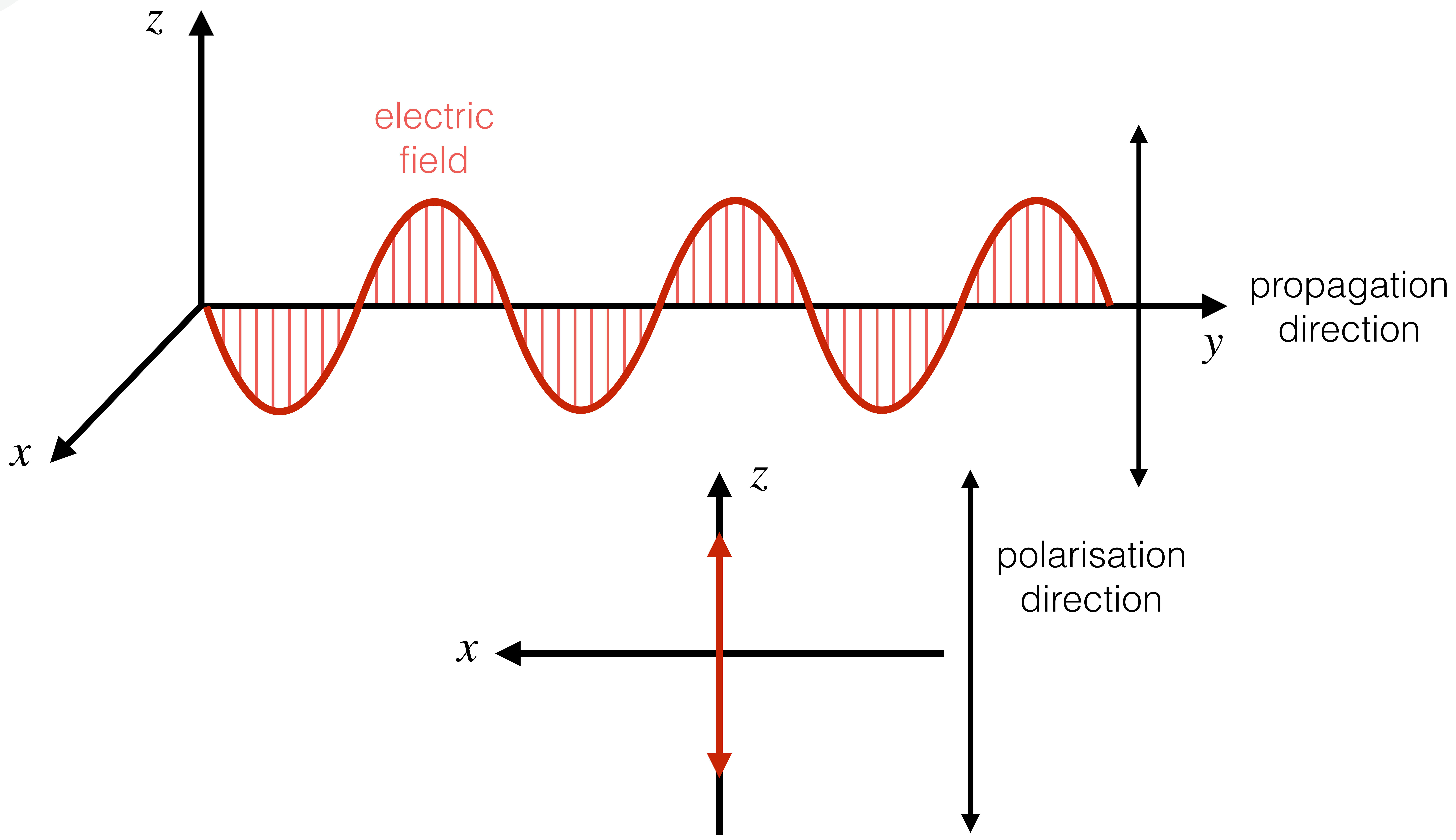
Professor M does Science

http://www.tcm.phy.cam.ac.uk/~bm418/

Electromagnetic waves

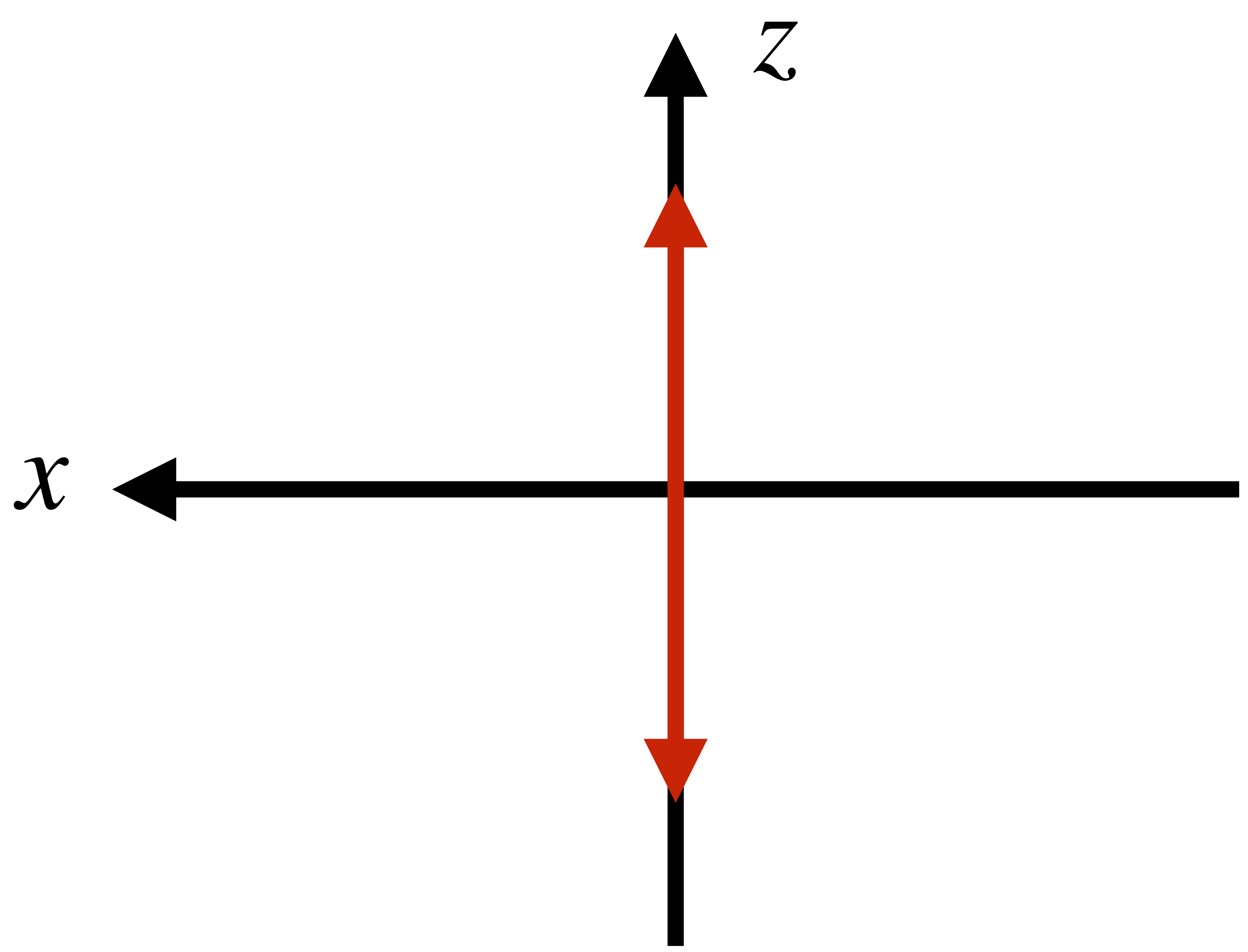


Electromagnetic waves



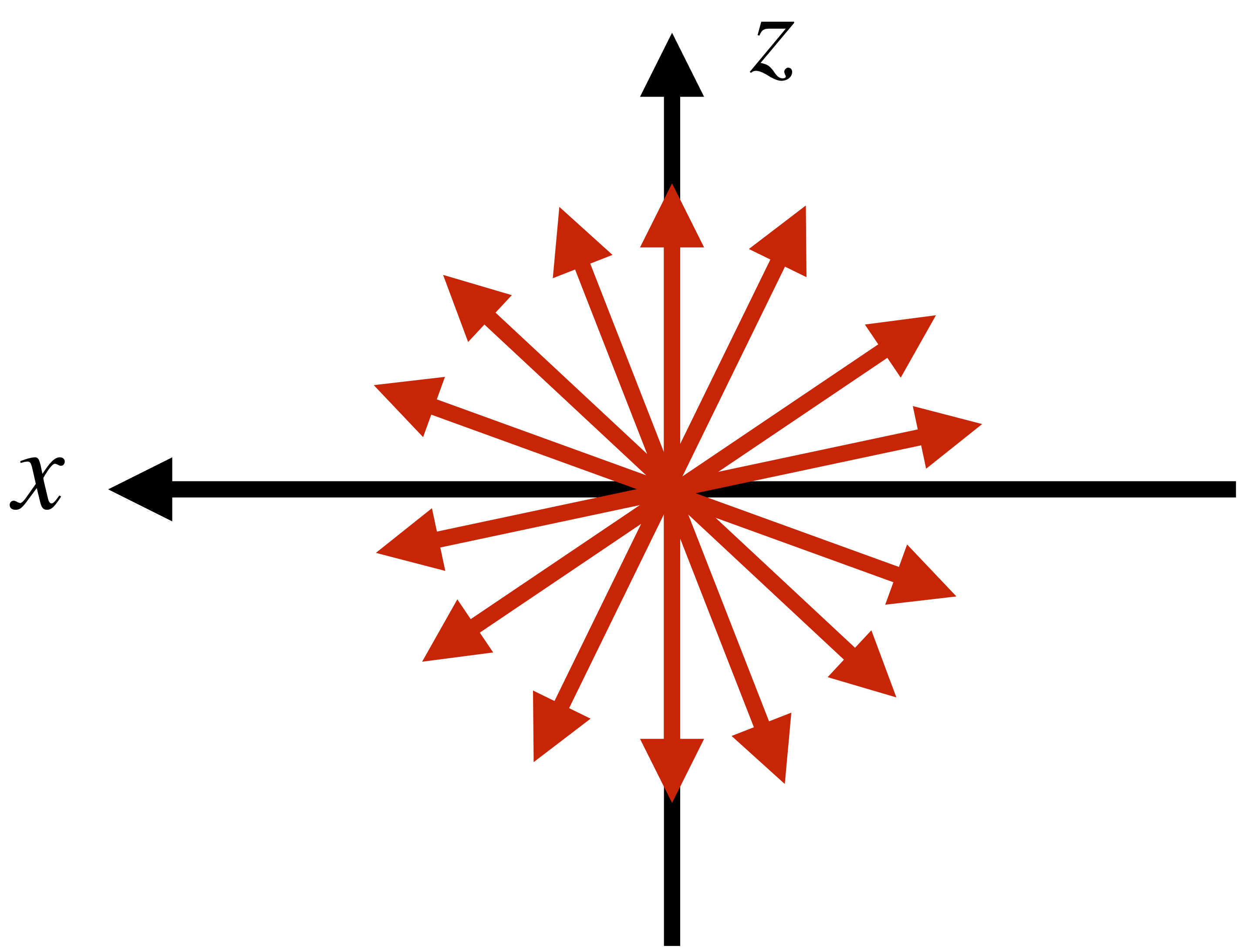
Polarised vs unpolarised light

polarised light



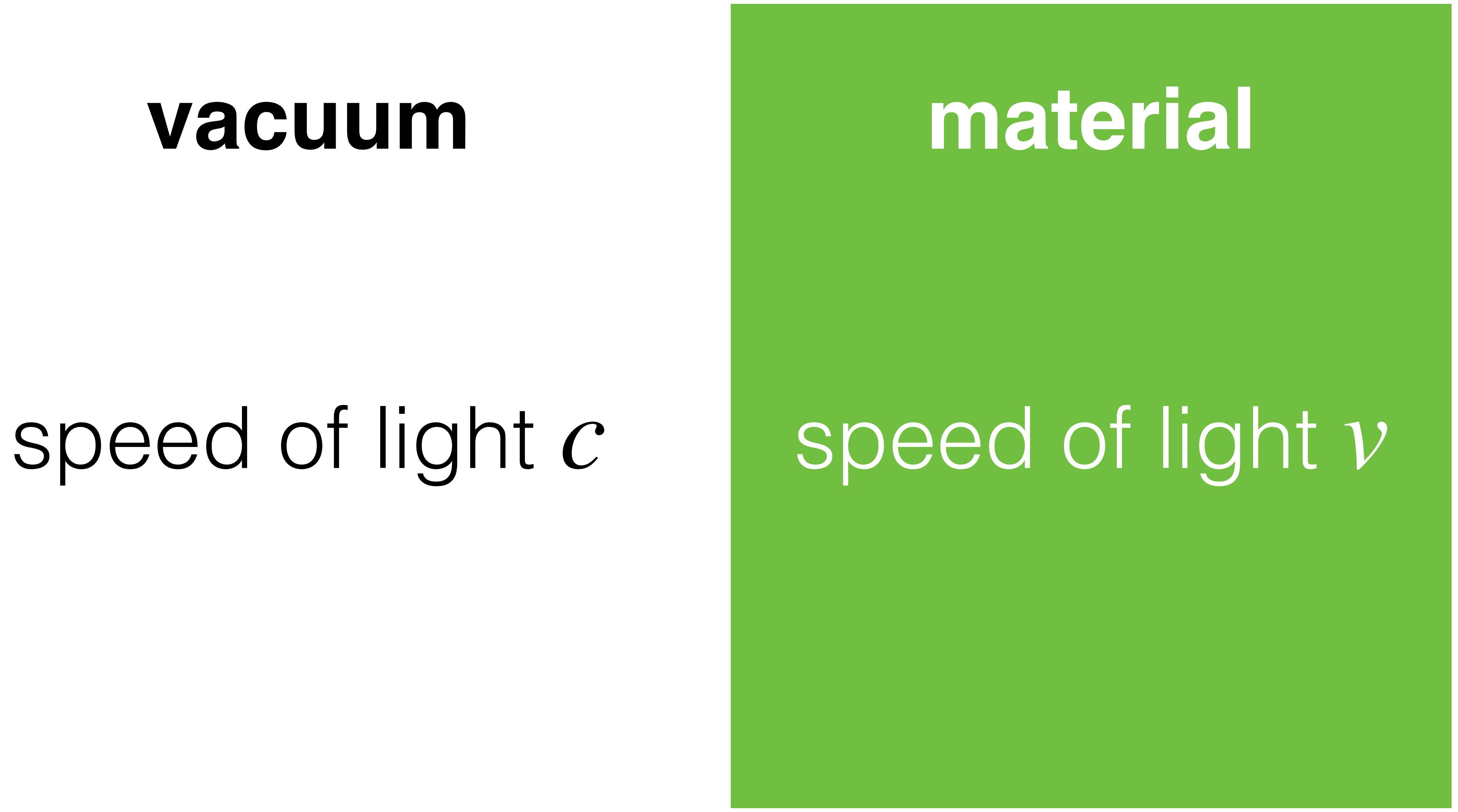
- Oscillations in a single direction

unpolarised light



- Oscillations in multiple directions
- Sun, flames, lamps, …

Light-matter interactions: refractive index



- Refractive index:

$$n = \frac{c}{v} \quad \text{[dimensionless]}$$

c : speed of light in vacuum

$[3.0 \times 10^{8}\,\mathrm{m\,s^{-1}}]$

v : speed of light in material $[\mathrm{m\,s^{-1}}]$

Light-matter interactions: refractive index

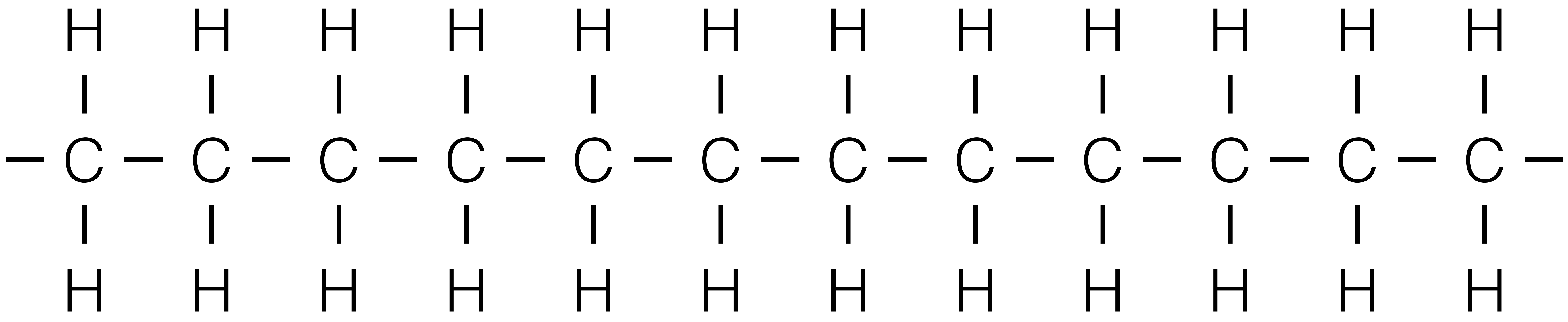
$$n = \frac{c}{v} \quad \text{[dimensionless]}$$

- **Microscopic origin:**
  - Oscillating electric field couples to electrons in material
  - Electrons oscillate and emit their own electromagnetic waves
  - Light in material is the superposition of the original and emitted waves

- **Properties:**
  - The speed of light in a material is frequency-dependent
  - Materials absorb light: e.g. metals absorb all light in the visible range of the spectrum

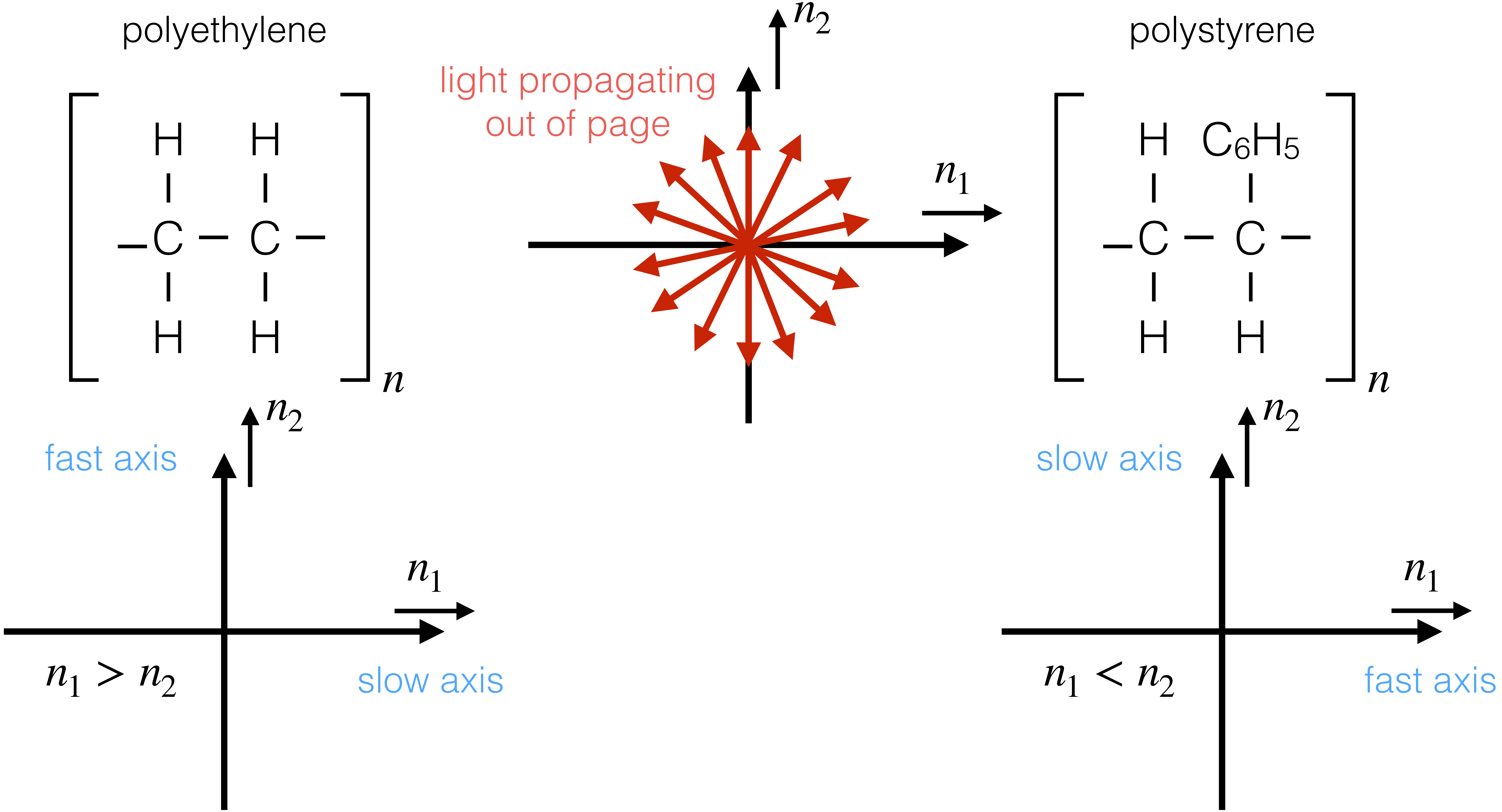
Light-matter interactions: refractive index

Light-polymer interactions



- Quasi-1D elongated structure of a polymer leads to different light-matter coupling in different directions:
  - ***Slow axis***: light couples strongly in this direction so light is significantly slowed
  - ***Fast axis***: light couples weakly in this direction, so light does not slow much
- Slow and fast axes are perpendicular, and collectively called the ***permitted vibration directions***

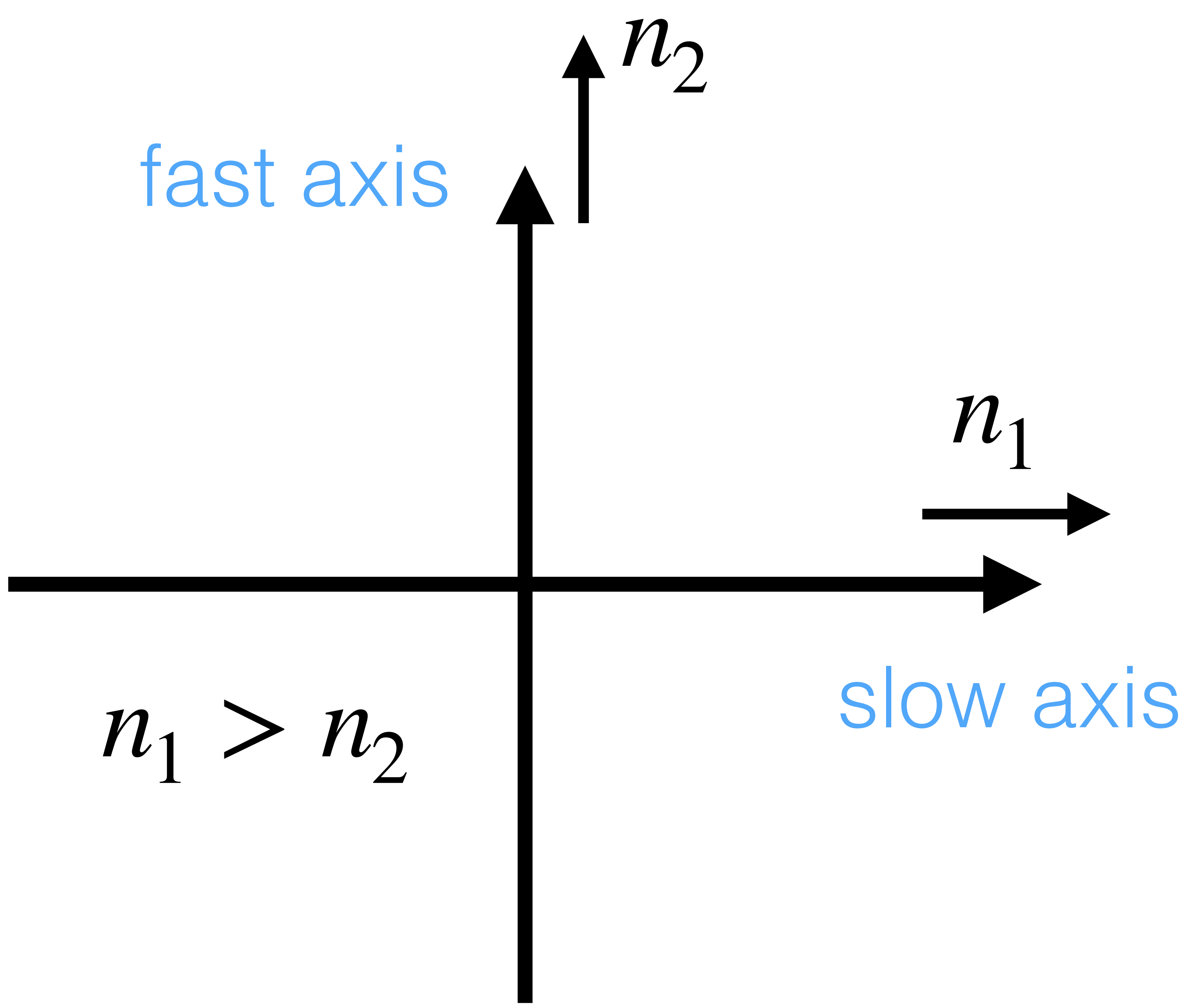
Light-polymer interactions



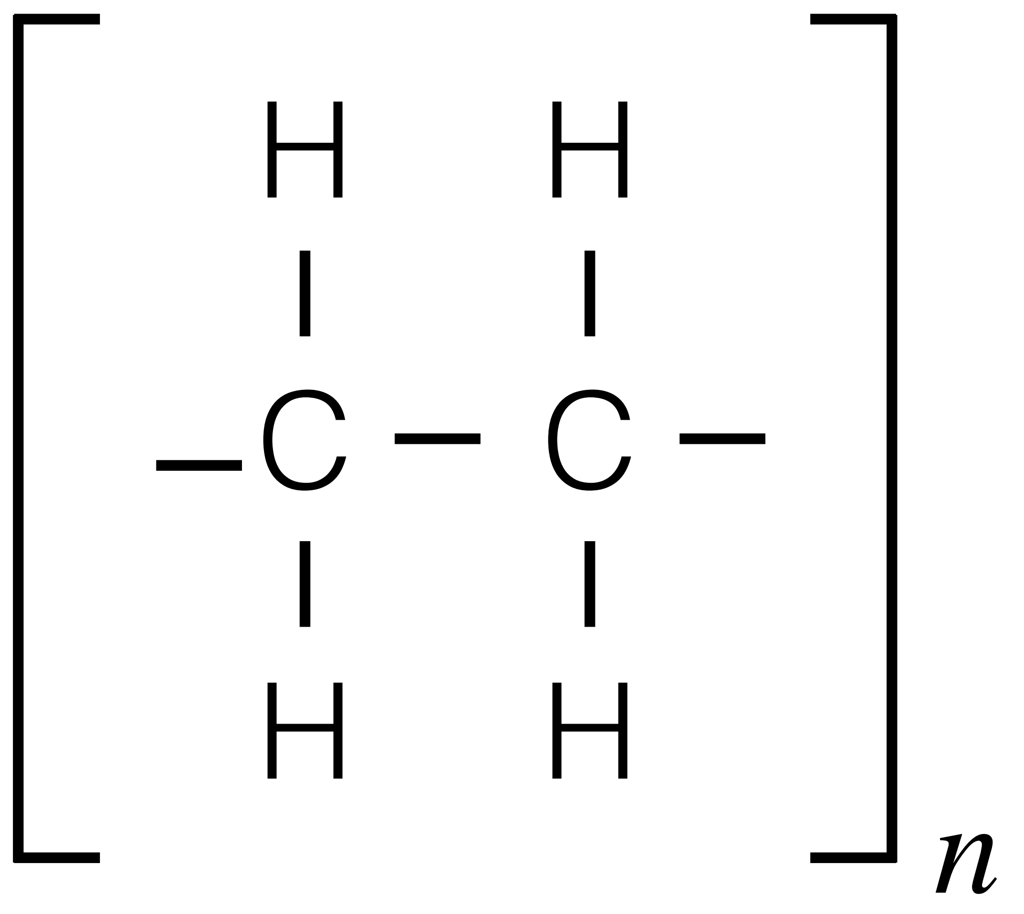
Birefringence

- Birefringence: property of a material with a refractive index that depends on the polarisation and propagation directions of light

$$\Delta n = n_1 - n_2$$



polyethylene



Birefringence

randomly oriented
polymer sample

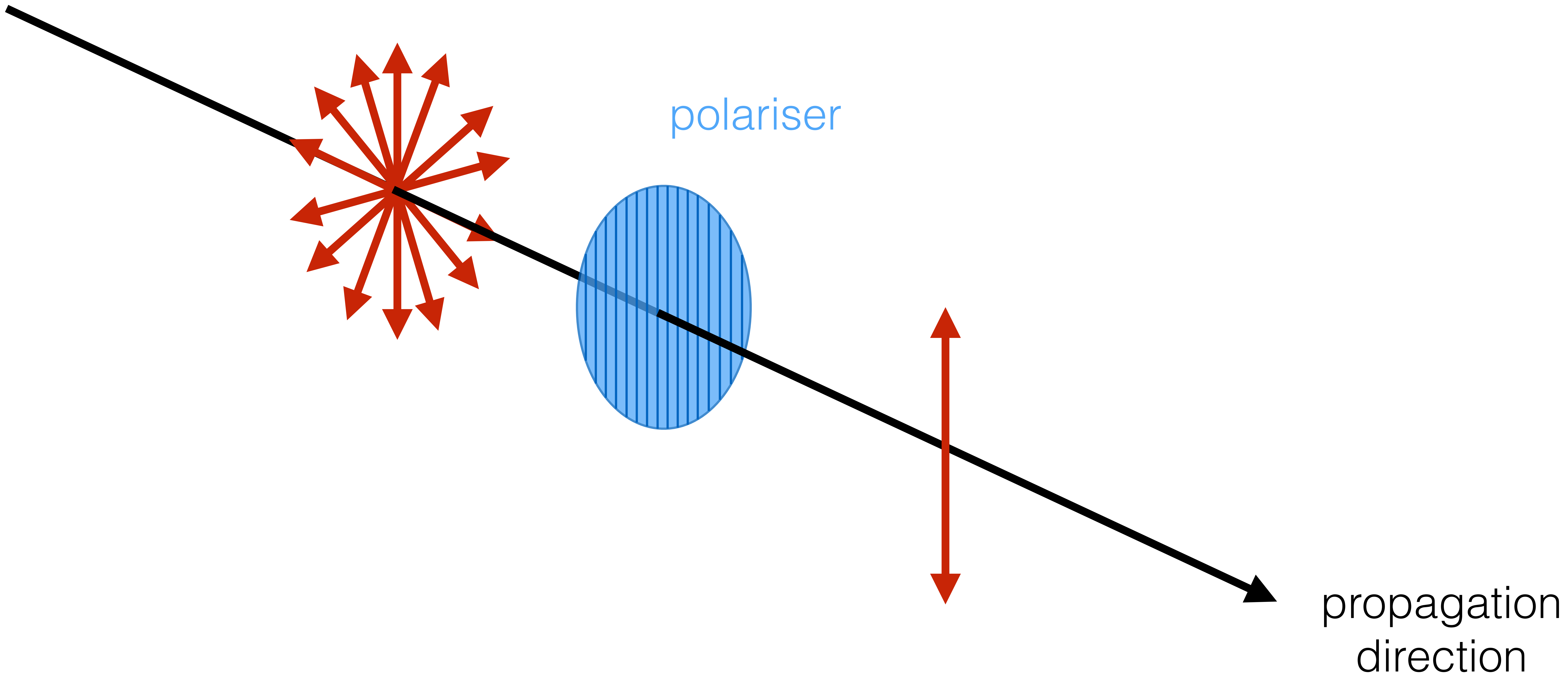
non-birefringent

oriented
polymer sample

birefringent

Polarisers

- Polariser: material that only allows light of a specific polarisation to pass through



Polarisers

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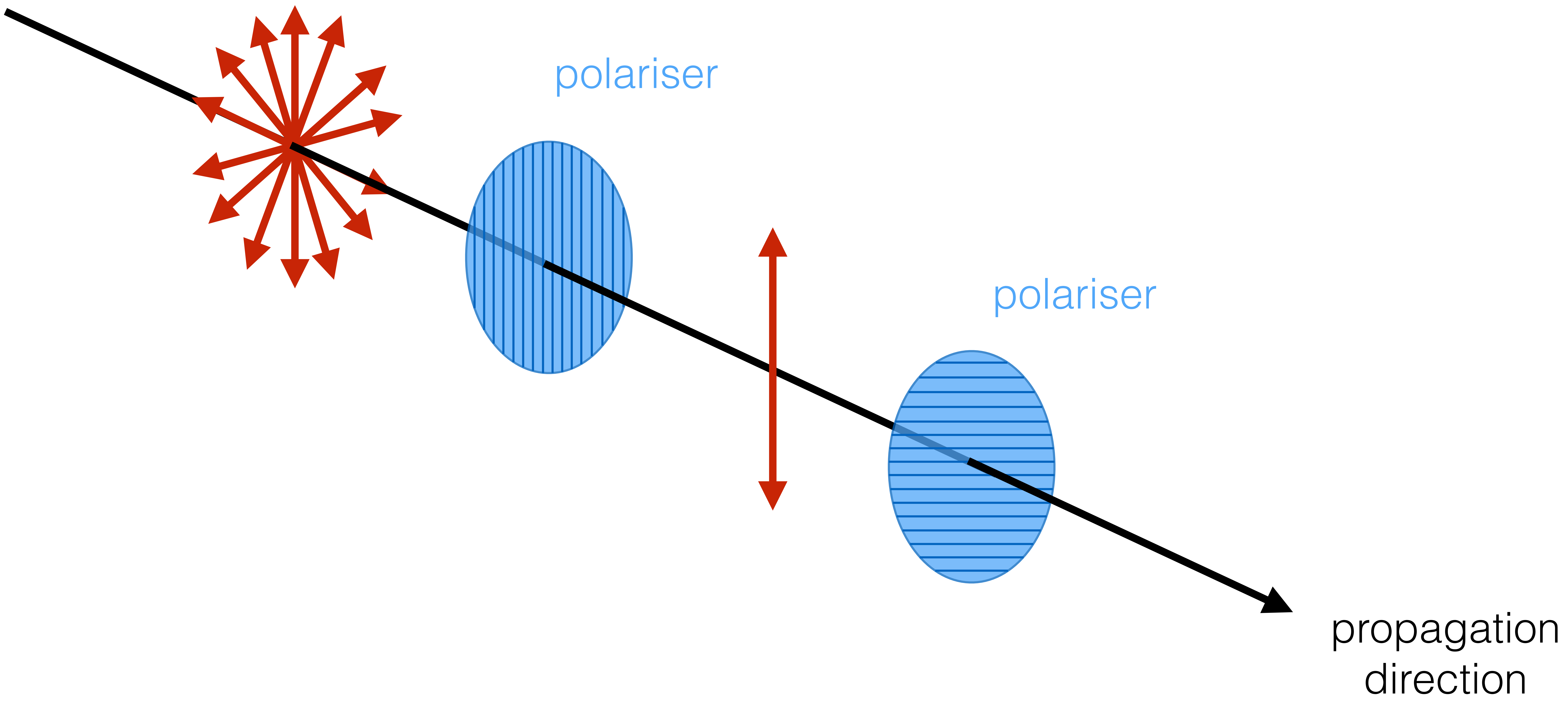
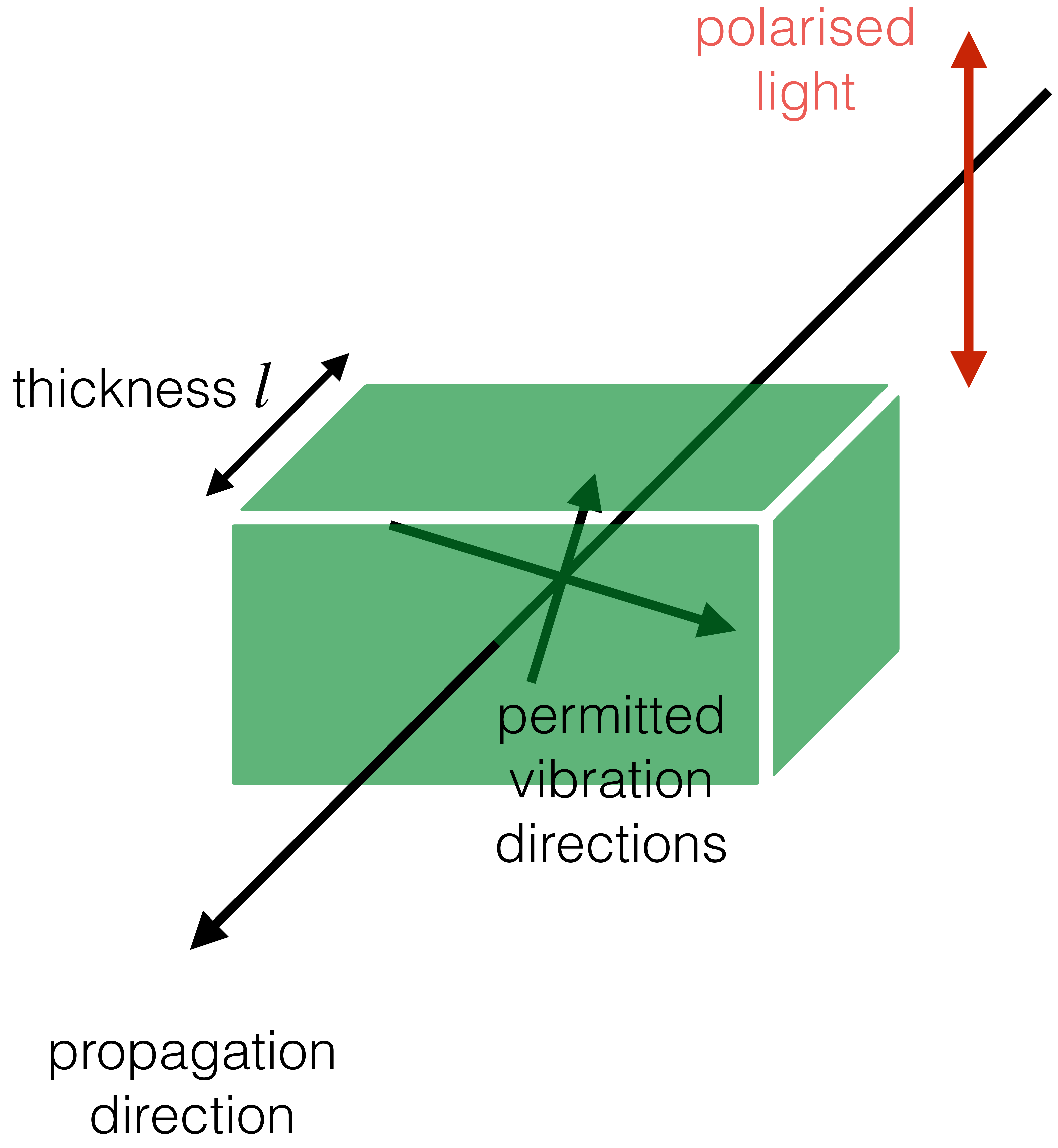


Polarised light passing through birefringent material

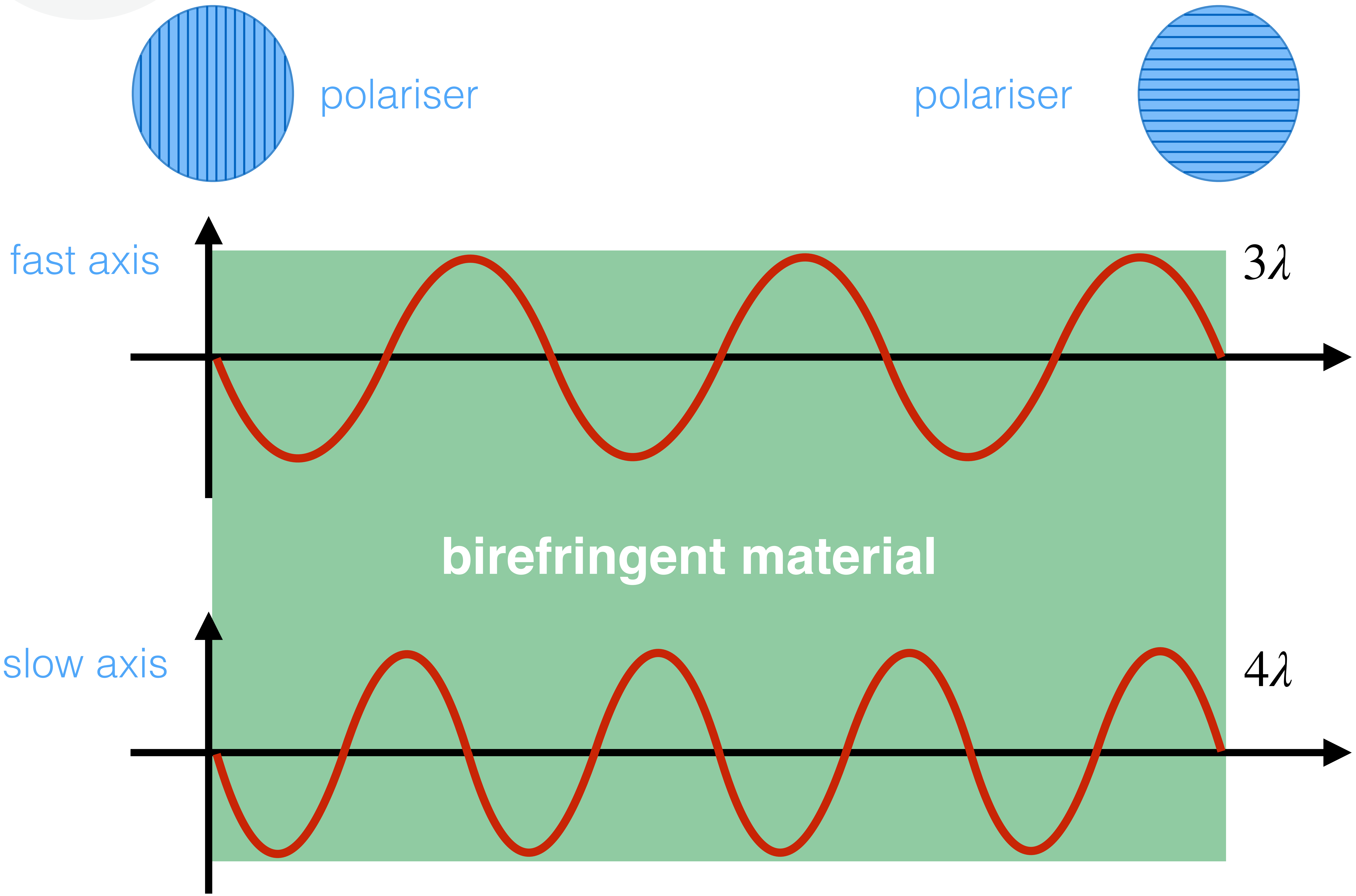
- *See derivation of optical path difference*

optical path difference (OPD) $= \Delta n \, l$

$$\frac{\delta}{2\pi} = \frac{\Delta n \, l}{\lambda}$$



Birefringent sample between crossed polarisers



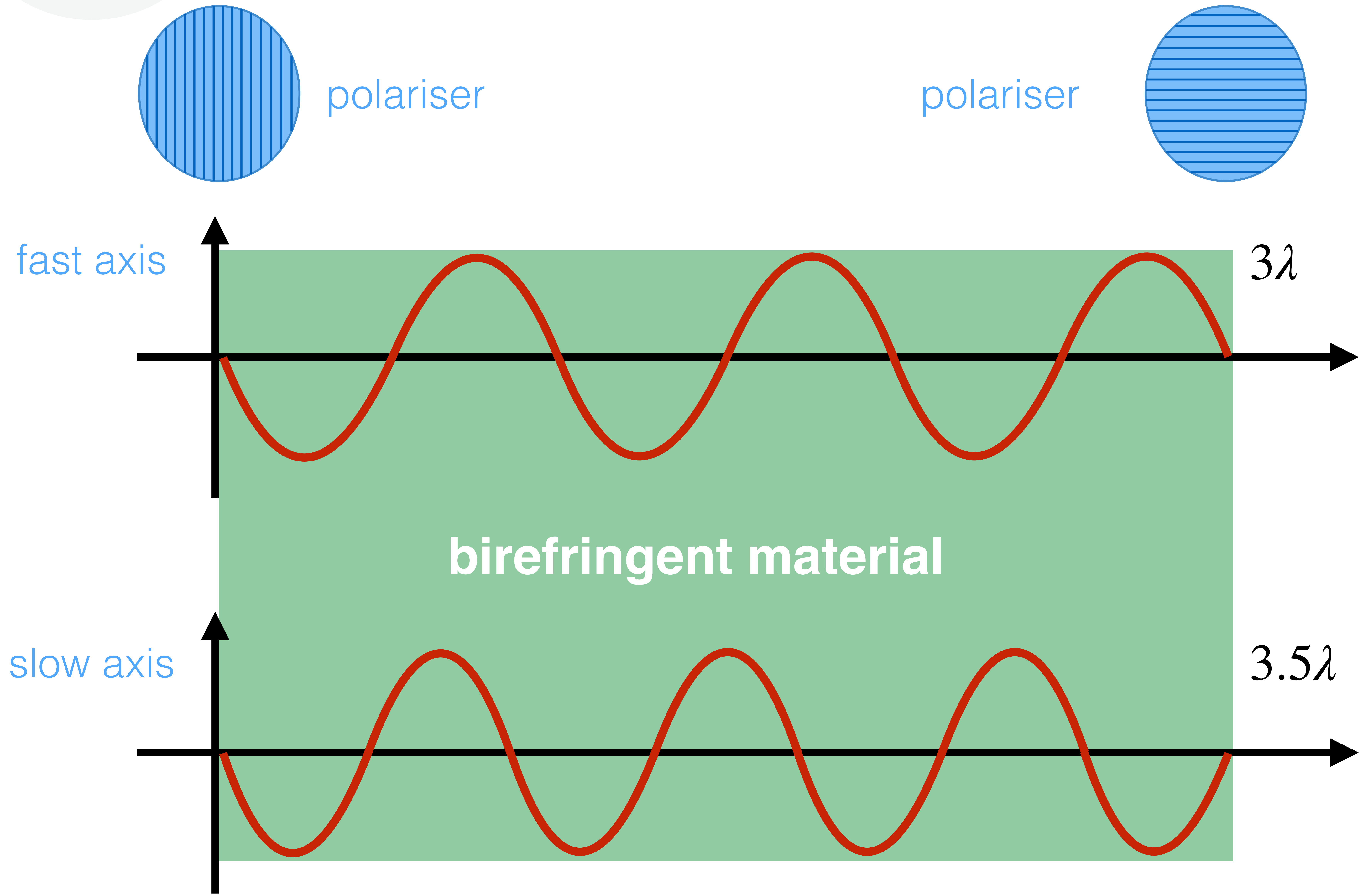
- *See derivation of outgoing light*

$$\text{OPD} = \lambda$$

$$\delta = 2\pi$$

- Light will not be transferred

Birefringent sample between crossed polarisers



- *See derivation of outgoing light*

$$\text{OPD} = \frac{\lambda}{2}$$

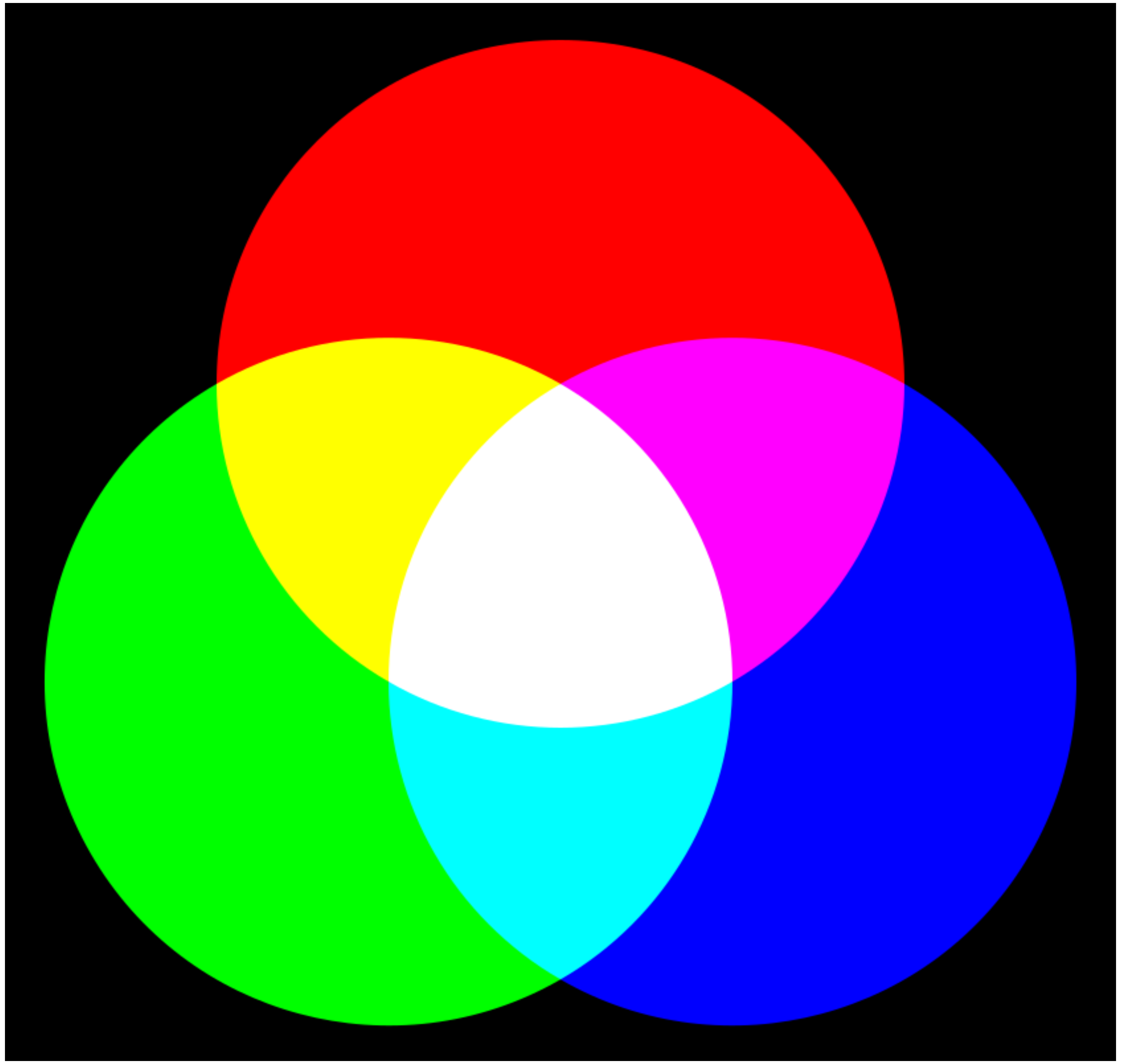
$$\delta = \pi$$

- Light will be transferred

White light passing through birefringent material

- White light is made of all possible wavelengths
- Phase difference depends on light wavelength: $\dfrac{\delta}{2\pi} = \dfrac{\Delta n \, l}{\lambda}$
- When birefringent material is place between cross polarisers:
  - Most wavelengths of white light will pass through
  - One wavelength of white light will be completely stopped ($\delta = 2\pi$)
  - Observed spectrum will be the original spectrum minus that specific wavelength

Complementary colour



- Complementary colour: the colour that is left when a frequency of light is removed.
- For example, the complementary of:
  - Blue is yellow
  - Green is magenta
  - Red is cyan

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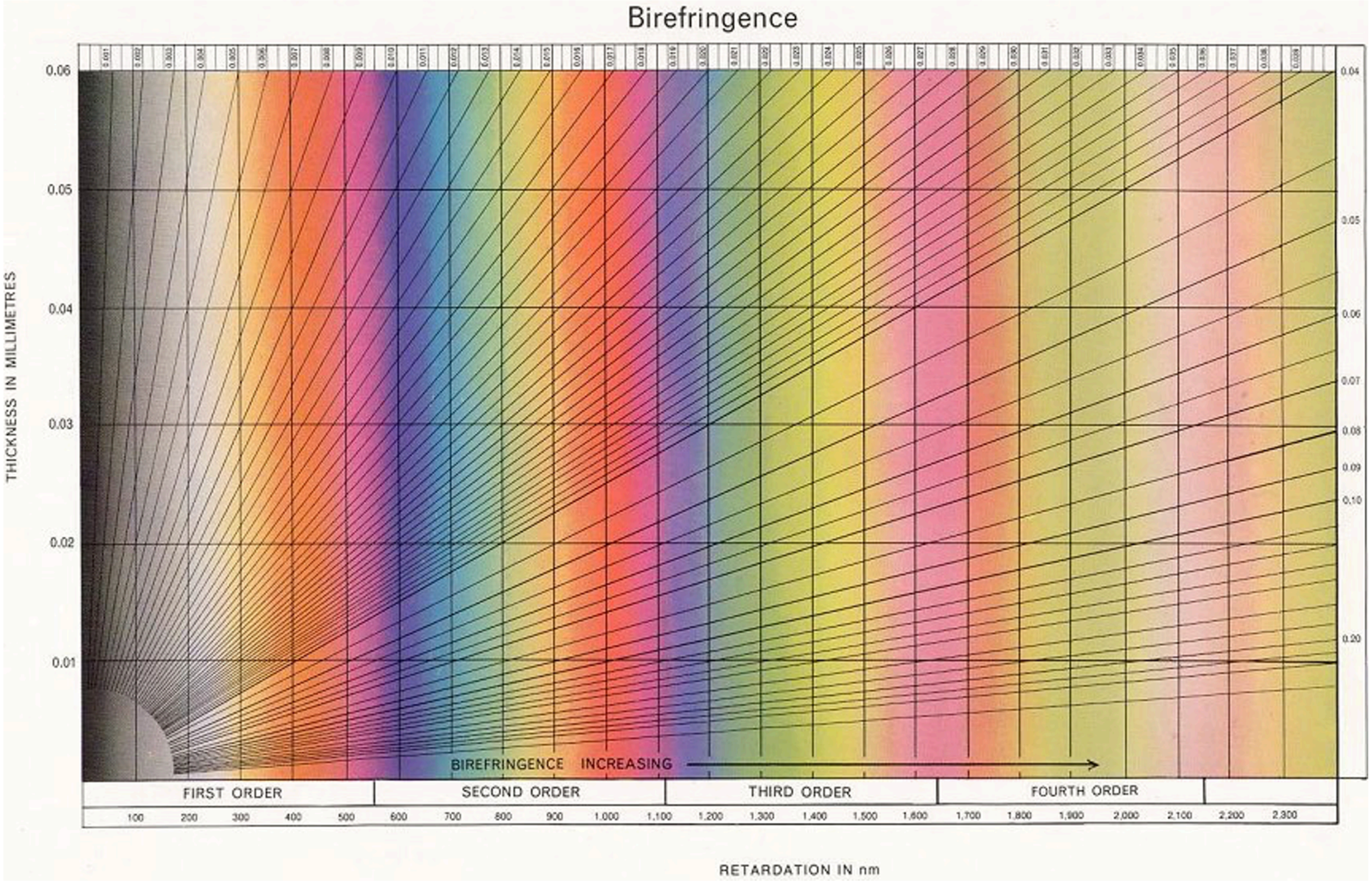
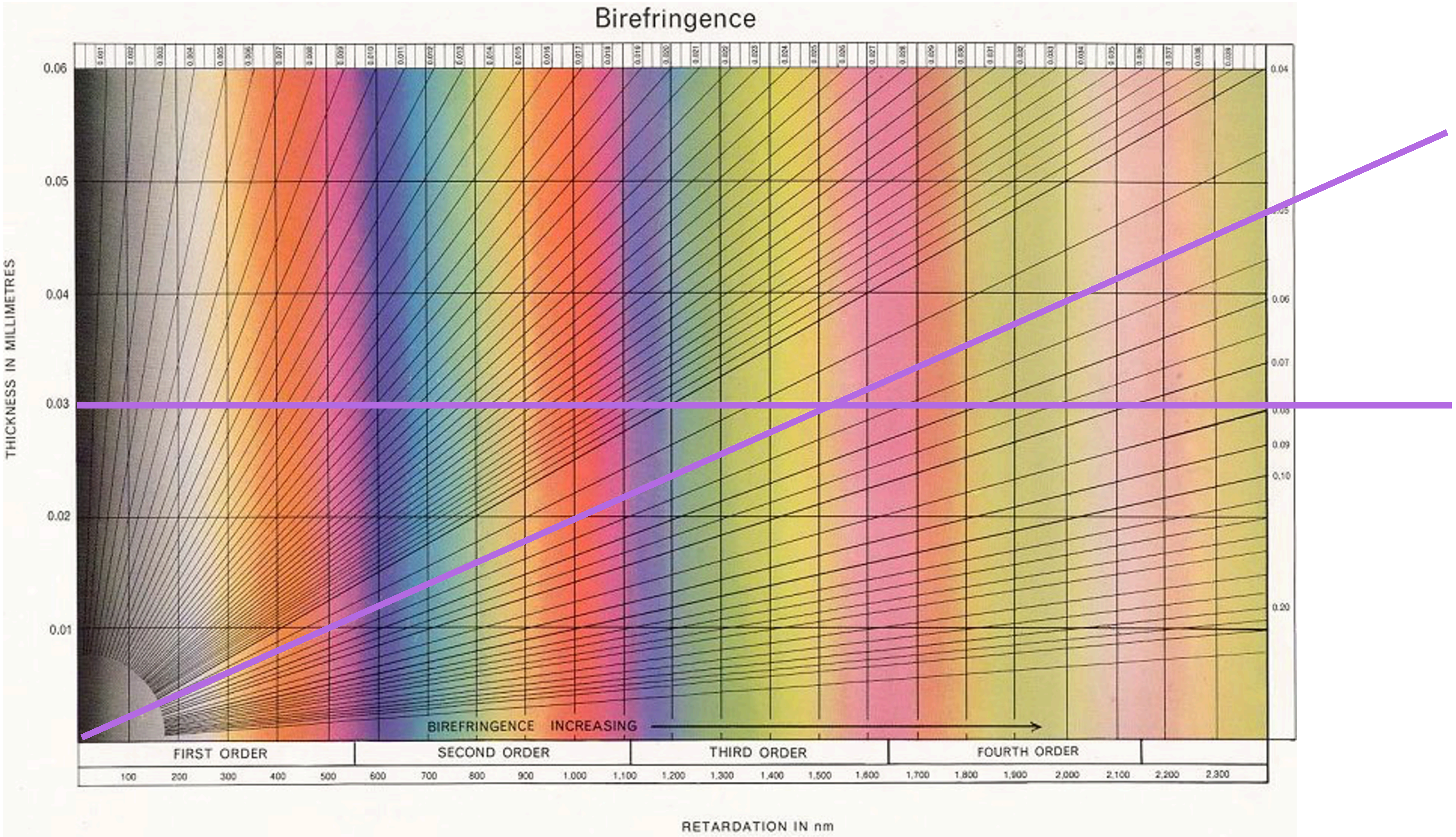
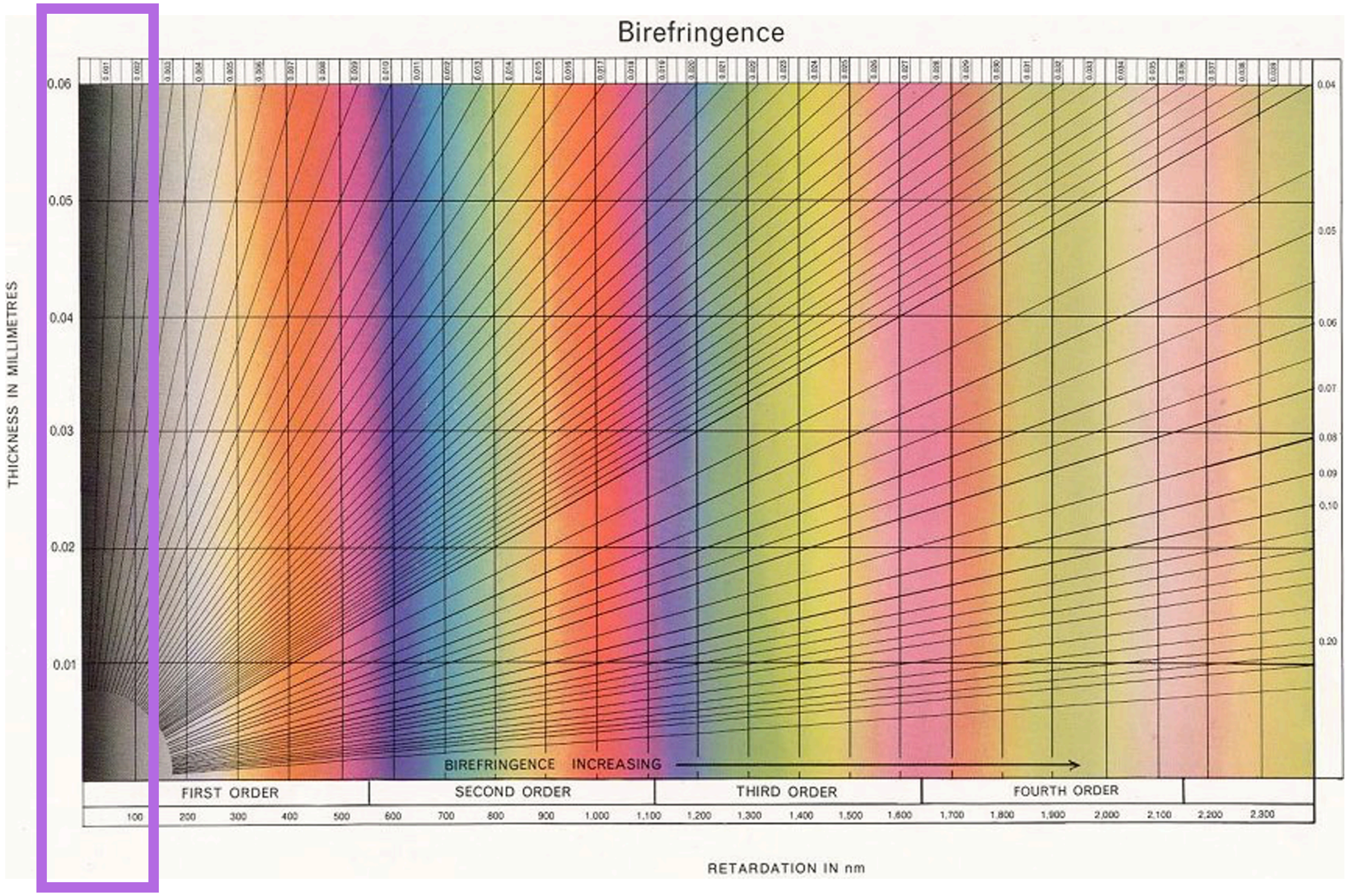
Michel-Levy chart



Michel-Levy chart: example

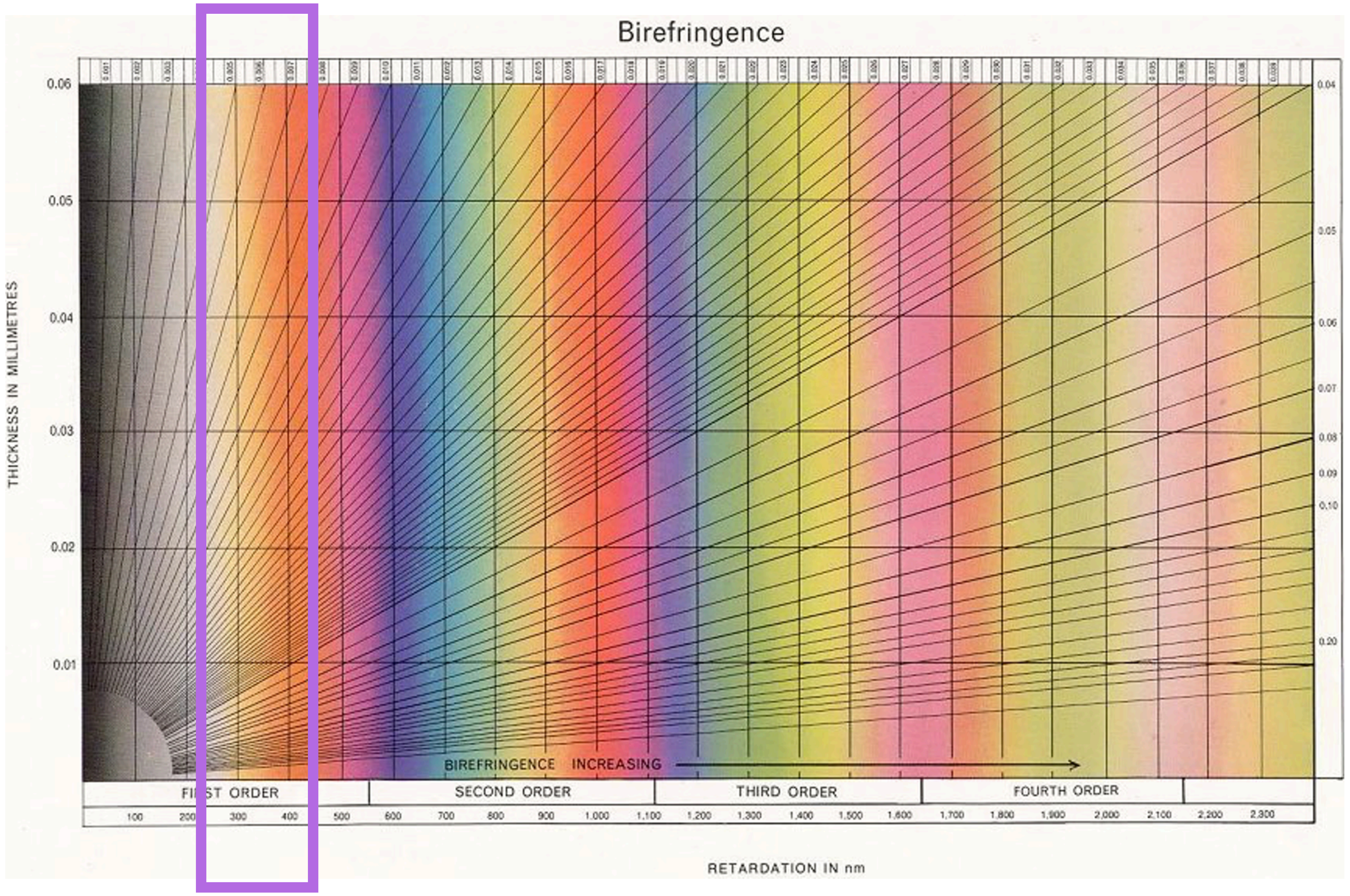


Michel-Levy chart



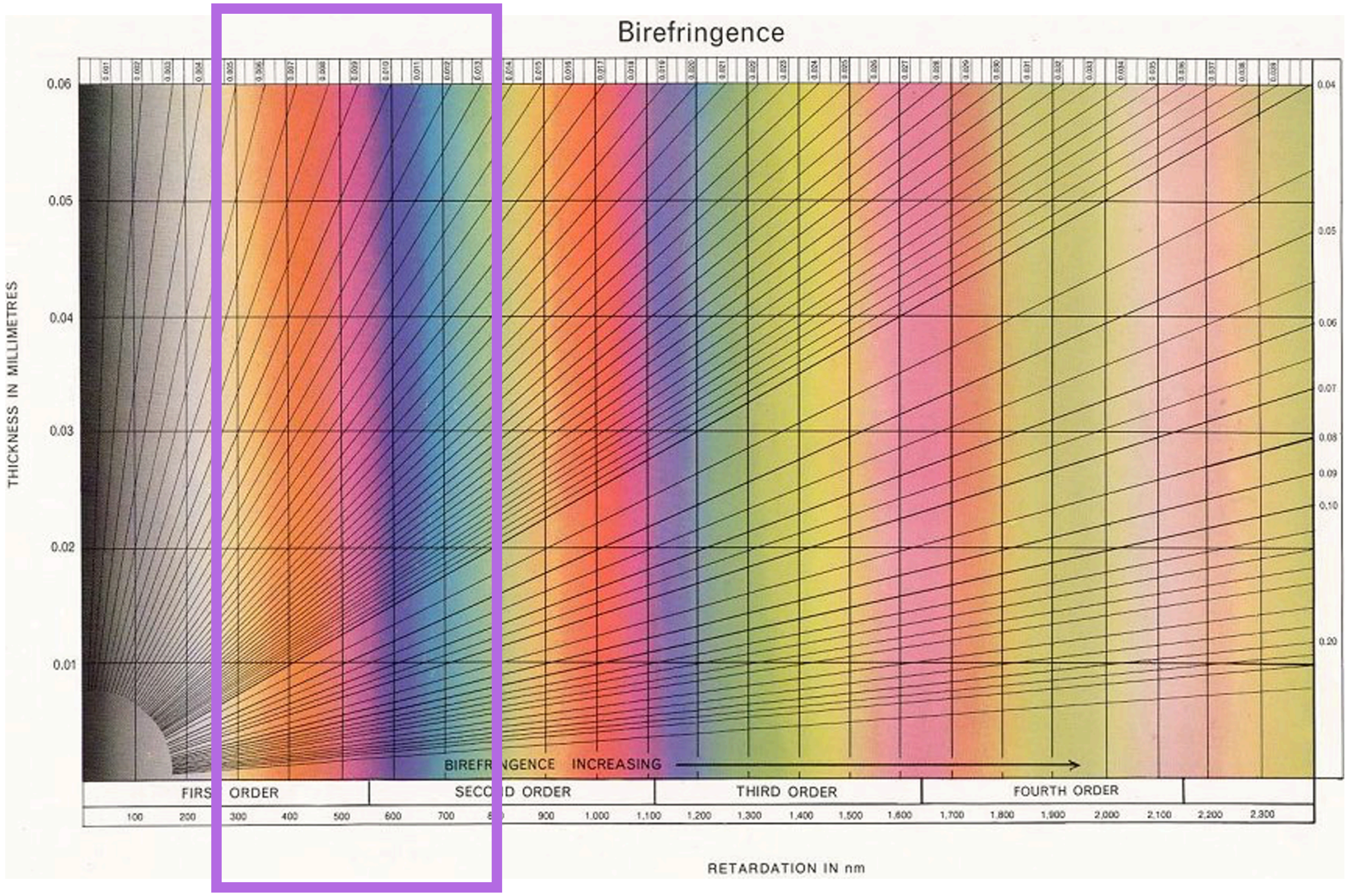
- Small optical path difference (right):
  - No rotation of light: black

Michel-Levy chart



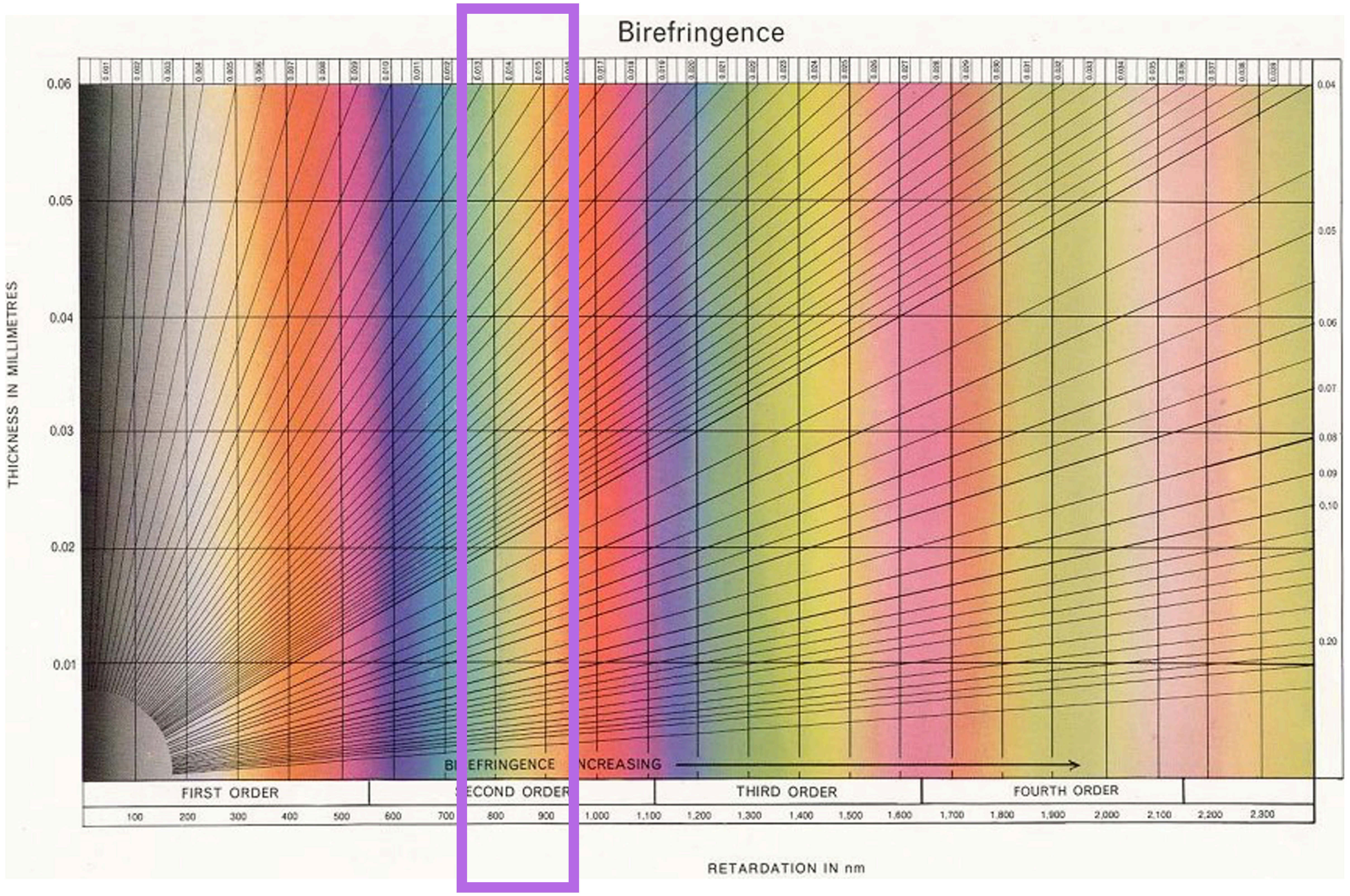
- Increasing optical path difference:
  - Yellow is the first colour we find
  - This means blue has been removed
  - Blue is the shortest wavelength colour in the visible spectrum

Michel-Levy chart



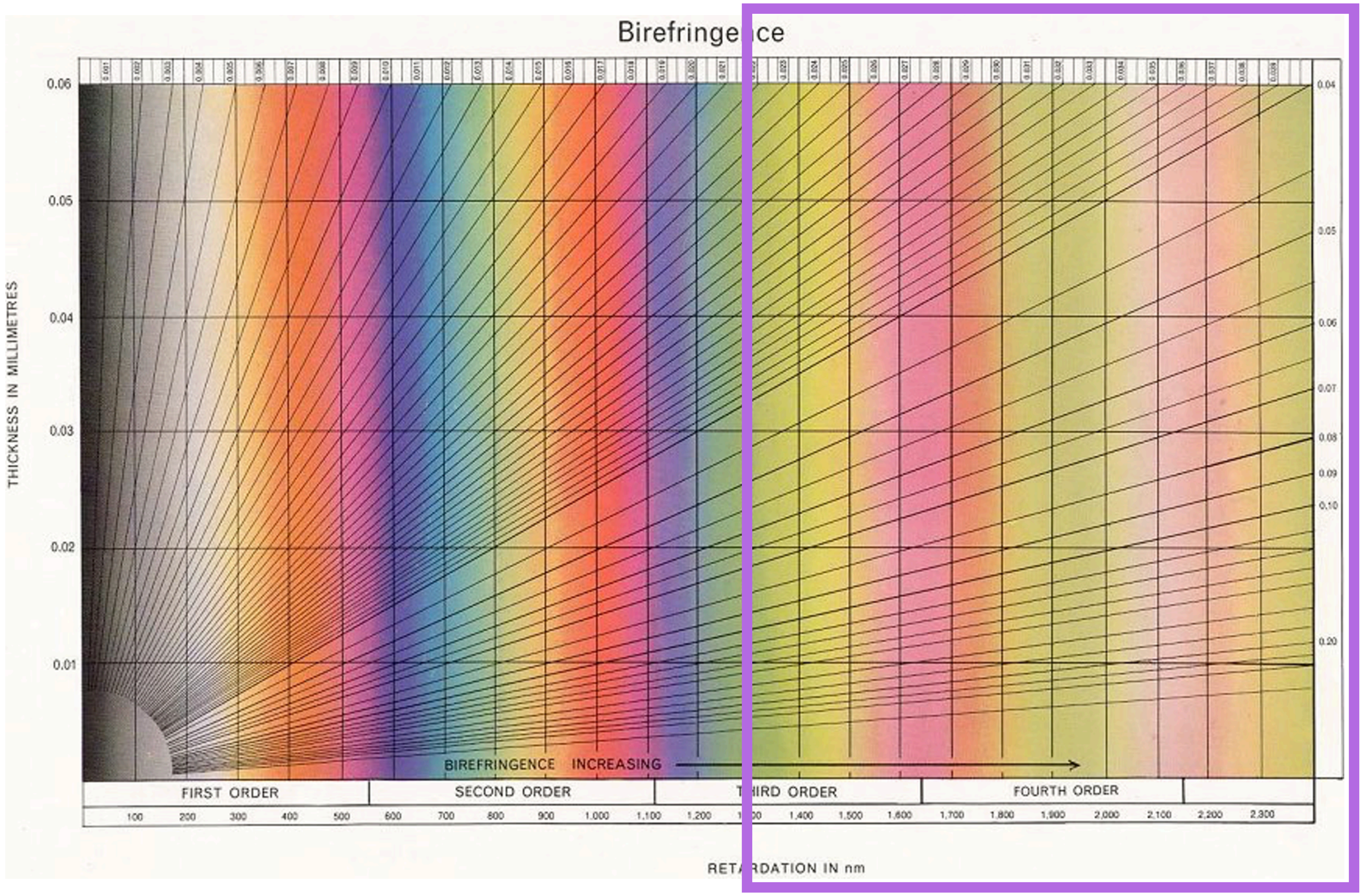
- Increasing optical path difference:
  - We encounter different colours
  - This is because longer wavelength light is being removed

Michel-Levy chart



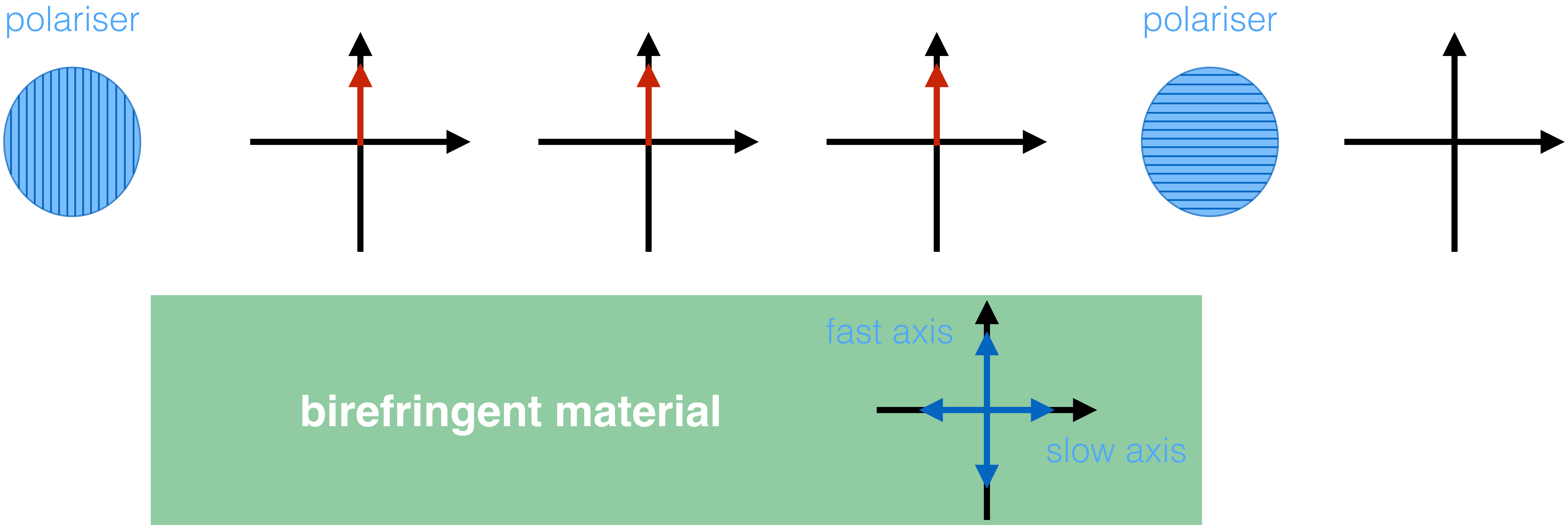
- Increasing optical path difference:
  - We encounter yellow again
  - This is because the optical path difference is now twice the wavelength of blue light

Michel-Levy chart



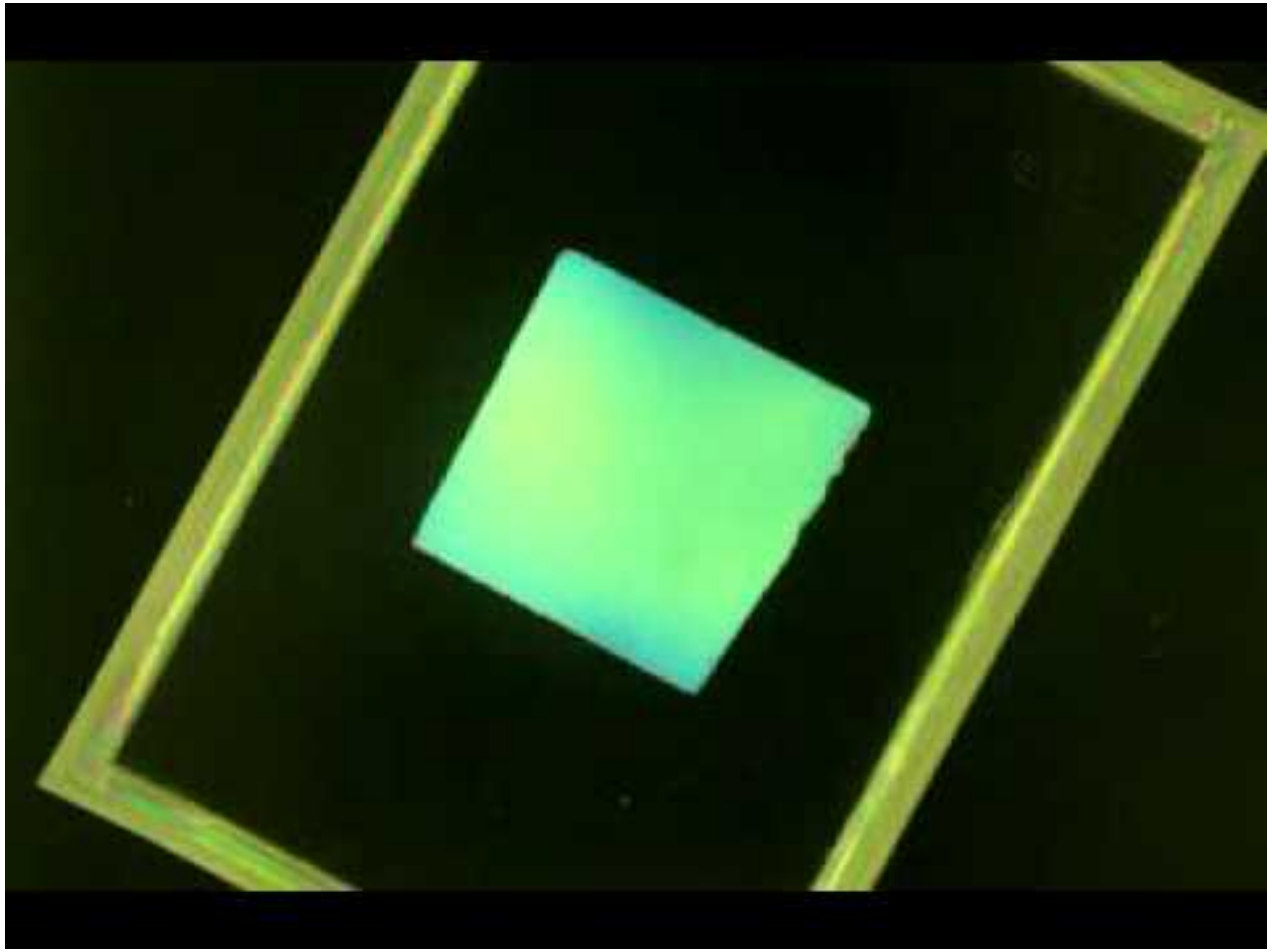
- Increasing optical path difference:
  - Pattern repeats
  - Colours become washed out
  - This is because for longer optical path differences, it becomes increasingly likely that it is a multiple of the wavelengths of multiple visible light wavelengths

Characterising birefringent materials

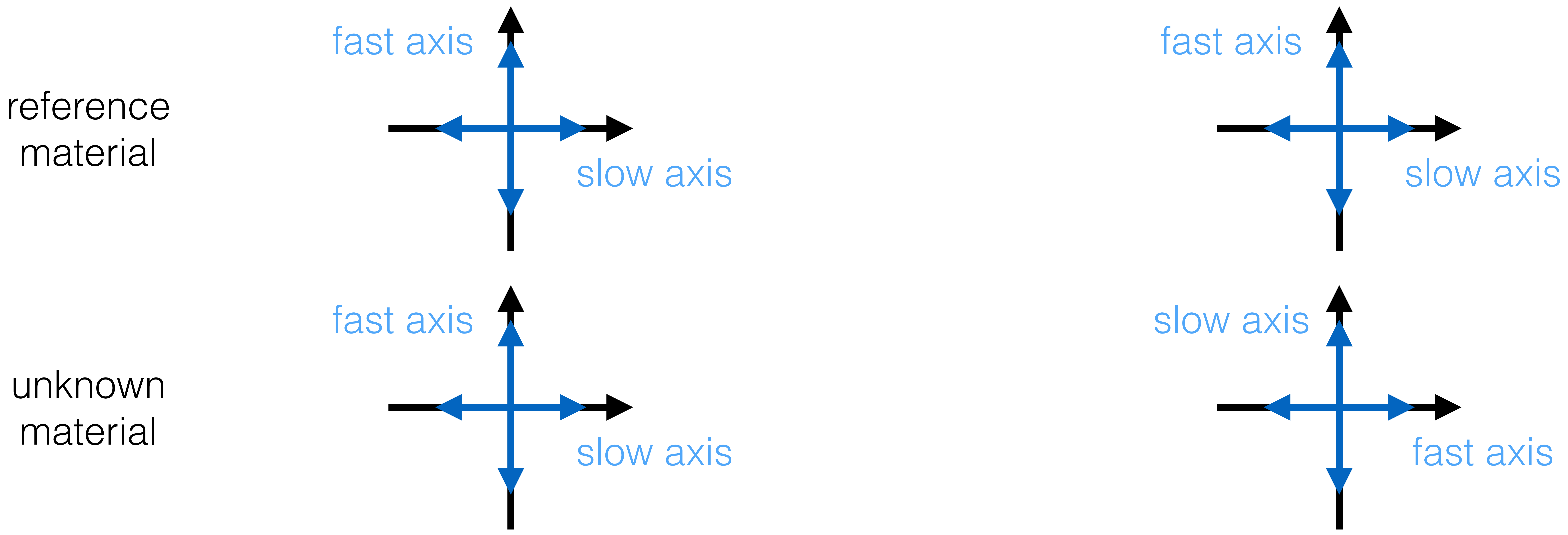


- If polariser aligned with fast or slow axis, then no path difference will develop, and no light will be transmitted after the second crossed polariser
- Sample will appear black: *extinction position*

Quartz rotating between cross polarisers



Characterising birefringent materials



- Larger total optical path difference
- Colour higher in Michel-Levy chart

- Smaller total optical path difference
- Colour lower in Michel-Levy chart