Polarisation, analyser chains and phase

GRE undergraduate preparation · local supported objectives

Polarisation, analyser chains and phase

- Apply **Malus's law** 马吕斯定律 through a chain of **polarisers** 偏振片.
- Treat **unpolarised** 非偏振的 light correctly at the first filter.
- Recognise linear, **circular polarisation** 圆偏振 and elliptical states, and what a **quarter-wave plate** 四分之一波片 does.
- Use **Brewster's angle** 布儒斯特角.

Malus's law, step by step

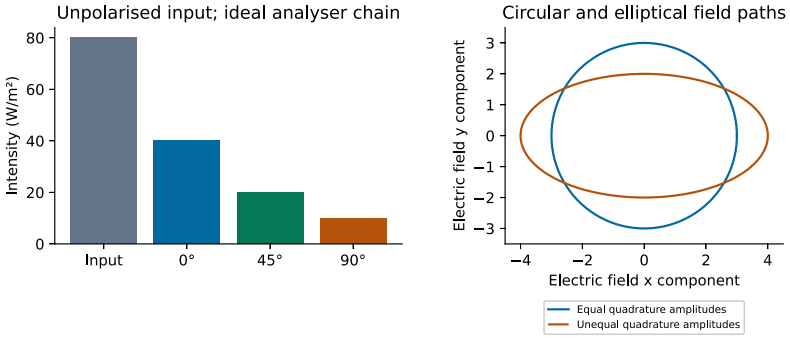
- θ is measured from the light's current polarisation, which is the axis of the previous polariser.
- Unpolarised light loses half its intensity at the first polariser, and leaves polarised along that axis. Only that first step uses the factor $\frac{1}{2}$.

$$I = I_{\text{in}} \cos^2 \theta$$

A chain of polarisers

- $I_0 \to I_0/2 \to (I_0/2)\cos^2 45^\circ = I_0/4 \to (I_0/4)\cos^2 45^\circ = I_0/8.$
- The middle filter does not add light; it turns the polarisation in two steps instead of one.

Figure: A chain of polarisers



- The first polariser halves unpolarised light; each later one applies **Malus's law**, $\cos^2\theta$
- Read the axes and units first.

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Polarisation states

- $\delta = 0$ or π: linear polarisation.
- $A = B$ and $\delta = \pm\pi/2$: **circular polarisation**; the field vector traces a circle.
- Any other case: elliptical. Circular light through any ideal linear polariser keeps half its intensity.

Wave plates

- A **quarter-wave plate** adds a phase of $\pi/2$. Linear light at 45° to its axes becomes circular; light along one axis stays linear.
- A polariser removes a component; a wave plate only shifts its phase.

Brewster's angle

- At this angle the reflected and refracted rays are at 90° to each other.
- Air to glass ($n = 1.5$): $\theta_B = 56.3°$. Polarising sunglasses block the horizontal glare reflected from roads and water.
- **Brewster's angle** is not the critical angle, which needs light going from a denser medium to a less dense one.

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Worked example: three filters

- After 0°: 40 W/m^2. After 45°: $40\cos^2 45^\circ = 20$ W/m^2. After 90°: $20\cos^2 45^\circ = 10$ W/m^2.
- Remove the middle filter and nothing gets through.
- Use six filters in 15° steps instead: each passes $\cos^2 15^\circ = 0.933$, so $40 \times 0.933^6 = 26$ W/m^2 survive. More, smaller steps lose less.

Worked example: glare from water

- $\theta_B = \tan^{-1}(1.33) = 53.1^\circ$ from the vertical.
- Light reflected at that angle is polarised horizontally (s).
- A polariser with a vertical axis blocks it, which is why polarising sunglasses have vertical axes.

Common errors

- Halving the intensity at every polariser, not just the first.
- Measuring θ from the first polariser instead of the previous one.
- Thinking a wave plate absorbs light.

Common errors (2)

- Confusing **Brewster's angle** with the critical angle.
- Saying circular light is blocked by a linear polariser; half gets through.

Key terms

- **Malus's law**: An ideal polariser passes $I\cos^2\theta$ of linearly polarised light.
- **polariser**: A filter that passes the electric field along one axis.
- **unpolarised**: With the field direction changing randomly, so no direction is preferred.
- **circular polarisation**: Light whose field vector turns in a circle as the wave passes.

Check yourself

- 100 W/m^2 of unpolarised light passes two polarisers 60° apart. What comes out?
- What is **Brewster's angle** from air into water ($n = 1.33$)?
- Linear light at 45° to the axes enters a **quarter-wave plate**. What comes out?