

Can two different lights look like the same colour?

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A lamp and a screen can produce a colour match without producing the same light. A spectrometer could distinguish them while a person comparing two adjacent patches could not. This is not necessarily a failure of attention. Human colour vision preserves some differences between spectra while losing others. The name for a match between spectrally different stimuli is metamerism. [1]

The word “same” therefore needs a condition attached to it. Same spectrum, same response in a specified colour-matching experiment and same appearance in two different rooms are three different claims. Understanding that distinction explains both why a display can reproduce many colours and why a satisfactory match can fail when the viewing conditions change.

1. What would count as two different lights?

Describe a light by how its power is distributed across wavelengths. One source might concentrate its output in a few narrow bands; another might distribute it across a much broader range. Equal total power would not make those distributions identical. Nor would equal power necessarily make them look equally bright. A spectral measurement asks how much radiation is present at each wavelength, whereas a colour match asks what differences a particular observer can detect under specified conditions.

A useful experiment presents two uniform patches side by side while keeping their size, surrounding background, viewing direction and adaptation conditions fixed. The observer adjusts one mixture until the patches match. Spectral measurements can then test whether the match required identical spectra. This procedure separates an empirical judgement from an assumption about what the eye must be measuring.

2. Three overlapping sensitivities

For ordinary photopic trichromatic colour matching, a model starts with the three classes of cone photoreceptors. Their spectral sensitivities overlap. A cone class does not report one wavelength, and its response is not a label saying red, green or blue. The Colour and Vision Research Laboratory provides cone-sensitivity functions used to quantify these overlapping responses. [2]

In a linear excitation model, the signal for cone class i is proportional to the integral of $P(\lambda) \times s_i(\lambda)$, where P describes the incident spectrum and s_i the relevant sensitivity. Different spectra can yield the same three integrals. The qualification “linear excitation model” matters: this is a model of receptor excitation for matching, not a complete theory of visual appearance, adaptation or neural processing.

The information loss can be understood without calculating a real cone response. Suppose a deliberately simplified instrument has three sensors and four narrow spectral channels. Its response matrix has three rows and four columns. Linear algebra guarantees a nonzero change in the four channel intensities that leaves all three outputs unchanged, provided that change lies in the matrix's null space. Starting from sufficiently positive channel intensities, a small enough change can keep every intensity nonnegative. Two physically admissible spectra then share one output vector.

This construction is a mathematical illustration, not a claim that any chosen four lamps make a perfect match for every human observer. It identifies the structural reason that a few weighted measurements cannot uniquely reconstruct an unrestricted spectrum.

3. A worked example of information lost

Take hypothetical sensor outputs $x_1 + x_4$, $x_2 + x_4$ and $x_3 + x_4$. The spectrum represented by channel intensities (2, 2, 2, 1) gives (3, 3, 3). The different spectrum (1, 1, 1, 2) also gives (3, 3, 3). Their total intensities even differ: seven units versus five. The sensors are not total-power meters, so that difference does not contradict equal outputs.

These made-up sensitivities are not human cone fundamentals. Their purpose is to make the inverse problem inspectable. Knowing the three outputs does not tell us which four inputs generated them. A calibrated spectrometer with more independent spectral measurements could distinguish the pair, even when this three-channel instrument cannot.

Real colour matching adds physiological and experimental constraints. A numerical match for a standard observer is a prediction for a defined observer model. It is not a guarantee about every person. CIE explicitly treats colour mismatches caused by substituting another normal-colour-vision observer for the standard observer. [3]

4. Why matching paint is a different test

For a nonfluorescent surface in a simple reflection model, the spectrum reaching the eye depends on both illumination and spectral reflectance. Multiplying two different reflectance curves by one illuminant can produce a match; multiplying them by another need not preserve it. Changing the light changes the stimulus before the eye does any processing.

This is different from saying that two fixed emitted spectra must cease matching whenever the room lights change. If the spectra arriving from the two patches and the relevant viewing conditions truly stayed fixed, the original comparison would remain the relevant one. In practice, illumination, reflected glare, surrounding contrast and adaptation can all change. They must be separated to diagnose a failed match.

Fluorescent materials require a more elaborate account because absorbed radiation at one wavelength can contribute to emission at another. The simple product of illuminant and reflectance is then insufficient. A useful model is not made more scientific by applying it beyond its stated domain.

5. What the match does and does not establish

Metamerism establishes that spectral identity is stronger than colorimetric identity. It does not establish that colour is arbitrary, that instruments are unnecessary, or that people invent colours without constraints. Matches are reproducible enough to measure, but their reproducibility depends on an observer and an experimental arrangement.

The quickest mistaken answer to the title is that every colour corresponds to one wavelength. Some colours can be elicited by narrow-band light, but mixtures greatly expand the problem. The better answer is conditional and experimentally useful: different spectra can produce a colour match because the visual system's relevant responses do not retain every detail of the incoming spectrum. A match tells us about those responses under those conditions, not that the two lights have become physically identical.

References

- [1] CIE. International Lighting Vocabulary, term 17-23-006: metamerism.
<https://cie.co.at/eilvterm/17-23-006>
- [2] Colour and Vision Research Laboratory. Human cone spectral sensitivities or cone fundamentals.
<https://www.cvrl.org/cones.htm>
- [3] CIE. Special metamerism index: Change in observer.
<https://www.cie.co.at/publications/special-metamerism-index-change-observer>

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