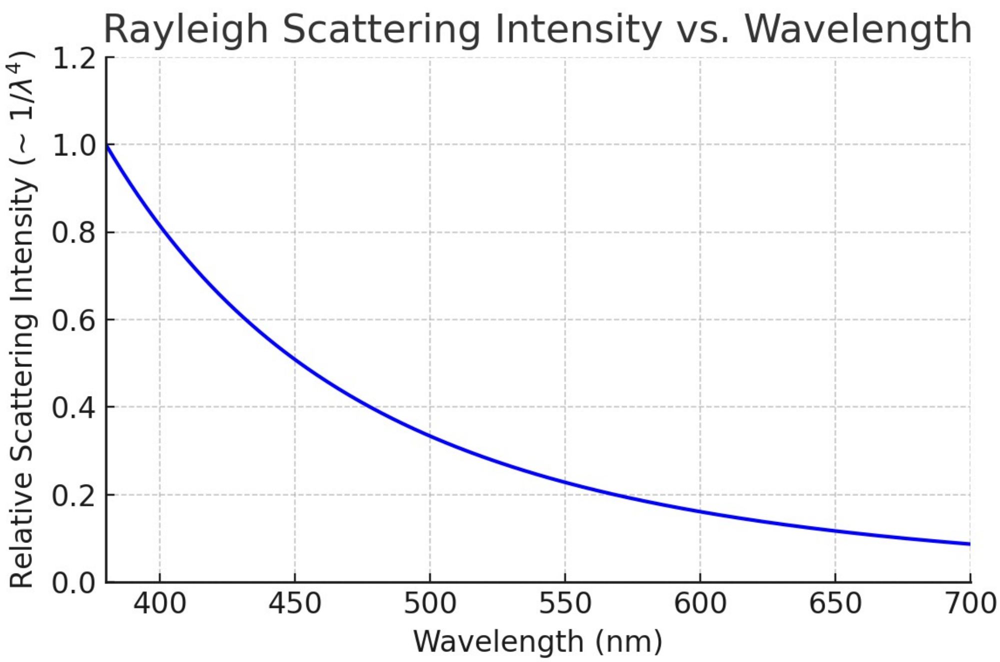
Why the Sky and Water Are Blue, and the Sun Appears Yellow (from Earth)

Why Is the Sky Blue?



Rayleigh scattering causes shorter (blue) wavelengths of sunlight to scatter much more strongly than longer (red) wavelengths, as shown by the $I \propto 1/\lambda^4$ dependence of scattered intensity on wavelength. [1]

- **White Sunlight & Color Spectrum:** Sunlight reaching Earth is **white light**, a mix of all visible colors (red, orange, yellow, green, blue, violet). Passing sunlight through a prism or seeing a rainbow shows it contains every color[2]. Each color corresponds to a different **wavelength** (blue/violet have shorter wavelengths, red has longer) [3].
- **Rayleigh Scattering:** The atmosphere is filled with tiny gas molecules (like N_2 and O_2) much smaller than the wavelengths of visible light. These molecules **scatter** incoming sunlight in all directions. The scattering is most effective for short wavelengths – mathematically, the scattering intensity I **is inversely proportional to** λ^4 (wavelength to the fourth power) [4] [5]. In other words, **blue/violet light (short λ) is scattered about 5–10 times more than red light** (long λ). This extreme wavelength dependence (a form of Rayleigh scattering) means blue light gets bounced around the sky far more than red light[6].
- **Blue Sky Color:** Because blue light is preferentially scattered in all directions, **we see blue light coming from every part of the sky**, making the sky appear blue[7]. Violet light has an even shorter wavelength and is scattered most of all; however, the sky doesn't look purple because the Sun emits slightly less violet, our eyes are less sensitive to violet, and **some violet is absorbed** by the upper atmosphere (e.g. by ozone). The net result is a bright blue sky.
- **Example – Midday vs. Sunset:** At noon with the Sun overhead (short path through

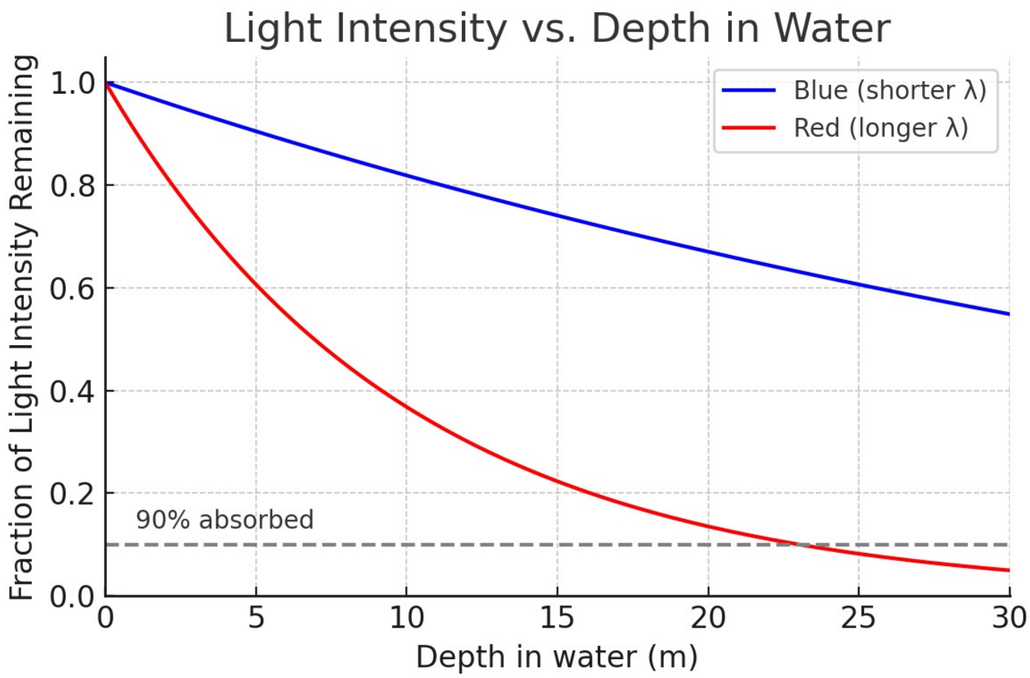
atmosphere), scattering is minimal and the Sun may look nearly white[8]. By contrast, at sunrise or sunset, sunlight travels through a much thicker slice of atmosphere. **Most of the blue light gets scattered out** (and goes to coloring the sky), so **the direct light left to reach your eyes is mainly red/orange**. This is why sunsets appear reddish-orange[9] [10]. (The sky near the horizon can also whiten because multiple scatterings mix colors together[11].)

Key Equation: *Rayleigh scattering intensity:*

$$I_{\text{scattered}} \propto \frac{1}{\lambda^4}.$$

This formula (where λ is wavelength) shows how shorter wavelengths produce much more scattered light[12]. For example, **400 nm (violet/blue) light is scattered about** $(700/400)^4 \approx 8$ **times more** than 700 nm (red) light.

Why Does Water Appear Blue?



Light intensity vs. depth in water for two wavelengths (illustrative values). ***Red light (longer λ)*** *is absorbed more strongly, dropping to 10% of its original intensity within only a few meters here, whereas* ***blue light (shorter λ)*** *penetrates further. This selective absorption gives large volumes of water an intrinsic bluish color.*

- **Small Amounts are Clear:** A glass of pure water has no obvious color – it looks transparent. **Water's blueness is very faint per unit length**, so you need a **large depth** of water to notice it. In small quantities, the absorption is negligible and water appears colorless[13].

- **Intrinsic Blue Color – Absorption of Red:** Pure water actually has a slight **intrinsic blue tint** due to its molecular properties. Water molecules preferentially **absorb longer-wavelength light (red, orange, yellow)** a little more than shorter wavelengths[14]. As a beam of white light travels deep into water, the red components are gradually absorbed, leaving a higher fraction of blue light. In a **deep column of water, so much red is removed that the remaining light is predominantly blue-cyan** [15 16]. (The absorption is due to vibrational transitions of the O–H bonds in water – essentially a series of overtone absorptions that begin in the red part of the visible spectrum.)

- **Beer–Lambert Law:** The light absorption in water approximately follows an exponential law: $I(d) = I_0 e^{-\alpha(\lambda)\,d}$, where $I(d)$ is intensity after traveling depth d, and $\alpha(\lambda)$ is the **absorption coefficient** at that wavelength. α **is larger for red light than for blue light** in water, so red light's intensity falls off faster with depth[17]. For example, if 10 m of water absorbs, say, ~90% of red light but only ~30% of blue light (as in the diagram above), the transmitted light will look bluish. After enough distance, virtually all colors are absorbed (very deep water looks dark/black), but **shallower depths leave a blue-green hue** because the reds and yellows are depleted[18].
- **Reflection of the Sky:** In addition to its intrinsic color, **water surfaces reflect the sky's color**. On a clear day, a lake or ocean will mirror the blue sky, enhancing its blue appearance[19]. This reflected light is often what gives the **bright blue** appearance to oceans in photographs (on overcast days, the reflection is gray, and indeed water looks gray then[20]). However, even in the absence of sky (e.g. in an indoor pool or a white-bottom tank), **pure water lit with white light will have a cyan-blue tint** when viewed in sufficient depth[21].
- **Scattering in Water:** If water contains particles (like plankton, minerals, or milk in a science demo), it can also scatter light (similar to the atmosphere). **Particle scattering** tends to be less wavelength-selective (Mie scattering) and can make water look whitish or greenish depending on what wavelengths are reflected back[22]. In the open ocean, the **blue color is primarily from water's intrinsic absorption** plus some Rayleigh scattering by very pure water and small particles[23]. In shallower or nutrient-rich waters, algae can absorb more in the blue, making the water look green instead of blue.

Key Point: The **main reason the ocean (and large bodies of water) appear blue-green is that water itself absorbs red light** more strongly, leaving the reflected/transmitted light enriched in blues and greens[24 25]. The blue sky reflection is a contributing factor, but even without sky, **pure water would have a pale blue color**.

Why Does the Sun Appear Yellow from Earth (if it's Actually White)?

- **Sun's True Color – White:** The Sun emits a broad continuous spectrum of light approximating a **5,778 K blackbody** (peaking in the green portion of the spectrum). It radiates strongly in all visible wavelengths[26 27]. When viewed from space or high altitude (with no atmospheric filtering) the Sun appears **brilliant white**, since our eyes receive the full mix of colors in roughly equal measure[28 29]. (The Sun is often called a "yellow dwarf" star, but that refers to its spectral class, not its actual color as seen by the eye.)
- **Atmospheric Filtering (Rayleigh Scattering):** As sunlight travels through Earth's atmosphere, the **same Rayleigh scattering that makes the sky blue also affects the direct sunlight**. The air molecules scatter away a portion of the blue and violet light out of the direct beam. **This means the sunlight that comes straight to your eyes is**

missing some of its blue component [30] [31]. The result is that the Sun takes on a slightly **yellowish tint**, since the remaining mix has relatively more reds and yellows. In essence, the atmosphere acts like a filter that subtracts some blue from the Sun's white light[32]. (Our eyes then interpret the light with "a little less blue" as yellow[33].)

- **Quantitative Note:** If no atmosphere, the Sun's light would be balanced white. With atmosphere, suppose (for example) 20% of the blue light is scattered out of the direct path. The direct beam would then have a deficit in blue, shifting its color point toward yellow. **Observers see the Sun as yellow-white** rather than pure white. (The scattered blue isn't lost – it's what paints the sky – but it's redirected away from the Sun's disk.)
- **Overhead vs. Horizon:** When the Sun is high in the sky (overhead), the path through the atmosphere is shorter (small air mass). **Only a little blue is scattered out**, so the Sun still looks nearly white or just slightly golden[34]. When the Sun is lower (morning or afternoon), the path is longer and the sunlight is **noticeably warmer (more yellow-orange)** because more blue/green has been removed[35]. At extreme cases like **sunset**, the path is so long that *most* of the blue and even green light is scattered out, leaving predominantly **red/orange light** to reach the eye[36] [37]. This is why the Sun can appear deep orange or red on the horizon. (Meanwhile, the scattered blue light is what makes the twilight sky glow red/orange in other directions.)
- **Other Factors:** The perception of the Sun's color can also be affected by human vision and brightness. Very bright light (like the Sun) can saturate our cone cells, sometimes making it hard to perceive color – the Sun may just appear dazzling. But the **yellow hue is most evident when the Sun is somewhat dimmed by the atmosphere** (e.g. shortly after sunrise, or through light haze). Additionally, *air pollution or dust* can scatter longer wavelengths too (Mie scattering), which can whiten the Sun's appearance. In pristine air, the **solar disk is a yellow-white** in midday and orange-red at sunset due to Rayleigh filtering[38] [39].

Summary: The Sun **emits white light**, but Earth's **atmosphere scatters blue/violet out of the direct beam**, so the Sun we perceive from the ground is tinged yellow[40] [41]. If you could view the Sun from space (with proper eye protection), it would look perfectly white[42] – the yellow color is an *illusion caused by our atmosphere*.

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