The Chemistry of Light Pollution and its Effects

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Light Pollution Basic Facts

Definition: Excess or inappropriate artificial light outdoors that disrupts natural darkness

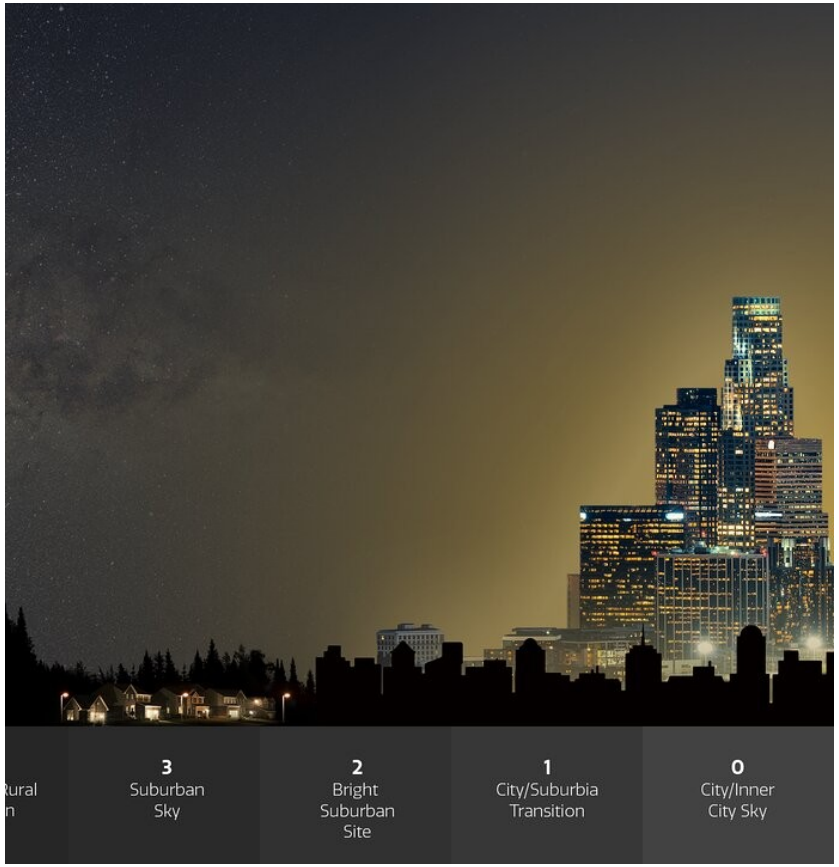
Light pollution occurs in three primary forms:

- **Glare**: Bright, uncomfortable light shining directly to the observer that interferes with vision
- **Light trespass**: Unintended spill of artificial light into others' property or space
- **Skyglow**: Brightening of the night sky from human-caused light scattered in the atmosphere

Not limited to urban environments - glow from cities has been documented at distances over 200 miles from national parks

Composed of different wavelengths of light, with blue light (450-495 nano meters) being particularly disruptive to atmospheric chemistry

Measured using the Bortle scale (1-9) or by sky brightness in magnitudes per square arcsecond



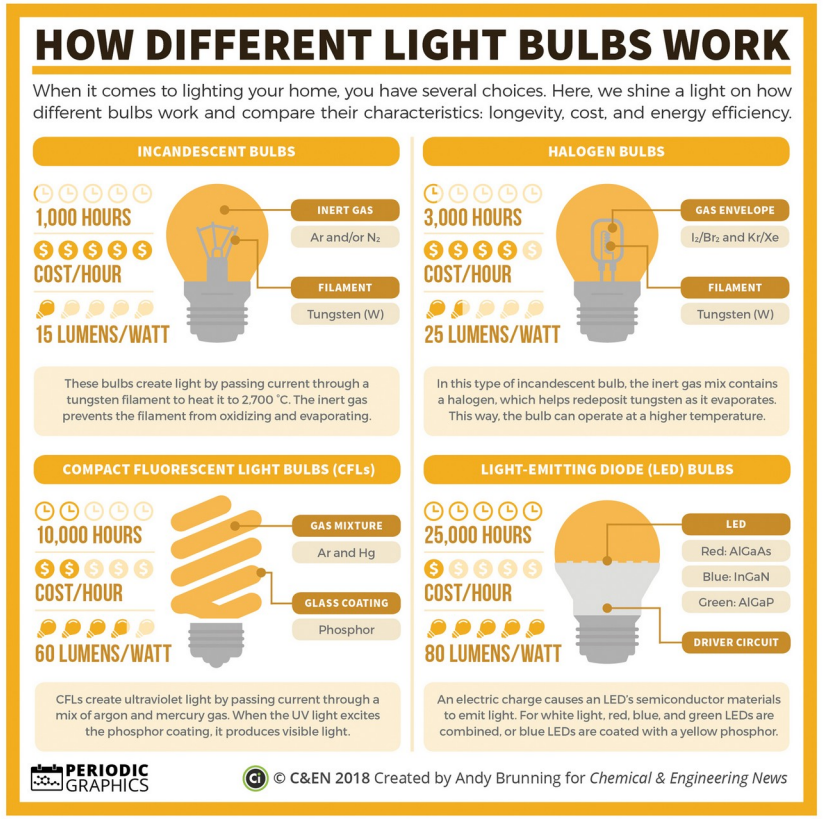
Chemistry of Different Light sources

Incandescent (2700K - warm yellow):
- Tungsten metal (W) filament heated until it glows to 2000°C
- Chemistry: simple thermal radiation of heated metal
- Low efficiency: 90-95% of energy wasted as heat

Fluorescent (3000-6500K - white to bluish):
- Mercury vapor (Hg) excited by electricity → UV light
- Phosphor coating converts UV to visible light
- Contains toxic mercury that can enter environment if broken

LED (2700-6500K - variable colors):
- Semiconductor materials (commonly InGaN) produce light directly
- Higher blue light content in "cooler" LEDs (5000K+)
- Most energy-efficient but blue-rich LEDs cause more light pollution

Why blue light matters for light pollution:
- Blue light scatters more in atmosphere (Rayleigh scattering)
- Blue wavelengths (450-495 nm) scatter 4x more than red light
- Explains why warm-colored lights cause less sky glow
- Blue wavelengths also have stronger biological effects on wildlife



Photochemical Reactions in the Night Atmosphere

Natural nighttime chemistry without light pollution:

- Nitrate radical (NO_3) dominates normal nighttime chemistry
- NO_3 forms through: $NO_2 + O_3 \rightarrow NO_3 + O_2$
- NO_3 helps remove pollutants overnight (natural cleansing)

Light pollution disrupts this process:

- Artificial light triggers photolysis reactions: $NO_3 + light \rightarrow NO + O_2$
- Destroys nitrate radical that normally cleans nighttime air
- Creates "daytime chemistry at night" when NO_3 is destroyed

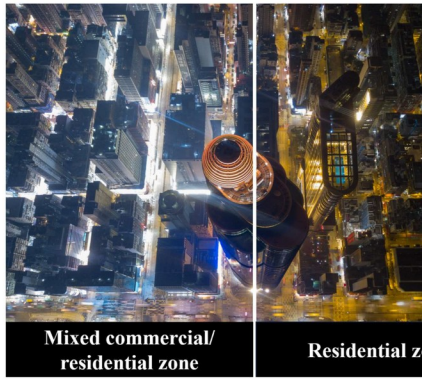
Key chemical consequence:

- Increased concentrations of pollutants remain in nighttime air
- Higher ozone (O_3) and nitrogen oxide (NO_x) levels near cities
- Disrupted oxidation processes affect air quality and public health

Blue-rich light (450-495 nm) causes greater photochemical disruption

- Higher energy wavelengths break chemical bonds more effectively
- Can trigger reactions normally only occurring during daylight

(a)



(b)


(c)

Environmental Chemistry Effects of Light Pollution

Disruption of natural biochemical processes:

- Artificial light interferes with biological rhythms and chemical signaling
- Alters melatonin production in wildlife
- Changes timing of biochemical activities

Changes in animal physiology:

- Stress hormones (glucocorticoids) increase under light exposure
- Immune system function altered by disrupted chemical cycles
- Metabolism and energy regulation affected

Plant photochemistry disrupted:

- Changes in timing of photosynthesis
- Altered photoperiodism affects plant flowering and chemical cycles
- Disrupted plant-pollinator chemical communication

Species interaction chemistry affected:

- Predator-prey chemical detection systems altered
- Chemical signaling for mating disrupted (e.g., fireflies, glow-worms)
- Trophic mismatches in food webs due to altered chemical timing

Case Study: Light Pollution in Coral Reef Ecosystems

Research location:

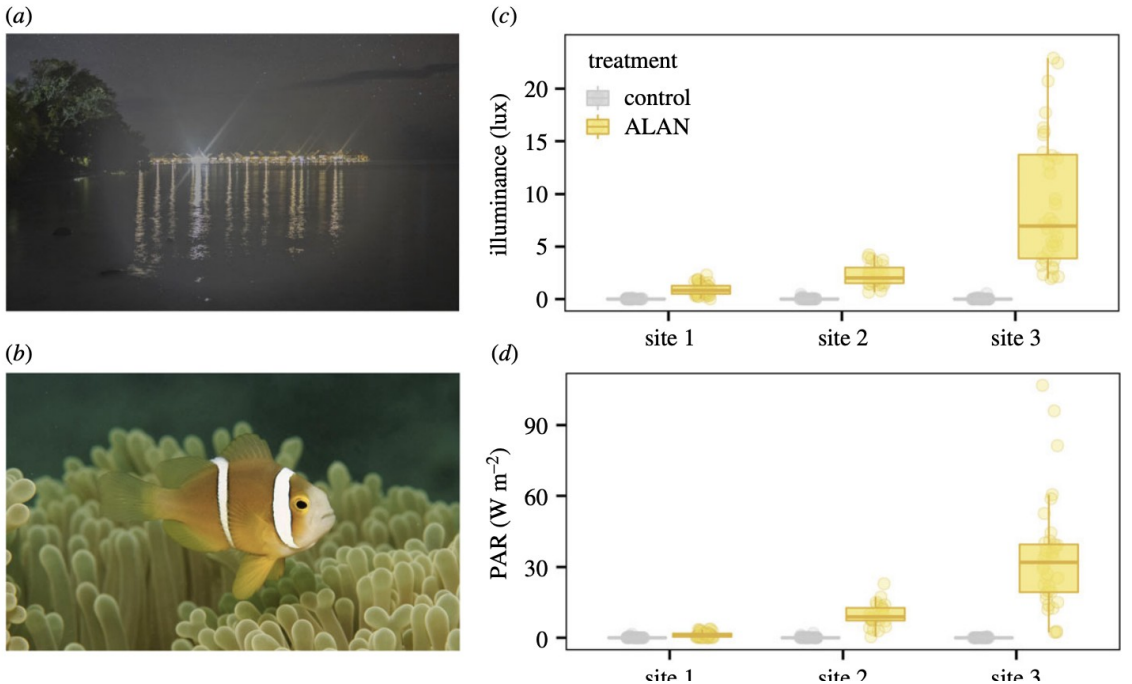
- Moorea, French Polynesia coral reef lagoon
- Long-term field experiment (18-23 months) on orange-fin anemonefish

Light pollution measurements:

- Control sites: Natural moonlight underwater (0.03 lux)
- ALAN sites: Artificial lighting (4.3 lux) - typical of coastal resort lighting
- Environmentally relevant conditions representing shoreline developments

Chemical impact on marine life:

- Disrupted biological rhythms and physiological processes
- Altered predator-prey chemical interactions
- Changed nocturnal chemical signaling between marine organisms



Case Study: Light Pollution in Coral Reef Ecosystems

Measured biological impacts:

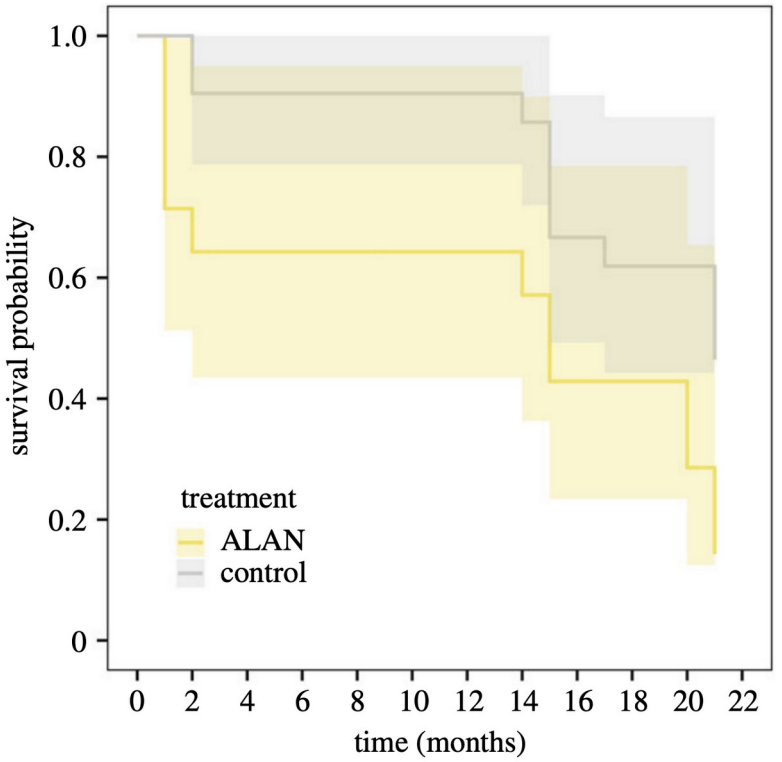
- 36% reduction in fish survival under artificial light conditions
- 44% decrease in growth rates (height, length, weight measurements)
- Changes most pronounced during juvenile development stage

Chemical mechanisms behind effects:

- Potential stress hormone elevation (glucocorticoids)
- Altered metabolic pathways requiring more energy
- Disruption of normal sleep/rest cycles affecting physiological recovery

Broader ecological implications:

- Reduced size at maturity affects reproductive capacity
- Cascading effects through food webs in illuminated areas
- Long-term population decline in light-polluted coastal waters



Conclusion

Light pollution disrupts critical atmospheric chemistry:

- Interferes with nocturnal cleansing of pollutants
- Alters NO_3 radical formation and breakdown cycles

Environmental impacts are significant and measurable:

- Field studies show 36% decreased survival in marine organisms
- Ecosystem processes disrupted at multiple levels

Best mitigation strategy:

- Reduce blue-spectrum lighting and shield fixtures
- Preserve dark zones to maintain natural chemical cycles

References

- “Light Pollution.” *National Parks Service*, U.S. Department of the Interior, 17 June 2024, www.nps.gov/subjects/nightskies/lightpollution.htm.
- James , James, et al. “Red Sky at Night: Long-Wavelength Photochemistry in The ...” *ACS Publications*, 11 June 2010, pubs.acs.org/doi/10.1021/es903680v.
- douglas, Peter, and Mike Garley. “Chemistry and Light.” *Science in School*, 16 Dec. 2022, www.scienceinschool.org/article/2010/chemlight/.
- Warmiński, Kazimierz, and Agnieszka Bęś. “Atmospheric Factors Affecting a Decrease in the Night-Time Concentrations of Tropospheric Ozone in a Low-Polluted Urban Area.” *Water, Air, and Soil Pollution*, U.S. National Library of Medicine, 25 Oct. 2018, pmc.ncbi.nlm.nih.gov/articles/PMC6208761/.
- Candolin, Ulrika. “Coping with Light Pollution in Urban Environments: Patterns and Challenges.” *iScience*, U.S. National Library of Medicine, 16 Feb. 2024, pmc.ncbi.nlm.nih.gov/articles/PMC10904992/.