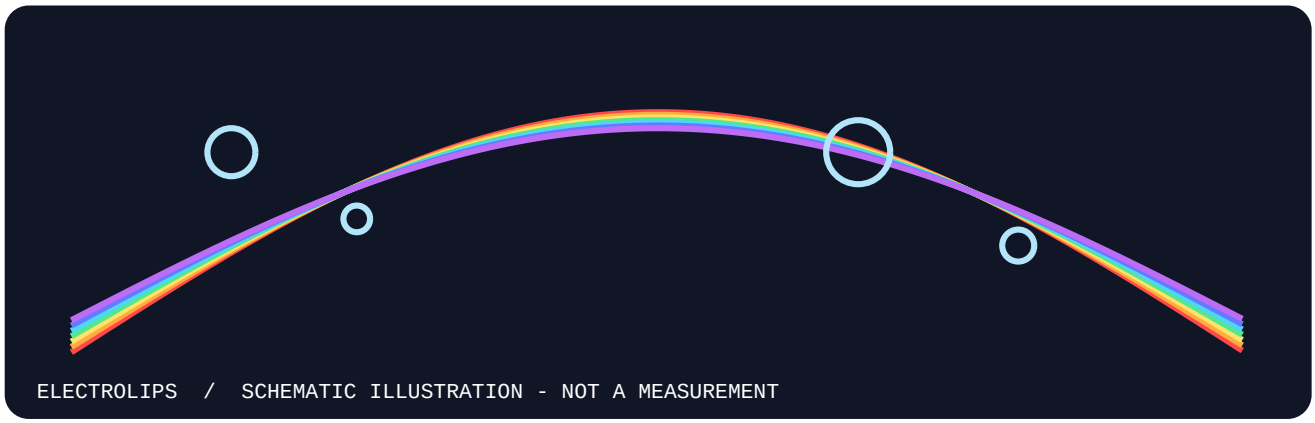
ELECTROLIPS SCIENCE REVIEW

RAINBOWS, ATMOSPHERIC OPTICS & ELECTROMAGNETIC WAVES

Expanded chapters 09–14 | Scientific reference edition | 9 November 2026

Illustrations are newly drawn conceptual diagrams representing the optical phenomena. They are not photographs or quantitative simulations. The interactive controls are provided in the companion HTML wave studios.

09. Atmospheric density, pressure, and temperature

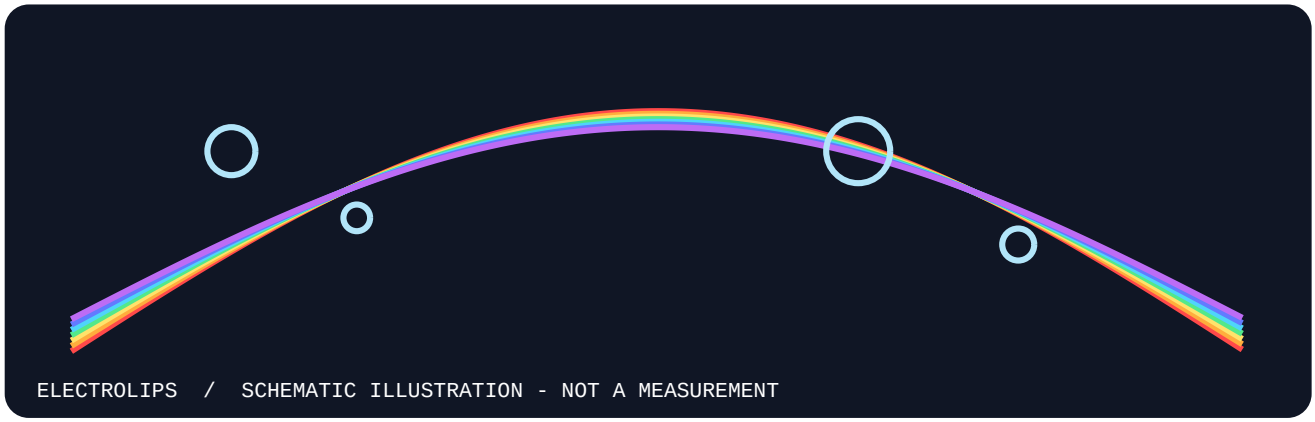


Air has a refractive index slightly above one, because the electric fields of light interact with atmospheric molecules. Temperature, pressure, and humidity alter the air density and composition, so they also change this refractive index. Across an ordinary rainbow scene, these changes generally shift or distort the apparent paths of sunlight much less than refraction inside the droplets themselves.

A temperature inversion can create a vertical gradient in refractive index, bending distant light rays and producing mirages or unusual apparent elevations. Such gradients can change the perceived location of distant clouds and rain shafts. The rainbow angle, however, is governed mainly by the wavelength-dependent refractive index of liquid water and by the droplet geometry.

Pressure systems influence rainbows indirectly by organizing clouds, precipitation, and clear-air gaps. A bright rainbow is often visible when low-angle sunlight illuminates rain while the observer faces away from the Sun. Atmospheric haze along the viewing path can reduce contrast even when the droplet geometry is favorable.

10. Droplet size, surface tension, and rain microphysics

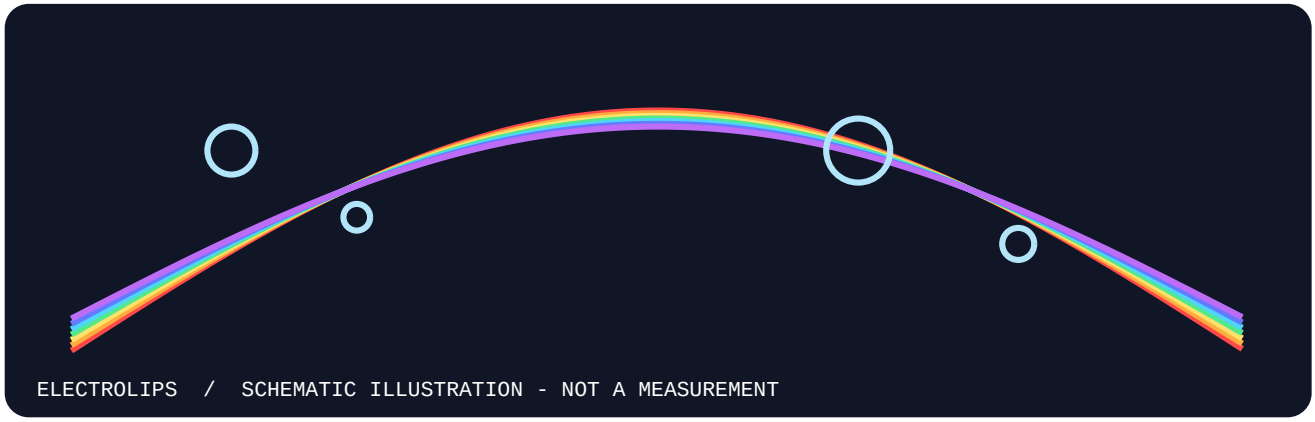


Surface tension tends to make small water droplets nearly spherical, the shape assumed by the standard rainbow model. Larger falling raindrops can become flattened by aerodynamic forces, and very large drops may oscillate or break apart. Departures from sphericity can broaden or deform optical features.

Droplet diameter changes the wave-optical fine structure of a rainbow. In a population of nearly equal small droplets, interference produces supernumerary bands just inside the primary bow. A broad mixture of droplet sizes averages these fine fringes away, leaving the familiar smoother arc.

Fog droplets are often much smaller than rain droplets. Their diffraction-dominated scattering can produce a broad, pale fogbow with weak color separation. Rainfall intensity alone does not determine color saturation: droplet size distribution, background darkness, sunlight intensity, and intervening haze all matter.

11. Altitude, humidity, cloud layers, and condensation

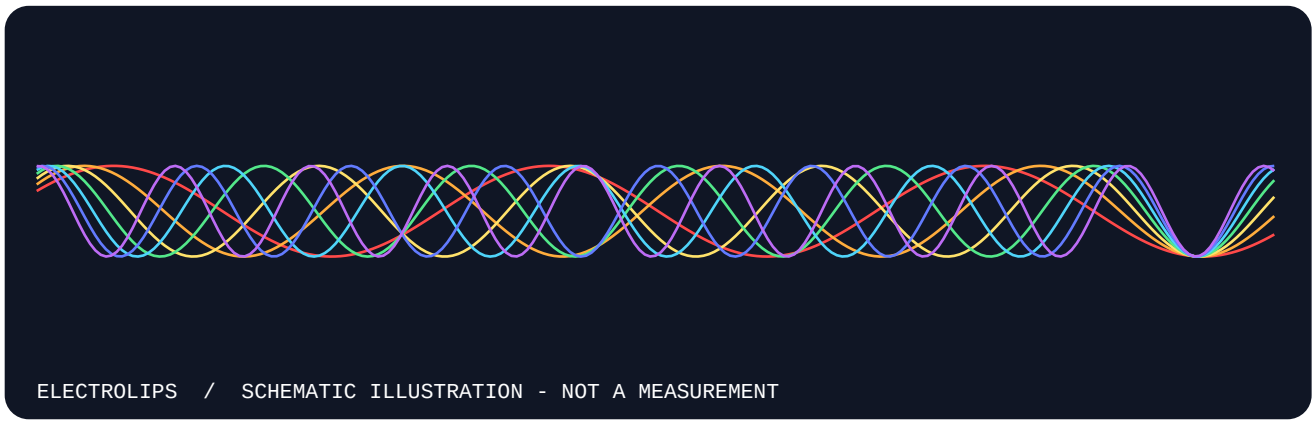


Relative humidity controls how close air is to saturation, but a rainbow requires suspended or falling droplets in the correct illuminated geometry. Condensation depends on temperature, available water vapor, and cloud condensation nuclei. Two nearby air masses with similar humidity can have very different optical appearances because their particle populations differ.

Cloud iridescence is most conspicuous in thin cloud regions containing droplets or small ice particles of relatively uniform sizes. Diffraction and interference create pastel patches that vary with viewing angle. Thick clouds often scatter light many times, washing out the delicate colors.

At higher altitudes, ice crystals become important. Hexagonal crystals in cirrus can produce 22-degree halos and sundogs by refraction, rather than the liquid-droplet mechanism of rainbows. Cloud height by itself does not identify the effect: particle phase, crystal orientation, and solar geometry are decisive.

12. Wavelength, polarization, and spectral intensity



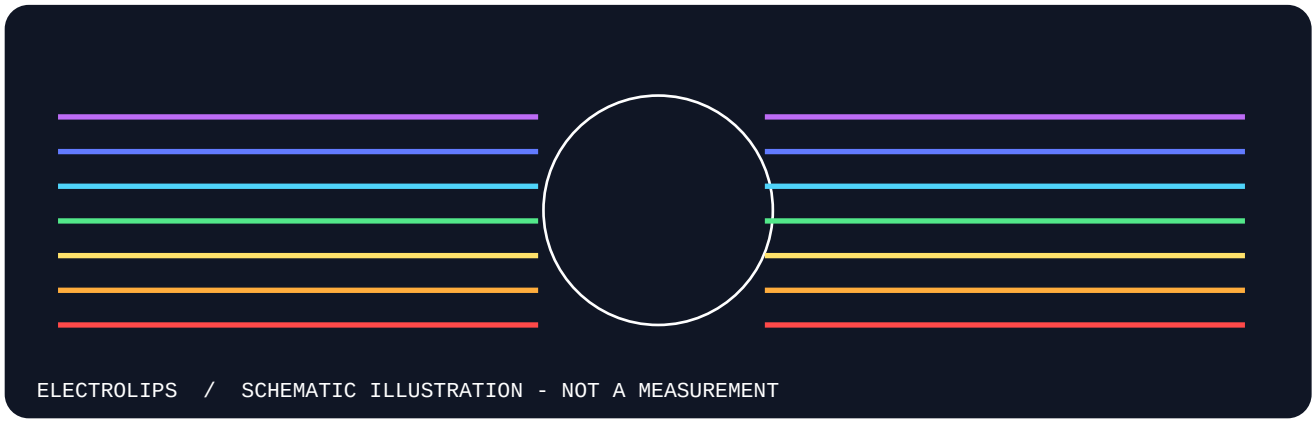
Visible light is a continuous portion of the electromagnetic spectrum, approximately 380 to 750 nanometers, rather than seven discrete physical bands. The familiar seven rainbow names are a useful convention. A water droplet refracts different wavelengths by different amounts, separating broadband sunlight into a spectrum.

For light in vacuum, frequency f = c / lambda and photon energy E = h f. A wavelength of 550 nm corresponds to approximately 545 THz and 2.25 electronvolts. Changing a wave drawing slider can represent these values, but it does not physically change light unless a real light source is being controlled.

Rainbows are partially polarized because Fresnel reflection and transmission depend on polarization. Polarizing sunglasses can therefore strengthen or weaken a rainbow as they rotate. Apparent color intensity also depends on the solar spectrum, atmospheric transmission, the eye or camera response, and background contrast.

Useful relationships: c = f lambda; E = h f; lambda = c/f. In vacuum c = 299,792,458 m/s and h = 6.62607015 x 10^-34 J s.

13. Quantum interactions with matter

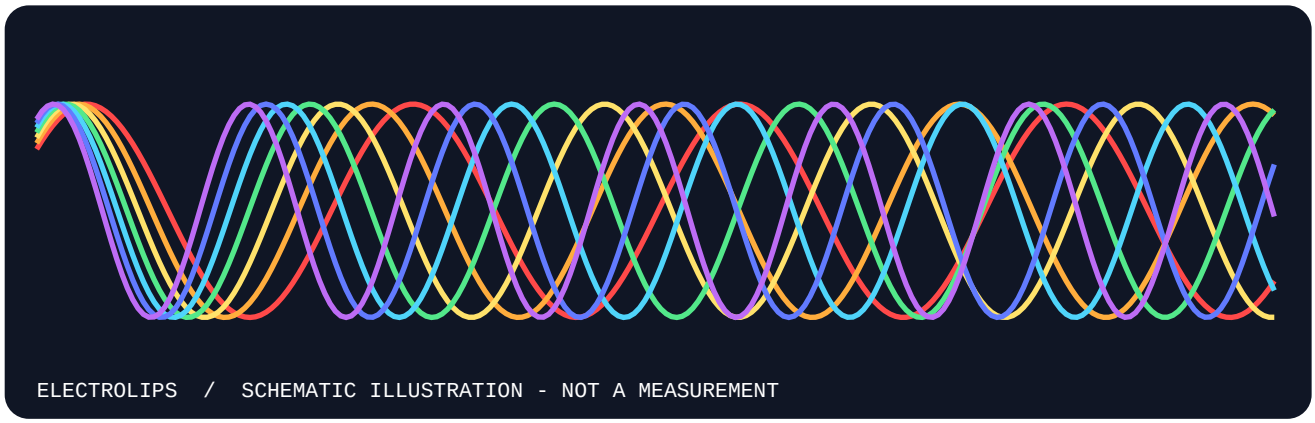


Electromagnetic radiation interacts with electrons and molecular charge distributions. Quantum mechanics describes discrete energy transitions responsible for many absorption and emission lines, while macroscopic optical constants summarize the combined response of enormous numbers of particles.

The ordinary rainbow is most efficiently described using classical geometrical optics for its main arc and wave optics for diffraction and interference. Quantum electrodynamics is consistent with these descriptions, but individual photon-level calculations are unnecessary to predict the everyday rainbow angle.

Atmospheric gases absorb selected wavelengths, while droplets scatter light broadly across the visible spectrum. These processes must be distinguished: absorption transfers energy into matter, scattering redirects radiation, and refraction changes propagation direction through a medium. None of these implies that the rainbow is a material object located at one fixed distance.

14. Artificial rainbows and engineered optical materials



A diffraction grating uses regularly spaced grooves or structures to direct different wavelengths into different angles. The grating relation d(sin theta_m - sin theta_i) = m lambda describes the principal diffraction orders under a chosen sign convention. This differs from the refractive and reflective paths inside a water droplet.

Thin-film interference colors arise when reflections from different interfaces combine constructively or destructively. Their appearance depends on thickness, refractive index, angle of illumination, and viewing angle. Soap bubbles and some coated plastics exhibit these colors, often shifting as the film thickness changes.

Flexible holographic films, embossed diffraction foils, and multilayer polymer films can produce rainbow-like color effects on manufactured surfaces. Adhesive compatibility, abrasion resistance, UV exposure, substrate stretching, and optical groove distortion determine whether a film can be successfully bonded to rubber or plastic. A prototype should be tested under bending and outdoor lighting before a durable design is claimed.

References and further reading

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