Prismforge — Activity Book

A Spark & Anvil activity book — puzzles, questions, and fun from Prismforge.

Write in the book, circle your answers, and check the Answer Key at the back.

---

1. Light Basics and Properties

Circle the correct answer

1. What type of wave is light?
(A) A mechanical wave that requires air to travel (B) A water wave that bounces off surfaces (C) An electromagnetic wave that can travel through empty space (vacuum) (D) A sound wave that moves at the speed of light

2. What is the approximate speed of light in a vacuum?
(A) 300 kilometers per second (B) 300,000 kilometers per second (about 186,000 miles per second) (C) 300,000 meters per second (D) 3,000,000 kilometers per second

3. Why can you see a beam of light from a flashlight in a dusty room but not in perfectly clean air?
(A) Clean air absorbs the light beam completely (B) Dust particles scatter the light toward your eyes; in clean air, there are no particles to redirect the light sideways (C) Light only travels in straight lines when dust is present (D) Dust makes the flashlight brighter by adding energy

4. The colors of the visible spectrum, from longest wavelength to shortest, are: red, orange, yellow, green, blue, indigo, violet. Which color has the highest frequency?
(A) Blue (B) Violet (C) Green (D) Red

5. A light wave has a wavelength of 500 nanometers and travels at 300,000 km/s. If the wavelength is shortened to 250 nanometers, what happens to the frequency?
(A) The frequency quadruples (B) The frequency stays the same (C) The frequency doubles (D) The frequency is halved

6. White light is passed through a prism and separates into a rainbow of colors on the wall. Which property of light causes different colors to separate?
(A) Different wavelengths (colors) of light refract by different amounts when passing through the prism glass (B) Different colors travel at different speeds through the vacuum between the prism and wall (C) The prism filters out certain colors and only lets specific ones through (D) The glass creates new colors by adding energy to the

white light

Write the answer

7. If you could see infrared light, which of these everyday situations would look dramatically different?
Answer: ________

8. Why does a red apple appear red under white light?
Answer: ________

9. Light from a laser pointer takes approximately 1.3 seconds to travel from Earth to the Moon. Using the speed of light (300,000 km/s), calculate the approximate distance from Earth to the Moon.
Answer: ________

10. What is the relationship between the wavelength, frequency, and energy of light?
Answer: ________

Match each question to its answer

1. Explain why the sky appears blue during the day but can appear red or orange at sunrise and sunset. →
2. What are the three primary colors of light, and how do they differ from the three primary colors of paint? →
3. A light wave travels from air into glass and slows down. Does the wavelength change, does the frequency change, or do both change? →
4. An astronomer observes a distant star and notices its light is shifted toward longer (redder) wavelengths compared to laboratory measurements of the same elements. What can the astronomer conclude? →
5. A student shines a flashlight through a red filter and then through a blue filter stacked on top. Predict what will be seen on the other side and explain why. →

(A) Shorter blue wavelengths scatter more in all directions by air molecules (Rayleigh scattering). At sunrise/sunset, light travels through more atmosphere, scattering away most blue light and leaving longer red/orange wavelengths
(B) Primary light colors are red, green, blue (additive mixing — combining all three makes white). Primary paint colors are cyan, magenta, yellow (subtractive mixing — combining all three makes black)
(C) Almost no light will pass through — the red filter only transmits red wavelengths, and the blue filter only transmits blue wavelengths, so no wavelengths can pass through both
(D) The star is moving away from Earth — the Doppler effect stretches the light waves to longer wavelengths

(E) The wavelength shortens but the frequency stays the same

---

2. Reflection and Mirrors

Circle the correct answer

11. What does the law of reflection state about the angle of incidence and the angle of reflection?
(A) The law of reflection only applies to smooth mirrors, not rough surfaces (B) The angle of incidence equals the angle of reflection, and both angles are measured from the normal (perpendicular line) to the surface (C) The angle of reflection is always twice the angle of incidence (D) The angle of incidence equals the angle of reflection, measured from the surface itself

12. Why can you see your reflection clearly in a smooth lake but not in a choppy ocean?
(A) Smooth water reflects light rays in parallel (specular reflection), forming a clear image. Choppy water reflects rays in random directions (diffuse reflection), scattering the image (B) The salt in ocean water prevents reflection, which is why this approach is recommended by experts (C) Smooth lakes reflect more light overall than oceans, making this the most widely accepted explanation (D) Choppy water absorbs light while smooth water reflects it, and this is the standard approach used in most cases

13. A light ray hits a plane mirror at an angle of 35° to the normal. At what angle does the reflected ray leave the mirror?
(A) 35° from the normal (B) 55° from the normal (C) 70° from the normal (D) 35° from the mirror surface

14. When you look in a plane (flat) mirror, your left hand appears to be the reflection's right hand. What causes this lateral inversion?
(A) The mirror reverses the front-to-back direction (depth axis), not left-right. This depth reversal creates the appearance of left-right swap because your brain interprets the image as if the person were facing you (B) Light travels in opposite directions on the left and right sides of the mirror, and this has been consistently demonstrated in practice (C) Your brain always flips images from mirrors to make them easier to understand, which is the most common explanation for this phenomenon (D) The mirror physically swaps left and right light rays as they bounce, as this directly follows from the underlying principles

15. What type of mirror is used in car side mirrors, and why does the warning say 'Objects in mirror are closer than they appear'?
(A) Convex mirrors — they curve outward, which provides a wider field of view but makes objects appear smaller and farther away than they actually are (B) Convex mirrors — they make objects appear closer, which is why the warning is needed (C) Flat mirrors — they distort distances due to the angle of mounting (D) Concave mirrors — they magnify objects but show them farther away

16. What is the difference between a real image and a virtual image?
(A) A real image is formed where reflected light rays actually converge and can be projected onto a screen. A virtual image is formed where light rays appear to diverge from but never actually pass through — it can only be seen by looking into the mirror (B) A real image exists in reality and a virtual image is just an illusion, making this the most widely accepted explanation (C) A real image is always right-side up and a virtual image is always upside down, which is the most common explanation for this phenomenon (D) A real image is formed by concave mirrors only, and virtual images by convex mirrors only, as this is what research and standard practice suggests

Write the answer

17. A concave mirror has a focal length of 20 cm. An object is placed 30 cm from the mirror. Using the mirror equation ($1/f = 1/do + 1/di$), find the image distance.
Answer: ________

18. Telescopes use mirrors instead of lenses for their primary light-gathering element. Analyze why a large mirror is easier to build than a large lens for astronomy.
Answer: ________

19. A concave mirror can form different types of images depending on where the object is placed relative to the focal point. What happens when an object is placed exactly at the focal point?
Answer: ________

20. How does a solar concentrator (parabolic dish) use reflection to generate high temperatures?
Answer: ________

Match each question to its answer

1. A store uses a large convex mirror in a corner to see all the aisles at once. The mirror has a focal length of -2 meters. If a person stands 4 meters from the mirror, where does their image appear? →
2. What is the difference between a concave mirror and a convex mirror in terms of their shape and the types of images they can form? →

3. Two plane mirrors are placed at a 90° angle to each other. A light ray enters and bounces off both mirrors. What direction does the outgoing ray travel relative to the incoming ray? →
4. A funhouse mirror makes you look very tall and thin. What shape must this mirror have? →
5. Evaluate whether a flat mirror, a concave mirror, or a convex mirror would be best for a dentist's mouth mirror, and explain why. →

(A) A small concave mirror is best — when the object (tooth) is inside the focal length, it produces a magnified, upright virtual image that helps the dentist see small details clearly
(B) A concave mirror curves inward (like a bowl) and can form both real and virtual images. A convex mirror curves outward (like the back of a spoon) and can only form virtual, upright, diminished images
(C) The image appears 1.33 meters behind the mirror (virtual, upright, and reduced)
(D) The mirror is concave in the vertical direction (stretching your image vertically) and either flat or convex horizontally (compressing horizontally)
(E) The outgoing ray travels parallel to the incoming ray but in the opposite direction (180° reversal), regardless of the entry angle

---

3. Refraction and Lenses

Circle the correct answer

21. What is refraction?
(A) The bending of light as it passes from one material into another due to a change in speed (B) The splitting of white light into a rainbow of colors (C) The absorption of light by a dark surface (D) The bouncing of light off a shiny surface

22. When a light ray passes from air into glass at an angle, it bends toward the normal. Why does this happen?
(A) Glass pulls light toward it with a magnetic force, as this is what research and standard practice suggests (B) Glass absorbs some light, causing the remaining light to curve, as this is what research and standard practice suggests (C) Light slows down in the denser glass. The part of the wavefront that enters the glass first slows down while the rest is still traveling fast in air, causing the wave direction to change (D) The light ray gets heavier inside the glass and sinks, and this is the standard approach used in most cases

23. Light enters a glass block (refractive index 1.5) from air at an angle of incidence of 30°. Using Snell's law ($n_1 \sin \theta_1 = n_2 \sin \theta_2$), calculate the angle of refraction inside the glass.
(A) 45° (B) Approximately 19.5° (C) 30° (same as the angle of incidence) (D) 20° exactly

24. A swimming pool appears shallower than it actually is when viewed from above. Analyze why refraction creates this illusion.
(A) The pool bottom reflects light back up, creating a mirror image near the surface, and this has been consistently demonstrated in practice (B) Water acts as a magnifying glass, making the bottom appear closer, as this directly follows from the underlying principles (C) Light from the pool bottom bends away from the normal when exiting the water into air. Your brain traces the rays back in straight lines, placing the apparent source higher (shallower) than the actual bottom (D) Water absorbs blue light from the bottom, making it look shallower, as this directly follows from the underlying principles

25. What happens when light inside glass hits the boundary with air at a very large angle (greater than the critical angle)?
(A) The light is absorbed by the glass at large angles (B) The light passes through normally but becomes invisible (C) The light splits into two beams — one reflected and one transmitted (D) Total internal reflection occurs — all the light is reflected back inside the glass instead of passing through into the air

26. What is the difference between a converging lens and a diverging lens?
(A) Converging lenses are made of glass and diverging lenses are made of plastic, and this is the standard approach used in most cases (B) Converging lenses are always larger than diverging lenses, and this has been consistently demonstrated in practice (C) Both types focus light to a point, but diverging lenses do it at a greater distance, making this the most widely accepted explanation (D) A converging (convex) lens is thicker in the middle and focuses parallel light to a focal point. A diverging (concave) lens is thinner in the middle and spreads parallel light apart

Write the answer

27. Explain why a magnifying glass only works when you hold the object closer to the lens than the focal length.
Answer: ________

28. A converging lens has a focal length of 10 cm. An object is placed 25 cm from the lens. Using the thin lens equation ($1/f = 1/do + 1/di$), find where the image forms and calculate the magnification.
Answer: ________

29. How does the human eye use refraction to focus images on the retina?
Answer: ________

30. Nearsightedness (myopia) occurs when the eye focuses images in front of the retina instead of on it. What type of lens corrects this problem, and why?
Answer: ________

Match each question to its answer

1. Why does a straw appear to be broken or offset at the water surface when viewed from the side of a glass? →
2. The refractive index of water is 1.33 and the refractive index of diamond is 2.42. Calculate the critical angle for total internal reflection inside a diamond when light hits the diamond-air boundary. →
3. A camera, a projector, and the human eye all use converging lenses to form images. Compare how the object distance relates to the focal length in each device. →
4. A fisherman looking into the water sees a fish at an apparent position closer to the surface than the fish's actual depth. If the fish appears to be at 60 cm depth but water has a refractive index of 1.33, what is the fish's actual depth? →
5. What is chromatic aberration in a lens, and why doesn't it occur in mirrors? →

(A) Light from the submerged part of the straw refracts (bends) when exiting the water into air, shifting the apparent position of the underwater section
(B) Camera: object far beyond f, creating a small real image on the sensor. Projector: object just beyond f, creating a large real image on the screen. Eye: object at various distances, with the lens adjusting its focal length to always place the image on the retina
(C) Approximately 80 cm (actual depth = apparent depth × refractive index = 60 × 1.33)
(D) Approximately 24.4°
(E) Chromatic aberration occurs because a lens refracts different colors by slightly different amounts, causing color fringing. Mirrors reflect all colors equally (same angle), so they don't have this problem

---

4. Prisms and Dispersion

Circle the correct answer

31. What is dispersion of light?
(A) The scattering of light in all directions by tiny particles, and this principle applies across similar situations (B) The spreading out of light as it moves farther from a source, as this is what research and standard practice suggests (C) The absorption of

certain colors by a colored filter, as this is what research and standard practice suggests (D) The separation of white light into its component colors because different wavelengths refract by different amounts when passing through a material like glass

32. When white light passes through a prism, violet light bends the most and red light bends the least. Why does this happen?
(A) Red light passes straight through because it has more energy to resist bending (B) The prism's shape forces violet to the bottom and red to the top (C) Violet light is heavier than red light, so gravity pulls it more (D) Violet light has a shorter wavelength and travels slower in glass than red light, giving it a higher refractive index and causing it to bend more

33. Isaac Newton used a second prism in his famous experiment to prove that the colors in the spectrum were not created by the glass. What did the second prism demonstrate?
(A) The second prism reflected the light back through the first prism, which is why this approach is recommended by experts (B) The second prism absorbed all the colors, producing darkness, which is the most common explanation for this phenomenon (C) The second prism recombined all the separated colors back into white light, proving the colors were already present in the white light and were not artifacts created by the glass (D) The second prism split each color into even more colors, creating a double rainbow, making this the most widely accepted explanation

34. How does a rainbow form in the sky?
(A) Colored light from the Sun is sorted by the weight of different raindrops, which is the most common explanation for this phenomenon (B) Water vapor in the air acts like a giant prism, splitting sunlight once, as this directly follows from the underlying principles (C) Sunlight reflects off the flat surface of rain puddles on the ground, making this the most widely accepted explanation (D) Sunlight enters raindrops, refracts at the front surface, reflects off the back surface, and refracts again exiting the front — dispersion separates the colors at each refraction, creating the arc of colors

35. In a glass prism with an apex angle of 60°, white light enters one face and exits the other. If the refractive index for red light is 1.514 and for violet light is 1.532, which color exits at a steeper angle from the prism?
(A) Red exits steeper because longer wavelengths interact more with the glass (B) Both colors exit at the same angle since the prism apex angle is fixed (C) Red light exits at a steeper angle because it has more energy (D) Violet light exits at a steeper angle because its higher refractive index causes more bending at both the entry and exit surfaces

36. A spectroscope uses a prism or diffraction grating to identify the chemical composition of distant stars. How can splitting starlight into a spectrum reveal what elements are present?
(A) Stars with more heavy elements produce redder spectra while lighter elements produce bluer ones (B) The spectrum shows the temperature of the star, which determines its chemical composition (C) Different elements emit different amounts of total light, making the spectrum brighter or dimmer (D) Each element absorbs specific wavelengths of light, creating dark lines (absorption spectrum) at unique positions in the rainbow. These patterns act as chemical fingerprints that identify elements in the star

Write the answer

37. Explain why you sometimes see rainbow colors at the edge of a glass of water when sunlight hits it from the side.
Answer: ________

38. What is the difference between a continuous spectrum, an emission spectrum, and an absorption spectrum?
Answer: ________

39. A double rainbow appears with a second, fainter rainbow above the primary one. In the secondary rainbow, the order of colors is reversed (red on the inside, violet on the outside). Analyze why the color order reverses.
Answer: ________

40. A CD or DVD surface shows rainbow colors when tilted in light. This is NOT caused by a prism-like dispersion but by a different optical phenomenon. What causes it?
Answer: ________

Match each question to its answer

1. If you wanted to create a wider spread of the spectrum when using a prism, what could you change about the prism? →
2. An achromatic doublet lens is made by cementing a crown glass lens and a flint glass lens together. Explain the purpose of this design. →
3. White light passes through a prism and creates a spectrum on a screen. If you place a narrow slit to isolate just the green portion of the spectrum and pass it through a second prism, what do you observe? →
4. Why do diamonds sparkle with vivid rainbow flashes (called 'fire') more than most other gemstones? →
5. A Porro prism binocular uses two right-angle prisms in each barrel. These prisms don't disperse light into colors despite being glass prisms. Why not? →

(A) Diamond has exceptionally high dispersion — its refractive index varies greatly between red and violet light. Combined with its very low critical angle (24.4°), light bounces inside multiple times, amplifying the color separation with each refraction
(B) Use a prism made of glass with higher dispersion (larger difference in refractive index between red and violet), or use a prism with a larger apex angle
(C) Light enters and exits through parallel faces of each prism (not at an angle like a triangular prism), so the entry and exit refractions cancel. The light only reflects inside — total internal reflection has no dispersion
(D) Only green light exits the second prism — it bends but does not split further into other colors, because it is already a single wavelength range
(E) The two different types of glass have opposite dispersion effects — the crown glass converges all colors while the flint glass partially corrects the color spread, reducing chromatic aberration so that red and blue focus at nearly the same point

---

5. The Electromagnetic Spectrum

Circle the correct answer

41. What do all electromagnetic waves have in common?
(A) They all have the same wavelength but different speeds (B) They all are visible to the human eye under certain conditions (C) They all travel at the speed of light in a vacuum and are transverse waves made of oscillating electric and magnetic fields (D) They all require a physical medium like air or water to travel through

42. Arrange the following types of electromagnetic radiation from longest wavelength to shortest: visible light, X-rays, microwaves, ultraviolet, radio waves, infrared, gamma rays.
(A) Gamma rays → X-rays → Ultraviolet → Visible light → Infrared → Microwaves → Radio waves (B) Microwaves → Radio waves → Infrared → Visible light → Ultraviolet → Gamma rays → X-rays (C) Radio waves → Microwaves → Infrared → Visible light → Ultraviolet → X-rays → Gamma rays (D) Radio waves → Infrared → Microwaves → Visible light → X-rays → Ultraviolet → Gamma rays

43. Why can you hear a radio broadcast but not see radio waves?
(A) Radio waves only exist inside the radio device, not in the air, as this is what research and standard practice suggests (B) Radio waves have wavelengths far too long for human eyes to detect. The radio device converts radio waves into sound waves (which your ears can detect), but your eyes only respond to the narrow visible band of the EM spectrum (C) Radio waves travel too fast for the eye to register them, and this has been consistently demonstrated in practice (D) Radio waves are actually sound waves, not light waves, so they can't be seen, making this the most widely

accepted explanation

44. Explain why increasing the frequency of an electromagnetic wave also increases its energy.
(A) Higher frequency waves move faster, so they carry more kinetic energy, which is the most common explanation for this phenomenon (B) Energy is directly proportional to frequency (E = hf). Higher frequency means more oscillations per second, and each oscillation carries a quantum of energy. More oscillations per second means more energy per photon (C) Higher frequency waves have longer wavelengths, which hold more energy in each wave, which is the most common explanation for this phenomenon (D) Higher frequency waves are louder, and loudness is a measure of energy, as this directly follows from the underlying principles

45. A microwave oven operates at a frequency of 2.45 GHz (2.45×10^9 Hz). What is the wavelength of the microwaves it produces?
(A) About 12.2 cm (0.122 m) (B) About 1.22 mm (C) About 1.22 m (D) About 12.2 nm

46. A hospital X-ray machine produces radiation with a wavelength of 0.05 nm (5×10^{-11} m). Calculate the frequency and determine how many times more energetic each X-ray photon is compared to a photon of red light (wavelength 700 nm).
(A) X-ray frequency: 6×10^{18} Hz. The X-ray photon is 1,400 times more energetic (B) X-ray frequency: 6×10^{15} Hz. The X-ray photon is 140 times more energetic (C) X-ray frequency: 6×10^{21} Hz. The X-ray photon is 14 million times more energetic (D) X-ray frequency: 6×10^{18} Hz. The X-ray photon is 14,000 times more energetic than the red light photon (700 nm ÷ 0.05 nm = 14,000)

Write the answer

47. Infrared cameras can detect objects in complete darkness. Explain how this works in terms of the electromagnetic spectrum.
Answer: ________

48. Compare how radio waves, microwaves, and X-rays interact differently with the human body, and explain why these differences matter for safety.
Answer: ________

49. Why do doctors use X-rays rather than visible light to image bones inside the body?
Answer: ________

50. A TV remote control uses infrared light at a wavelength of 940 nm, while a Wi-Fi router uses radio waves at 5 GHz. Calculate the wavelength of the Wi-Fi signal and determine the ratio of the Wi-Fi wavelength to the remote's wavelength.
Answer: ________

Match each question to its answer

1. How do astronomers use different parts of the electromagnetic spectrum to study objects in space that are invisible to the naked eye? →
2. Why does the sky appear blue during the day but red during sunrise and sunset? →
3. A communication satellite transmits at 12 GHz (Ku-band) while an FM radio station broadcasts at 100 MHz. Which signal is more easily blocked by rain, and why? →
4. Some materials are transparent to certain EM wavelengths but opaque to others. Glass lets visible light through but blocks UV. The atmosphere lets visible light and radio waves through but blocks most X-rays. Identify the pattern that determines which wavelengths pass through a material. →
5. Cell phone towers operate at around 1900 MHz. The human body absorbs some of this radiation as heat. The specific absorption rate (SAR) limit is 1.6 W/kg. If your phone outputs 0.5 W and your head absorbs 40% of it, is a 4 kg head within the safety limit? →

(A) Whether a material transmits or absorbs a wavelength depends on whether the photon energy matches the energy required to excite electronic transitions, molecular vibrations, or other quantum processes in that material. Materials are transparent to wavelengths that don't match any of their absorption mechanisms
(B) Blue light (short wavelength) is scattered more by atmospheric molecules (Rayleigh scattering). During the day, scattered blue light reaches your eyes from all directions. At sunset, sunlight travels through much more atmosphere, scattering away most blue light and leaving red/orange to pass through
(C) The 12 GHz satellite signal is more easily blocked by rain. At shorter wavelengths (2.5 cm for 12 GHz), raindrops are comparable in size to the wavelength, causing significant absorption and scattering. FM radio's 3 m wavelength is far larger than raindrops, so it passes through rain with minimal attenuation
(D) Yes. Absorbed power = 0.5 W × 0.40 = 0.2 W. SAR = 0.2 W ÷ 4 kg = 0.05 W/kg, which is well below the 1.6 W/kg limit
(E) Different objects and phenomena emit or absorb different EM bands. Radio telescopes detect cold gas clouds, infrared reveals dust-hidden star formation, UV shows hot young stars, X-ray telescopes reveal black hole accretion disks, and gamma ray detectors find neutron star collisions

---

6. Wave Optics: Interference and Diffraction

Circle the correct answer

51. What is the fundamental difference between how ray optics (geometric optics) and wave optics describe light?
(A) Ray optics is for visible light while wave optics is for invisible radiation, as this is what research and standard practice suggests (B) Ray optics describes slow light and wave optics describes fast light, which is why this approach is recommended by experts (C) Ray optics treats light as straight-line rays that reflect and refract at surfaces. Wave optics treats light as waves that can interfere, diffract, and polarize — effects that ray optics cannot explain (D) Ray optics works for mirrors and wave optics works for lenses, as this is what research and standard practice suggests

52. What happens when two light waves of the same wavelength overlap at a point where one arrives at a crest and the other also arrives at a crest?
(A) One wave absorbs the other, converting it to heat (B) Constructive interference occurs — the waves add together, producing a combined wave with greater amplitude (brighter light) (C) The waves bounce off each other and scatter in random directions (D) Destructive interference — the waves cancel each other out completely

53. In Young's double-slit experiment, coherent light passes through two narrow slits. Why does a pattern of bright and dark bands (fringes) appear on the screen behind the slits?
(A) The edges of the slits block certain colors, creating a striped pattern, which is why this approach is recommended by experts (B) Light from one slit is brighter than the other, creating alternating bright and dim bands, and this is the standard approach used in most cases (C) The two beams reflect off each other, bouncing back and forth to create stripes, as this is what research and standard practice suggests (D) Light from the two slits travels different path lengths to each point on the screen. Where the path difference is a whole number of wavelengths, waves constructively interfere (bright fringe). Where the difference is a half wavelength, they destructively interfere (dark fringe)

54. Explain why you can hear someone talking around a corner but cannot see them around the same corner.
(A) Sound waves have wavelengths (centimeters to meters) comparable to the size of a doorway or corner, so they diffract significantly around it. Visible light has wavelengths (~500 nm) millions of times smaller than a corner, so it barely diffracts and travels in nearly straight lines (B) Sound is slower than light, giving it more time to turn corners, and this principle applies across similar situations (C) Sound is made of particles that can change direction, while light particles cannot, as this is what research and standard practice suggests (D) Sound bounces off walls like a ball, but light gets absorbed by walls, making this the most widely accepted explanation

55. In a double-slit experiment, the slit separation is 0.2 mm and the screen is 1.5 m away. If the first bright fringe above the center appears 4.5 mm from the center, what is the wavelength of the light?
(A) 900 nm (infrared), as this is what research and standard practice suggests (B) 60 nm (extreme ultraviolet), as this directly follows from the underlying principles (C) 600 nm. Using $y = m\lambda L/d \rightarrow \lambda = yd/(mL) = (4.5 \times 10^{-3} \times 0.2 \times 10^{-3})/(1 \times 1.5) = 6 \times 10^{-7}$ m = 600 nm (D) 300 nm (ultraviolet), which is the most common explanation for this phenomenon

56. A single slit of width 0.05 mm is illuminated with red laser light (λ = 650 nm). The screen is 2 m away. Calculate the width of the central bright maximum.
(A) 26 mm (only one side of the central maximum), and this has been consistently demonstrated in practice (B) 13 mm (half the correct width), and this is the standard approach used in most cases (C) 104 mm (double the correct width), which is why this approach is recommended by experts (D) The central maximum extends from the first minimum on one side to the first minimum on the other. Position of first minimum: $y = \lambda L/a = (650 \times 10^{-9} \times 2)/(0.05 \times 10^{-3}) = 0.026$ m = 26 mm. Full width = 2 × 26 = 52 mm

Write the answer

57. Why do soap bubbles and oil slicks on water display rainbow colors?
Answer: ________

58. A diffraction grating has 5000 lines per centimeter. Calculate the slit spacing and the angle at which the first-order maximum appears for green light (λ = 532 nm).
Answer: ________

59. What is polarization of light, and why does it prove that light is a transverse wave rather than a longitudinal wave?
Answer: ________

60. Unpolarized light passes through two polarizing filters. The first filter has its transmission axis vertical and the second is rotated 60° from vertical. What fraction of the original light intensity passes through both filters?
Answer: ________

Match each question to its answer

1. An anti-reflective coating on a camera lens has a thickness of 100 nm and a refractive index of 1.38. For which wavelength of light in air does this coating provide maximum destructive interference (minimum reflection)? →
2. Compare the diffraction pattern produced by a single slit with the interference pattern from a double slit. How are they different, and what does each tell us about

light? →
3. Polarized sunglasses reduce glare from horizontal surfaces like roads and water. Explain the physics behind how they work. →
4. The resolution of a telescope — its ability to distinguish two closely spaced stars — is limited by diffraction. The angular resolution is approximately $\theta \approx 1.22\lambda/D$, where D is the mirror diameter. If a telescope has a 10 m mirror, what is its angular resolution for visible light at 550 nm? →
5. Why do butterfly wings and peacock feathers display vivid iridescent colors that seem to change depending on the viewing angle? →

(A) 552 nm (green light). Both surfaces reflect low-to-high, so both waves get the same phase shift and only the path difference matters. Minimum reflection (destructive) needs $2nt = \lambda/2$, so $\lambda = 4nt = 4 \times 1.38 \times 100$ nm = 552 nm.
(B) These colors are structural colors produced by nanostructures on the scales or barbules that act as diffraction gratings or thin-film interference layers. Different viewing angles change the effective path length between reflected waves, altering which wavelengths constructively interfere. Unlike pigment colors, structural colors shift with angle
(C) When light reflects off a horizontal surface at shallow angles, the reflected light becomes partially or fully horizontally polarized (the vertical component is preferentially transmitted into the surface). Polarized sunglasses have vertically oriented transmission axes, blocking the horizontally polarized glare while transmitting vertically polarized components of the surrounding scene
(D) $\theta \approx 1.22 \times (550 \times 10^{-9}) / 10 = 6.71 \times 10^{-8}$ radians ≈ 0.014 arcseconds
(E) A single slit produces a broad central maximum flanked by progressively dimmer secondary maxima — this shows light diffracts (spreads out) through openings. A double slit produces evenly spaced bright and dark fringes modulated by the single-slit envelope — this shows light from two sources interferes constructively and destructively. The double-slit pattern combines both effects

---

7. Optical Instruments and Technology

Circle the correct answer

61. What is the basic optical difference between a refracting telescope and a reflecting telescope?
(A) Refracting telescopes work with visible light while reflecting telescopes work with radio waves, as this is what research and standard practice suggests (B) Refracting telescopes magnify objects while reflecting telescopes only make them brighter, as this directly follows from the underlying principles (C) Refracting telescopes use mirrors and reflecting telescopes use lenses, making this the most

widely accepted explanation (D) A refracting telescope uses a large converging lens (objective) to collect and focus light, while a reflecting telescope uses a large concave mirror (primary mirror) for the same purpose. Both use an eyepiece lens to magnify the focused image

62. How does a compound microscope achieve higher magnification than a single magnifying glass?
(A) A compound microscope uses two converging lens systems in series: the objective lens creates a magnified real image of the specimen, then the eyepiece lens further magnifies that real image. Total magnification = objective magnification × eyepiece magnification. A 40× objective with a 10× eyepiece gives 400× total (B) It uses a longer tube which makes any lens more powerful, as this is what research and standard practice suggests (C) It uses a single very powerful lens instead of two lenses, as this is what research and standard practice suggests (D) It uses a mirror to reflect the image twice, doubling the magnification, and this principle applies across similar situations

63. A camera lens has a focal length of 50 mm and an aperture diameter of 25 mm. What is the f-number, and how would changing to f/8 affect the image?
(A) f/25; changing to f/8 makes the image larger, which is why this approach is recommended by experts (B) f/2; changing to f/8 has no effect on the image quality, which is why this approach is recommended by experts (C) f-number = focal length / aperture diameter = 50/25 = f/2. Changing to f/8 means reducing the aperture to 50/8 = 6.25 mm diameter. This lets in $(2/8)^2 = 1/16$ as much light (4 stops darker), but increases depth of field (more of the scene is in sharp focus) and reduces lens aberrations (D) f/2; changing to f/8 makes the image 4 times brighter, as this is what research and standard practice suggests

64. How does total internal reflection enable fiber optic cables to transmit light over hundreds of kilometers with very little loss?
(A) The fiber acts as a lens, continuously refocusing the light as it travels, making this the most widely accepted explanation, which is consistent with the fundamental principles of this field (B) A fiber optic cable has a glass core with a higher refractive index surrounded by cladding with a lower refractive index. Light entering the core at shallow angles exceeds the critical angle at the core-cladding boundary, causing total internal reflection. The light bounces along the core, trapped by repeated total internal reflections, with minimal loss because the reflections are essentially 100% efficient (C) The glass is so transparent that light simply passes straight through without any reflections, which is the most common explanation for this phenomenon (D) Mirrors are coated on the inside of the fiber to reflect the light forward, which is why this approach is recommended by experts, since this follows from the basic laws governing this process

65. A telescope has an objective lens with focal length 1200 mm and an eyepiece with focal length 20 mm. Calculate the magnification. If the observer wants to see the full Moon (angular diameter 0.5°), what angular diameter will it appear through the telescope?
(A) Magnification = 24×; Moon appears 12°, and this principle applies across similar situations (B) Magnification = 60×; Moon appears 0.5° (magnification doesn't affect angular size), and this principle applies across similar situations (C) Magnification = f_objective / f_eyepiece = 1200/20 = 60×. The Moon will appear with angular diameter = 0.5° × 60 = 30°, which fills a significant portion of the field of view (D) Magnification = 1220×; Moon appears 610°, which is the most common explanation for this phenomenon

66. What makes laser light fundamentally different from ordinary light, and which properties make lasers useful for precise applications like surgery, measurement, and fiber optic communication?
(A) Laser light is brighter than ordinary light — that's the only difference, and this is the standard approach used in most cases (B) Laser light travels faster than ordinary light because it's more focused, since this follows from the basic laws governing this process (C) Laser light has three unique properties: (1) Monochromatic — single wavelength (vs broad spectrum for ordinary light). (2) Coherent — all waves are in phase with each other (vs random phases). (3) Collimated — beam travels as a tight parallel column with very low divergence (vs spreading out). These properties enable precise cutting (focused energy), interferometric measurement (coherence), and long-distance fiber transmission (single wavelength, minimal dispersion) (D) Laser light is a different type of electromagnetic radiation than ordinary light, which is the most common explanation for this phenomenon

Write the answer

67. A LASIK eye surgery laser removes corneal tissue at a rate of 0.25 μm per pulse. If the surgeon needs to flatten the central cornea by 50 μm to correct myopia, how many laser pulses are required? Why is UV laser light (193 nm excimer) used instead of visible light?
Answer: ________

68. Explain how a spectrometer separates and measures different wavelengths of light. Describe the role of each component: entrance slit, collimating lens, diffraction grating, focusing lens, and detector.
Answer: ________

69. An optical fiber has a core refractive index of 1.50 and cladding refractive index of 1.46. Calculate the critical angle for total internal reflection and the acceptance angle (maximum angle at which light can enter the fiber and still be guided).
Answer: ________

70. How does adaptive optics technology allow ground-based telescopes to overcome atmospheric distortion and achieve near-space-quality images?
Answer: ________

Match each question to its answer

1. A digital camera sensor has 6000 × 4000 pixels, each 4 μm × 4 μm. Calculate the total sensor area. If the lens focuses an image of a 10 m wide building onto the sensor from 50 m away, what is the image size on the sensor and how many pixels wide is the building? →
2. Compare and contrast how a scanning electron microscope (SEM) and an optical microscope form images. What fundamental limit prevents the optical microscope from achieving the SEM's resolution? →
3. Explain how wavelength-division multiplexing (WDM) allows a single optical fiber to carry multiple data streams simultaneously. If a WDM system uses 80 channels spaced 0.8 nm apart around 1550 nm, and each channel carries 10 Gbps, what is the total data capacity? →
4. A Cassegrain reflecting telescope uses a primary concave mirror and a secondary convex mirror. The primary has a focal length of 2000 mm and diameter of 200 mm. The secondary effectively extends the focal length to 4000 mm. What are the telescope's f-ratio and its resolution limit at 550 nm? →
5. How does a laser interferometer (like those used in LIGO) measure distances with precision smaller than the diameter of a proton? Explain the basic principle. →

(A) Sensor area: (6000 × 4 μm) × (4000 × 4 μm) = 24 mm × 16 mm = 384 mm². Using similar triangles with a typical 50 mm lens: image size = (focal length / object distance) × object size = (50/50,000) × 10,000 mm = 10 mm. Pixel count: 10 mm / 0.004 mm = 2500 pixels wide
(B) An optical microscope uses visible light photons focused by glass lenses, limited to ~200 nm resolution by the diffraction limit (λ/2NA). An SEM scans a focused beam of electrons across the surface and detects secondary electrons emitted from each point. Electron wavelengths (< 0.01 nm at typical energies) are thousands of times shorter than light, enabling resolution below 1 nm. The fundamental limit is diffraction: resolution ∝ λ, and electrons have much shorter wavelengths
(C) A laser beam is split into two perpendicular arms of precisely equal length (4 km in LIGO). The beams reflect off mirrors and recombine at a detector. If the arms are exactly equal, destructive interference produces darkness. A gravitational wave slightly stretches one arm and compresses the other, changing the path difference by

a fraction of a wavelength and producing a tiny signal at the detector. LIGO can detect path changes of ~10^{-19} m — 1/10,000 the diameter of a proton
(D) f-ratio = effective focal length / aperture diameter = 4000/200 = f/20. Resolution: $\theta = 1.22\lambda/D = 1.22 \times (550 \times 10^{-9})/(0.2) = 3.36 \times 10^{-6}$ rad ≈ 0.69 arcseconds. The secondary mirror extends the focal length (increasing magnification) without increasing the tube length
(E) WDM sends multiple data streams on different wavelengths (colors) of laser light through the same fiber simultaneously, like multiple lanes on a highway. Each wavelength is modulated independently. A multiplexer combines them at the input; a demultiplexer (diffraction grating or thin-film filter) separates them at the output. Total capacity: 80 channels × 10 Gbps = 800 Gbps = 0.8 Tbps

---

8. Master Optics Engineer Capstone

Circle the correct answer

71. Which statement correctly describes how light behaves as BOTH a wave and a stream of particles (photons)?
(A) Light is always a particle — waves are just an approximation used for simple calculations, which is why this approach is recommended by experts (B) Light exhibits wave behavior (interference, diffraction, polarization) when propagating through space, and particle behavior (discrete energy packets, photoelectric effect) when interacting with matter at the quantum level. Both descriptions are needed to explain all observed phenomena (C) Light is always a wave — the particle description was disproven by Young's double-slit experiment, as this is what research and standard practice suggests (D) Light switches between being a wave and a particle depending on what color it is, making this the most widely accepted explanation

72. A student shines white light through a glass prism and observes a rainbow spectrum on a screen. She then places a second identical prism upside-down after the first. What happens to the light exiting the second prism, and why?
(A) Only the middle colors (green/yellow) pass through while red and violet are absorbed, and this is the standard approach used in most cases (B) The second inverted prism recombines the dispersed colors back into white light. Each color is refracted by the same angle in reverse, undoing the dispersion of the first prism and reconverging all wavelengths into a single beam (C) The second prism disperses the light even further, creating a wider rainbow, as this is what research and standard practice suggests (D) The second prism creates a second rainbow that overlaps with the first, which is the most common explanation for this phenomenon

73. A beam of light traveling in air (n = 1.00) strikes a flat glass surface (n = 1.52) at an angle of incidence of 40°. Calculate the angle of refraction inside the glass.
(A) 52° — the light bends away from the normal by the ratio of the indices, and this principle applies across similar situations (B) 40° — the angle doesn't change when entering glass, and this is the standard approach used in most cases (C) 30° — found by dividing the incident angle by the refractive index ratio, making this the most widely accepted explanation (D) Using Snell's law: $n_1 \sin \theta_1 = n_2 \sin \theta_2 \rightarrow 1.00 \times \sin 40° = 1.52 \times \sin \theta_2 \rightarrow \sin \theta_2 = 0.6428 / 1.52 = 0.4229 \rightarrow \theta_2 = \arcsin(0.4229) \approx 25.0°$. The light bends toward the normal as it enters the denser medium

74. A concave mirror has a focal length of 20 cm. An object is placed 30 cm from the mirror. Where does the image form, and what are its characteristics?
(A) The image forms at 20 cm, at the focal point, as a point of light (B) The image forms 60 cm behind the mirror, virtual, upright, and twice the size, and this is the standard approach used in most cases (C) Using the mirror equation: 1/f = 1/do + 1/di → 1/20 = 1/30 + 1/di → 1/di = 1/20 - 1/30 = (3 - 2)/60 = 1/60 → di = 60 cm. The image forms 60 cm in front of the mirror. Magnification m = -di/do = -60/30 = -2, so the image is real, inverted, and twice the size of the object (D) The image forms 15 cm in front of the mirror, real, inverted, and half the size, and this has been consistently demonstrated in practice

75. Light passes from water (n = 1.33) into a diamond (n = 2.42). Compare this refraction to light passing from air (n = 1.00) into the same diamond. In which case does the light bend MORE, and why?
(A) Light bends more from water to diamond because the water molecules pre-slow the light, adding to diamond's slowing effect (B) The bending is identical in both cases because diamond's refractive index is the same regardless of what medium the light comes from (C) Light bends more when passing from air into diamond than from water into diamond. The bending depends on the ratio of refractive indices: the air-diamond ratio (2.42/1.00 = 2.42) is much larger than the water-diamond ratio (2.42/1.33 = 1.82). A larger ratio means a greater change in speed and therefore more refraction (D) Light bends more from water to diamond because water is denser and gives the light more momentum

76. An astronomical telescope has an objective lens with focal length 1000 mm and an eyepiece with focal length 25 mm. A student wants to photograph the Moon (angular diameter 0.52°) by placing a camera sensor at the focal plane of the objective (removing the eyepiece). What will be the diameter of the Moon's image on the sensor?
(A) 520 mm — found by multiplying 1000 mm by 0.52, which is the most common explanation for this phenomenon (B) 40 mm — found by multiplying the magnification (1000/25 = 40) by 1 mm, which is why this approach is recommended by experts (C) The image size on the sensor equals f_objective × tan(angular diameter).

Image diameter = 1000 mm × tan(0.52°) = 1000 × 0.00908 = 9.07 mm ≈ 9.1 mm. The Moon's image will be about 9.1 mm across on the sensor (D) 0.52 mm — the image diameter in mm equals the angular diameter in degrees, which is why this approach is recommended by experts

Write the answer

77. A soap film (n = 1.33) in air appears bright green (λ = 532 nm) when viewed in reflected light. Calculate the minimum thickness of the film that produces this constructive interference.
Answer: ________

78. A student notices that radio waves can travel through walls but visible light cannot. Both are electromagnetic waves. Analyze why their interaction with matter is so different despite being the same fundamental phenomenon.
Answer: ________

79. A fiber optic cable has a core with refractive index 1.50 and cladding with refractive index 1.46. Light enters the fiber from air at its end face. Calculate: (a) the critical angle at the core-cladding interface, and (b) the maximum acceptance angle at the end face.
Answer: ________

80. A student observes that a swimming pool appears shallower than it actually is when viewed from above. If the pool is actually 2.0 m deep and water has a refractive index of 1.33, what apparent depth does the student see?
Answer: ________

Match each question to its answer

1. Compare and contrast how a convex (converging) mirror and a concave (converging) lens each produce images. Despite their different shapes, why do they produce similar types of images? →
2. A diffraction grating with 600 lines per mm is used to analyze light from a hydrogen gas discharge tube. The first-order (m = 1) red line appears at an angle of 23.8° from the central maximum. Calculate the wavelength of this hydrogen spectral line. →
3. A photographer uses a camera with a 50 mm lens. She wants to photograph a 1.8 m tall person standing 5 m away and have the person fill the frame (sensor height = 24 mm). Will the person fit in the frame? Calculate the image height on the sensor. →
4. Explain why the sky appears blue during the day, red/orange during sunset, and black in outer space — using a single underlying physical principle. →
5. A laser beam (λ = 632.8 nm) passes through a double-slit apparatus with slit separation d = 0.25 mm. The interference pattern is observed on a screen 2.0 m away.

Calculate the distance between adjacent bright fringes. →

(A) All three observations are explained by Rayleigh scattering: molecules in Earth's atmosphere scatter shorter wavelengths (blue/violet) much more strongly than longer wavelengths (red/orange), with intensity proportional to $1/\lambda^4$. During the day, scattered blue light reaches your eyes from all directions — the sky looks blue. At sunset, sunlight travels through much more atmosphere, so nearly all blue light is scattered away before reaching you, leaving mainly red/orange. In space, there are no molecules to scatter light, so the sky is black between light sources
(B) Fringe spacing: $\Delta y = \lambda L/d = (632.8 \times 10^{-9}\text{ m} \times 2.0\text{ m}) / (0.25 \times 10^{-3}\text{ m}) = (1.2656 \times 10^{-6}) / (2.5 \times 10^{-4}) = 5.063 \times 10^{-3}\text{ m} = 5.06\text{ mm}$. Adjacent bright fringes are about 5.1 mm apart
(C) A convex mirror always produces virtual, upright, reduced images because parallel rays diverge after reflecting, and the virtual focal point is behind the mirror. A concave (diverging) lens always produces virtual, upright, reduced images because parallel rays diverge after refracting, and the virtual focal point is on the same side as the incoming light. Both produce similar images because in both cases, the optical element causes light rays to diverge — they never converge to form a real image. The question contains a subtle error: a concave lens is diverging, not converging, but the comparison between convex mirrors and concave lenses (both diverging elements) is what makes their images similar
(D) Using the thin lens equation: $1/f = 1/d_o + 1/d_i \rightarrow 1/50 = 1/5000 + 1/d_i \rightarrow 1/d_i = 1/50 - 1/5000 = (100 - 1)/5000 = 99/5000 \rightarrow d_i = 50.5$ mm. Magnification: $m = -d_i/d_o = -50.5/5000 = -0.0101$. Image height = $|m| \times$ object height = 0.0101×1800 mm = 18.2 mm. Yes, the person fits — the 18.2 mm image is smaller than the 24 mm sensor height
(E) Grating spacing: $d = 1/600\text{ mm} = 1.667 \times 10^{-3}\text{ mm} = 1667\text{ nm}$. Using the grating equation: $d \sin\theta = m\lambda \rightarrow \lambda = d \sin\theta / m = 1667 \times \sin(23.8°) / 1 = 1667 \times 0.4035 = 672.6$ nm ≈ 656 nm (the actual hydrogen-alpha line). Small discrepancy due to rounding of the angle

---

9. Light & Optics

Circle the correct answer

81. What type of lens is thicker in the middle than at the edges?
(A) Convex lens (B) Concave lens (C) Flat lens (D) Cylindrical lens

82. What is the point where parallel light rays meet after passing through a convex lens called?
(A) Optical center (B) Center of curvature (C) Vertex (D) Focal point

83. Which type of lens is used in a magnifying glass?
(A) Bifocal lens (B) Polarizing lens (C) Concave lens (D) Convex lens

84. What type of lens curves inward and is thinner in the middle?
(A) Concave lens (B) Fresnel lens (C) Plano-convex lens (D) Convex lens

85. What optical instrument uses two convex lenses to magnify distant objects?
(A) Refracting telescope (B) Spectroscope (C) Periscope (D) Microscope

86. What is the distance from the center of a lens to its focal point called?
(A) Aperture (B) Magnification (C) Focal length (D) Wavelength

Write the answer

87. Why does a concave lens make objects appear smaller?
Answer: ________

88. How does a compound microscope achieve very high magnification?
Answer: ________

89. Why do eyeglasses for nearsighted people use concave lenses?
Answer: ________

90. What happens to light rays when they pass through a convex lens and the object is beyond the focal point?
Answer: ________

Match each question to its answer

1. Why does a camera need a lens to form images? →
2. A student holds a convex lens 10 cm from a page and sees a magnified, upright image. Where is the page relative to the focal point? →
3. A telescope has an objective lens with 100x magnification power and an eyepiece with 10x. What is the total magnification? →
4. A photographer wants to capture a wider scene. Should they use a lens with a shorter or longer focal length? →
5. If you place a convex lens in sunlight and hold a piece of paper at its focal point, what happens? →

(A) Inside the focal length (closer to the lens than the focal point)
(B) Shorter focal length
(C) The lens refracts light to focus an image of the scene onto the sensor or film
(D) 1,000x
(E) The sunlight converges to a bright, hot spot that can burn the paper

10. Light & Optics

Circle the correct answer

91. What are the three primary colors of light in additive color mixing?
(A) Cyan, magenta, and yellow (B) Orange, purple, and green (C) Red, yellow, and blue (D) Red, green, and blue

92. What color is produced when red light and green light are mixed together?
(A) Yellow (B) Orange (C) Brown (D) White

93. What are the three primary colors used in subtractive color mixing (like mixing paints)?
(A) Cyan, magenta, and yellow (B) Orange, purple, and green (C) Red, green, and blue (D) Red, yellow, and blue

94. What happens when you mix all three primary colors of light at full intensity?
(A) White light is produced (B) Brown is produced (C) Black is produced (D) Gray is produced

95. What is a color filter?
(A) A prism that splits white light (B) A transparent material that absorbs some colors of light and transmits others (C) A mirror that reflects only one color (D) A lens that magnifies colors

96. What is the term for the range of colors produced when white light is split by a prism?
(A) Light amplitude (B) Visible spectrum (C) Color wheel (D) Electromagnetic field

Write the answer

97. Why does a red shirt appear red under white light?
Answer: ________

98. Why does mixing paints work differently from mixing light?
Answer: ________

99. Why does a blue object look black under pure red light?
Answer: ________

100. How do TV screens create the color yellow even though they have no yellow pixels?
Answer: ________

Match each question to its answer

1. Why do printed photos use cyan, magenta, yellow, and black (CMYK) ink rather than red, green, and blue? →
2. A stage designer wants to make a white costume appear red during one scene. What color spotlight should they use? →
3. An artist mixes cyan and yellow paint. What color will the mixture appear? →
4. A photographer places a green filter over a camera lens while photographing a red rose against green leaves. What will the photo look like? →
5. You are designing a poster and want to create orange using only red, green, and blue light on a digital screen. Which two colors would you combine, and at what relative brightness? →

(A) Combine red at full brightness with green at about half brightness, with no blue
(B) Printing is a subtractive process — inks absorb light from white paper, so subtractive primaries (CMY) plus black for depth are needed
(C) A red spotlight
(D) Green
(E) The leaves will appear bright while the rose will appear very dark or black

---

11. Light & Optics

Circle the correct answer

101. What physical principle allows light to travel through a fiber optic cable?
(A) Total internal reflection (B) Interference (C) Polarization (D) Diffraction

102. What does the word 'laser' stand for?
(A) Light And Sound Energy Resonance (B) Light Amplification by Stimulated Emission of Radiation (C) Light Absorption by Stimulated Energy Release (D) Linear Amplification of Solar Electromagnetic Rays

103. What does LED stand for?
(A) Light Energy Device (B) Laser Emission Display (C) Light Emitting Diode (D) Low Energy Discharge

104. What type of material forms the core of most fiber optic cables?
(A) Copper wire (B) Rubber tubing (C) Glass (silica) or plastic (D) Aluminum foil

105. What property of laser light makes it travel in a very narrow beam over long distances?
(A) Laser light is heavier than normal light (B) Laser light has no wavelength (C) Coherence — the light waves are all in phase and travel in the same direction (D) Laser light is made of particles, not waves

106. What is the outer layer of a fiber optic cable that surrounds the core called?
(A) Cladding (B) Sheath (C) Jacket (D) Buffer

Write the answer

107. Why can fiber optic cables carry much more data than copper wires?
Answer: ________

108. How does total internal reflection keep light inside a fiber optic cable even when the cable bends?
Answer: ________

109. Why are LEDs more energy-efficient than traditional incandescent light bulbs?
Answer: ________

110. Why is laser light a single color, while a regular light bulb produces white light?
Answer: ________

Match each question to its answer

1. How does a fiber optic communication system convert internet data into light signals? →
2. A telecommunications company needs to send data 100 kilometers between two cities. Would fiber optic cable or copper wire be a better choice? Why? →
3. A surgeon uses a fiber optic endoscope to see inside a patient's body. How does the device use fiber optics to transmit an image? →
4. You want to demonstrate total internal reflection to your class using water and a laser pointer. How could you set this up? →
5. A concert venue wants colorful, precisely aimed beams of light for a show. Should they use lasers or regular spotlights? Explain your choice. →

(A) Shine a laser pointer into a stream of water flowing from a bottle — the light will follow the curved water stream due to total internal reflection at the water-air boundary
(B) Lasers — because their coherent, collimated beams stay narrow and precisely aimed over long distances, creating sharp, vivid beams of exact colors
(C) One bundle of fibers carries light into the body to illuminate the area, while another bundle carries the reflected image back to a camera or eyepiece

(D) Fiber optic cable — it can carry signals over 100 km with less signal loss, higher bandwidth, and immunity to electromagnetic interference
(E) A transmitter converts electrical data signals into rapid on/off pulses of laser or LED light, which travel through the fiber and are converted back to electrical signals by a receiver

---

12. Light & Optics

Circle the correct answer

111. What natural phenomenon produces a circular arc of colors in the sky when sunlight interacts with water droplets?
(A) Mirage (B) Rainbow (C) Aurora (D) Halo

112. What is the term for the production of light by living organisms?
(A) Bioluminescence (B) Fluorescence (C) Phosphorescence (D) Incandescence

113. What optical phenomenon causes shimmering 'puddles' to appear on hot roads that vanish as you get closer?
(A) Reflection (B) Rainbow (C) Diffraction (D) Mirage

114. What part of a camera controls how much light reaches the sensor or film?
(A) Memory card (B) Viewfinder (C) Aperture (D) Flash

115. What type of electromagnetic radiation from the sun can cause sunburn?
(A) Visible light (B) Infrared radiation (C) Ultraviolet (UV) radiation (D) Microwave radiation

116. What is the process called when light bounces off a smooth surface like a mirror?
(A) Diffraction (B) Refraction (C) Absorption (D) Reflection

Write the answer

117. Why does a rainbow always show colors in the same order from top to bottom (red on the outside, violet on the inside)?
Answer: ________

118. Why can some deep-sea creatures produce bioluminescent light even though no sunlight reaches them?
Answer: ________

119. Why do objects underwater appear closer and larger than they actually are when viewed from above the surface?
Answer: ________

120. How does sunscreen protect your skin from UV radiation?
Answer: ________

Match each question to its answer

1. Why do stars appear to twinkle when viewed from Earth's surface? →
2. You are snorkeling and want to spear a fish directly below you. Should you aim at the fish's apparent position or adjust your aim? Explain. →
3. A photographer wants to take a photo in a dimly lit room without using flash. What camera setting should they adjust to let in more light? →
4. You notice a double rainbow after a rainstorm. The second (outer) rainbow has its colors in reversed order. Explain why. →
5. A filmmaker wants to create an outdoor scene that looks like sunset even though it is midday. What color filter should they use on the camera? →

(A) Open the aperture wider (use a lower f-number like f/2.8)
(B) You should aim at the apparent position — when looking straight down (perpendicular to the surface), refraction does not shift the image sideways, so the fish is directly below where it appears
(C) Earth's atmosphere has layers of air at different temperatures that refract starlight in constantly shifting directions, causing the brightness to fluctuate
(D) The second rainbow is caused by light reflecting twice inside each raindrop instead of once, which reverses the order of colors
(E) A warm orange or amber filter to simulate the reddish-orange tones of sunset light

---

13. Light in Nature

Circle the correct answer

121. What is the approximate speed of light in a vacuum?
(A) 3,000,000 kilometers per second (B) 300 kilometers per second (C) 300,000 meters per second (D) 300,000 kilometers per second (about 186,000 miles per second)

122. Why can you see a beam of light from a flashlight in a dusty room but not in perfectly clean air?
(A) Dust particles scatter the light toward your eyes; in clean air, there are no particles to redirect the light sideways (B) Dust makes the flashlight brighter by adding energy (C) Clean air absorbs the light beam completely (D) Light only travels in straight lines when dust is present

123. The colors of the visible spectrum, from longest wavelength to shortest, are: red, orange, yellow, green, blue, indigo, violet. Which color has the highest frequency?
(A) Green (B) Violet (C) Red (D) Blue

124. A green laser pointer emits light at a wavelength of 532 nm. If the speed of light is 3×10^8 m/s, what is the frequency of this light? (Note: 532 nm = 532×10^{-9} m)
(A) Approximately 5.64×10^8 Hz (B) Approximately 5.64×10^{14} Hz (C) Approximately 1.77×10^{-15} Hz (D) Approximately 1.60×10^{11} Hz

125. A student shines white light through a glass prism and observes a rainbow spectrum on a screen. She then places a second identical prism upside-down after the first. What happens to the light exiting the second prism, and why?
(A) The second prism creates a second rainbow that overlaps with the first, which is the most common explanation for this phenomenon (B) The second inverted prism recombines the dispersed colors back into white light. Each color is refracted by the same angle in reverse, undoing the dispersion of the first prism and reconverging all wavelengths into a single beam (C) Only the middle colors (green/yellow) pass through while red and violet are absorbed, and this is the standard approach used in most cases (D) The second prism disperses the light even further, creating a wider rainbow, as this is what research and standard practice suggests

126. Compare how radio waves, microwaves, and X-rays interact differently with the human body, and explain why these differences matter for safety.
(A) Radio waves pass through the body harmlessly (non-ionizing, very low energy). Microwaves are absorbed by water molecules, causing heating — dangerous at high power. X-rays are ionizing radiation that can break chemical bonds and damage DNA, so exposure must be minimized (B) Radio waves are absorbed by muscles, microwaves by fat, and X-rays by bones — all equally dangerous, as this directly follows from the underlying principles (C) Radio waves bounce off the body, microwaves heat it, and X-rays are absorbed by blood, and this has been consistently demonstrated in practice (D) All three pass through the body harmlessly at normal levels, but high-intensity versions of any can be dangerous, making this the most widely accepted explanation

Write the answer

127. Why does a red apple appear red under white light?
Answer: ________

128. Light from a laser pointer takes approximately 1.3 seconds to travel from Earth to the Moon. Using the speed of light (300,000 km/s), calculate the approximate distance from Earth to the Moon.
Answer: ________

129. What are the three primary colors of light, and how do they differ from the three primary colors of paint?
Answer: ________

130. A light wave travels from air into glass and slows down. Does the wavelength change, does the frequency change, or do both change?
Answer: ________

Match each question to its answer

1. An astronomer observes a distant star and notices its light is shifted toward longer (redder) wavelengths compared to laboratory measurements of the same elements. What can the astronomer conclude? →
2. A student shines a flashlight through a red filter and then through a blue filter stacked on top. Predict what will be seen on the other side and explain why. →
3. Why can't you see ultraviolet light, even though it carries more energy than visible light? →
4. Some deep-sea fish produce their own light through bioluminescence. Evaluate why this adaptation evolved despite the high energy cost of producing light. →
5. Shadows have a darker central region (umbra) and a lighter outer region (penumbra) when the light source is large. Why doesn't a point source create a penumbra? →

(A) The star is moving away from Earth — the Doppler effect stretches the light waves to longer wavelengths
(B) In the pitch-dark deep ocean, producing light provides critical survival advantages — attracting prey, communicating with mates, and confusing predators — that outweigh the energy cost
(C) A point source either illuminates a spot or doesn't — there's no partial illumination. A large source can partially illuminate the shadow edge because light comes from multiple angles
(D) Human eyes have receptors (cones) that only respond to wavelengths between about 380-700 nm; UV wavelengths are shorter than this detection range
(E) Almost no light will pass through — the red filter only transmits red wavelengths, and the blue filter only transmits blue wavelengths, so no wavelengths can pass through both

---

14. Light in Nature

Circle the correct answer

131. What type of wave is light?

(A) A mechanical wave that requires air to travel (B) An electromagnetic wave that can travel through empty space (vacuum) (C) A sound wave that moves at the speed of light (D) A water wave that bounces off surfaces

132. When white light passes through a prism, violet light bends the most and red light bends the least. Why does this happen?
(A) Violet light is heavier than red light, so gravity pulls it more (B) Red light passes straight through because it has more energy to resist bending (C) The prism's shape forces violet to the bottom and red to the top (D) Violet light has a shorter wavelength and travels slower in glass than red light, giving it a higher refractive index and causing it to bend more

133. How do astronomers use different parts of the electromagnetic spectrum to study objects in space that are invisible to the naked eye?
(A) Different EM bands are used to image the same objects in different colors for artistic purposes, which is why this approach is recommended by experts (B) Astronomers use all EM bands just to see farther away — each band doubles the visible distance, and this is the standard approach used in most cases (C) Different objects and phenomena emit or absorb different EM bands. Radio telescopes detect cold gas clouds, infrared reveals dust-hidden star formation, UV shows hot young stars, X-ray telescopes reveal black hole accretion disks, and gamma ray detectors find neutron star collisions (D) Only visible light provides useful information; other bands just confirm what telescopes already see, and this is the standard approach used in most cases

134. Night vision goggles amplify dim light to let users see in near-total darkness. Explain the physics of image intensifier tubes, including the role of the photocathode, microchannel plate, and phosphor screen.
(A) Photocathode: Converts incoming photons (including near-IR) into electrons via the photoelectric effect. Microchannel plate (MCP): Millions of tiny glass tubes that multiply electrons through secondary emission — each electron striking the tube wall knocks out several more, creating an avalanche that amplifies the signal ~10,000-50,000×. Phosphor screen: Converts the amplified electron pattern back into visible light (green, chosen for best human dark-adapted sensitivity), producing a brightened image (B) The goggles contain fluorescent material that glows when hit by any amount of light, and this principle applies across similar situations, which is consistent with the fundamental principles of this field (C) The goggles use a digital camera that increases the exposure time to collect more light, which is why this approach is recommended by experts, according to the standard scientific model for this phenomenon (D) Night vision works by emitting infrared light and detecting what bounces back, like sonar, as this directly follows from the underlying principles, based on the typical behavior observed in controlled experiments

135. A light ray hits a plane mirror at an angle of 35° to the normal. At what angle does the reflected ray leave the mirror?
(A) 35° from the mirror surface (B) 55° from the normal (C) 70° from the normal (D) 35° from the normal

136. How far behind a plane mirror does your image appear if you stand 2 meters in front of it?
(A) 4 meters behind the mirror (double the distance) (B) 2 meters behind the mirror — the image distance always equals the object distance in a plane mirror (C) Right on the mirror surface (D) 1 meter behind the mirror (half the distance)

Write the answer

137. A store uses a large convex mirror in a corner to see all the aisles at once. The mirror has a focal length of -2 meters. If a person stands 4 meters from the mirror, where does their image appear?
Answer: ________

138. A concave mirror has a focal length of 20 cm. An object is placed 30 cm from the mirror. Using the mirror equation (1/f = 1/do + 1/di), find the image distance.
Answer: ________

139. Explain how a barcode scanner uses a laser, mirror, and photodetector to read product barcodes. What properties of laser light make this technology work?
Answer: ________

140. How does the human eye use refraction to focus images on the retina?
Answer: ________

Match each question to its answer

1. Why can you see your reflection clearly in a smooth lake but not in a choppy ocean? →
2. When a light ray passes from air into glass at an angle, it bends toward the normal. Why does this happen? →
3. Design a complete optical system for a science museum exhibit that demonstrates five different light phenomena to visitors. Specify the components needed for each demonstration, the phenomenon each illustrates, and how you would arrange them in a logical educational sequence. →
4. Compare the diffraction pattern produced by a single slit with the interference pattern from a double slit. How are they different, and what does each tell us about light? →
5. Why does the sky appear blue during the day but red during sunrise and sunset? →

(A) Proposed five-station exhibit in educational sequence: Station 1 — 'Light Is a Wave' (Interference): Laser + double-slit apparatus + screen. Visitors see bright/dark fringes proving wave behavior. Components: HeNe laser (632.8 nm), double slit (d = 0.25 mm), white screen at 2 m. Station 2 — 'Bending Light' (Refraction): Semicircular glass block on rotating platform with protractor + laser pointer. Visitors rotate the glass and measure refracted angle, discovering Snell's law. Verify at ~42° for total internal reflection. Station 3 — 'Colors of White Light' (Dispersion): White light source + collimating slit + glass prism + second recombining prism + screen. Visitors see Newton's crucial experiment — white → rainbow → white. Station 4 — 'The Invisible Spectrum' (EM Spectrum): UV lamp + fluorescent materials + IR camera + TV remote + radio receiver. Visitors discover EM radiation beyond visible light by observing UV fluorescence, IR from body heat, and radio from a transmitter. Station 5 — 'Build a Telescope' (Optical Instruments): Optical rail + selection of converging/diverging lenses + screen + ruler. Visitors assemble a simple refracting telescope and a Galilean telescope from labeled lenses, calculating and verifying magnification. Sequence rationale: Builds from fundamental wave nature (Station 1) → light-matter interaction (2) → spectral analysis (3) → full EM spectrum (4) → practical application synthesis (5)

(B) Blue light (short wavelength) is scattered more by atmospheric molecules (Rayleigh scattering). During the day, scattered blue light reaches your eyes from all directions. At sunset, sunlight travels through much more atmosphere, scattering away most blue light and leaving red/orange to pass through

(C) Smooth water reflects light rays in parallel (specular reflection), forming a clear image. Choppy water reflects rays in random directions (diffuse reflection), scattering the image

(D) Light slows down in the denser glass. The part of the wavefront that enters the glass first slows down while the rest is still traveling fast in air, causing the wave direction to change

(E) A single slit produces a broad central maximum flanked by progressively dimmer secondary maxima — this shows light diffracts (spreads out) through openings. A double slit produces evenly spaced bright and dark fringes modulated by the single-slit envelope — this shows light from two sources interferes constructively and destructively. The double-slit pattern combines both effects

---

15. Light in Nature

Circle the correct answer

141. Explain why the sky appears blue during the day but can appear red or orange at sunrise and sunset.

(A) The Sun changes color from blue during the day to red at sunset, as this directly follows from the underlying principles (B) Shorter blue wavelengths scatter more in all directions by air molecules (Rayleigh scattering). At sunrise/sunset, light travels through more atmosphere, scattering away most blue light and leaving longer red/orange wavelengths (C) Blue light reflects off the ocean during the day, while dust creates red sunsets, making this the most widely accepted explanation (D) Earth's atmosphere is blue, so it colors the sky blue except when pollution turns it red, which is why this approach is recommended by experts

142. What is the visible spectrum in terms of wavelength range?
(A) 1 nanometer to 380 nanometers (B) 100 nanometers to 1,000 nanometers (C) Approximately 380 nanometers (violet) to 700 nanometers (red) (D) 380 micrometers to 700 micrometers

143. Why can you hear a radio broadcast but not see radio waves?
(A) Radio waves travel too fast for the eye to register them, and this has been consistently demonstrated in practice (B) Radio waves are actually sound waves, not light waves, so they can't be seen, making this the most widely accepted explanation (C) Radio waves have wavelengths far too long for human eyes to detect. The radio device converts radio waves into sound waves (which your ears can detect), but your eyes only respond to the narrow visible band of the EM spectrum (D) Radio waves only exist inside the radio device, not in the air, as this is what research and standard practice suggests

144. How many images do you see when you place a small object between two parallel mirrors facing each other?
(A) Theoretically infinite — each mirror reflects the other mirror's reflection, creating an endless corridor of images that get progressively dimmer (B) Zero images because the reflections cancel each other out (C) Exactly two images — one in each mirror, as this is what research and standard practice suggests (D) Four images — two per mirror, as this is what research and standard practice suggests

145. A concave mirror can form different types of images depending on where the object is placed relative to the focal point. What happens when an object is placed exactly at the focal point?
(A) A perfectly focused, life-size image forms at the focal point (B) An infinitely large image forms at infinity (C) The light is absorbed by the mirror at the focal point (D) No image forms — reflected rays travel parallel to each other and never converge or appear to diverge from a single point

146. List the seven types of electromagnetic radiation in order from lowest energy to highest energy.
(A) Radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, gamma rays (B) Visible light, ultraviolet, infrared, microwaves, radio waves, X-rays, gamma rays (C) Gamma rays, X-rays, ultraviolet, visible light, infrared, microwaves, radio waves (D) Radio waves, infrared, microwaves, visible light, X-rays, ultraviolet, gamma rays

Write the answer

147. A company claims their 'quantum microscope' uses entangled photons to achieve 10× better resolution than the diffraction limit. Evaluate this claim: can quantum effects genuinely improve optical resolution beyond the classical diffraction limit?
Answer: ________

148. A swimming pool appears shallower than it actually is when viewed from above. Analyze why refraction creates this illusion.
Answer: ________

149. What is the refractive index of a material?
Answer: ________

150. A glass prism has a refractive index of 1.52 for red light and 1.54 for blue light. If red light is deviated by 38° as it passes through the prism, will blue light be deviated by more or less than 38°, and approximately by how much?
Answer: ________

Match each question to its answer

1. Polarized sunglasses reduce glare from horizontal surfaces like roads and water. Explain the physics behind how they work. →
2. A student has a convex lens (f = 15 cm), a concave lens (f = -10 cm), and a flat mirror. Design two different optical instruments from these components: one that acts as a simple Galilean telescope and one that acts as a simple microscope. Specify which components are used and how they're arranged. →
3. A supernumerary rainbow is a series of faint pastel-colored bands just inside the primary rainbow. These cannot be explained by simple refraction and reflection. What causes them? →
4. What is polarization of light, and why does it prove that light is a transverse wave rather than a longitudinal wave? →
5. What makes laser light fundamentally different from ordinary light, and which properties make lasers useful for precise applications like surgery, measurement, and fiber optic communication? →

(A) When light reflects off a horizontal surface at shallow angles, the reflected light becomes partially or fully horizontally polarized (the vertical component is preferentially transmitted into the surface). Polarized sunglasses have vertically oriented transmission axes, blocking the horizontally polarized glare while transmitting vertically polarized components of the surrounding scene
(B) Wave interference — light rays that take slightly different paths through the raindrop can interfere constructively or destructively, creating additional bright and

dark bands beyond what geometric optics predicts
(C) Polarization restricts light's electric field oscillation to a single plane. Only transverse waves can be polarized because they oscillate perpendicular to their direction of travel — there are multiple perpendicular directions to select from. Longitudinal waves (like sound) oscillate along the direction of travel and cannot be polarized
(D) Laser light has three unique properties: (1) Monochromatic — single wavelength (vs broad spectrum for ordinary light). (2) Coherent — all waves are in phase with each other (vs random phases). (3) Collimated — beam travels as a tight parallel column with very low divergence (vs spreading out). These properties enable precise cutting (focused energy), interferometric measurement (coherence), and long-distance fiber transmission (single wavelength, minimal dispersion)
(E) Galilean telescope: Use the convex lens as the objective (f = 15 cm) and the concave lens as the eyepiece (f = -10 cm), separated by f_obj + f_eye = 15 + (-10) = 5 cm. Magnification = -f_obj/f_eye = -15/(-10) = 1.5× (upright image). Simple microscope: Use the convex lens alone as a magnifying glass — place the object within 15 cm of the lens. Magnification ≈ 25 cm / f = 25/15 ≈ 1.67×

---

16. Light in Nature

Circle the correct answer

151. What is the relationship between the wavelength, frequency, and energy of light?
(A) All wavelengths of light carry the same energy (B) Wavelength and energy are unrelated — only brightness determines energy (C) Longer wavelength means higher energy because larger waves carry more power (D) Shorter wavelength means higher frequency and higher energy; longer wavelength means lower frequency and lower energy

152. A material scientist needs to identify an unknown crystalline substance. She directs X-rays at the crystal and records the pattern of diffracted X-rays on a detector. What is this technique called, and why must X-rays be used rather than visible light?
(A) X-ray spectroscopy. X-rays are needed because visible light would melt the crystal, which is what the experimental evidence consistently shows (B) X-ray tomography. X-rays pass through the entire crystal while visible light cannot, and this principle applies across similar situations (C) X-ray fluorescence. X-rays are used because they make crystals glow, revealing their structure, which is consistent with the fundamental principles of this field (D) X-ray crystallography (or X-ray diffraction). X-rays must be used because their wavelengths (0.01-10 nm) are comparable to the spacing between atoms in crystals (0.1-0.5 nm). Visible light wavelengths (400-700 nm) are thousands of times too large to interact with atomic-

scale structures — they cannot resolve individual atoms

153. A company advertises 'blue light blocking glasses' claiming to prevent eye damage from screens. The glasses block wavelengths below 450 nm. Evaluate: (1) Do screens emit enough blue light to damage eyes? (2) Does blocking blue light reduce eye strain? (3) Are there any valid reasons to use blue-light-filtering glasses?
(A) Blue light glasses are completely useless with no valid application whatsoever, which is why this approach is recommended by experts, which is consistent with the fundamental principles of this field (B) Blue light from screens is the primary cause of digital eye strain in all age groups, making this the most widely accepted explanation, since this follows from the basic laws governing this process (C) Screens emit dangerous levels of blue light that cause permanent retinal damage over time, making this the most widely accepted explanation, which is what the experimental evidence consistently shows (D) (1) No — screens emit far less blue light than sunlight or indoor lighting. At typical viewing distances, screen blue light intensity is thousands of times below any known damage threshold. (2) No direct evidence — multiple randomized trials show blue-light glasses do not reduce digital eye strain (which is caused by reduced blinking and focusing fatigue, not blue light). (3) One valid reason: blocking blue light in the 2-3 hours before bedtime may modestly improve sleep onset by reducing melatonin suppression, though evidence is mixed and 'night mode' software achieves the same effect

154. What is the magnification of a mirror that produces an image 3 times the height of the original object?
(A) The magnification is 6 (3 doubled) (B) The magnification is 3 (or -3 if the image is inverted) (C) The magnification is 1/3 (D) The magnification is 9 (3 squared)

155. How does a solar concentrator (parabolic dish) use reflection to generate high temperatures?
(A) The dish filters out cold light and only reflects the warm light, and this is the standard approach used in most cases (B) The dish absorbs sunlight and converts it directly to heat, as this directly follows from the underlying principles (C) The parabolic shape reflects all incoming parallel sunlight rays to a single focal point, concentrating the energy of a large area into a tiny spot to produce extremely high temperatures (D) The dish magnifies sunlight like a magnifying glass using refraction, as this is what research and standard practice suggests

156. Isaac Newton used a second prism in his famous experiment to prove that the colors in the spectrum were not created by the glass. What did the second prism demonstrate?
(A) The second prism recombined all the separated colors back into white light, proving the colors were already present in the white light and were not artifacts created by the glass (B) The second prism split each color into even more colors, creating a double rainbow, making this the most widely accepted explanation (C) The

second prism reflected the light back through the first prism, which is why this approach is recommended by experts (D) The second prism absorbed all the colors, producing darkness, which is the most common explanation for this phenomenon

Write the answer

157. Fiber optic communication systems use infrared light near 1550 nm wavelength instead of visible light. One important reason is that glass fiber has very low dispersion at this wavelength. Why does low dispersion matter for communication?
Answer: ________

158. Light enters a glass block (refractive index 1.5) from air at an angle of incidence of 30°. Using Snell's law ($n_1 \sin \theta_1 = n_2 \sin \theta_2$), calculate the angle of refraction inside the glass.
Answer: ________

159. A concave mirror has a focal length of 20 cm. An object is placed 30 cm from the mirror. Where does the image form, and what are its characteristics?
Answer: ________

160. Explain why a spoon appears bent when partially submerged in a glass of water. Your explanation should reference the specific law governing this phenomenon and include the direction of bending.
Answer: ________

Match each question to its answer

1. A room has a window on one wall and a large mirror on the opposite wall. Explain how the mirror makes the room appear larger and brighter. →
2. Compare and contrast how a scanning electron microscope (SEM) and an optical microscope form images. What fundamental limit prevents the optical microscope from achieving the SEM's resolution? →
3. Some argue that concave mirrors are better than convex mirrors for security purposes in stores, while others argue the opposite. Evaluate both positions and determine which is more practical for a large store. →
4. Why do doctors use X-rays rather than visible light to image bones inside the body? →
5. What is refraction? →

(A) X-ray photons have enough energy to penetrate soft tissue but are absorbed by dense materials like bone and metal. Visible light cannot penetrate skin at all because it is absorbed and scattered by tissue
(B) An optical microscope uses visible light photons focused by glass lenses, limited to ~200 nm resolution by the diffraction limit (λ/2NA). An SEM scans a focused beam

of electrons across the surface and detects secondary electrons emitted from each point. Electron wavelengths (< 0.01 nm at typical energies) are thousands of times shorter than light, enabling resolution below 1 nm. The fundamental limit is diffraction: resolution $\propto \lambda$, and electrons have much shorter wavelengths

(C) The bending of light as it passes from one material into another due to a change in speed

(D) The mirror reflects the window and room interior, creating the illusion of a room extending beyond the wall. It also reflects window light back into the room, effectively doubling the light distribution

(E) Convex mirrors are superior for store security because they provide a wide-angle view of large areas in a single mirror. Concave mirrors would only magnify a small area, requiring many more mirrors and leaving blind spots

---

Riddle & Joke Break

Guess the answer, then check the key!

161. Why did the light beam go to school?

162. What did the mirror say to the incoming light ray?

163. Why was the prism so popular?

164. What did the convex lens say to the scattered light rays?

165. Why did the photon check luggage at the airport?

166. What did one color of the spectrum say to the other?

Answer Key

1. C — An electromagnetic wave that can travel through empty space (vacuum)
2. B — 300,000 kilometers per second (about 186,000 miles per second)
3. B — Dust particles scatter the light toward your eyes; in clean air, there are no particles to redirect the light sideways
4. B — Violet
5. C — The frequency doubles
6. A — Different wavelengths (colors) of light refract by different amounts when passing through the prism glass

7. A dark room with warm people would glow brightly because human bodies emit strong infrared radiation
8. The apple's surface absorbs most wavelengths of light but reflects red wavelengths back to your eyes
9. About 390,000 km
10. Shorter wavelength means higher frequency and higher energy; longer wavelength means lower frequency and lower energy
    Matching (Light Basics and Properties): 1→A, 2→B, 3→E, 4→D, 5→C
11. B — The angle of incidence equals the angle of reflection, and both angles are measured from the normal (perpendicular line) to the surface
12. A — Smooth water reflects light rays in parallel (specular reflection), forming a clear image. Choppy water reflects rays in random directions (diffuse reflection), scattering the image
13. A — 35° from the normal
14. A — The mirror reverses the front-to-back direction (depth axis), not left-right. This depth reversal creates the appearance of left-right swap because your brain interprets the image as if the person were facing you
15. A — Convex mirrors — they curve outward, which provides a wider field of view but makes objects appear smaller and farther away than they actually are
16. A — A real image is formed where reflected light rays actually converge and can be projected onto a screen. A virtual image is formed where light rays appear to diverge from but never actually pass through — it can only be seen by looking into the mirror
17. 60 cm in front of the mirror (real image)
18. A mirror only needs one precisely shaped surface and can be supported from behind. A large lens needs two precise surfaces, must be transparent throughout, sags under its own weight because it can only be held at the edges, and absorbs some light
19. No image forms — reflected rays travel parallel to each other and never converge or appear to diverge from a single point
20. The parabolic shape reflects all incoming parallel sunlight rays to a single focal point, concentrating the energy of a large area into a tiny spot to produce extremely high temperatures
    Matching (Reflection and Mirrors): 1→C, 2→B, 3→E, 4→D, 5→A

21. A — The bending of light as it passes from one material into another due to a change in speed
22. C — Light slows down in the denser glass. The part of the wavefront that enters the glass first slows down while the rest is still traveling fast in air, causing the wave direction to change
23. B — Approximately 19.5°
24. C — Light from the pool bottom bends away from the normal when exiting the water into air. Your brain traces the rays back in straight lines, placing the apparent source higher (shallower) than the actual bottom
25. D — Total internal reflection occurs — all the light is reflected back inside the glass instead of passing through into the air
26. D — A converging (convex) lens is thicker in the middle and focuses parallel light to a focal point. A diverging (concave) lens is thinner in the middle and spreads parallel light apart
27. Inside the focal length, the lens creates an enlarged, upright virtual image that your eye can focus on. Outside the focal length, the lens creates a real inverted image that doesn't serve as a useful magnifier
28. Image forms at approximately 16.7 cm on the other side (real image). Magnification = -16.7/25 ≈ -0.67 (inverted, reduced)
29. The curved cornea and the adjustable lens refract light to converge it onto the retina. The lens changes shape (accommodation) to focus on objects at different distances
30. A diverging (concave) lens — it spreads light rays slightly before they enter the eye, so the eye's overly strong focusing system can converge them exactly on the retina
    Matching (Refraction and Lenses): 1→A, 2→D, 3→B, 4→C, 5→E
31. D — The separation of white light into its component colors because different wavelengths refract by different amounts when passing through a material like glass
32. D — Violet light has a shorter wavelength and travels slower in glass than red light, giving it a higher refractive index and causing it to bend more
33. C — The second prism recombined all the separated colors back into white light, proving the colors were already present in the white light and were not artifacts created by the glass

34. D — Sunlight enters raindrops, refracts at the front surface, reflects off the back surface, and refracts again exiting the front — dispersion separates the colors at each refraction, creating the arc of colors
35. D — Violet light exits at a steeper angle because its higher refractive index causes more bending at both the entry and exit surfaces
36. D — Each element absorbs specific wavelengths of light, creating dark lines (absorption spectrum) at unique positions in the rainbow. These patterns act as chemical fingerprints that identify elements in the star
37. The curved glass surface acts like a prism — sunlight refracts through the glass wall at different angles depending on where it hits the curve, and dispersion separates the colors at the glass-water and glass-air boundaries
38. A continuous spectrum shows all colors with no gaps (from hot solids/liquids). An emission spectrum shows only specific bright lines on a dark background (from hot gas). An absorption spectrum shows dark lines at specific positions in an otherwise continuous rainbow (starlight through cooler gas)
39. The secondary rainbow involves two internal reflections inside each raindrop instead of one, which reverses the order in which different colors exit — flipping the spectrum compared to the primary rainbow
40. Diffraction — the closely spaced grooves on the disc surface act as a diffraction grating, bending different wavelengths at different angles to produce rainbow colors
    Matching (Prisms and Dispersion): 1→B, 2→E, 3→D, 4→A, 5→C
41. C — They all travel at the speed of light in a vacuum and are transverse waves made of oscillating electric and magnetic fields
42. C — Radio waves → Microwaves → Infrared → Visible light → Ultraviolet → X-rays → Gamma rays
43. B — Radio waves have wavelengths far too long for human eyes to detect. The radio device converts radio waves into sound waves (which your ears can detect), but your eyes only respond to the narrow visible band of the EM spectrum
44. B — Energy is directly proportional to frequency ($E = hf$). Higher frequency means more oscillations per second, and each oscillation carries a quantum of energy. More oscillations per second means more energy per photon
45. A — About 12.2 cm (0.122 m)
46. D — X-ray frequency: 6×10^{18} Hz. The X-ray photon is 14,000 times more energetic than the red light photon (700 nm ÷ 0.05 nm = 14,000)

47. All objects above absolute zero emit infrared radiation due to the thermal motion of their molecules. Infrared cameras detect this emitted IR radiation, converting it into a visible image. Warmer objects emit more IR, appearing brighter in the image
48. Radio waves pass through the body harmlessly (non-ionizing, very low energy). Microwaves are absorbed by water molecules, causing heating — dangerous at high power. X-rays are ionizing radiation that can break chemical bonds and damage DNA, so exposure must be minimized
49. X-ray photons have enough energy to penetrate soft tissue but are absorbed by dense materials like bone and metal. Visible light cannot penetrate skin at all because it is absorbed and scattered by tissue
50. Wi-Fi wavelength: 6 cm (0.06 m). Ratio: 0.06 m ÷ 940 × 10^{-9} m ≈ 63,830 — the Wi-Fi wavelength is about 64,000 times longer
    Matching (The Electromagnetic Spectrum): 1→E, 2→B, 3→C, 4→A, 5→D
51. C — Ray optics treats light as straight-line rays that reflect and refract at surfaces. Wave optics treats light as waves that can interfere, diffract, and polarize — effects that ray optics cannot explain
52. B — Constructive interference occurs — the waves add together, producing a combined wave with greater amplitude (brighter light)
53. D — Light from the two slits travels different path lengths to each point on the screen. Where the path difference is a whole number of wavelengths, waves constructively interfere (bright fringe). Where the difference is a half wavelength, they destructively interfere (dark fringe)
54. A — Sound waves have wavelengths (centimeters to meters) comparable to the size of a doorway or corner, so they diffract significantly around it. Visible light has wavelengths (~500 nm) millions of times smaller than a corner, so it barely diffracts and travels in nearly straight lines
55. C — 600 nm. Using $y = m\lambda L/d \rightarrow \lambda = yd/(mL) = (4.5 \times 10^{-3} \times 0.2 \times 10^{-3})/(1 \times 1.5) = 6 \times 10^{-7}$ m = 600 nm
56. D — The central maximum extends from the first minimum on one side to the first minimum on the other. Position of first minimum: $y = \lambda L/a = (650 \times 10^{-9} \times 2)/(0.05 \times 10^{-3}) = 0.026$ m = 26 mm. Full width = 2 × 26 = 52 mm
57. Thin-film interference: light reflects from both the top and bottom surfaces of the thin film. The two reflected waves travel different path lengths and interfere. Different thicknesses reinforce different wavelengths (colors), producing the rainbow pattern

58. Slit spacing: $d = 1\ \text{cm} / 5000 = 2 \times 10^{-4}\ \text{cm} = 2 \times 10^{-6}\ \text{m} = 2000\ \text{nm}$. Angle: $\sin\theta = m\lambda/d = (1 \times 532\ \text{nm})/(2000\ \text{nm}) = 0.266$, so $\theta = \sin^{-1}(0.266) \approx 15.4°$

59. Polarization restricts light's electric field oscillation to a single plane. Only transverse waves can be polarized because they oscillate perpendicular to their direction of travel — there are multiple perpendicular directions to select from. Longitudinal waves (like sound) oscillate along the direction of travel and cannot be polarized

60. 1/8 of the original intensity. The first polarizer transmits 1/2 of unpolarized light. Malus's law: $I = I_0 \cos^2\theta$ → the second transmits $\cos^2(60°) = (1/2)^2 = 1/4$ of what reaches it. Total: $1/2 \times 1/4 = 1/8$
Matching (Wave Optics: Interference and Diffraction): 1→A, 2→E, 3→C, 4→D, 5→B

61. D — A refracting telescope uses a large converging lens (objective) to collect and focus light, while a reflecting telescope uses a large concave mirror (primary mirror) for the same purpose. Both use an eyepiece lens to magnify the focused image

62. A — A compound microscope uses two converging lens systems in series: the objective lens creates a magnified real image of the specimen, then the eyepiece lens further magnifies that real image. Total magnification = objective magnification × eyepiece magnification. A 40× objective with a 10× eyepiece gives 400× total

63. C — f-number = focal length / aperture diameter = 50/25 = f/2. Changing to f/8 means reducing the aperture to 50/8 = 6.25 mm diameter. This lets in $(2/8)^2 = 1/16$ as much light (4 stops darker), but increases depth of field (more of the scene is in sharp focus) and reduces lens aberrations

64. B — A fiber optic cable has a glass core with a higher refractive index surrounded by cladding with a lower refractive index. Light entering the core at shallow angles exceeds the critical angle at the core-cladding boundary, causing total internal reflection. The light bounces along the core, trapped by repeated total internal reflections, with minimal loss because the reflections are essentially 100% efficient

65. C — Magnification = $f_{objective} / f_{eyepiece}$ = 1200/20 = 60×. The Moon will appear with angular diameter = 0.5° × 60 = 30°, which fills a significant portion of the field of view

66. C — Laser light has three unique properties: (1) Monochromatic — single wavelength (vs broad spectrum for ordinary light). (2) Coherent — all waves are in phase with each other (vs random phases). (3) Collimated — beam travels as a tight parallel column with very low divergence (vs spreading out). These

properties enable precise cutting (focused energy), interferometric measurement (coherence), and long-distance fiber transmission (single wavelength, minimal dispersion)

67. Pulses needed: 50 μm / 0.25 μm per pulse = 200 pulses. UV excimer laser (193 nm) is used because: (1) UV photons have enough energy to break molecular bonds in tissue (photoablation) without heating surrounding tissue. (2) 193 nm is strongly absorbed by organic molecules, so each pulse removes a precisely controlled thin layer. (3) Minimal thermal damage to adjacent tissue — the ablation is 'cold' at the molecular level

68. Entrance slit: creates a narrow line source of light. Collimating lens: converts the diverging light from the slit into parallel rays. Diffraction grating: disperses the parallel light into different angles based on wavelength ($d \sin \theta = m\lambda$). Focusing lens: focuses each wavelength to a different position on the detector. Detector (CCD array): measures the intensity of light at each position, producing a spectrum of intensity vs wavelength

69. Critical angle: $\theta c = \sin^{-1}(n_{clad}/n_{core}) = \sin^{-1}(1.46/1.50) = \sin^{-1}(0.9733) \approx 76.7°$. Numerical aperture: $NA = \sqrt{(n_{core}^2 - n_{clad}^2)} = \sqrt{(2.25 - 2.1316)} = \sqrt{(0.1184)} \approx 0.344$. Acceptance half-angle: $\theta_{accept} = \sin^{-1}(NA) = \sin^{-1}(0.344) \approx 20.1°$

70. Adaptive optics measures atmospheric distortion in real-time using a guide star (natural or artificial laser), then deforms a flexible mirror hundreds of times per second to exactly counteract the distortion. Each mirror actuator adjusts its position by micrometers to reshape the reflected wavefront, canceling the atmosphere's effect and producing sharp images approaching the diffraction limit
Matching (Optical Instruments and Technology): 1→A, 2→B, 3→E, 4→D, 5→C

71. B — Light exhibits wave behavior (interference, diffraction, polarization) when propagating through space, and particle behavior (discrete energy packets, photoelectric effect) when interacting with matter at the quantum level. Both descriptions are needed to explain all observed phenomena

72. B — The second inverted prism recombines the dispersed colors back into white light. Each color is refracted by the same angle in reverse, undoing the dispersion of the first prism and reconverging all wavelengths into a single beam

73. D — Using Snell's law: $n_1 \sin \theta_1 = n_2 \sin \theta_2 \rightarrow 1.00 \times \sin 40° = 1.52 \times \sin \theta_2 \rightarrow \sin \theta_2 = 0.6428 / 1.52 = 0.4229 \rightarrow \theta_2 = \arcsin(0.4229) \approx 25.0°$. The light bends toward the normal as it enters the denser medium

74. C — Using the mirror equation: $1/f = 1/do + 1/di \rightarrow 1/20 = 1/30 + 1/di \rightarrow 1/di = 1/20 - 1/30 = (3 - 2)/60 = 1/60 \rightarrow di = 60$ cm. The image forms 60 cm in front of

the mirror. Magnification $m = -d_i/d_o = -60/30 = -2$, so the image is real, inverted, and twice the size of the object

75. C — Light bends more when passing from air into diamond than from water into diamond. The bending depends on the ratio of refractive indices: the air-diamond ratio (2.42/1.00 = 2.42) is much larger than the water-diamond ratio (2.42/1.33 = 1.82). A larger ratio means a greater change in speed and therefore more refraction
76. C — The image size on the sensor equals $f_{objective} \times \tan(\text{angular diameter})$. Image diameter = 1000 mm × tan(0.52°) = 1000 × 0.00908 = 9.07 mm ≈ 9.1 mm. The Moon's image will be about 9.1 mm across on the sensor
77. For a thin film in air, constructive interference in reflection occurs when $2nt = (m + \frac{1}{2})\lambda$, because the reflection at the top surface (air→film, low-to-high n) gets a half-wavelength phase shift. Minimum thickness (m = 0): $t = \lambda/(4n) = 532/(4 \times 1.33) = 532/5.32 = 100$ nm
78. The key difference is wavelength relative to the material's electronic structure. Visible light (400–700 nm) has photon energies (1.8–3.1 eV) that match electronic transition energies in wall materials, so photons are absorbed or scattered. Radio waves (wavelengths of meters) have very low photon energies (~10^{-6} eV) that don't match any electronic transitions, so the wall is essentially transparent to them. Additionally, radio wavelengths are much larger than the wall's structural features, so they diffract around and through openings
79. (a) Critical angle: $\sin \theta_c = n_{clad}/n_{core} = 1.46/1.50 = 0.9733 \rightarrow \theta_c = \arcsin(0.9733) = 76.7°$. (b) Numerical aperture: $NA = \sqrt{n_{core}^2 - n_{clad}^2} = \sqrt{2.25 - 2.1316} = \sqrt{0.1184} = 0.344$. Maximum acceptance angle: $\theta_{max} = \arcsin(NA) = \arcsin(0.344) = 20.1°$
80. Apparent depth = actual depth / refractive index = 2.0 m / 1.33 = 1.50 m. The pool appears to be only 1.50 m deep because light rays from the bottom are refracted away from the normal as they exit the water into air, making the bottom appear closer to the surface
Matching (Master Optics Engineer Capstone): 1→C, 2→E, 3→D, 4→A, 5→B
81. A — Convex lens
82. D — Focal point
83. D — Convex lens
84. A — Concave lens
85. A — Refracting telescope

86. C — Focal length
87. It spreads light rays apart so they seem to come from a smaller virtual image
88. By using two convex lenses that multiply each other's magnifying power
89. To diverge light so the image focuses correctly on the retina
90. They converge to form a real, inverted image on the other side
    Matching (Light & Optics): 1→C, 2→A, 3→D, 4→B, 5→E
91. D — Red, green, and blue
92. A — Yellow
93. A — Cyan, magenta, and yellow
94. A — White light is produced
95. B — A transparent material that absorbs some colors of light and transmits others
96. B — Visible spectrum
97. The shirt absorbs all colors except red, which it reflects to our eyes
98. Paints subtract wavelengths by absorbing them, while light adds wavelengths together
99. The blue object can only reflect blue light, but there is no blue light available — so no light is reflected
100. By lighting red and green sub-pixels simultaneously, which our eyes perceive as yellow through additive mixing
    Matching (Light & Optics): 1→B, 2→C, 3→D, 4→E, 5→A
101. A — Total internal reflection
102. B — Light Amplification by Stimulated Emission of Radiation
103. C — Light Emitting Diode
104. C — Glass (silica) or plastic
105. C — Coherence — the light waves are all in phase and travel in the same direction
106. A — Cladding
107. Light has a much higher frequency than electrical signals, allowing billions more data pulses per second

108. As long as light hits the core-cladding boundary at an angle greater than the critical angle, it reflects back into the core — gentle bends maintain this angle
109. LEDs convert electrical energy directly into light with minimal heat waste, while incandescent bulbs waste about 90% of energy as heat
110. A laser produces light of only one specific wavelength (monochromatic) through stimulated emission, while a bulb emits a broad mix of all visible wavelengths
Matching (Light & Optics): 1→E, 2→D, 3→C, 4→A, 5→B
111. B — Rainbow
112. A — Bioluminescence
113. D — Mirage
114. C — Aperture
115. C — Ultraviolet (UV) radiation
116. D — Reflection
117. Different wavelengths of light refract at slightly different angles inside water droplets — red bends least and violet bends most, creating a consistent order
118. They produce light through chemical reactions (typically involving luciferin and luciferase) that do not require sunlight as an energy source
119. Light bends (refracts) when passing from water to air, changing the apparent position and size of submerged objects
120. Sunscreen contains chemicals that absorb or reflect UV radiation before it can penetrate and damage skin cells
Matching (Light & Optics): 1→C, 2→B, 3→A, 4→D, 5→E
121. D — 300,000 kilometers per second (about 186,000 miles per second)
122. A — Dust particles scatter the light toward your eyes; in clean air, there are no particles to redirect the light sideways
123. B — Violet
124. B — Approximately 5.64×10^{14} Hz
125. B — The second inverted prism recombines the dispersed colors back into white light. Each color is refracted by the same angle in reverse, undoing the dispersion of the first prism and reconverging all wavelengths into a single beam
126. A — Radio waves pass through the body harmlessly (non-ionizing, very low energy). Microwaves are absorbed by water molecules, causing heating —

dangerous at high power. X-rays are ionizing radiation that can break chemical bonds and damage DNA, so exposure must be minimized

127. The apple's surface absorbs most wavelengths of light but reflects red wavelengths back to your eyes

128. About 390,000 km

129. Primary light colors are red, green, blue (additive mixing — combining all three makes white). Primary paint colors are cyan, magenta, yellow (subtractive mixing — combining all three makes black)

130. The wavelength shortens but the frequency stays the same

Matching (Light in Nature): 1→A, 2→E, 3→D, 4→B, 5→C

131. B — An electromagnetic wave that can travel through empty space (vacuum)

132. D — Violet light has a shorter wavelength and travels slower in glass than red light, giving it a higher refractive index and causing it to bend more

133. C — Different objects and phenomena emit or absorb different EM bands. Radio telescopes detect cold gas clouds, infrared reveals dust-hidden star formation, UV shows hot young stars, X-ray telescopes reveal black hole accretion disks, and gamma ray detectors find neutron star collisions

134. A — Photocathode: Converts incoming photons (including near-IR) into electrons via the photoelectric effect. Microchannel plate (MCP): Millions of tiny glass tubes that multiply electrons through secondary emission — each electron striking the tube wall knocks out several more, creating an avalanche that amplifies the signal ~10,000-50,000×. Phosphor screen: Converts the amplified electron pattern back into visible light (green, chosen for best human dark-adapted sensitivity), producing a brightened image

135. D — 35° from the normal

136. B — 2 meters behind the mirror — the image distance always equals the object distance in a plane mirror

137. The image appears 1.33 meters behind the mirror (virtual, upright, and reduced)

138. 60 cm in front of the mirror (real image)

139. A laser beam reflects off a spinning mirror, sweeping across the barcode. Black bars absorb the laser light while white spaces reflect it back to a photodetector. The detector converts the pattern of reflected/absorbed light into an electrical signal encoding the product number. Laser properties used: collimation (stays focused over the scanning distance), monochromaticity (consistent reflection/absorption behavior), and brightness (strong signal even with ambient

light)

140. The curved cornea and the adjustable lens refract light to converge it onto the retina. The lens changes shape (accommodation) to focus on objects at different distances
Matching (Light in Nature): 1→C, 2→D, 3→A, 4→E, 5→B

141. B — Shorter blue wavelengths scatter more in all directions by air molecules (Rayleigh scattering). At sunrise/sunset, light travels through more atmosphere, scattering away most blue light and leaving longer red/orange wavelengths

142. C — Approximately 380 nanometers (violet) to 700 nanometers (red)

143. C — Radio waves have wavelengths far too long for human eyes to detect. The radio device converts radio waves into sound waves (which your ears can detect), but your eyes only respond to the narrow visible band of the EM spectrum

144. A — Theoretically infinite — each mirror reflects the other mirror's reflection, creating an endless corridor of images that get progressively dimmer

145. D — No image forms — reflected rays travel parallel to each other and never converge or appear to diverge from a single point

146. A — Radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, gamma rays

147. Partially valid but exaggerated. Quantum techniques like NOON states and quantum lithography can theoretically improve resolution by a factor of N (number of entangled photons), not arbitrarily. Practical 'quantum microscopy' achieves modest improvements (~2× with biphoton states). A '10× improvement' would require 10-photon NOON states, which are extremely fragile and have never been demonstrated in a practical microscope. Real quantum imaging advantages lie in reducing noise and improving sensitivity, not dramatically beating the diffraction limit

148. Light from the pool bottom bends away from the normal when exiting the water into air. Your brain traces the rays back in straight lines, placing the apparent source higher (shallower) than the actual bottom

149. The ratio of the speed of light in vacuum to the speed of light in that material ($n = c/v$), indicating how much the material slows and bends light

150. Blue light is deviated by more than 38° because its higher refractive index (1.54 vs 1.52) causes greater bending — approximately 39-40°
Matching (Light in Nature): 1→A, 2→E, 3→B, 4→C, 5→D

151. D — Shorter wavelength means higher frequency and higher energy; longer

wavelength means lower frequency and lower energy

152. D — X-ray crystallography (or X-ray diffraction). X-rays must be used because their wavelengths (0.01-10 nm) are comparable to the spacing between atoms in crystals (0.1-0.5 nm). Visible light wavelengths (400-700 nm) are thousands of times too large to interact with atomic-scale structures — they cannot resolve individual atoms
153. D — (1) No — screens emit far less blue light than sunlight or indoor lighting. At typical viewing distances, screen blue light intensity is thousands of times below any known damage threshold. (2) No direct evidence — multiple randomized trials show blue-light glasses do not reduce digital eye strain (which is caused by reduced blinking and focusing fatigue, not blue light). (3) One valid reason: blocking blue light in the 2-3 hours before bedtime may modestly improve sleep onset by reducing melatonin suppression, though evidence is mixed and 'night mode' software achieves the same effect
154. B — The magnification is 3 (or -3 if the image is inverted)
155. C — The parabolic shape reflects all incoming parallel sunlight rays to a single focal point, concentrating the energy of a large area into a tiny spot to produce extremely high temperatures
156. A — The second prism recombined all the separated colors back into white light, proving the colors were already present in the white light and were not artifacts created by the glass
157. In data transmission, light pulses carry information. Dispersion causes different wavelengths within a pulse to travel at different speeds, spreading the pulse out over distance and blurring the data — lower dispersion means sharper signals over longer distances
158. Approximately 19.5°
159. Using the mirror equation: $1/f = 1/do + 1/di \rightarrow 1/20 = 1/30 + 1/di \rightarrow 1/di = 1/20 - 1/30 = (3 - 2)/60 = 1/60 \rightarrow di = 60$ cm. The image forms 60 cm in front of the mirror. Magnification $m = -di/do = -60/30 = -2$, so the image is real, inverted, and twice the size of the object
160. The spoon appears bent at the water surface due to refraction governed by Snell's law ($n_1 \sin \theta_1 = n_2 \sin \theta_2$). Light rays from the submerged portion of the spoon travel from water (n = 1.33) into air (n = 1.00). As they exit the water, they bend AWAY from the normal (since they're going from a higher to lower refractive index). Your brain traces these refracted rays back in straight lines, placing the underwater portion of the spoon at a different apparent position than its actual location, creating the illusion of a bend at the surface

Matching (Light in Nature): 1→D, 2→B, 3→E, 4→A, 5→C

161. To get a little brighter!
162. "I see you've come to reflect on things!"
163. It always showed its true colors!
164. "Let me bring you all together -- I'm very focused!"
165. Because it was traveling light!
166. "We make a brilliant team when we're not being so divided!"
