Waveforge — Activity Book

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

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

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1. Sound

Circle the correct answer

1. What must an object do to produce a sound?
(A) Grow (B) Shrink (C) Vibrate (D) Melt

2. What is the name for the back-and-forth movement that creates sound?
(A) Vibration (B) Magnetism (C) Rotation (D) Evaporation

3. Sound travels fastest through which state of matter?
(A) Vacuum (B) Liquids (C) Solids (D) Gases

4. What word describes how loud or soft a sound is?
(A) Wavelength (B) Volume (C) Frequency (D) Pitch

5. Why does a drum make a louder sound when you hit it harder?
(A) The drum skin vibrates with greater amplitude (B) The drum absorbs more sound energy (C) The drum creates fewer vibrations (D) The drum changes its pitch

6. How does sound travel from a ringing bell to your ear?
(A) Light carries the sound to your ear (B) Sound only travels through solid objects (C) Sound waves travel through the air as vibrations of air molecules (D) The bell sends tiny particles to your ear

Write the answer

7. Why can't astronauts hear each other talk in the vacuum of space without using radios?
Answer: ________

8. What is the relationship between the speed of a vibration and the pitch of the sound it makes?
Answer: ________

9. Why does a small bird make a higher-pitched sound than a large lion?
Answer: ________

10. Why does stretching a rubber band tighter make a higher sound when you pluck it?
Answer: ________

Match each question to its answer

1. A student claps near a large empty room and hears the sound repeat a moment later. This repeated sound is called an echo. If the student moves to a smaller room and claps, what will happen to the echo? →
2. You are holding two rubber bands of the same length. One is thick and one is thin. Which one will produce a higher-pitched sound when plucked with the same force? →
3. A teacher fills three identical glass bottles with different amounts of water and taps them with a spoon. Bottle A is almost full, Bottle B is half full, and Bottle C is nearly empty. Which bottle will produce the lowest-pitched sound when tapped? →
4. You put your ear against a metal fence and a friend taps the other end 50 meters away. You also hear the tap through the air. Which sound reaches your ear first? →
5. Your teacher says that turning up the volume on a speaker makes the sound louder but does not change the pitch. Use what you know about sound waves to predict what is changing inside the speaker. →

(A) The speaker cone vibrates with larger movements but at the same speed
(B) Bottle C, because it has the most air to vibrate
(C) The thin rubber band
(D) The echo will return faster because the walls are closer
(E) The sound through the metal fence

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2. Properties of Waves

Circle the correct answer

11. What is the highest point of a transverse wave called?
(A) Crest (B) Trough (C) Frequency (D) Wavelength

12. If you make bigger waves by shaking a rope harder, which wave property are you increasing?
(A) Amplitude (B) Wavelength (C) Frequency (D) Speed

13. A wave in a pool has a height of 10 cm from rest to crest. Another wave has a height of 20 cm. Which wave carries more energy?
(A) Neither wave carries energy (B) The 20 cm wave (C) They carry equal energy
(D) The 10 cm wave

14. Two students create waves in identical ropes. Student A's wave is tall with a small amplitude compared to Student B's very tall wave. Why does Student B's wave feel stronger when it hits the end of the rope?
(A) Student B's wave moves faster (B) Student B's wave has greater amplitude, so it carries more energy (C) Student B's wave has a longer wavelength (D) Student B's rope is heavier

15. Would a whisper or a shout create sound waves with a larger amplitude? Explain why based on what you know about energy and waves.
(A) A shout, because it has a higher frequency (B) A whisper, because quiet sounds have taller waves (C) A shout, because it uses more energy to push air molecules farther from their resting position (D) They have the same amplitude but different speeds

16. What is wavelength?
(A) The height of a wave (B) The distance from one crest to the next crest (C) How fast a wave moves (D) The number of waves per second

Write the answer

17. Why do radio waves have much longer wavelengths than visible light waves?
Answer: ________

18. A wave has a wavelength of 2 meters. If you measure from one crest to a point three crests later, what is the total distance?
Answer: ________

19. You observe two waves traveling in the same medium. Wave A has a wavelength of 1 meter and Wave B has a wavelength of 3 meters. Both travel at the same speed. What can you conclude about their frequencies?
Answer: ________

20. A scientist measures a wave with a wavelength of 0.5 meters. Her colleague measures the same wave and reports a wavelength of 50 centimeters. Are both measurements correct? Why or why not?
Answer: ________

Match each question to its answer

1. What does the frequency of a wave measure? →
2. How does increasing the frequency of a wave affect its wavelength, assuming the wave speed stays the same? →
3. A wave has a frequency of 5 Hz. How many complete wave cycles pass a point in 4 seconds? →

4. Two tuning forks are struck. Fork A vibrates at 256 Hz and Fork B vibrates at 512 Hz. How do the sounds they produce compare? →
5. A music producer wants to create a very low bass sound. Should they use a wave with a high frequency or a low frequency? Justify your choice based on wave properties. →

(A) Fork B produces a higher-pitched sound because it has a higher frequency
(B) The wavelength decreases
(C) 20 cycles
(D) A low frequency, because low-frequency sound waves produce low-pitched bass sounds
(E) The number of complete wave cycles that pass a point per second

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3. Wave Behavior: Reflection & Refraction

Circle the correct answer

21. What happens when a wave bounces off a surface and changes direction?
(A) Reflection (B) Absorption (C) Diffraction (D) Refraction

22. According to the law of reflection, how does the angle at which a wave hits a surface compare to the angle at which it bounces away?
(A) The angle of incidence equals the angle of reflection (B) The reflection angle is always larger (C) The reflection angle is always smaller (D) The angles are unrelated to each other

23. A light beam hits a flat mirror at an angle of 30 degrees from the normal. At what angle from the normal will the reflected beam leave the mirror?
(A) 60 degrees (B) 15 degrees (C) 30 degrees (D) 90 degrees

24. A smooth lake reflects a mountain clearly, but a choppy lake creates a blurry, distorted image. What causes this difference in reflection quality?
(A) Smooth surfaces reflect light in a uniform direction (specular reflection), while rough surfaces scatter light in many directions (diffuse reflection) (B) Wind changes the color of the light waves, and this is the standard approach used in most cases (C) Rough water reflects light at a higher frequency, making this the most widely accepted explanation (D) Choppy water absorbs more light than calm water, and this has been consistently demonstrated in practice

25. A student claims that black objects do not reflect any light at all. Is this claim fully accurate? Evaluate using your understanding of reflection.
(A) Incorrect — black objects reflect just as much light as white objects (B) Fully accurate — black objects absorb all light completely (C) Incorrect — black objects

only reflect infrared light (D) Not fully accurate. Black objects reflect very little visible light, but they still reflect a small amount — no common surface absorbs 100% of light

26. What is refraction?
(A) The bending of a wave as it passes from one medium into another (B) The bouncing of a wave off a surface (C) The disappearance of a wave in a material (D) The splitting of a wave into smaller waves

Write the answer

27. Why does a pencil appear to be broken or bent at the point where it enters water in a glass?
Answer: ________

28. Light travels from air into a glass block at an angle. If the speed of light is slower in glass than in air, which direction does the light bend?
Answer: ________

29. On a hot day, you see what looks like a pool of water on the road ahead, but when you get closer, it disappears. Using your knowledge of refraction, explain what causes this mirage.
Answer: ________

30. A student argues that refraction proves light is a wave, not a particle. Evaluate this claim. Does refraction support the wave nature of light?
Answer: ________

Match each question to its answer

1. What happens to a wave's energy when it is absorbed by a material? →
2. Why do dark-colored cars get hotter in the sun than light-colored cars? →
3. You are designing a solar cooker for a science project. Should you paint the inside surface black or white to maximize heat absorption? Apply your knowledge of absorption. →
4. Sunscreen is designed to protect skin from ultraviolet (UV) rays. Does sunscreen primarily work by reflecting UV waves, absorbing them, or both? Analyze how this protects the skin. →
5. A building designer wants to keep a room cool in summer but warm in winter. Should the windows have special coatings that absorb infrared light or reflect it? Evaluate the trade-offs. →

(A) Reflect infrared in summer to keep heat out, but this also blocks solar heating in winter — a switchable or seasonal coating would be ideal for both goals
(B) Dark colors absorb more light energy and convert it to heat, while light colors reflect more light away
(C) The wave's energy is converted into heat (thermal energy) in the material
(D) Black, because dark surfaces absorb the most light energy and convert it to heat
(E) Most sunscreens primarily absorb UV waves and convert the energy to harmless heat, though some also contain minerals that reflect UV

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4. Sound & Music: Frequency & Pitch

Circle the correct answer

31. How do string instruments like guitars and violins produce sound?
(A) By creating electrical signals that become sound (B) By pushing air through a tube (C) By striking a membrane with a mallet (D) By vibrating strings that cause the surrounding air to vibrate, creating sound waves

32. Why does a flute produce a different quality of sound than a trumpet, even when both play the same note at the same volume?
(A) The trumpet is louder so its sound waves are wider (B) The flute is made of a different material so it reflects sound differently (C) Each instrument produces a unique combination of harmonics (overtones) that gives it a distinctive tone color, called timbre (D) The flute plays at a higher frequency than the trumpet

33. A drummer tightens the drumhead on a snare drum. How will this change the sound the drum produces?
(A) The drum will get louder but stay the same pitch (B) The tightness does not affect the sound (C) The drum will produce a lower-pitched sound (D) The drum will produce a higher-pitched sound because a tighter drumhead vibrates faster

34. A xylophone has wooden bars of different lengths arranged in order. The shortest bar produces the highest note. Analyze why shorter bars produce higher-pitched sounds than longer bars.
(A) Shorter bars vibrate at a higher frequency because there is less material to vibrate back and forth, so the vibrations complete each cycle more quickly (B) Shorter bars trap more air underneath them, as this is what research and standard practice suggests (C) Shorter bars are hit harder by the mallet, and this has been consistently demonstrated in practice (D) Shorter bars are made of denser wood that vibrates faster, and this is the standard approach used in most cases

35. A music teacher claims that electronic synthesizers can perfectly replicate any acoustic instrument's sound. Evaluate this claim based on your understanding of how different instruments produce sound.
(A) This is true because all instruments produce the same basic sound waves, since this follows from the basic laws governing this process (B) This is completely true because synthesizers can produce any frequency, based on the typical behavior observed in controlled experiments (C) This is wrong because synthesizers only make electronic sounds, which is consistent with the fundamental principles of this field (D) Synthesizers can closely approximate but not perfectly replicate acoustic instruments, because the complex, ever-changing harmonic patterns and physical resonances of real instruments are extremely difficult to duplicate exactly

36. What determines the pitch of a sound?
(A) The frequency of the sound wave (B) The amplitude of the sound wave (C) The direction of the sound wave (D) The speed of the sound wave

Write the answer

37. How does the length of a vibrating string affect the pitch of the note it produces?
Answer: ________

38. A guitar string produces a note at 330 Hz. If the player presses the string at exactly the halfway point, reducing the vibrating length by half, what frequency will the new note have?
Answer: ________

39. A piano has both very long, thick strings and very short, thin strings. Compare how string thickness and length work together to produce the piano's wide range of pitches from deep bass to high treble.
Answer: ________

40. A musician claims that a note played on a thick string always sounds lower than the same note played on a thin string. Is this claim accurate? Evaluate this statement considering all factors that affect pitch.
Answer: ________

Match each question to its answer

1. What is a harmonic in music? →
2. Why does the note middle C sound different when played on a piano versus a clarinet, even though both are the same pitch? →
3. A guitar string has a fundamental frequency of 200 Hz. What is the frequency of its 3rd harmonic? →
4. When a singer produces an 'oo' vowel sound and then changes to an 'ee' vowel

sound on the same note, the pitch stays the same but the sound quality changes. Analyze what is happening to the harmonics when the vowel changes. →
5. Design a simple experiment to show that a single vibrating string produces multiple harmonics simultaneously, not just one frequency. →

(A) The fundamental frequency stays the same, but the singer's mouth shape changes which harmonics are amplified and which are dampened, altering the timbre without changing the pitch
(B) 600 Hz
(C) Lightly touch the midpoint of a vibrating guitar string to mute the fundamental while allowing the 2nd harmonic to ring out, producing a note one octave higher that proves the harmonic was already present
(D) A frequency that is a whole-number multiple of the fundamental frequency, produced naturally when an instrument plays a note
(E) Each instrument produces a different set of harmonics with different relative strengths, giving each its unique timbre or tone quality

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5. The Electromagnetic Spectrum

Circle the correct answer

41. Which type of electromagnetic wave has the longest wavelength?
(A) Ultraviolet waves (B) X-rays (C) Radio waves (D) Gamma rays

42. How are radio waves used in everyday life?
(A) Only for heating food in microwaves, and this is the standard approach used in most cases (B) Only for medical X-ray imaging, and this principle applies across similar situations (C) Only for military radar systems, which is the most common explanation for this phenomenon (D) For broadcasting AM/FM radio, television signals, WiFi, Bluetooth, and cell phone communication

43. An AM radio station broadcasts at 1,000 kHz and an FM station broadcasts at 100 MHz. Which station uses a longer wavelength?
(A) They use the same wavelength because both are radio waves (B) The AM station, because lower frequency corresponds to longer wavelength (C) The FM station, because MHz is a larger unit than kHz (D) The FM station, because it has a higher number

44. Radio telescopes detect radio waves from space. Analyze why radio telescopes need to be much larger (often 25+ meters across) than optical telescopes (typically 1-10 meters) to capture useful images.
(A) Radio waves are heavier than light waves so they need bigger collectors (B)

Radio telescopes are larger because they need to amplify weaker signals (C) Radio telescopes must be large to generate the radio waves they send into space (D) Radio waves have much longer wavelengths than visible light, so radio telescopes need much larger dishes to collect and focus enough radio wave energy to produce detailed images

45. Some people worry that radio waves from cell towers cause health problems. Based on what you know about radio waves' position on the electromagnetic spectrum, evaluate whether this concern is scientifically supported.
(A) Radio waves are dangerous because they travel at the speed of light, based on the typical behavior observed in controlled experiments (B) Radio waves have the lowest energy of all electromagnetic waves and are classified as non-ionizing radiation, meaning they lack sufficient energy to damage DNA. Scientific consensus, based on extensive research, has not found evidence that normal cell tower exposure causes health problems (C) Radio waves are completely safe because they are invisible, since this follows from the basic laws governing this process (D) Radio waves are dangerous because all electromagnetic radiation is harmful, according to the standard scientific model for this phenomenon

46. What are the colors of visible light in order from longest wavelength to shortest wavelength?
(A) Red, orange, yellow, green, blue, indigo, violet (B) Red, yellow, blue, green, orange, violet, indigo (C) White, gray, black, red, blue, green, yellow (D) Violet, indigo, blue, green, yellow, orange, red

Write the answer

47. Why do we see a rainbow when sunlight passes through a glass prism?
Answer: ________

48. A leaf appears green in sunlight. What is happening to the visible light that hits the leaf?
Answer: ________

49. Under a red light, a white shirt appears red and a blue shirt appears nearly black. Analyze why the blue shirt looks black under red light using your understanding of color and light absorption.
Answer: ________

50. Some animals, like bees, can see ultraviolet light that humans cannot. Design a thought experiment that would demonstrate whether a flower has UV-visible patterns that human eyes cannot detect.
Answer: ________

Match each question to its answer

1. What type of electromagnetic radiation from the sun can cause sunburn? →
2. Why is ultraviolet radiation more dangerous to living cells than visible light, even though both are electromagnetic waves? →
3. A dermatologist recommends wearing sunscreen rated SPF 30 or higher. SPF 30 blocks about 97% of UV-B rays. If 1,000 UV-B photons hit sunscreen-protected skin, approximately how many get through to the skin? →
4. The ozone layer in Earth's atmosphere blocks most UV-C and much UV-B radiation from the sun, but allows visible light through. Analyze why the ozone layer selectively blocks UV while transmitting visible light. →
5. A student says, 'Since UV light is harmful, we should try to block all UV from reaching Earth's surface.' Evaluate whether this would be a good idea, considering all the effects of UV radiation. →

(A) Ultraviolet (UV) radiation
(B) UV has a shorter wavelength and higher frequency than visible light, giving each UV photon more energy — enough to damage DNA and cause mutations in cells
(C) Ozone molecules (O3) absorb electromagnetic radiation specifically in the UV wavelength range due to their molecular structure, but they do not absorb visible light wavelengths, which pass through unaffected
(D) This would be unwise because moderate UV exposure is essential for human health (vitamin D production) and for ecosystems (plant growth signaling, water purification). The goal should be to limit excessive UV exposure, not eliminate it entirely
(E) About 30 photons

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6. Light Waves & Optics

Circle the correct answer

51. What is the approximate speed of light in a vacuum?
(A) 300 kilometers per second (B) 3,000 kilometers per second (C) 30,000 kilometers per second (D) 300,000 kilometers per second (3×10^8 m/s)

52. Unlike sound waves, light waves can travel through the vacuum of outer space. Why is this possible?
(A) Light waves are so small they can fit between the molecules in a vacuum (B) Outer space is not actually a vacuum — it contains invisible air (C) Light waves create their own medium as they travel (D) Light is an electromagnetic wave that consists of oscillating electric and magnetic fields, which do not require a physical medium to

propagate

53. Light travels at 3×10^8 m/s in a vacuum but slows to about 2×10^8 m/s in glass. Calculate the ratio of light's speed in vacuum to its speed in glass (this ratio is called the index of refraction).
(A) 2.0 (B) 0.67 (C) 3.0 (D) 1.5

54. Light behaves as both a wave and a particle. In the double-slit experiment, light passing through two narrow slits creates an interference pattern on a screen. However, when scientists detect which slit each photon passes through, the interference pattern disappears. Analyze what this tells us about the nature of light.
(A) The measurement equipment blocks the light and ruins the pattern, which is the most common explanation for this phenomenon (B) Light is always a particle and the interference pattern is just an illusion, which is the most common explanation for this phenomenon (C) Light exhibits wave behavior (interference) when unobserved, but when measured as individual photons, it behaves like particles. This wave-particle duality means light's behavior depends on how it is observed (D) Light is always a wave and the detectors break the wave apart, and this has been consistently demonstrated in practice

55. Some scientists in the 1800s believed light was purely a wave, while others believed it was purely a particle. Given what we now know about wave-particle duality, evaluate why both groups were partially correct and partially wrong.
(A) Both groups correctly identified real properties of light — wave theorists explained interference and diffraction, particle theorists explained the photoelectric effect. Both were wrong to insist light was exclusively one or the other (B) Both groups were completely wrong because light is actually neither a wave nor a particle (C) The particle theorists were completely right because photons are real (D) The wave theorists were completely right and particle theorists were completely wrong, as this is what research and standard practice suggests

56. What type of lens is thicker in the middle than at the edges and bends light rays inward toward a focal point?
(A) A cylindrical lens (B) A convex lens (converging lens) (C) A concave lens (D) A flat lens

Write the answer

57. How does a concave lens differ from a convex lens in how it bends light?
Answer: ________

58. A student who is nearsighted (can see nearby objects clearly but distant objects appear blurry) needs corrective eyeglasses. Should the lenses be convex or concave?
Answer: ________

59. A camera lens system uses a combination of convex and concave lenses. The convex lens focuses the image, but it also creates color fringing (chromatic aberration) because different wavelengths bend by different amounts. Analyze how adding a concave lens made of a different type of glass helps correct this problem.
Answer: ________

60. Evaluate whether a single convex lens or a combination of convex and concave lenses would produce a better image in a high-quality telescope. Justify your answer using your understanding of how lenses affect light.
Answer: ________

Match each question to its answer

1. What type of mirror curves inward like the inside of a bowl and can focus parallel light rays to a single point? →
2. Why are convex mirrors used as side-view mirrors on cars instead of flat mirrors? →
3. A concave mirror has a focal length of 20 cm. An object is placed 40 cm from the mirror. Where will the image form? →
4. A reflecting telescope uses a large concave primary mirror instead of a large lens to collect light. Analyze what advantages a mirror has over a lens for building very large telescopes. →
5. The Hubble Space Telescope was launched with a primary mirror that had been ground to the wrong shape by a fraction of a human hair's width. This tiny error caused blurry images. Evaluate why such an incredibly small manufacturing error could have such a significant effect on a telescope designed to observe distant galaxies. →

(A) Visible light wavelengths are extremely small (400-700 nanometers), so mirror surfaces must be accurate to a fraction of a wavelength. An error of even a few micrometers is many times the wavelength of light, significantly misfocusing the reflected rays
(B) A concave mirror (converging mirror)
(C) At 40 cm from the mirror, on the same side as the object
(D) Convex mirrors curve outward and diverge reflected light, providing a wider field of view than flat mirrors so drivers can see more of the area beside and behind the car
(E) Mirrors can be supported from behind (lenses can only be held at edges), mirrors have no chromatic aberration, and mirrors can be made much larger — the largest telescope mirrors exceed 10 meters while the largest lenses are about 1 meter

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7. Wave Interference & Resonance

Circle the correct answer

61. What happens when the crests of two waves meet at the same point at the same time?
(A) They cancel each other out completely (B) They combine to produce a wave with a larger amplitude (constructive interference) (C) They pass through each other without any change (D) They bounce off each other and reverse direction

62. Why does constructive interference result in a louder sound when two speakers play the same tone in phase?
(A) The sound waves travel faster when there are two sources, and this principle applies across similar situations (B) The speakers create twice as many sound waves, and this has been consistently demonstrated in practice (C) The speakers push more air molecules into the room, and this principle applies across similar situations (D) The pressure waves from both speakers add together at points where crests align, creating larger amplitude pressure variations that our ears perceive as louder sound

63. Two water waves with amplitudes of 3 cm each undergo constructive interference at a point. What is the maximum possible amplitude at that point?
(A) 3 cm (B) 6 cm (C) 9 cm (D) 1.5 cm

64. At a concert, certain seats in the venue sound noticeably louder than others, even though no seat is significantly closer to the stage. Analyze what wave phenomenon could cause these 'hot spots' of louder sound.
(A) The speakers are pointed directly at those seats, and this has been consistently demonstrated in practice (B) Constructive interference from sound waves reflecting off walls and ceiling. At certain seats, the direct sound and reflected sound arrive in phase, combining to create louder perceived volume (C) Sound travels faster to certain parts of the room, as this directly follows from the underlying principles (D) The seats are made of different materials that amplify sound differently, and this principle applies across similar situations

65. A sound engineer claims that placing two identical speakers facing each other and playing the same tone will always create louder sound everywhere between them. Evaluate this claim.
(A) Correct, because the waves reinforce each other at every point, according to the standard scientific model for this phenomenon (B) Incorrect. While constructive interference creates loud spots where crests meet, destructive interference creates quiet spots where crests meet troughs. The result is an alternating pattern of loud and quiet zones, not uniformly louder sound (C) Correct, because two speakers always produce more sound than one, since this follows from the basic laws governing this process (D) Incorrect, because the speakers would cancel all sound completely, based on the typical behavior observed in controlled experiments

66. What happens when the crest of one wave meets the trough of another wave of equal amplitude?
(A) They create a wave that moves sideways, and this principle applies across similar situations (B) They create a wave twice as tall, as this is what research and standard practice suggests (C) They merge into one wave permanently, as this directly follows from the underlying principles (D) They cancel each other out, producing zero displacement at that point (destructive interference)

Write the answer

67. How do noise-canceling headphones use destructive interference to reduce unwanted sound?
Answer: ________

68. Wave A has an amplitude of 8 cm and Wave B has an amplitude of 5 cm. They undergo destructive interference at a point. What is the resulting amplitude?
Answer: ________

69. In a physics lab, two speakers emit identical sound waves. A student walks slowly from one speaker toward the other and notices the sound alternately gets louder and softer in a regular pattern. Analyze what is creating this pattern and what determines the spacing of the loud and quiet zones.
Answer: ________

70. A student says, 'Destructive interference destroys energy because the waves cancel out.' Evaluate whether this statement is consistent with the law of conservation of energy.
Answer: ________

Match each question to its answer

1. What is a standing wave? →
2. Why do standing waves form on a guitar string but not on an infinitely long rope? →
3. A guitar string is 60 cm long. The fundamental standing wave has nodes at both ends and one antinode in the middle. What is the wavelength of this fundamental standing wave? →
4. When a singer produces a note in a shower stall, certain frequencies sound noticeably louder than others. The shower stall acts like a resonant chamber. Analyze why the dimensions of the shower determine which frequencies are amplified. →
5. Design an experiment using a long spring toy (Slinky) to demonstrate the first three standing wave patterns (harmonics). Describe exactly how you would create each pattern. →

(A) 120 cm (1.2 meters)
(B) Fix one end of the Slinky and shake the other end. For the 1st harmonic, shake slowly until one large antinode forms. For the 2nd harmonic, shake twice as fast to get two antinodes with a node in the middle. For the 3rd harmonic, shake three times faster to get three antinodes with two nodes
(C) A guitar string is fixed at both ends, so waves reflect back and interfere with incoming waves. An infinite rope has no endpoints to reflect waves, so standing wave patterns cannot form
(D) Standing waves form between the shower walls at frequencies whose wavelengths fit exactly within the stall dimensions (whole number of half-wavelengths). These resonant frequencies are amplified while others are not reinforced
(E) A wave pattern that appears to stay in place, formed when two waves of the same frequency travel in opposite directions and interfere, creating fixed points of no movement (nodes) and points of maximum movement (antinodes)

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8. Waves in Communication Technology

Circle the correct answer

71. What type of electromagnetic wave is used to transmit AM and FM radio signals?
(A) Microwaves (B) X-rays (C) Radio waves (D) Infrared waves

72. What is the difference between how AM radio and FM radio encode audio information onto a carrier wave?
(A) AM transmits in mono while FM transmits in stereo, and this principle applies across similar situations (B) AM uses analog signals while FM uses digital signals, as this directly follows from the underlying principles (C) AM uses higher frequencies than FM, as this is what research and standard practice suggests (D) AM (Amplitude Modulation) varies the amplitude of the carrier wave to encode audio, while FM (Frequency Modulation) varies the frequency of the carrier wave

73. AM radio signals can often be received hundreds of kilometers away, especially at night, while FM signals typically reach only about 50-100 km. Why do AM signals travel farther?
(A) AM waves travel faster than FM waves, which is the most common explanation for this phenomenon (B) AM transmitters use more power than FM transmitters, as this directly follows from the underlying principles (C) AM's longer wavelengths can bounce off the ionosphere (a layer of charged particles in the upper atmosphere) and return to Earth at distant locations, while FM's shorter wavelengths pass through the ionosphere into space (D) FM signals are absorbed by buildings while AM signals are

not, making this the most widely accepted explanation

74. In the early days of radio, AM was the only broadcast technology. Analyze why FM radio eventually became preferred for music broadcasting despite AM's greater range advantage.
(A) FM uses less energy than AM so it is cheaper to operate, which is why this approach is recommended by experts (B) FM was invented later so it must be better technology, and this is the standard approach used in most cases (C) FM became popular only because AM stations were already taken (D) FM provides higher fidelity sound because its frequency modulation is naturally resistant to electrical noise (which affects amplitude), supports a wider audio bandwidth for full musical range, and can broadcast in stereo

75. With internet streaming now available, some argue that traditional AM/FM radio broadcasting is obsolete and should be phased out. Evaluate this position, considering both the strengths and limitations of each technology.
(A) Radio broadcasting is not obsolete because it provides free, universally accessible communication that works without internet infrastructure, is critical during emergencies when cellular networks fail, and reaches areas without broadband access. However, streaming offers on-demand content, higher quality, and interactivity that radio cannot match (B) Radio will never be replaced because it sounds better than streaming, which is consistent with the fundamental principles of this field (C) Radio is completely obsolete because everyone has smartphones, based on the typical behavior observed in controlled experiments (D) Radio and streaming serve identical purposes so keeping both is wasteful, and this has been consistently demonstrated in practice, according to the standard scientific model for this phenomenon

76. What type of electromagnetic wave do cell phones use to communicate with cell towers?
(A) Radio waves (specifically in the microwave frequency range, typically between 700 MHz and 2600 MHz for 4G, and up to 39 GHz for 5G) (B) Visible light waves, and this is the standard approach used in most cases (C) Sound waves, as this is what research and standard practice suggests (D) Infrared waves, as this is what research and standard practice suggests

Write the answer

77. Why are cell phone networks divided into many small coverage areas called 'cells' instead of using a single powerful transmitter to cover a whole city?
Answer: ________

78. When you make a phone call while driving on a highway, your phone automatically switches from one cell tower to the next without dropping the call. What is this seamless transfer called?
Answer: ________

79. 5G networks use higher frequencies (up to 39 GHz) than 4G (up to 2.6 GHz). These higher frequencies can carry much more data, but 5G cell towers must be placed much closer together. Analyze the physics behind why higher-frequency signals require more closely spaced towers.
Answer: ________

80. A concerned citizen argues that 5G towers should be banned from residential neighborhoods because the higher frequencies are dangerous. Given that 5G frequencies (up to 39 GHz) are still far below the ionizing radiation threshold, evaluate this health concern scientifically.
Answer: ________

Match each question to its answer

1. What frequency band does standard WiFi (802.11) primarily use for wireless internet? →
2. Your WiFi router broadcasts at both 2.4 GHz and 5 GHz. Why does the 2.4 GHz signal reach your bedroom on the second floor better than the 5 GHz signal? →
3. Your family's WiFi becomes slow when many devices connect simultaneously. If the router has a bandwidth of 100 Mbps and 10 devices are actively streaming, approximately how much bandwidth does each device get? →
4. A student notices that their WiFi router broadcasts a '2.4 GHz' network and a '5 GHz' network. Microwave ovens also operate at 2.4 GHz. Analyze why a microwave oven might sometimes interfere with a WiFi connection and suggest what a user could do to avoid this interference. →
5. Evaluate whether WiFi should replace Ethernet (wired) connections entirely in a school computer lab where students take timed standardized tests online. Consider reliability, speed, and interference. →

(A) Ethernet should be kept for standardized testing because it provides consistent, reliable connections without interference from other wireless devices, environmental factors, or bandwidth sharing — all critical when many students need simultaneous reliable internet during timed tests
(B) The 2.4 GHz signal has a longer wavelength, which allows it to better penetrate walls and floors and diffract around obstacles, giving it greater range despite lower speeds
(C) 2.4 GHz and 5 GHz bands
(D) About 10 Mbps per device

(E) Both the microwave oven and WiFi router use the 2.4 GHz frequency band. Microwave ovens can leak small amounts of 2.4 GHz radiation that interferes with WiFi signals at the same frequency. Switching to the 5 GHz WiFi band eliminates this interference since microwaves do not operate at 5 GHz

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9. Waves & Energy

Circle the correct answer

81. What type of electromagnetic wave has the longest wavelength?
(A) X-rays (B) Gamma rays (C) Radio waves (D) Ultraviolet waves

82. Which type of electromagnetic wave is visible to the human eye?
(A) Infrared waves (B) Ultraviolet waves (C) Microwaves (D) Visible light

83. What do all electromagnetic waves have in common regarding their speed in a vacuum?
(A) They all travel at the speed of light (B) They all travel at different speeds (C) They all travel at the speed of sound (D) They all travel faster than light

84. Which type of electromagnetic wave has the highest frequency?
(A) Visible light (B) Radio waves (C) Gamma rays (D) Microwaves

85. What is the name for the full range of electromagnetic wave frequencies?
(A) The electromagnetic spectrum (B) The frequency chart (C) The radio band (D) The visible spectrum

86. Which type of electromagnetic wave is commonly used to heat food?
(A) Gamma rays (B) X-rays (C) Ultraviolet waves (D) Microwaves

Write the answer

87. Why do gamma rays pose a greater health risk than radio waves?
Answer: ________

88. How are wavelength and frequency related for electromagnetic waves?
Answer: ________

89. Why can infrared waves be felt as heat even though they are invisible?
Answer: ________

90. What does it mean when we say electromagnetic waves do not need a medium to travel?
Answer: ________

Match each question to its answer

1. Why does a prism split white light into a rainbow of colors? →
2. A hospital uses a type of EM wave to create images of bones inside the body. Which type of wave is most likely being used? →
3. A TV remote control sends a signal to the television. Which type of electromagnetic wave does it most likely use? →
4. If an electromagnetic wave has a very short wavelength, what can you predict about its energy? →
5. Sunscreen protects skin from sunburn. Which type of electromagnetic wave does sunscreen primarily block? →

(A) Different wavelengths of visible light refract by different amounts
(B) Infrared waves
(C) It has high energy
(D) X-rays
(E) Ultraviolet (UV) waves

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10. Waves & Energy

Circle the correct answer

91. What type of wave is a sound wave?
(A) An electromagnetic wave (B) A longitudinal wave (C) A surface wave (D) A transverse wave

92. What is the unit used to measure the loudness of sound?
(A) Hertz (Hz) (B) Meters (m) (C) Watts (W) (D) Decibels (dB)

93. What must sound waves have in order to travel?
(A) A light source (B) A medium such as air, water, or a solid (C) A vacuum (D) Electromagnetic energy

94. What property of a sound wave determines its pitch?
(A) Wavelength (B) Speed (C) Frequency (D) Amplitude

95. What is the term for a repeated reflection of sound off a surface?
(A) Diffraction (B) Resonance (C) Refraction (D) Echo

96. In which medium does sound typically travel fastest?
(A) Vacuum (B) Gases (C) Solids (D) Liquids

Write the answer

97. Why does sound travel faster in warm air than in cold air?
Answer: ________

98. How does increasing the amplitude of a sound wave affect what we hear?
Answer: ________

99. Why can you hear a train approaching by placing your ear on the railroad track before you can hear it through the air?
Answer: ________

100. What causes the Doppler effect with sound?
Answer: ________

Match each question to its answer

1. Why do concert halls often have curved walls and special ceiling panels? →
2. A guitar player tightens a string and plucks it. What happens to the pitch of the sound produced? →
3. A student blows across the top of a bottle and hears a tone. If she adds water to the bottle and blows again, how will the pitch change? →
4. During a thunderstorm, you see lightning and hear thunder 3 seconds later. Using the speed of sound in air (343 m/s), approximately how far away is the lightning? →
5. A submarine uses sonar to detect objects underwater. If a sonar pulse takes 4 seconds for the round trip, and sound travels at 1,480 m/s in water, how far away is the object? →

(A) To control how sound waves reflect and distribute evenly throughout the space
(B) The pitch will increase because the air column is shorter
(C) The pitch increases because the string vibrates at a higher frequency
(D) 2,960 meters
(E) About 1,029 meters (approximately 1 km)

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11. Waves & Energy

Circle the correct answer

101. What is the principle of superposition?
(A) Waves always cancel each other out (B) When two waves meet, their displacements add together (C) Waves cannot pass through each other (D) Waves merge permanently into one wave

102. What type of interference occurs when two wave crests meet?
(A) Constructive interference (B) Reflective interference (C) Neutral interference (D) Destructive interference

103. What is diffraction?
(A) The bouncing of waves off a surface (B) The bending or spreading of waves around obstacles or through openings (C) The absorption of wave energy by a material (D) The speeding up of waves in a new medium

104. What happens during destructive interference?
(A) Two crests combine to make a bigger wave (B) Waves are absorbed by the medium (C) A crest meets a trough and the waves partially or fully cancel out (D) Waves bounce off each other

105. What is reflection in the context of waves?
(A) When a wave bends as it enters a new medium (B) When a wave bounces off a surface and changes direction (C) When a wave spreads out through an opening (D) When a wave loses all its energy

106. What is refraction?
(A) The bouncing of a wave off a surface (B) The bending of a wave as it passes from one medium to another due to a change in speed (C) The combining of two waves into one (D) The splitting of a wave into two separate waves

Write the answer

107. Why does constructive interference result in a louder sound when two speakers play the same tone in phase?
Answer: ________

108. Why can you hear someone talking around a corner even though you cannot see them?
Answer: ________

109. What happens to a wave's speed and wavelength when it refracts into a denser medium, while frequency stays the same?
Answer: ________

110. Why do noise-canceling headphones use destructive interference to reduce unwanted sound?
Answer: ________

Match each question to its answer

1. Why does a wave passing through a small opening spread out more than a wave passing through a large opening? →
2. Two water waves meet. Wave A has a displacement of +3 cm and Wave B has a displacement of +2 cm at the same point. What is the resulting displacement? →
3. Wave A has a displacement of +4 cm and Wave B has a displacement of -4 cm at the same point. What is the resulting displacement? →
4. A student shines a laser through a very narrow slit and observes the pattern on a wall. The light spreads out into a wider band instead of a sharp line. What wave phenomenon is this? →
5. You drop two stones into a calm pond at the same time, a short distance apart. Where the expanding ripples overlap, you notice some areas with extra-tall waves and some areas where the water is nearly flat. Identify the two types of interference occurring. →

(A) Diffraction is more pronounced when the opening size is close to the wavelength of the wave
(B) 0 cm (complete cancellation)
(C) +5 cm
(D) Constructive interference creates the tall waves; destructive interference creates the flat areas
(E) Diffraction

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12. Waves & Energy

Circle the correct answer

111. What type of wave do radio stations use to transmit music and voice?
(A) Radio waves (B) Gamma rays (C) X-rays (D) Sound waves

112. What technology uses sound waves bouncing off objects underwater to detect their location?
(A) Wi-Fi (B) GPS (C) Radar (D) Sonar

113. What type of wave does Wi-Fi use to transmit data wirelessly?
(A) Sound waves (B) Infrared waves (C) Ultraviolet waves (D) Radio waves (microwaves)

114. What medical imaging technology uses high-frequency sound waves to create images of internal body structures?
(A) Ultrasound (B) X-ray (C) CT scan (D) MRI

115. What instrument measures ground vibrations caused by earthquakes using seismic waves?
(A) Barometer (B) Anemometer (C) Thermometer (D) Seismograph (seismometer)

116. What does the acronym RADAR stand for?
(A) Reflective Analysis of Distant Areas and Regions (B) Radio Direction and Rotation (C) Rapid Audio Detection and Recording (D) Radio Detection and Ranging

Write the answer

117. Why do cell phones use electromagnetic waves instead of sound waves for communication?
Answer: ________

118. How does sonar calculate the distance to an underwater object?
Answer: ________

119. Why can X-rays create images of bones but visible light cannot?
Answer: ________

120. Why do earthquake P-waves (primary waves) arrive at a seismograph station before S-waves (secondary waves)?
Answer: ________

Match each question to its answer

1. Why does Wi-Fi signal strength decrease the farther you are from the router? →
2. A fishing boat uses sonar and detects an echo from the ocean floor after 0.5 seconds. If the speed of sound in seawater is 1,480 m/s, how deep is the water? →
3. A meteorologist uses radar to track a storm. The radar pulse takes 0.001 seconds to return from the storm. If radio waves travel at 3 x 10^8 m/s, how far away is the storm? →
4. An engineer needs to inspect the inside of a metal bridge for hidden cracks without cutting it open. Which wave-based technology would be most appropriate? →
5. A self-driving car uses a sensor that emits light pulses and measures the time for them to bounce back from objects. What wave property makes this technology work? →

(A) The radio waves spread out as they travel, reducing the energy per unit area at greater distances
(B) 370 meters
(C) Ultrasound testing — high-frequency sound waves can detect internal flaws in metal
(D) 150,000 meters (150 km)

(E) The constant, known speed of light allows the car to calculate distances from the round-trip travel time

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13. Sound

Circle the correct answer

121. A student notices that clapping hands together makes a sharp, quick sound while hitting a large gong makes a long, ringing sound. Use what you know about vibrations to explain why the gong's sound lasts longer.
(A) The gong is closer to the ground, which is the most common explanation for this phenomenon (B) The gong is larger and made of metal, so it continues vibrating for a longer time after being struck (C) The gong makes louder sound waves, making this the most widely accepted explanation (D) Clapping creates more sound waves than the gong, and this is the standard approach used in most cases

122. A scientist measures a wave with a wavelength of 0.5 meters. Her colleague measures the same wave and reports a wavelength of 50 centimeters. Are both measurements correct? Why or why not?
(A) No, they must have measured different waves (B) No, wavelength can only be measured in meters (C) No, only the meter measurement is correct (D) Yes, both are correct because 0.5 meters and 50 centimeters are the same length in different units

123. What is an echo?
(A) A sound wave that changes pitch as it bounces (B) A reflected sound wave that is heard after a delay because it traveled to a distant surface and back (C) A new sound created by two sounds colliding (D) A sound wave that gets louder over time

124. An architect must design a concert hall where the stage area resonates to amplify performers' voices, but the seating area does not create excessive resonance that would muddy the sound. Evaluate the design challenge and suggest how materials might help solve it.
(A) Make the entire hall from hard stone to maximize all resonance, and this is the standard approach used in most cases (B) Use only soft materials everywhere to eliminate all resonance, which is the most common explanation for this phenomenon (C) Use hard, reflective surfaces near the stage to create beneficial resonance that projects sound, and use absorptive materials (padded seats, wall panels) in the audience area to control unwanted resonance and prevent muddiness (D) The shape of the room does not matter — only the speaker system matters, as this is what research and standard practice suggests

125. A student says, 'Since UV light is harmful, we should try to block all UV from reaching Earth's surface.' Evaluate whether this would be a good idea, considering all the effects of UV radiation.
(A) This would be unwise because moderate UV exposure is essential for human health (vitamin D production) and for ecosystems (plant growth signaling, water purification). The goal should be to limit excessive UV exposure, not eliminate it entirely (B) This is a great idea because UV has no benefits at all, which is consistent with the fundamental principles of this field (C) This is impossible because UV cannot be blocked by anything, based on the typical behavior observed in controlled experiments (D) This is unnecessary because UV is only dangerous in outer space, since this follows from the basic laws governing this process

126. What type of lens is thicker in the middle than at the edges and bends light rays inward toward a focal point?
(A) A convex lens (converging lens) (B) A flat lens (C) A cylindrical lens (D) A concave lens

Write the answer

127. When a singer produces a note in a shower stall, certain frequencies sound noticeably louder than others. The shower stall acts like a resonant chamber. Analyze why the dimensions of the shower determine which frequencies are amplified.
Answer: ________

128. What frequency band does standard WiFi (802.11) primarily use for wireless internet?
Answer: ________

129. Your teacher says that turning up the volume on a speaker makes the sound louder but does not change the pitch. Use what you know about sound waves to predict what is changing inside the speaker.
Answer: ________

130. You push and pull one end of a spring toy (Slinky) along its length. What type of wave are you creating?
Answer: ________

Match each question to its answer

1. A sound engineer records a violin and a flute both playing the note A at 440 Hz. Using audio software, she analyzes the frequency content of each recording. How would the frequency analysis graphs differ? →
2. Gamma-ray bursts (GRBs) from distant galaxies are the most powerful explosions in the universe, releasing more energy in seconds than our sun will produce in its entire

lifetime. If a GRB were aimed directly at Earth from a nearby star, evaluate what threat this would pose and whether any practical shielding could protect us. →
3. A telecommunications engineer must choose between copper wire and fiber optic cable for a new 50-kilometer data link. Analyze the advantages of fiber optics over copper for this application, considering speed, signal loss, and interference. →
4. What is a standing wave? →
5. SpaceX's Starlink uses thousands of satellites in low Earth orbit (550 km altitude) instead of a few in geostationary orbit (36,000 km). Analyze the trade-offs between these two approaches for providing internet service. →

(A) A nearby GRB could strip away Earth's ozone layer and deliver lethal radiation doses, and no practical shielding exists at planetary scale. However, the probability is extremely low because GRBs are rare and narrowly focused
(B) A wave pattern that appears to stay in place, formed when two waves of the same frequency travel in opposite directions and interfere, creating fixed points of no movement (nodes) and points of maximum movement (antinodes)
(C) Both would show a strong peak at 440 Hz, but the violin would show stronger and more numerous harmonic peaks above 440 Hz compared to the flute, which would have fewer and weaker harmonics
(D) Fiber optics offers higher bandwidth (speed), lower signal loss over long distances (light degrades less than electrical signals over 50 km), and immunity to electromagnetic interference because light signals are not affected by nearby electrical equipment or lightning
(E) LEO satellites provide much lower latency (20-40 ms vs 500+ ms) due to their closer distance and can serve polar regions, but require thousands of satellites in coordinated constellations with complex handoff systems. GEO needs only 3 satellites for global coverage but has high latency and cannot serve polar areas well

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14. Sound

Circle the correct answer

131. Sound travels fastest through which state of matter?
(A) Solids (B) Gases (C) Vacuum (D) Liquids

132. How does increasing the frequency of a wave affect its wavelength, assuming the wave speed stays the same?
(A) The wavelength stays the same (B) The wavelength increases (C) The wavelength decreases (D) The wavelength doubles

133. A student claims that black objects do not reflect any light at all. Is this claim fully accurate? Evaluate using your understanding of reflection.
(A) Incorrect — black objects only reflect infrared light (B) Not fully accurate. Black objects reflect very little visible light, but they still reflect a small amount — no common surface absorbs 100% of light (C) Fully accurate — black objects absorb all light completely (D) Incorrect — black objects reflect just as much light as white objects

134. A guitar string has a fundamental frequency of 200 Hz. What is the frequency of its 3rd harmonic?
(A) 300 Hz (B) 600 Hz (C) 800 Hz (D) 400 Hz

135. Radio telescopes detect radio waves from space. Analyze why radio telescopes need to be much larger (often 25+ meters across) than optical telescopes (typically 1-10 meters) to capture useful images.
(A) Radio waves are heavier than light waves so they need bigger collectors (B) Radio waves have much longer wavelengths than visible light, so radio telescopes need much larger dishes to collect and focus enough radio wave energy to produce detailed images (C) Radio telescopes are larger because they need to amplify weaker signals (D) Radio telescopes must be large to generate the radio waves they send into space

136. Light behaves as both a wave and a particle. In the double-slit experiment, light passing through two narrow slits creates an interference pattern on a screen. However, when scientists detect which slit each photon passes through, the interference pattern disappears. Analyze what this tells us about the nature of light.
(A) Light is always a wave and the detectors break the wave apart, and this has been consistently demonstrated in practice (B) The measurement equipment blocks the light and ruins the pattern, which is the most common explanation for this phenomenon (C) Light is always a particle and the interference pattern is just an illusion, which is the most common explanation for this phenomenon (D) Light exhibits wave behavior (interference) when unobserved, but when measured as individual photons, it behaves like particles. This wave-particle duality means light's behavior depends on how it is observed

Write the answer

137. Why do standing waves form on a guitar string but not on an infinitely long rope?
Answer: ________

138. When you stream a video call, the audio and video are converted to digital signals, compressed, sent as data packets over the internet, and reassembled at the other end. Sometimes packets arrive out of order or are lost. Analyze how a video calling application handles lost packets differently for audio versus video.

Answer: ________

139. A wave in a pool has a height of 10 cm from rest to crest. Another wave has a height of 20 cm. Which wave carries more energy?
Answer: ________

140. Why do you hear echoes in a large empty gymnasium but not in a small carpeted bedroom?
Answer: ________

Match each question to its answer

1. What is a harmonic in music? →
2. How are gamma rays used in cancer treatment? →
3. A reflecting telescope uses a large concave primary mirror instead of a large lens to collect light. Analyze what advantages a mirror has over a lens for building very large telescopes. →
4. Wave A has an amplitude of 8 cm and Wave B has an amplitude of 5 cm. They undergo destructive interference at a point. What is the resulting amplitude? →
5. In the early days of radio, AM was the only broadcast technology. Analyze why FM radio eventually became preferred for music broadcasting despite AM's greater range advantage. →

(A) Mirrors can be supported from behind (lenses can only be held at edges), mirrors have no chromatic aberration, and mirrors can be made much larger — the largest telescope mirrors exceed 10 meters while the largest lenses are about 1 meter
(B) Focused beams of gamma rays are directed at cancer tumors to destroy the cancer cells by damaging their DNA, in a treatment called radiation therapy
(C) FM provides higher fidelity sound because its frequency modulation is naturally resistant to electrical noise (which affects amplitude), supports a wider audio bandwidth for full musical range, and can broadcast in stereo
(D) A frequency that is a whole-number multiple of the fundamental frequency, produced naturally when an instrument plays a note
(E) 3 cm

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15. Sound

Circle the correct answer

141. What is the relationship between the speed of a vibration and the pitch of the sound it makes?
(A) Slower vibrations produce higher-pitched sounds (B) Faster vibrations produce lower-pitched sounds (C) Faster vibrations produce higher-pitched sounds (D) Vibration speed does not affect pitch

142. Two students create waves in identical ropes. Student A's wave is tall with a small amplitude compared to Student B's very tall wave. Why does Student B's wave feel stronger when it hits the end of the rope?
(A) Student B's wave has greater amplitude, so it carries more energy (B) Student B's rope is heavier (C) Student B's wave moves faster (D) Student B's wave has a longer wavelength

143. According to the law of reflection, how does the angle at which a wave hits a surface compare to the angle at which it bounces away?
(A) The angle of incidence equals the angle of reflection (B) The angles are unrelated to each other (C) The reflection angle is always larger (D) The reflection angle is always smaller

144. How are radio waves used in everyday life?
(A) Only for heating food in microwaves, and this is the standard approach used in most cases (B) Only for medical X-ray imaging, and this principle applies across similar situations (C) Only for military radar systems, which is the most common explanation for this phenomenon (D) For broadcasting AM/FM radio, television signals, WiFi, Bluetooth, and cell phone communication

145. Why do we see rainbows after rainstorms when the sun comes out?
(A) Rainbows are reflections of light off the cloud surfaces, which is the most common explanation for this phenomenon (B) The water vapor in the air reflects the colors of the ground below, and this principle applies across similar situations (C) Rain washes pollution from the air, letting us see colors normally hidden, and this is the standard approach used in most cases (D) Raindrops act like tiny prisms, refracting, dispersing, and reflecting sunlight. Each color exits at a slightly different angle, and millions of drops together create the arc of colors we see as a rainbow

146. What happens when the crest of one wave meets the trough of another wave of equal amplitude?
(A) They cancel each other out, producing zero displacement at that point (destructive interference) (B) They create a wave that moves sideways, and this principle applies across similar situations (C) They create a wave twice as tall, as this is what research and standard practice suggests (D) They merge into one wave permanently, as this directly follows from the underlying principles

Write the answer

147. What type of electromagnetic wave is used to transmit AM and FM radio signals?
Answer: ________

148. Why does stretching a rubber band tighter make a higher sound when you pluck it?
Answer: ________

149. Design a simple demonstration using household items that shows the difference between transverse and longitudinal waves. Describe what you would use and what each demonstration would look like.
Answer: ________

150. A singer shatters a wine glass by singing a sustained note at exactly the right pitch. What principle explains this, and what specific conditions must be met?
Answer: ________

Match each question to its answer

1. Some scientists in the 1800s believed light was purely a wave, while others believed it was purely a particle. Given what we now know about wave-particle duality, evaluate why both groups were partially correct and partially wrong. →
2. What happens when the crests of two waves meet at the same point at the same time? →
3. Your WiFi router broadcasts at both 2.4 GHz and 5 GHz. Why does the 2.4 GHz signal reach your bedroom on the second floor better than the 5 GHz signal? →
4. You are holding two rubber bands of the same length. One is thick and one is thin. Which one will produce a higher-pitched sound when plucked with the same force? →
5. What is wavelength? →

(A) The thin rubber band
(B) They combine to produce a wave with a larger amplitude (constructive interference)
(C) The 2.4 GHz signal has a longer wavelength, which allows it to better penetrate walls and floors and diffract around obstacles, giving it greater range despite lower speeds
(D) Both groups correctly identified real properties of light — wave theorists explained interference and diffraction, particle theorists explained the photoelectric effect. Both were wrong to insist light was exclusively one or the other
(E) The distance from one crest to the next crest

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16. Sound

Circle the correct answer

151. Two sound waves travel through the same room. Wave A has a frequency of 200 Hz and Wave B has a frequency of 400 Hz. Compare their speeds and explain your reasoning.
(A) Wave B travels twice as fast because it has double the frequency (B) Wave A travels faster because it has a longer wavelength (C) Both waves travel at the same speed because sound speed depends on the medium, not frequency (D) Wave B is faster because higher frequency means more energy

152. A drummer tightens the drumhead on a snare drum. How will this change the sound the drum produces?
(A) The drum will produce a higher-pitched sound because a tighter drumhead vibrates faster (B) The tightness does not affect the sound (C) The drum will produce a lower-pitched sound (D) The drum will get louder but stay the same pitch

153. At what condition does resonance occur?
(A) When any two objects vibrate at different frequencies, making this the most widely accepted explanation (B) When a vibrating source applies energy at the natural frequency of an object, causing the object to vibrate with increasing amplitude (C) When an object stops vibrating due to friction, and this has been consistently demonstrated in practice (D) When a wave reflects off a surface and disappears, and this principle applies across similar situations

154. Why is there a noticeable delay (about 0.5 seconds round trip) during a phone call routed through a geostationary satellite?
(A) The signal must travel approximately 36,000 km up to the satellite and 36,000 km back down (72,000 km total each way), and even at the speed of light this journey takes about 0.24 seconds each way, creating a round-trip delay of about 0.5 seconds (B) The satellite must process and translate the signal, which takes time, as this directly follows from the underlying principles (C) The satellite stores the signal before forwarding it, which is why this approach is recommended by experts (D) The signal travels slower in space than on Earth, and this has been consistently demonstrated in practice

155. A student plucks a guitar string and notices the sound gets softer over time until it stops. What is happening to the energy of the vibrating string?
(A) The energy moves into the guitar's body and stays there forever (B) The string's vibration energy is gradually transferred to the air as sound and converted to heat through friction (C) The string creates new energy each time it vibrates (D) The energy disappears when the sound stops

156. Design a simple experiment to show that a single vibrating string produces multiple harmonics simultaneously, not just one frequency.
(A) Tighten the string while it vibrates to hear the pitch change, as this is what research and standard practice suggests (B) Pluck the string harder to hear more frequencies, and this principle applies across similar situations (C) Use a microphone to record the sound and measure its volume, and this has been consistently demonstrated in practice (D) Lightly touch the midpoint of a vibrating guitar string to mute the fundamental while allowing the 2nd harmonic to ring out, producing a note one octave higher that proves the harmonic was already present

Write the answer

157. A camera lens system uses a combination of convex and concave lenses. The convex lens focuses the image, but it also creates color fringing (chromatic aberration) because different wavelengths bend by different amounts. Analyze how adding a concave lens made of a different type of glass helps correct this problem.
Answer: ________

158. Some people claim they can hear 'binaural beats' — a beat frequency perceived when slightly different frequencies are played in each ear through headphones (e.g., 400 Hz in the left ear and 410 Hz in the right). Evaluate whether true physical beats can occur in this situation, and explain why or why not.
Answer: ________

159. Space debris is an increasing concern as thousands of satellites are launched. Evaluate the long-term sustainability of launching large constellations of thousands of LEO satellites, considering the risks of orbital collisions and the Kessler Syndrome.
Answer: ________

160. Design a simple experiment using common classroom materials to demonstrate that sound is caused by vibrations. Describe what materials you would use, what you would do, and what you would observe.
Answer: ________

Match each question to its answer

1. Two tuning forks are struck. Fork A vibrates at 256 Hz and Fork B vibrates at 512 Hz. How do the sounds they produce compare? →
2. What happens when a wave bounces off a surface and changes direction? →
3. A guitar string produces a note at 330 Hz. If the player presses the string at exactly the halfway point, reducing the vibrating length by half, what frequency will the new note have? →
4. At a concert, certain seats in the venue sound noticeably louder than others, even

though no seat is significantly closer to the stage. Analyze what wave phenomenon could cause these 'hot spots' of louder sound. →
5. 5G networks use higher frequencies (up to 39 GHz) than 4G (up to 2.6 GHz). These higher frequencies can carry much more data, but 5G cell towers must be placed much closer together. Analyze the physics behind why higher-frequency signals require more closely spaced towers. →

(A) Reflection
(B) Constructive interference from sound waves reflecting off walls and ceiling. At certain seats, the direct sound and reflected sound arrive in phase, combining to create louder perceived volume
(C) Higher-frequency radio waves are more easily absorbed by air, rain, and obstacles (buildings, trees), and they diffract less around obstacles due to their shorter wavelength. This causes the signal to weaken over shorter distances, requiring more towers to maintain coverage
(D) Fork B produces a higher-pitched sound because it has a higher frequency
(E) 660 Hz

Answer Key

1. C — Vibrate
2. A — Vibration
3. C — Solids
4. B — Volume
5. A — The drum skin vibrates with greater amplitude
6. C — Sound waves travel through the air as vibrations of air molecules
7. Sound needs a medium like air to travel through, and space is a vacuum with no air
8. Faster vibrations produce higher-pitched sounds
9. The bird's smaller vocal structures vibrate faster than the lion's larger ones
10. Tighter tension makes the rubber band vibrate faster, raising the pitch
    Matching (Sound): 1→D, 2→C, 3→B, 4→E, 5→A
11. A — Crest
12. A — Amplitude

13. B — The 20 cm wave
14. B — Student B's wave has greater amplitude, so it carries more energy
15. C — A shout, because it uses more energy to push air molecules farther from their resting position
16. B — The distance from one crest to the next crest
17. Radio waves vibrate at a much lower frequency, so each wave cycle stretches over a longer distance
18. 6 meters
19. Wave A has a higher frequency than Wave B
20. Yes, both are correct because 0.5 meters and 50 centimeters are the same length in different units
    Matching (Properties of Waves): 1→E, 2→B, 3→C, 4→A, 5→D
21. A — Reflection
22. A — The angle of incidence equals the angle of reflection
23. C — 30 degrees
24. A — Smooth surfaces reflect light in a uniform direction (specular reflection), while rough surfaces scatter light in many directions (diffuse reflection)
25. D — Not fully accurate. Black objects reflect very little visible light, but they still reflect a small amount — no common surface absorbs 100% of light
26. A — The bending of a wave as it passes from one medium into another
27. Light waves refract (bend) as they pass from water into air because the two materials have different densities
28. Toward the normal (the perpendicular line at the surface)
29. Hot air near the road surface is less dense than cooler air above it, bending light upward so you see a refracted image of the sky that looks like water
30. Refraction is consistent with wave behavior because waves change speed and direction when entering a new medium, but refraction alone does not disprove particles since particles could also change direction at boundaries
    Matching (Wave Behavior: Reflection & Refraction): 1→C, 2→B, 3→D, 4→E, 5→A
31. D — By vibrating strings that cause the surrounding air to vibrate, creating sound waves

32. C — Each instrument produces a unique combination of harmonics (overtones) that gives it a distinctive tone color, called timbre
33. D — The drum will produce a higher-pitched sound because a tighter drumhead vibrates faster
34. A — Shorter bars vibrate at a higher frequency because there is less material to vibrate back and forth, so the vibrations complete each cycle more quickly
35. D — Synthesizers can closely approximate but not perfectly replicate acoustic instruments, because the complex, ever-changing harmonic patterns and physical resonances of real instruments are extremely difficult to duplicate exactly
36. A — The frequency of the sound wave
37. A shorter string vibrates faster, producing a higher-frequency wave and a higher pitch
38. 660 Hz
39. Long, thick strings vibrate slowly (low frequency) for bass notes, while short, thin strings vibrate quickly (high frequency) for treble notes. Both length and thickness affect how fast a string vibrates
40. Not necessarily accurate. While thicker strings tend to vibrate slower, a thick string under high tension or with a short length can produce the same pitch as a thin string. Tension and length also affect frequency
    Matching (Sound & Music: Frequency & Pitch): 1→D, 2→E, 3→B, 4→A, 5→C
41. C — Radio waves
42. D — For broadcasting AM/FM radio, television signals, WiFi, Bluetooth, and cell phone communication
43. B — The AM station, because lower frequency corresponds to longer wavelength
44. D — Radio waves have much longer wavelengths than visible light, so radio telescopes need much larger dishes to collect and focus enough radio wave energy to produce detailed images
45. B — Radio waves have the lowest energy of all electromagnetic waves and are classified as non-ionizing radiation, meaning they lack sufficient energy to damage DNA. Scientific consensus, based on extensive research, has not found evidence that normal cell tower exposure causes health problems
46. A — Red, orange, yellow, green, blue, indigo, violet

47. White light contains all visible colors. Each color has a slightly different wavelength and bends by a different amount during refraction, separating the colors
48. The leaf absorbs most colors of visible light but reflects green wavelengths, which reach our eyes and make the leaf look green
49. The blue shirt normally reflects only blue wavelengths and absorbs others. Under red light, there are no blue wavelengths to reflect, so the shirt absorbs all the red light and appears black
50. Photograph flowers using a camera modified to capture ultraviolet light (with a UV-pass filter). Compare the UV photos to normal visible-light photos — patterns invisible to human eyes would appear in the UV images
    Matching (The Electromagnetic Spectrum): 1→A, 2→B, 3→E, 4→C, 5→D
51. D — 300,000 kilometers per second (3×10^8 m/s)
52. D — Light is an electromagnetic wave that consists of oscillating electric and magnetic fields, which do not require a physical medium to propagate
53. D — 1.5
54. C — Light exhibits wave behavior (interference) when unobserved, but when measured as individual photons, it behaves like particles. This wave-particle duality means light's behavior depends on how it is observed
55. A — Both groups correctly identified real properties of light — wave theorists explained interference and diffraction, particle theorists explained the photoelectric effect. Both were wrong to insist light was exclusively one or the other
56. B — A convex lens (converging lens)
57. A concave lens is thinner in the middle and spreads light rays apart (diverges them), while a convex lens is thicker in the middle and brings light rays together (converges them)
58. Concave lenses, because they spread light rays slightly before they enter the eye, allowing the nearsighted eye to focus distant objects correctly on the retina
59. The concave lens, made of glass with a different refractive index, partially reverses the color separation caused by the convex lens, bringing the different colors back to a common focus point without undoing the overall convergence
60. A combination is better because it corrects for chromatic aberration and other optical distortions that a single lens cannot avoid, producing sharper, more

accurate images
Matching (Light Waves & Optics): 1→B, 2→D, 3→C, 4→E, 5→A

61. B — They combine to produce a wave with a larger amplitude (constructive interference)
62. D — The pressure waves from both speakers add together at points where crests align, creating larger amplitude pressure variations that our ears perceive as louder sound
63. B — 6 cm
64. B — Constructive interference from sound waves reflecting off walls and ceiling. At certain seats, the direct sound and reflected sound arrive in phase, combining to create louder perceived volume
65. B — Incorrect. While constructive interference creates loud spots where crests meet, destructive interference creates quiet spots where crests meet troughs. The result is an alternating pattern of loud and quiet zones, not uniformly louder sound
66. D — They cancel each other out, producing zero displacement at that point (destructive interference)
67. A microphone detects incoming noise, and the headphones generate a sound wave that is exactly out of phase (inverted) with the noise. When these two waves combine, they destructively interfere, canceling the noise
68. 3 cm
69. The pattern is caused by alternating constructive and destructive interference. At points where path length differences equal whole wavelengths, constructive interference makes it loud; at half-wavelength differences, destructive interference makes it quiet. The spacing depends on the wavelength of the sound
70. Incorrect. Energy is not destroyed — it is redistributed. Where destructive interference reduces amplitude, the energy shifts to nearby regions of constructive interference where amplitude is increased. Total energy is conserved
Matching (Wave Interference & Resonance): 1→E, 2→C, 3→A, 4→D, 5→B
71. C — Radio waves
72. D — AM (Amplitude Modulation) varies the amplitude of the carrier wave to encode audio, while FM (Frequency Modulation) varies the frequency of the carrier wave

73. C — AM's longer wavelengths can bounce off the ionosphere (a layer of charged particles in the upper atmosphere) and return to Earth at distant locations, while FM's shorter wavelengths pass through the ionosphere into space
74. D — FM provides higher fidelity sound because its frequency modulation is naturally resistant to electrical noise (which affects amplitude), supports a wider audio bandwidth for full musical range, and can broadcast in stereo
75. A — Radio broadcasting is not obsolete because it provides free, universally accessible communication that works without internet infrastructure, is critical during emergencies when cellular networks fail, and reaches areas without broadband access. However, streaming offers on-demand content, higher quality, and interactivity that radio cannot match
76. A — Radio waves (specifically in the microwave frequency range, typically between 700 MHz and 2600 MHz for 4G, and up to 39 GHz for 5G)
77. Dividing into cells allows the same frequencies to be reused in non-adjacent cells, dramatically increasing the network's capacity to handle many simultaneous calls and data connections
78. A handoff (or handover)
79. Higher-frequency radio waves are more easily absorbed by air, rain, and obstacles (buildings, trees), and they diffract less around obstacles due to their shorter wavelength. This causes the signal to weaken over shorter distances, requiring more towers to maintain coverage
80. 5G radio waves are non-ionizing radiation with photon energies millions of times too low to damage DNA or cells. While higher in frequency than 4G, they remain well below the threshold where electromagnetic radiation becomes harmful (ultraviolet and above). Scientific consensus from major health organizations finds no established health risks from 5G at regulated exposure levels
    Matching (Waves in Communication Technology): 1→C, 2→B, 3→D, 4→E, 5→A
81. C — Radio waves
82. D — Visible light
83. A — They all travel at the speed of light
84. C — Gamma rays
85. A — The electromagnetic spectrum
86. D — Microwaves
87. Gamma rays carry much more energy per photon

88. As wavelength increases, frequency decreases
89. Infrared waves transfer thermal energy to molecules in our skin
90. They can travel through the vacuum of space
Matching (Waves & Energy): 1→A, 2→D, 3→B, 4→C, 5→E
91. B — A longitudinal wave
92. D — Decibels (dB)
93. B — A medium such as air, water, or a solid
94. C — Frequency
95. D — Echo
96. C — Solids
97. Warm air molecules move faster and transmit vibrations more quickly
98. The sound becomes louder
99. Sound travels faster through the solid steel rail than through air
100. The motion of the sound source or listener compresses or stretches the perceived wavelength
Matching (Waves & Energy): 1→A, 2→C, 3→B, 4→E, 5→D
101. B — When two waves meet, their displacements add together
102. A — Constructive interference
103. B — The bending or spreading of waves around obstacles or through openings
104. C — A crest meets a trough and the waves partially or fully cancel out
105. B — When a wave bounces off a surface and changes direction
106. B — The bending of a wave as it passes from one medium to another due to a change in speed
107. The crests of both sound waves align, adding their amplitudes together and increasing the sound energy
108. Sound waves have longer wavelengths than light waves, so they diffract more easily around obstacles
109. Speed decreases and wavelength shortens, but frequency remains constant
110. They generate sound waves that are exactly out of phase with the incoming

noise, so the waves cancel out
Matching (Waves & Energy): 1→A, 2→C, 3→B, 4→E, 5→D

111. A — Radio waves
112. D — Sonar
113. D — Radio waves (microwaves)
114. A — Ultrasound
115. D — Seismograph (seismometer)
116. D — Radio Detection and Ranging
117. Electromagnetic waves travel at the speed of light, work over long distances, and do not require a physical medium
118. It measures the time for a sound pulse to travel to the object and back, then uses the speed of sound in water to calculate distance
119. X-rays have enough energy to pass through soft tissue but are absorbed by dense bone, creating contrast; visible light is blocked by skin
120. P-waves travel faster because they are longitudinal compression waves that move through all types of material
Matching (Waves & Energy): 1→A, 2→B, 3→D, 4→C, 5→E
121. B — The gong is larger and made of metal, so it continues vibrating for a longer time after being struck
122. D — Yes, both are correct because 0.5 meters and 50 centimeters are the same length in different units
123. B — A reflected sound wave that is heard after a delay because it traveled to a distant surface and back
124. C — Use hard, reflective surfaces near the stage to create beneficial resonance that projects sound, and use absorptive materials (padded seats, wall panels) in the audience area to control unwanted resonance and prevent muddiness
125. A — This would be unwise because moderate UV exposure is essential for human health (vitamin D production) and for ecosystems (plant growth signaling, water purification). The goal should be to limit excessive UV exposure, not eliminate it entirely
126. A — A convex lens (converging lens)
127. Standing waves form between the shower walls at frequencies whose

wavelengths fit exactly within the stall dimensions (whole number of half-wavelengths). These resonant frequencies are amplified while others are not reinforced

128. 2.4 GHz and 5 GHz bands

129. The speaker cone vibrates with larger movements but at the same speed

130. A longitudinal wave
Matching (Sound): 1→C, 2→A, 3→D, 4→B, 5→E

131. A — Solids

132. C — The wavelength decreases

133. B — Not fully accurate. Black objects reflect very little visible light, but they still reflect a small amount — no common surface absorbs 100% of light

134. B — 600 Hz

135. B — Radio waves have much longer wavelengths than visible light, so radio telescopes need much larger dishes to collect and focus enough radio wave energy to produce detailed images

136. D — Light exhibits wave behavior (interference) when unobserved, but when measured as individual photons, it behaves like particles. This wave-particle duality means light's behavior depends on how it is observed

137. A guitar string is fixed at both ends, so waves reflect back and interfere with incoming waves. An infinite rope has no endpoints to reflect waves, so standing wave patterns cannot form

138. For audio, lost packets are usually replaced with brief silence or interpolated from surrounding packets, since small audio gaps are less noticeable. For video, lost packets may cause brief freezing, pixelation, or reduced resolution as the system fills in missing frame data from previous frames until new data arrives

139. The 20 cm wave

140. The gymnasium's large hard surfaces reflect sound with enough delay to hear an echo, while the bedroom's soft carpeted surfaces absorb sound and the room is too small for a delay
Matching (Sound): 1→D, 2→B, 3→A, 4→E, 5→C

141. C — Faster vibrations produce higher-pitched sounds

142. A — Student B's wave has greater amplitude, so it carries more energy

143. A — The angle of incidence equals the angle of reflection

144. D — For broadcasting AM/FM radio, television signals, WiFi, Bluetooth, and cell phone communication
145. D — Raindrops act like tiny prisms, refracting, dispersing, and reflecting sunlight. Each color exits at a slightly different angle, and millions of drops together create the arc of colors we see as a rainbow
146. A — They cancel each other out, producing zero displacement at that point (destructive interference)
147. Radio waves
148. Tighter tension makes the rubber band vibrate faster, raising the pitch
149. Use a Slinky: shake it side-to-side for a transverse wave (wave moves forward, coils move sideways) and push-pull it along its length for a longitudinal wave (wave moves forward, coils compress and expand)
150. Resonance — the singer matches the glass's natural frequency, causing it to vibrate with increasing amplitude until the glass exceeds its structural limit and breaks
   Matching (Sound): 1→D, 2→B, 3→C, 4→A, 5→E
151. C — Both waves travel at the same speed because sound speed depends on the medium, not frequency
152. A — The drum will produce a higher-pitched sound because a tighter drumhead vibrates faster
153. B — When a vibrating source applies energy at the natural frequency of an object, causing the object to vibrate with increasing amplitude
154. A — The signal must travel approximately 36,000 km up to the satellite and 36,000 km back down (72,000 km total each way), and even at the speed of light this journey takes about 0.24 seconds each way, creating a round-trip delay of about 0.5 seconds
155. B — The string's vibration energy is gradually transferred to the air as sound and converted to heat through friction
156. D — Lightly touch the midpoint of a vibrating guitar string to mute the fundamental while allowing the 2nd harmonic to ring out, producing a note one octave higher that proves the harmonic was already present
157. The concave lens, made of glass with a different refractive index, partially reverses the color separation caused by the convex lens, bringing the different colors back to a common focus point without undoing the overall convergence

158. True physical beats cannot form because the two sound waves never actually meet and interfere — each ear hears only one frequency. Any perceived beat effect is created by the brain's processing of the two separate signals, not by physical wave interference
159. Large constellations pose a real risk. Kessler Syndrome describes a chain reaction where one collision creates debris that causes more collisions, potentially making certain orbits unusable. Active debris mitigation (deorbiting at end-of-life, collision avoidance, debris cleanup) is essential, but current regulations may be insufficient for the scale of planned constellations
160. Stretch a rubber band over an open box, pluck it, and observe the rubber band vibrating back and forth while hearing a sound; when you stop the vibration by touching the band, the sound stops immediately
Matching (Sound): 1→D, 2→A, 3→E, 4→B, 5→C
