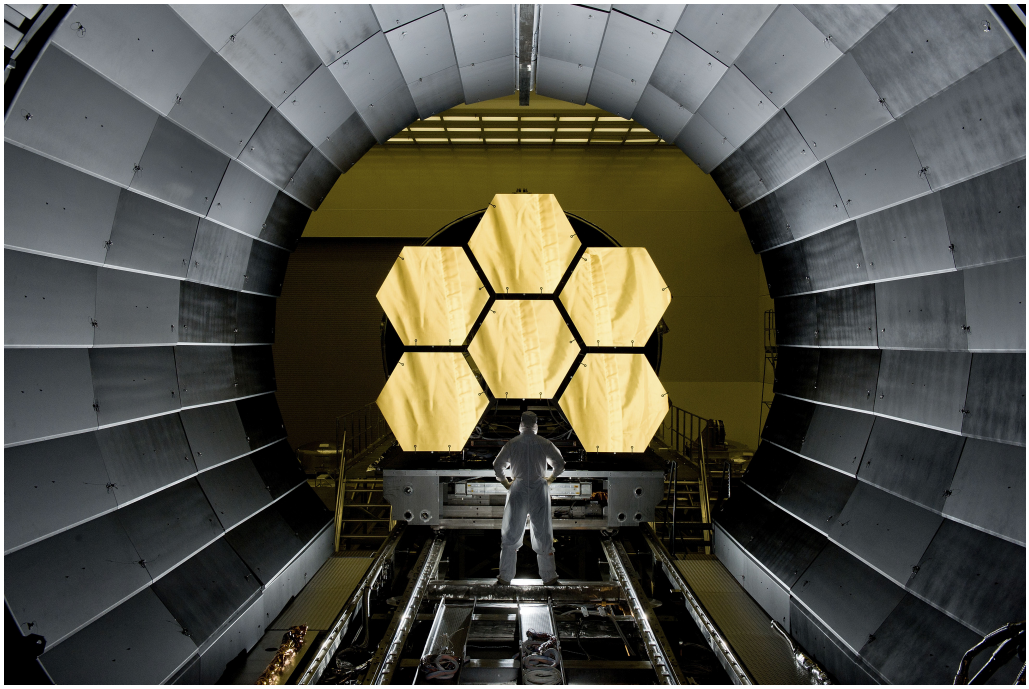
# Science Olympiad
# Crave the Wave
# UT Regional 2022

February 26, 2022



**Directions:**

- Do **not** open this exam until told to start!
- This exam is a class set. Please write all answers on your answer sheet. Answers written elsewhere (including on this test) will not be scored.
- Use of correct significant figures will **not** be enforced
- Whenever needed, take the speed of light, $c$, to be $3 \times 10^8$ m/s and Planck's constant, $h$ to be $6.626 \times 10^{-34}$ $\mathrm{m^2\,kg\,s^{-1}}$

## Section A: Short Answer (80 points total)

**Directions:** For the following questions, answer with a number or short phrase (four words or less). Each question is worth the same (2 points) but are not necessarily the same difficulty. There is no partial credit and no penalty for guessing.

1. What is the name of the telescope pictured on the cover? *Hint: it was launched on December 25, 2021.*
2. True or false: sound is a longitudinal wave.
3. True or false: light is a longitudinal wave.
4. Given a light ray traveling in sapphire ($n = 1.77$) surrounded by water ($n = 1.33$), determine the incidence angle which will result in the refracted and reflected rays being orthogonal to each other.
5. Determine the index of refraction of a medium given that the speed of light through the medium is $2.29\times10^8$ m/s.
6. What are the three primary additive colors, and what do you get when you mix them all together? (4 answers required)
7. What are the three primary subtractive colors, and what do you get when you mix them all together? (4 answers required)
8. Find the minimum deviation angle of a glass isosceles triangular prism with base angles of $70^\circ$ and index of refraction $n = 1.5640$ submerged in water ($n = 1.33$).
9. Consider a swimming pool with perfectly still and clear water. At the bottom is a light source. What is the smallest angle possible that a light ray from the source can make with a normal line to the water so that the light ray doesn't leave the water? Recall that for water $n = 1.33$.
10. Suppose that the pool in the question above is 2 meters deep. Find the area, in square meters, of the circle of light visible on the surface of the water.
11. This type of complex lens eliminates spherical aberrations perfectly for two specific wavelengths. What is the name of this type of lens?
12. Given an angular wave number of $6.9813\times10^6$ rad/m, determine the energy of the wave in Joules.
13. Consider a series of ten 20 cm thick slabs of glass each adjacent to each other and ordered in increasing index of refraction. The incident angle is $45^\circ$, what is the emergence angle?
14. The ionization energy of hydrogen is 13.6 eV. If a photon has a wavelength of 700 nm, will it be able to ionize a hydrogen electron?
15. At what speed, in meters per second, should a source be moving in order for an emitted light ray ($\lambda = 250nm$) to have a redshift ($z$) of 0.5? Do not ignore relativistic effects.
16. What is the ratio of red to green to blue pixels in a Bayer mosaic?
17. True or false: a smaller aperture produces a shallower depth of field.
18. Light emitted from the Sun is (polarized or unpolarized)
19. A ray of UV light has a frequency of 9 PHz (recall that 1 PHz = $10^{15}$ Hz). What is its wavelength, in nanometers?
20. A certain photon has a wavelength of 550 nanometers. What is the energy of this photon?
21. A concave mirror has focal length $f = +20$ cm. An object with height $h = 5$ cm is placed at a distance $d_o = +45$ cm. What is $d_i$?
22. The magnitude of the focal length, $f$, of a convex mirror is 12 cm. If an object 6 cm high is placed 24 cm away from the mirror, what will the image distance be, in cm?
23. True or false: a negative lens diverges light.
24. A converging lens shows the sun at a distance of 20 cm from the center of the lens. What is the magnitude of the focal length of this lens?
25. An object is placed 30 cm from a converging lens with a radius of curvature of 20 cm. What is the position of the image ($d_i$)?

26. A cord of fixed length and uniform density, when held between two fixed points under tension $T$, vibrates with a fundamental frequency $f$. If the tension is doubled, by what factor does the fundamental frequency increase?

27. A plano-convex lens submerged in water ($n = 1.33$) has a focal length of 36 cm and is made of a material with an index of refraction of 1.50. What is the radius of the convex surface? Assume that the lens is thin.

28. A biconvex lens is made of a material with an index of refraction of 1.6. The radii of the lens are the same. What must the radii be to give a focal length of 25 cm when the lens is in air? Don't worry about sign convention in your answer.

29. What is the name of the principle that states that every point on a wavefront is a source of wavelets?

30. What color can no mixture of colored pigments create?

31. A telescope being used has an effective diameter of 8 m. What is its limiting angular resolution for 450 nm light, in arcseconds?

32. Monochromatic light of wavelength 646.8 nm is incident normally on a diffraction grating containing 5,000 grooves per centimeter. Find the angle at which the third-order maxima is observed.

33. A train whistle has a frequency of 100 hertz as heard by the engineer on the train. If the train is approaching a stationary listener on a windless day at a velocity of 30 meters per second, what is the frequency of the sound from the whistle that the listener hears? Assume that the velocity of sound in air is 330 meters per second.

34. At what angle must a beam of light traveling through air strike the surface of sapphire (n=1.77) in order to completely polarize the resulting reflection?

35. What is the exact speed of light in a vacuum, in meters per second?

36. Light that is normally 600 nanometers in a vacuum is 300 nanometers when travelling in a certain substance. What is the index of refraction of that substance?

37. Light of wavelength 550 nm passes through a slit $10^{-6}$ meters wide. How wide is the central maximum in degrees?

38. What is the radius, in meters, of the $4^{\text{th}}$ bright ring of a Newton's Rings setup, where the incident light has wavelength $\lambda = 700$ nm and the radius of curvature for the glass lens is 20 cm?

39. In the setup in the question above, is the center of the interference pattern dark or light?

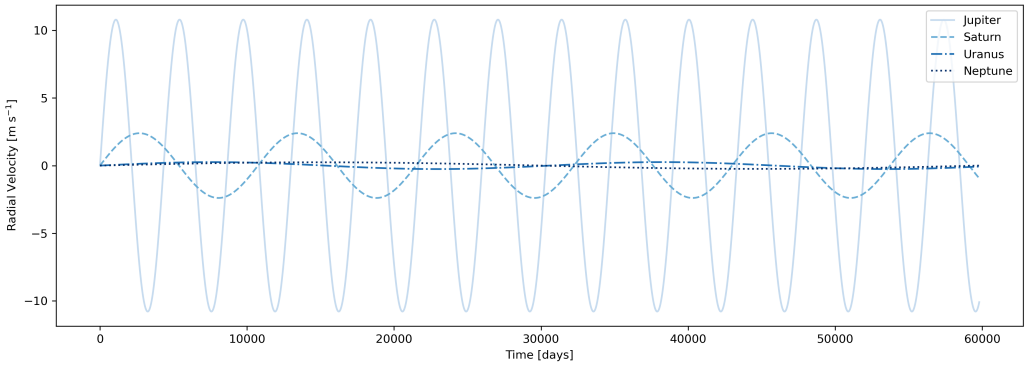
40. Lyman, Balmer, and Paschen refer to the emission spectrum of which element?

## Section B: Free Response (40 points total)

1. (a) (4 points) Sketch an idealized plot of the intensity of electrons ejected from a metal as a function of the frequency of incident light.
   (b) (4 points) Sketch an idealized plot of the kinetic energy of the electrons as a function of the frequency of incident light.
   (c) (4 points) Based on these observations, what does the photoelectric effect imply about the wave-like or particle-like nature of light?
   (d) (4 points) Sketch the double slit experiment and its resulting diffraction pattern. How is the spacing of the peaks in this pattern related to the de Broglie wavelength of whatever is passing through the slits?
   (e) (4 points) What does the double slit experiment imply about the wave-like or particle-like nature of light?

2. A long tube contains air at a temperature of 303 Kelvin. The tube is open at one end and closed at the other by a movable piston. A tuning fork near the open end of the tube vibrates with a fixed frequency.
   (a) (2 points) Estimate the speed of sound, in m/s, at these conditions.
   (b) (4 points) In the ideal case, this tube would have displacement antinodes and nodes at exactly the open and closed ends of the tube, respectively. Why would this be the case?
   (c) (4 points) You experimentally determine that resonance is produced when the piston is at distances of 11.5, 36.5, and 61.5 cm from the open end. These data show that the displacement antinode is slightly outside of the open end of the tube. How far outside is it?
   (d) (4 points) Intuitively, why would the displacement antinode be slightly outside of the open end of the tube? Would this effect be more pronounced in tubes with larger or smaller radii?

3. When a planet orbits around a star, it tugs on the star, moving it back and forth. More massive planets cause the stars to move more quickly. Astronomers determine how quickly the star is moving by measuring its redshift and blueshift. Imagine an alien civilization is observing our Solar System at an inclination of 60° (i.e., the normal vector of the plane our planets orbit in makes an angle of 60° with the aliens' line of sight). They separate the signals for each planet and make the following plot:




   (a) (2 points) Estimate Saturn's period, in days. It's tough to do precisely from this plot, so don't worry too much about being exact. We'll accept a range of answers on the key.
   (b) (2 points) Which planet has the highest frequency? What is it, in Hz? Again, don't stress about being exact.
   (c) (2 points) Suppose that instead of viewing the Solar System at an angle, the aliens viewed it "edge-on" ($i = 90°$). By what factor would the amplitudes of the curves in this plot increase?