Closed book; no notes; no calculators. A straightedge and pencil are needed for the ray diagram. All necessary numerical calculations can be done easily without a calculator. Partial credit of 1 point may be given on multiple-choice questions in case your response is wrong if you clearly write down a relevant equation or concept. You may assume that any numerical constant provided in this exam is accurate to two significant figures. This exam includes 8 pages and 20 problems. (Version A)

The following constants and equations may or may not be needed:

- Speed of sound in air: $350 \text{ m/s}$.
- Speed of light in vacuum: $3.0 \times 10^8 \text{ m/s}$.
- Relation between pressure and displacement amplitudes in a longitudinal sound wave: $P_{\max} = BkA$.
- Doppler shift formula: $f_\Delta = \frac{1}{1 + \frac{v_\parallel}{v}} f_s$.
- Angle of a shock wave: $\sin \alpha = \frac{v}{v_\parallel}$.
- Equation for images formed by a single refracting surface: $\frac{n_1 + n_2}{s} = \frac{n_1 - n_2}{R}$.
- Lateral magnification of a single refracting surface: $m = -\frac{n_2s'}{n_1s}$.
- Thin lens equation: $\frac{1}{S} + \frac{1}{S'} = (n - 1) \left( \frac{1}{f_1} - \frac{1}{f_2} \right)$.
1. (3 pts) A student fills a spherical glass flask with air, seals it, and submerges it in water to be used as a lens for sound waves. Such a lens will
   a) have no effect on the sound.
   b) cause the transmitted sound waves to diverge.
   c) cause the transmitted sound waves to converge.
2. (3 pts) An object is placed between a concave mirror and its focal point. The image is
   a) real, magnified, and inverted.
   b) real, demagnified, and upright.
   c) virtual, magnified, and upright.
   d) virtual, demagnified, and inverted.
3. (3 pts) Light waves traveling through air are incident upon glass at an angle of incidence that is somewhere between 45° and 90°. The angle of refraction in the glass is
   a) less than 0.
   b) equal to 0.
   c) greater than 0.
   d) not defined—there is no refracted ray, as the light is totally reflected.
4. (3 pts) A dog listens to two incoherent sources of sound. The pressure amplitude at the ear of the dog of the sound from one source is 10 times greater than the pressure amplitude of the sound from the other source. How do the sound intensity levels of the two sounds compare (at the dog’s ear)?
   a) They differ by 30 dB.
   b) Their ratio is 10 dB.
   c) They differ by 20 dB.
   d) Their ratio is 100 dB.
5. (3 pts) The figure below shows two identical speakers that are connected to the same amplifier, but Speaker B is wired backwards such that it oscillates 180° out of phase with respect to Speaker A.

   ![Diagram of two speakers](image)

   If the wavelength of the sound waves is 2 m, then the point P is
   a) a point of negative sound intensity.
   b) a point of zero sound intensity.
   c) a point of minimum sound intensity.
   d) a point of maximum sound intensity.
6. (3 pts) The wavelength of visible light is closest to
   a) 1 millimeter (10^-3 m)
   b) 1 micron (10^-6 m)
   c) 1 nanometer (10^-9 m)
   d) 1 Ångström (10^-10 m)
7. (3 pts) The sky appears blue on a sunny day because
(a) short wavelength light is scattered by the atmosphere more than long wavelength.
(b) long wavelength light is scattered by the atmosphere more than short wavelength.
(c) air molecules fluoresce blue after absorbing sunlight.
(d) the atmosphere absorbs more red light than blue light from the sun.

8. (3 pts) Suppose that you live 10 km due east of a vertical radio transmitter antenna (charges moving up and down). The radio waves at your house will be
(a) vertically polarized.
(b) polarized north-south.
(c) polarized east-west.
(d) non-existent—the antenna will not transmit in that direction.

9. (3 pts) To make a high-quality reflecting telescope lens with minimal chromatic aberration (to focus all colors the same), one would choose glass with
(a) minimum density.
(b) minimum refractive index.
(c) maximum refractive index.
(d) minimum dispersion.

10. (3 pts) The space shuttle glides over the Atlantic Ocean on its way to land at Kennedy Space Flight Center. Fishermen on the ocean hear a "sonic boom" from an acoustic shock wave.
(a) whenever the shuttle passes by flying faster than the speed of sound.
(b) only after the moment that the shuttle passes through the "sound barrier.
(c) never, since the engines are making no sound and the shuttle is slowing down.
(d) whenever the shuttle is directly overhead.

11. (3 pts) Consider the drawing to the right. Unpolarized light is incident upon the apparatus, which consists of two polarizing filters and a transparent box of air with chalk dust in suspension. Some of the light scatters from the chalk dust at 90 degrees, as indicated. In which of the following polarizing filter configurations will the observer see the most scattered light?
(a) Filter f, blocks light with x polarization while filter f' blocks light with z polarization.
(b) Filter f, blocks light with x polarization while filter f' blocks light with y polarization.
(c) Filter f is removed while filter f' blocks light with z polarization.
(d) Filter f, blocks light with z polarization while filter f', is removed.
12. (3 pts) Which one of the following wave functions could represent a circularly polarized electromagnetic wave traveling in the z direction?

a) \( E_x = E_0 \sin(\omega t - k z) \) \( E_y = E_0 \sin(\omega t - k z) \) \( E_z = 0 \)
b) \( E_x = E_0 \sin(\omega t - k z) \) \( E_y = E_0 \cos(\omega t - k z) \) \( E_z = E_0 \)
c) \( E_x = E_0 \sin(\omega t - k z) \) \( E_y = E_0 \cos(\omega t - k z) \) \( E_z = 0 \)
d) \( E_x = E_0 \sin(\omega t - k z) \) \( E_y = 0 \) \( E_z = 0 \)

13. The following graph represents the time dependence of the pressure amplitude of a sound wave as heard by a listener at a particular location. The wave is formed by interference of sound from two different sources of equal power.

![Graph showing pressure amplitude over time](image)

a) (3 pts) Based on the graph, which of the following statements is very likely to be true?

i) The two interfering sound waves are harmonics of each other.
ii) The sound travels at different speeds from the two sources.
iii) The two sources are at different distances from the listener.
iv) One of the two sources is moving faster than the speed of sound.

b) (6 pts) What is the difference in frequency, \( f_1 - f_2 \), of the sound from the two sources?

\[
\frac{f_1 - f_2}{f_0} = \frac{1}{T_{b_1}} + \frac{1}{T_{b_2}} = \frac{1}{\omega_1} + \frac{1}{\omega_2}
\]

\[
= \pm \frac{5}{\omega_0}
\]
14. (3 pts) A glass optical thin lens, with spherical surfaces, that is thicker near the edges than at the center is
   a) always a converging lens.
   b) always a diverging lens.
   c) a diverging lens only if the second surface has a larger radius of curvature than the first.
   d) a diverging lens only if both surfaces are concave.

15. (3 pts) Which of the following best explains why when a (1st order) rainbow is formed, the sunlight reflected from the rain droplets is brightest in the region of an arc of radius about 41°?
   a) Red light is refracted more strongly than blue light.
   b) The angle of refraction of light by water is about 41°.
   c) The equation for the angle of deviation $\beta$ between the incident and reflected rays is stationary (a minimum) with respect to the angle of incidence at an angle of about $\beta = 139°$.
   d) In the case of a single reflection inside the raindrop, the angle of deviation $\beta$ cannot exceed approximately 139°.
   e) Because of the refraction of light by the water, the sunlight cannot reflect straight backwards.

16. (6 pts) A converging lens of focal length $f_1 = 10 \text{ cm}$ is placed immediately in front of and touching a diverging lens of focal length $f_2 = 20 \text{ cm}$. Then the lens combination is used to focus light from the sun. How far from the lenses is the image of the sun?

   \[
   \frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} = \frac{1}{10} + \frac{1}{-20} = \frac{10}{200}
   \]
   \[
   f = 2.0 \text{ cm}
   \]

   The sun's image will be at the focus of the combination.
17. A speaker suspended in air radiates sound equally in all directions.
   a) (5 pts) What is the ratio of intensity of the sound at point A, 1 meter from the
      speaker, to the intensity at point B, 100 meters from the speaker?

\[
\frac{I_A}{I_B} = \frac{V_A}{V_B} = \left(\frac{r_B}{r_A}\right)^2 = \left(\frac{100}{1}\right)^2 = 10^4
\]

b) (5 pts) What is the difference, in dB, of the sound intensity level at point A
   relative to that at point B?

\[
\Delta\beta = 10 \log \frac{I_A}{I_B} = 10 \log 10^4 = 40 \text{ dB}
\]

18. (6 pts) A bicyclist is riding downwind at a speed of 25 m/s toward a stationary
   listener while blowing a whistle with a frequency of 500 Hz. If the wind is blowing
   with a speed of 35 m/s, what is the frequency of sound heard by the listener? The
   speed of sound in air is 330 m/s.

   The velocities must be measured relative to the air, not the ground.
   So \( \omega_s = 0 \)

\[
\omega_L = 35 \text{ m/s}
\]

\[
f = \left(1 + \frac{\omega_L}{\omega_s}\right) f_s = \left(1 + \frac{35}{35}\right)500
\]

\[
= (1.1)500 = 550 \text{ Hz}
\]
19. Unpolarized light is incident from air upon a liquid surface of refractive index $n$.
   a) (2 pts) Draw a diagram showing the reflected and refracted rays of a light ray going from the air into a liquid at the polarization angle (Brewster's angle). Indicate clearly the angle between the refracted and reflected rays.

   ![Diagram showing light rays](image)

   b) (2 pts) What is the direction of polarization of the reflected light?
      - in or out of page (parallel to the surface)

   c) (3 pts) The transmitted light is
      - i) also 100% polarized in the same direction as the reflected light.
      - ii) 100% polarized in the opposite polarization from the reflected light.
      - iii) only slightly polarized.
      - iv) unpolarized.

d) (5 pts) Starting from Snell's law, derive a formula relating the polarizing angle $\theta_b$ (Brewster's angle) to the index of refraction.

   \[
   n_{\text{air}} \sin \theta_b = n \sin \theta_b
   \]

   \[\theta_b = 90 - \theta_p\]

   \[\sin \theta_b = \cos \theta_p\]

   \[\frac{\sin \theta_b}{\cos \theta_p} = \frac{n}{n_{\text{air}}}\]

   \[\tan \theta_b = \frac{n}{n_{\text{air}}} = n\]
20. A lens with focal length \( f = +10 \text{ cm} \) is placed 25 cm to the right of a concave mirror of radius of curvature \( R = 30 \text{ cm} \). An object of height \( h = 2.0 \text{ cm} \) is placed 15 cm to the right of the lens.

a) (5 pts) Draw with a straight-edge a principal ray diagram showing the formation of the object’s intermediate image from the lens (as if the mirror were not there). Then, using the image from the lens as an object for the mirror, more principal rays showing the formation of the final image from the mirror. (The lens will form a third image, using the mirror’s image as an object, but do not show it.)

b) (4 pts) Calculate the image distance for the intermediate image from the lens.

\[
\frac{1}{s'} = \frac{1}{f} - \frac{1}{s} = \frac{1}{10} - \frac{1}{152} = \frac{152 - 10}{1520} = \frac{5}{1520}
\]

\[
s' = \frac{5}{5} = 3.0 \text{ cm}
\]

c) (1 pt) Does the intermediate image form a real or virtual object for the mirror?

d) (4 pts) Calculate the image distance for the image from the mirror.

\[
\frac{1}{s'} = \frac{1}{15} - \frac{1}{5} = \frac{5 - 3}{75} = \frac{20}{75}
\]

\[
s' = \frac{75}{2} = 37.5 \text{ cm}
\]

e) (1 pt) Is the image from the mirror real or virtual?