This is a test to determine whether you're familiar with the content of **Scholars Middle School Physics 1**.

To use this test, we recommend:

- Take the test. You may use a calculator, but don't get other outside help.
- Have someone else check your responses using the solutions that start on page 6 of this document. They should only tell you whether your answer was correct or not.
- Take a second try on any problems you got wrong the first time.

If by the second try you can solve at least 8 of the problems, then significant portions of the course would be a review for you.

Some of the questions on this test involve making a measurement or an estimate. For these questions, all answers within a range are counted as correct.

1. At a certain time of day, a short pole has a height of $1.2\ \mathrm{m}$ and casts a shadow of length $0.8\ \mathrm{m}$. A taller pole is too tall to measure directly, but at the same time of day, its shadow length is $3.6\ \mathrm{m}$. How tall is the taller pole?

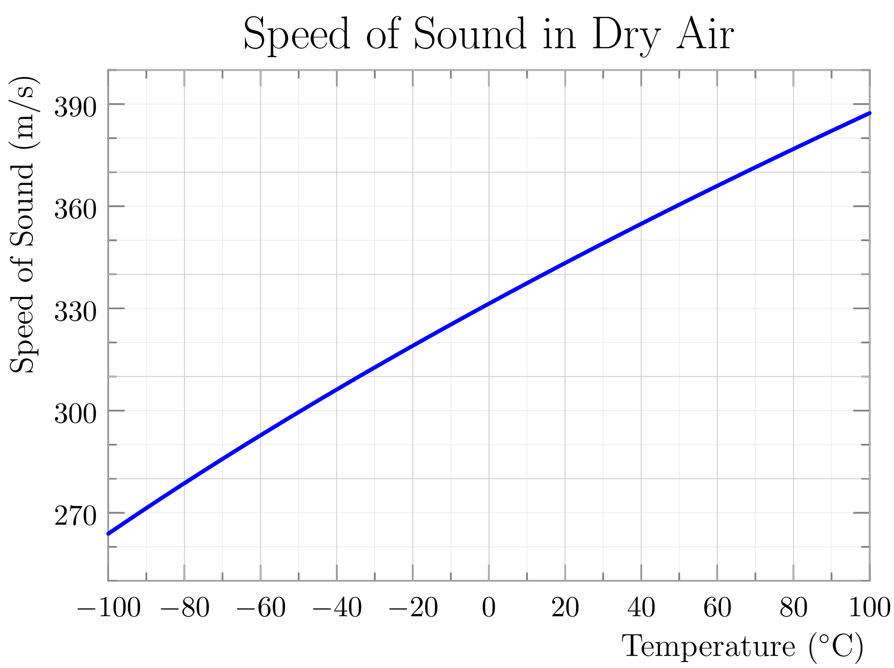
2. Below are three photos of toys. In the third photo, the horizontal distance along the table between the front faces of the two toys was $30.0\ \mathrm{cm}$. How far was the camera from the closer toy when the third photo was taken? Your answer will be an estimate based on measurements and an analysis of the photos.

3. The *luminous efficacy* of a light source is the illumination it provides (measured in lumens, lm) divided by the power it consumes (measured in watts, W). A typical LED has a luminous efficacy of $90\ \mathrm{lm/W}$, while an incandescent light has a luminous efficacy of $15\ \mathrm{lm/W}$. If a room is lit with $900\ \mathrm{lm}$ of illumination, how many kilojoules of energy would be saved every $8\ \mathrm{h}$ (a typical day's worth of use) by switching from incandescent to LED illumination in the room? Recall that the prefix k stands for "kilo," or thousand, and that one watt is one joule per second.

4. Select all the letters below that appear unchanged (aside from being larger or smaller) when viewed in a pinhole camera.

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z

5. Amir and Brittney stood at opposite ends of a long rod. Amir hit one end of the rod, causing a sound to travel down the rod and a sound to travel through the air. Brittney was at the other end of the rod. The sound that traveled through the rod arrived at Brittney 0.260 s before the sound that traveled through the air. The speed of sound in the rod is 3500 m/s. The length of the rod was 100.0 m. The speed of sound in air depends on the temperature as shown below. (Assume the air in the experiment is dry, so the graph is accurate.) What was the temperature during the experiment?



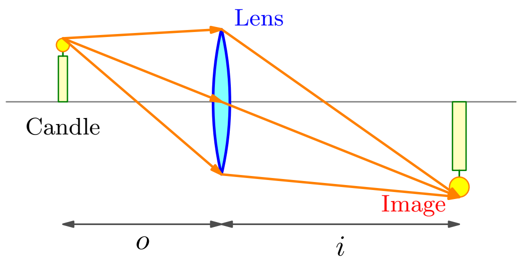
6. A simple model of colors is that the primary colors for light mixing are red, green, and blue. Red and green make yellow, green and blue make cyan, and red and blue make magenta. Red, green, and blue make white.

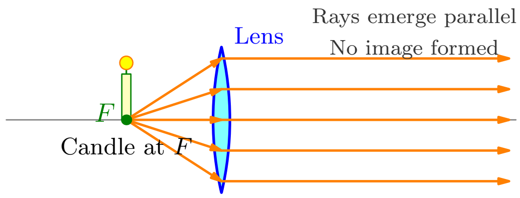
   In a simple printing model, there are three inks: cyan, yellow, and magenta. Each absorbs a single primary color of light, allowing the other primary colors to reflect off the white paper the ink is printed on. For example, yellow ink absorbs blue light and allows red and green to reflect off the paper. The red and green viewed together are yellow.

   According to this model, what color is seen when cyan and magenta ink are printed on top of each other on a piece of white paper?

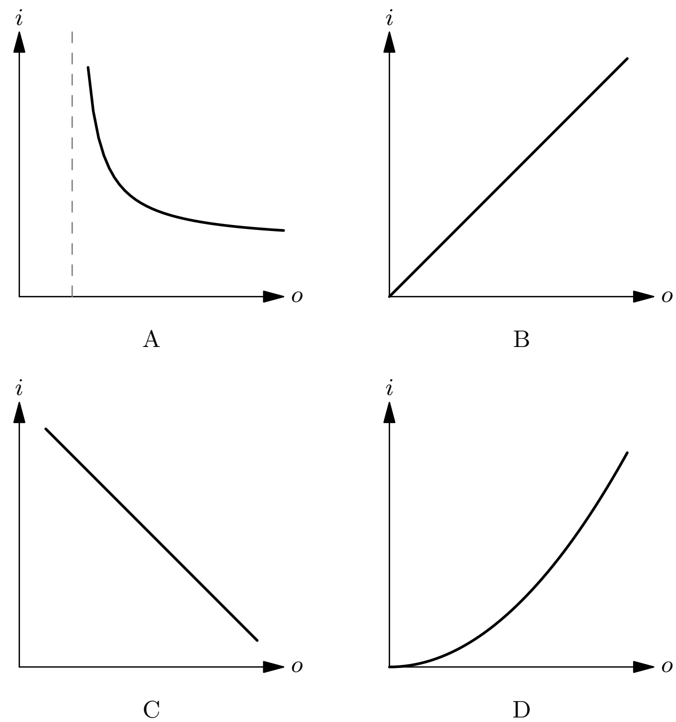
7. A child attaches a trading card to the frame of their bicycle so that each spoke on the rear wheel strikes the card as the wheel spins. If the rear tire has a diameter of 60 cm, there are 32 spokes on the wheel, and the card makes a sound of frequency 160 Hz as the spokes hit it (i.e. the card hits 160 spokes each second), how fast is the child riding? Give your answer to the nearest 0.1 m/s.

8. A candle is placed a distance o from a lens as shown below. The lens forms a real image of the object a distance i from the lens on the opposite side. Which of the following plots best shows i as a function of o? (The plot is drawn only for real images.)





Hint: If the candle were moved closer to the lens, it would eventually reach the lens's focal point. Then light rays from the candle would emerge from the lens parallel and would not form an image.



9. An observer stands on the ground while an ambulance drives directly away from them and directly toward a large, flat wall. The ambulance siren plays at a frequency of $700\ \mathrm{Hz}$, as heard inside the ambulance. Sound travels backward from the siren to the observer. Sound also travels forward from the siren, reflects off the wall, and bounces back to the observer. The direct and reflected sounds from the siren cause a beating pattern at the observer's location. The frequency of the beats is $40\ \mathrm{Hz}$. What is the speed of the ambulance, to the nearest $1\ \mathrm{m/s}$?

   Recall the beat formula $f_{\text{beat}} = |f_1 - f_2|$ where f_1 and f_2 are the frequencies of the two sounds, and recall that the Doppler shift formula for a moving source is $f' = f \cdot \frac{v}{v - v_s}$, where v is the speed of sound ($343\ \mathrm{m/s}$), v_s is the speed of the source (positive when moving toward the observer), and f is the original frequency.

   Hint: You may want to simplify things by assuming that the frequency in front of the ambulance is Doppler-shifted up in frequency by the same number of hertz that the frequency behind the ambulance is Doppler-shifted down. This is not precisely correct, but the assumption will not affect the final answer when rounded to the nearest $1\ \mathrm{m/s}$.

10. A brick hangs from the end of a thin steel wire of length $64\ \mathrm{cm}$. When plucked gently, the wire vibrates with a fundamental frequency of an A2, $110\ \mathrm{Hz}$. Recall that in modern tuning there are twelve semitones in an octave, each with a frequency a factor of $2^{1/12}$ higher than the last. Three semitones above A2 is C3. What should the length of the wire be changed to, assuming the same brick will hang from it, to make it play a C3 when plucked? Give your answer to the nearest $1\ \mathrm{cm}$.

    Recall that the frequency of a plucked wire is inversely proportional to its length when the tension in the wire is not changed.

Don't look at the next page until you've attempted all the problems!

The answers are below.

1. $5.4\ \mathrm{m}$.

   The ratio of height to shadow length is constant: $\frac{\text{height}}{\text{shadow}} = \frac{1.2\ \mathrm{m}}{0.8\ \mathrm{m}} = 1.5$. For the taller pole, height $= 1.5 \times 3.6\ \mathrm{m} = 5.4\ \mathrm{m}$.

2. $60\ \mathrm{cm}$ to $75\ \mathrm{cm}$.

   The top of the rear toy's head is $12.3\ \mathrm{cm}$ high. In the photo, that point appears at the same vertical level as a point about halfway up the crown of the front toy. That point is $8.5\ \mathrm{cm}$ high on the front toy. Reasoning proportionally,

   $$\frac{d + 30.0\ \mathrm{cm}}{12.3\ \mathrm{cm}} = \frac{d}{8.5\ \mathrm{cm}},$$

   where d is the distance from the camera to the front toy. Solving for d, we find $d \approx 67\ \mathrm{cm}$. To account for measurement uncertainty, any answer from $60\ \mathrm{cm}$ to $75\ \mathrm{cm}$ should be counted correct.

3. $1440\ \mathrm{kJ}$.

   Power for incandescent: $P_{\text{inc}} = \frac{900\ \mathrm{lm}}{15\ \mathrm{lm/W}} = 60\ \mathrm{W}$.

   Power for LED: $P_{\text{LED}} = \frac{900\ \mathrm{lm}}{90\ \mathrm{lm/W}} = 10\ \mathrm{W}$.

   Power saved: $60\ \mathrm{W} - 10\ \mathrm{W} = 50\ \mathrm{W}$.

   Time per day: $8\ \mathrm{h} = 8 \times 3600\ \mathrm{s} = 28800\ \mathrm{s}$.

   Energy saved: $50\ \mathrm{W} \times 28800\ \mathrm{s} = 1{,}440{,}000\ \mathrm{J} = 1440\ \mathrm{kJ}$.

4. H, I, N, O, S, X, Z.

   A pinhole camera inverts the image both horizontally and vertically (equivalent to a 180° rotation). Letters that have 180° rotational symmetry appear unchanged. These are: H, I, N, O, S, X, and Z.

5. $22^\circ\mathrm{C}$ to $28^\circ\mathrm{C}$.

   Time for sound in rod: $t_{\text{rod}} = \frac{100\ \mathrm{m}}{3500\ \mathrm{m/s}} \approx 0.0286\ \mathrm{s}$.

   Time for sound in air: $t_{\text{air}} = t_{\text{rod}} + 0.260\ \mathrm{s} = 0.0286\ \mathrm{s} + 0.260\ \mathrm{s} = 0.2886\ \mathrm{s}$.

   Speed of sound in air: $v_{\text{air}} = \frac{100\ \mathrm{m}}{0.2886\ \mathrm{s}} \approx 347\ \mathrm{m/s}$.

   Looking at the chart, a speed of sound of approximately $347\ \mathrm{m/s}$ corresponds to a temperature of about $25^\circ\mathrm{C}$. Answers in a small range around this value are counted correct due to the difficulty of reading the chart exactly.

6. Blue.

   Cyan ink absorbs red light (transmits green and blue). Magenta ink absorbs green light (transmits red and blue).

   When both inks are on white paper:

- White light hits the ink on top of the paper.
- Cyan absorbs the red component.
- Magenta absorbs the green component.
- Only blue light is reflected.

The answer is blue.

7. 9.4 m/s.

   Each revolution of the wheel causes 32 clicks (one per spoke). Frequency of clicks: 160 Hz means 160 clicks per second.

   Revolutions per second: $\dfrac{160 \text{ clicks/s}}{32 \text{ clicks/rev}} = 5 \text{ rev/s}$.

   Circumference of wheel: $C = \pi d = \pi \times 0.60 \text{ m} = 0.60\pi \text{ m}$.

   Speed: $v = 5 \text{ rev/s} \times 0.60\pi \text{ m/rev} = 3\pi \text{ m/s} \approx 9.42 \text{ m/s}$.

8. A.

   Imagine starting with a large object distance (object far from the lens) and moving the object closer. As the object approaches the lens's focal point, light from a given point on the object emerges from the lens very nearly parallel. The light would take a very long distance to converge, so the image distance has a vertical asymptote at the focal length. The only graph showing this behavior is graph A. Note that the horizontal asymptote as the object distance goes to infinity is to an image distance value that is also the focal length of the lens.

   More formally, the thin lens equation is $\dfrac{1}{o} + \dfrac{1}{i} = \dfrac{1}{f}$, which gives $i = \dfrac{of}{o - f}$.

   For a converging lens, $f > 0$:

   - When $o = f$, the denominator is zero, so $i \to \infty$ (vertical asymptote).
   - When $o \to \infty$, $i \to f$ (horizontal asymptote).
   - When $o > f$, i is positive and decreases from ∞ toward f.

   This describes a hyperbola with a vertical asymptote at $o = f$ and approaching $i = f$ as o increases, which is graph A.

9. 10 m/s.

   The siren frequency is $f_0 = 700 \text{ Hz}$. The observer behind the ambulance hears two sounds: the direct sound from the siren (Doppler-shifted down because the ambulance is moving away) and the reflection off the wall (Doppler-shifted up because the ambulance is moving toward the wall).

   Because the ambulance is moving much slower than the speed of sound, these two Doppler shifts are approximately equal in size. The beat frequency of 40 Hz comes from the difference between the shifted-up and shifted-down frequencies, so each individual shift is about half the beat frequency, or 20 Hz.

For small speeds, the Doppler shift is approximately $\Delta f \approx f_0 \cdot \frac{v_s}{v}$, where v_s is the speed of the ambulance and $v = 343\ \mathrm{m/s}$ is the speed of sound. Setting this equal to $20\ \mathrm{Hz}$:

$$20\ \mathrm{Hz} \approx 700\ \mathrm{Hz} \cdot \frac{v_s}{343\ \mathrm{m/s}}.$$

Solving for v_s:

$$v_s \approx \frac{20\ \mathrm{Hz} \times 343\ \mathrm{m/s}}{700\ \mathrm{Hz}} \approx 9.8\ \mathrm{m/s} \approx 10\ \mathrm{m/s}.$$

Another solution is to use the Doppler shift formula twice: once for the reflection and once for the sound directly from the ambulance. The difference between the two expressions can be solved algebraically for v_s. This approach requires solving a quadratic equation and is beyond the mathematical level of this course.

10. $54\ \mathrm{cm}$.

The fundamental frequency of a vibrating wire obeys $f \propto \frac{1}{L}\sqrt{T}$, where T is tension and L is length.

Since the same brick hangs from the wire, the tension is the same. Therefore $f \propto \frac{1}{L}$, or $fL =$ constant.

Three semitones correspond to a frequency ratio of $2^{3/12} = 2^{1/4} \approx 1.189$.

C3 frequency: $f_{C3} = 110\ \mathrm{Hz} \times 2^{3/12} \approx 130.8\ \mathrm{Hz}$.

Since $f_1 L_1 = f_2 L_2$:

$$110\ \mathrm{Hz} \times 64\ \mathrm{cm} = 130.8\ \mathrm{Hz} \times L_2.$$

$$L_2 = \frac{110\ \mathrm{Hz} \times 64\ \mathrm{cm}}{130.8\ \mathrm{Hz}} \approx 53.8\ \mathrm{cm} \approx 54\ \mathrm{cm}.$$