Allowed: One sheet of notes, pencils, scratch paper, calculator, ruler. No time limit.

Each multiple choice problem is worth 4 points. Unless otherwise indicated, for multiple choice questions with numerical answers, the choices represent the answer rounded to three significant figures. Answers to the multiple choice problems should be recorded on your bubble sheet.

Each of the worked problems is worth 9 points. Your work and answers to the worked problems should be done on your “Worked Problem Answer Sheet.” Put your correct CID on the Worked Problem Answer Sheet or you will lose 5 points! If you choose to keep your note sheet or your scratch paper, make sure they are stapled well and aligned with the answer sheet, or you will lose up to 5 points!

To receive full credit on the worked problems section, please show all work clearly and write neatly. If you wish to get partial credit on problems with incorrect answers, be sure to solve all questions algebraically first, then plug in numbers (with units) to get the final answer. Unless otherwise instructed, give all numerical answers to three significant digits in SI units.

Do not do work for one problem in space allotted for another problem.

Remember to keep extra digits in intermediate results, otherwise your final answer may be off. Also, check that your results make sense and have correct units. You can also consider what happens when you set a variable to a value that gives you a known result.

**Possibly Useful Information**

Acceleration due to Gravity \( g = 9.8 \text{ m/s}^2 \)

Atmospheric Pressure \( P_0 = 1.013 \times 10^5 \text{ Pa} \)

Density of Water \( \rho_w = 1000 \text{ kg/m}^3 \)

**Multiple Choice**

1. You are tuning a guitar string by playing the guitar string at the same time you play the same note on an electric keyboard. The keyboard is playing a note with a frequency of 147 Hz. The guitar string is making a pitch which is slightly higher in frequency, causing the combined sound of the guitar and keyboard to get louder and softer, with a time of 0.209 seconds between each loud beat. What is the frequency of the sound being produced by the guitar?

   (a) 157 Hz
   (b) 149 Hz
   (c) 137 Hz
   (d) 145 Hz
   (e) 152 Hz
   (f) 142 Hz
   (g) None of the above

2. A pot of water is on top of a precision scale which reads weight in Newtons. I stick one end of a pencil into the water. The pencil is a cylinder with a diameter of 6.48 mm and I push it a distance of 7.72 cm into the water. How much does the reading on the scale change?

   (a) 3.37 N
   (b) \( 9.98 \times 10^{-2} \text{ N} \)
   (c) \( 2.55 \times 10^{-3} \text{ N} \)
   (d) \( 2.50 \times 10^{-5} \text{ N} \)
   (e) 30.8 N
   (f) \( 2.50 \times 10^6 \text{ N} \)
   (g) None of the above

3. When a particular submarine is submerged such that the center of its volume is 103 m below
surface of the water, the buoyant force on the submarine is $1.86 \times 10^7$ N. What would the buoyant force on the submarine be if it was instead at a depth of 147 m?

(a) $1.86 \times 10^7$ N  
(b) $1.31 \times 10^7$ N  
(c) $2.65 \times 10^7$ N  
(d) $3.78 \times 10^7$ N  
(e) $1.91 \times 10^7$ N  
(f) $2.01 \times 10^7$ N  
(g) None of the above

4. Water is flowing from a storage tank, through a pipe with a diameter of 2.23 cm, and into a bucket. The end of the pipe connected to the storage tank is 7.14 m above the end just above the bucket. The pressure of the water at the top of the pipe is not given, but the end of the pipe over the bucket is open to atmospheric pressure. The bucket has a volume of $3.03 \times 10^{-2}$ m$^3$. It takes a time of 8.43 seconds for the bucket to fill up. What is the velocity of the water in the pipe?

(a) 11.8 m/s  
(b) 2.30 m/s  
(c) $9.20 \times 10^{-4}$ m/s  
(d) 18.5 m/s  
(e) $9.20$ m/s  
(f) 654 m/s  
(g) None of the above

5. Iron Man dives into a lake of liquid gallium. At one point a sensor in Iron Man’s supersuit indicates that the absolute pressure is $3.59 \times 10^9$ Pa. How deep under the surface of the gallium is Iron Man? The density of gallium is $6.10 \times 10^3$ kg/m$^3$. Assume that the surface of the liquid gallium is at atmospheric pressure.

(a) 356 m  
(b) 60.1 m  
(c) $2.09 \times 10^{11}$ m  
(d) 61.7 m  
(e) $58.4$ m  
(f) $2.15 \times 10^{11}$ m  
(g) None of the above

6. An organ pipe which is open at both ends is 0.669 m long. What is the frequency of the lowest-frequency resonance in the pipe? Assume that the speed of sound is 343 m/s.

(a) $128$ Hz  
(b) $459$ Hz  
(c) $256$ Hz  
(d) $513$ Hz  
(e) $1.34$ Hz  
(f) $229$ Hz  
(g) None of the above

7. A bottle is surrounded by air at atmospheric pressure. Inside the bottle the pressure is $4.08 \times 10^4$ Pa. There is a stopper in the bottle with a radius of 1.12 cm. Neglecting things like friction or compression of the stopper, and only considering pressure, how much force do you need to apply to remove the stopper?

(a) $23.8$ N  
(b) $9.78 \times 10^{-4}$ N  
(c) 56.0 N  
(d) 5.96 N  
(e) $1.54 \times 10^8$ N  
(f) 16.1 N  
(g) None of the above

8. A string with a linear mass density of $8.17 \times 10^{-2}$ kg/m is stretched to a tension of 7.41 N and held between two clamps which are 1.83 m apart. What is the frequency of the fundamental mode (the first harmonic) of this string?

(a) $34.9$ Hz  
(b) $49.6$ Hz  
(c) $4.98$ Hz  
(d) $5.20$ Hz  
(e) $24.8$ Hz  
(f) $2.60$ Hz  
(g) None of the above

9. You are sitting a distance of 14.0 m from a small speaker which is playing music. The sound level at your location is 55.0 dB. Assuming that the waves emitted are approximately spherical, how far from the speaker should you sit if you want the sound level to be $8.00$ dB?

(a) $30.4$ m  
(b) $6.25 \times 10^{-2}$ m  
(c) $7.02 \times 10^5$ m  
(d) $3.13 \times 10^3$ m  
(e) $4.43 \times 10^{24}$ m  
(f) $3.95 \times 10^{11}$ m  
(g) None of the above
10. You hook one end of a hose up to a water pump. You put a nozzle on the other end. The hose has an inner diameter of 26.7 mm, and the nozzle has an inner diameter of 3.07 mm. If you want the water to come out of the nozzle with a velocity of 13.8 m/s, what pressure does the pump need to generate in the hose? Assume that the height difference between the pump and the nozzle is negligible, and assume that the water exiting the nozzle is at atmospheric pressure.

(a) $1.86 \times 10^5$ Pa
(b) $7.66 \times 10^5$ Pa
(c) $1.97 \times 10^5$ Pa
(d) $2.92 \times 10^5$ Pa
(e) $1.08 \times 10^5$ Pa
(f) $9.40 \times 10^4$ Pa
(g) None of the above

11. You are standing still and Iron Man is flying toward you while whistling at a frequency of 517 Hz. But you hear a frequency of $2.02 \times 10^3$ Hz. How fast is Iron Man flying? Assume that the speed of sound is 343 m/s.

(a) $1.68 \times 10^3$ m/s
(b) $1.34 \times 10^3$ m/s
(c) 87.8 m/s
(d) 997 m/s
(e) 431 m/s
(f) $255$ m/s
(g) None of the above

12. A clothesline is tied to the trunk of a tree at one end. The other end is tied to a brick with a weight of 21.0 N and tossed over a horizontal branch of another tree 18.0 m away. You flick the line, and you notice that the wave travels from one end of the clothesline to the other in 0.484 s. What is the linear mass density of the line?

(a) $1.52 \times 10^{-2}$ kg/m
(b) $6.07 \times 10^{-2}$ kg/m
(c) 11.9 kg/m
(d) 0.565 kg/m
(e) $2.90 \times 10^4$ kg/m
(f) 23.7 kg/m
(g) None of the above

13. I dip the end of a stick into a pond. I wiggle it up and down once every 0.670 seconds. I notice that the ripples going out from the stick have a wavelength of 0.192 m. At what speed do the waves travel on the water?

(a) $0.287$ m/s
(b) $1.80$ m/s
(c) $3.49$ m/s
(d) $4.56 \times 10^{-2}$ m/s
(e) $0.129$ m/s
(f) $1.87$ m/s
(g) None of the above

14. An organ pipe with a length of 7.44 m is open at both ends. I want to make another organ pipe which is open at one end and closed at the other which has the same fundamental frequency (lowest harmonic) as the first pipe. How long should I make it?

(a) 1.86 m
(b) 7.44 m
(c) 29.8 m
(d) 11.2 m
(e) 14.9 m
(f) $3.72$ m
(g) None of the above

15. A Bothan spaceship is approaching Earth. The Bothan ship shoots a laser at you. You know that Bothan ships have lasers with a wavelength of 834 nm, but you measure the light to be at a wavelength of 111 nm. How fast is the Bothan ship approaching Earth? Note that the speed of light is $2.9979 \times 10^8$ m/s.

(a) $5.13 \times 10^6$ m/s
(b) $2.29 \times 10^8$ m/s
(c) $1.63 \times 10^{10}$ m/s
(d) $2.79 \times 10^8$ m/s
(e) $2.89 \times 10^8$ m/s
(f) $2.95 \times 10^8$ m/s
(g) None of the above

16. Two speakers are vibrating in phase with each other at a frequency of 973 Hz. You set the first speaker down facing north. You then walk directly north a distance $x$ and set the second speaker down facing north. Then you walk three more meters north. Then you stop and listen to the sound. What is the smallest $x$ can be such that the sound from the two speakers will interfere destructively, producing maximum cancellation, when you stop and listen to them? Assume that the speed of sound is 343 m/s.

(a) $6.67 \times 10^5$ m
(b) $8.81 \times 10^{-2}$ m
(c) $0.176$ m
(d) $1.67 \times 10^5$ m
(e) 0.353 m
(f) 0.705 m
(g) None of the above
Free Response

17. You carefully align two high-speed video cameras so that they are pointing straight up. One of the cameras is placed 95.0 meters away from the other one. A plane flies over the two cameras. Analyzing the video, you discover that the plane flew directly over the second camera 0.136 seconds after it flew directly over the first camera. You also discover that the sonic boom hit the microphone on the first camera 17.2 seconds after it passed directly over that camera. How high was the plane flying? Assume that the speed of sound is 343 m/s.

18. When a particular string is put on a cello and tightened to a tension of 149 N, the 3rd harmonic on the string has a frequency of 323 Hz. What should I change the tension to so that the 3rd harmonic has a frequency of 116 Hz? Assume that changing the tension does not change the length or the linear mass density of the string.

19. A pump is pumping water from a lake up a hill to a spigot a height of 34.2 meters above the outlet of the pump. The pipe carrying the water has a radius of 24.8 cm at the outlet of the pump, and the pipe tapers such that it has a radius of 11.4 cm at the spigot. Water flows out of the spigot with a velocity of 6.94 meters per second. What is the pressure in the tube at the outlet of the pump?

20. A cube of wood which is 8.93 cm on a side is floating in water. What is the distance from the bottom of the cube to the top of the water? Assume that the top of the cube is parallel to the surface of the water, and assume that the density of wood is 784 kg/m$^3$. 

Solutions

17. If the distance between the cameras is $L$ and the time between the plane flying over the two cameras is $t_f$, then the velocity of the plane is

$$v_b = \frac{L}{t_f}.$$

This means that the angle of the Mach cone is given by

$$\theta = \arcsin \left( \frac{vt_f}{L} \right).$$

If the time from when the plane passes the first camera to when the sonic boom hits the first camera is $t_b$, then the plane is a distance $v_s t_b$ past the camera when the sonic boom hits. Using this distance and the angle of the Mach cone, we get

$$\tan \theta = \frac{h}{v_s t_b}$$

$$h = v_s t_b \tan \theta$$

$$h = \frac{L}{t_f} t_b \tan \left( \arcsin \left( \frac{vt_f}{L} \right) \right)$$

$$h = \frac{95.0 \text{ m}}{0.136 \text{ s} \cdot 17.2 \text{ s} \cdot \tan \left( \arcsin \left( \frac{343 \text{ m/s}}{95.0 \text{ m}} \right) \right)}$$

$$h = 6.77 \times 10^3 \text{ m}$$

18. The frequency of the $n^{\text{th}}$ harmonic on a string is given by

$$f_n = \frac{v}{2L}.$$

So to change the frequency, we need to change the wave velocity, which is given by

$$v = \sqrt{\frac{T}{\mu}}$$

So if I call the first frequency $f_a$ and the new frequency $f_b$, our basic equations are

$$f_a = \frac{\sqrt{T_a}}{2L\sqrt{\mu}}$$

and

$$f_b = \frac{\sqrt{T_b}}{2L\sqrt{\mu}}.$$  

Dividing the two equations makes the $2L\sqrt{\mu}$ cancel, giving us

$$\frac{f_b}{f_a} = \frac{\sqrt{T_b}}{\sqrt{T_a}}$$

$$T_b = T_a \left( \frac{f_b}{f_a} \right)^2$$

$$T_b = 149 \text{ N} \left( \frac{116}{323} \right)^2$$

$$T_b = 19.2 \text{ N}$$
19. If I call the outlet of the pump point \( a \) and the spigot point \( b \), then Bernoulli’s equation tells us that

\[
P_a + \frac{1}{2} \rho v_a^2 + \rho g h_a = P_b + \frac{1}{2} \rho v_b^2 + \rho g h_b.
\]

Solving this for \( P_a \) we get

\[
P_a = P_b + \frac{1}{2} \rho v_a^2 + \rho g h_a - \frac{1}{2} \rho v_b^2 - \rho g h_b
\]

or

\[
P_a = P_b + \frac{1}{2} \rho \left( v_a^2 - v_b^2 \right) + \rho g (h_b - h_a).
\]

The pressure at the spigot is atmospheric pressure, and we are given \( v_b \), \( \rho \), \( h_b - h_a \), and \( g \). So all we are missing is \( v_a \).

The continuity equation tells us that \( A_a v_a = A_b v_b \). So

\[
v_a = \frac{A_b}{A_a} v_b = \left( \frac{r_b}{r_a} \right)^2 v_b
\]

and

\[
P_a = P_b + \frac{1}{2} \rho v_b^2 \left[ 1 - \left( \frac{r_b}{r_a} \right)^4 \right] + \rho g (h_b - h_a).
\]

Plugging numbers in we get

\[
P_a = 1.013 \times 10^5 \text{Pa} + \frac{1}{2} \times 1.00 \times 10^3 \text{kg/m}^3 \left( \frac{6.94 \text{m}}{s} \right)^2 \left( 1 - \left( \frac{0.114}{0.248} \right)^4 \right) + 1.00 \times 10^3 \text{kg/m}^3 \times 9.80 \text{m/s}^2 \times 34.2 \text{m}
\]

\[
= 1.013 \times 10^5 \text{Pa} + 2.30 \times 10^4 \text{kg/ms}^2 + 3.35 \times 10^5 \text{kg/ms}^2
\]

Or

\[
P_a = 4.59 \times 10^5 \text{Pascals}
\]

20. If I call the length of the cube side \( L \) and the density of the wood \( \rho \), then the mass of the cube is

\[m = \rho L^3.\]

To be in equilibrium, an equal mass of water must be displaced. So the volume of the displaced water is such that

\[\rho L^3 = \rho_{\text{water}} V_{\text{displaced}}.\]

This means that

\[V_{\text{displaced}} = L^3 \frac{\rho}{\rho_{\text{water}}}.\]

But the volume of the displaced water is \( L^2 h \), where \( h \) is the depth of the bottom of the cube. So

\[h = L \frac{\rho}{\rho_{\text{water}}}.\]

\[h = 8.93 \text{ m} \frac{784}{1.00 \times 10^3} \]

\[h = 7.00 \text{ cm}\]