Some useful relations:

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Problem #1

This problem has two parts. A guitar string has length $L$ and mass $m$. The string produces isotropic sound waves with fundamental frequency $f_0$.

a) Draw on a plot the fundamental mode generated on the string and find its wavelength.

b) Find the tension $T$ of the string.

c) Find the wavelength of the sound wave produced by the string in air.

Assume the speed of sound in air is $v_o$ and write your results only in terms of $v_o$, $L$, $m$, and $f_0$.

d) At a distance $d$ from the string the intensity of the wave in air is $I_o$ and the displacement of the sound wave can be described by the function $z = A cos(2\pi f_0 t)$. What is the wave intensity at half the distance?

e) Write the function describing the displacement of the wave at half the distance (ignore any phase shift).
Problem #2

An ideal gas has with molar heat capacity at constant pressure $c_p$. A quantity of $n$ moles of the gas is initially at pressure $p_o$ and volume $V_o$. The gas first expands isothermally to twice the volume, it is then compressed isobarically (constant pressure) to the initial volume and it is finally brought back to the original state through an isochoric process (constant volume). Write your results only in terms of $n$, $p_o$, $V_o$, and $c_p$.

a) Draw the process on the p-V diagram on the left.

b) Calculate the change in entropy during the isothermal process.

c) Calculate the change in entropy during the isobaric process.

d) Calculate the change in entropy during the isochoric process.

e) Calculate the total change in entropy during the whole cycle.
Problem #3

A sonar uses sound waves to find the direction, distance, and speed of an unknown object. The sonar emits a short sound wave isotropically at frequency $f_0$ and with average power $P_0$. The sound is reflected by a moving object and is detected back by the sonar. A stationary submarine uses a sonar to identify a ship moving toward it with speed $v_0$.

a) Find the frequency of the sound wave heard aboard the ship.
b) Find the frequency of the sound wave received by the submarine.
c) Find the wavelength of the sound reflected by the ship.
d) If the intensity of the sound received by the ship is $I$, what is the distance of the ship from the submarine?

Assume that the speed of sound is $v$ and write your results in terms only of $v, f_0, P_0, v_0$, and $I$. 

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Some useful relations:
(Feel free to detach this page and keep for your own record)

Density: \[ \rho = \frac{m}{V} \]
Pressure & depth: \[ dp = \rho g dy; \quad \text{if } \rho \text{ is constant: } p = p_o + \rho gh \]
Continuity: \[ A_1 v_1 = A_2 v_2 \]
Bernoulli: \[ p_1 + \rho gh_1 + \frac{1}{2} \rho v_1^2 = p_2 + \rho gh_2 + \frac{1}{2} \rho v_2^2 \]
Volume expansion: \[ dV = V_0 \beta dT \]
Specific heat capacity: \[ dQ = mc dT \]
Latent heat: \[ Q = \pm mL \]
Heat transfer: \[ \frac{dQ}{dt} = k_A \frac{T_H - T_C}{L} \]
Ideal gas equation of state: \[ pV = nRT \]
Adiabatic processes: \[ p V^\gamma = \text{const.}, \quad T V^{\gamma - 1} = \text{const.} \]
Average molecular energy: \[ \frac{1}{2} s k_B T, \quad \text{with } s = \text{number of degrees of freedom.} \]
1st lat of thermodynamic: \[ \Delta U = Q - W \]
Heat in an isobaric process: \[ dQ = n c_p dT \]
Heat in an isochoric process: \[ dQ = n c_V dT; \quad c_p = c_V + R \]
Work: \[ dW = pdV \]
Engine efficiency: \[ e = \frac{W}{Q_H}; \quad \text{Carnot: } e = 1 - \frac{T_C}{T_H} \]
Coefficient of Performance: \[ K = \frac{Q_C}{|W|}; \quad \text{Carnot: } K = \frac{T_C}{T_H - T_C} \]
Entropy: \[ dS = \frac{dQ}{T} \]

Speed of propagation of a wave on a string: \[ v = \sqrt{\frac{T}{\mu}} \]
Wave equation: \[ \frac{\partial^2 y(x,t)}{\partial x^2} = \frac{1}{v^2} \frac{\partial^2 y(x,t)}{\partial t^2} \]
Doppler shift: \[ f_r = \frac{v - v_L}{v - v_S} f_s \] (remember sign convention: S R)
Intensity: \[ I = \frac{<\text{Power}>}{\text{Area}} \]
For periodic sound wave: \[ I = \frac{1}{2} A^2 \omega^2 \sqrt{\rho B} \]
Speed of propagation of sound in an ideal gas: \[ v = \sqrt{\frac{\gamma RT}{M}} \]