Physics 4C Spring 2017 Final Exam

Name: ________________________

June 26, 2017

Please show your work! Answers are not complete without clear reasoning. When asked for an expression, you must give your answer in terms of the variables given in the question and/or fundamental constants.

Answer as many questions as you can, in any order. Calculators are allowed. Books and notes are not allowed. Use any blank space to answer questions, but please make sure it is clear which question your answer refers to.

$g = 9.8$ ms^{-2}

$c = 3.00 \times 10^8$ m/s

atmospheric pressure $P_0 = 1.013 \times 10^5$ Pa

density of water $\rho_w = 1000$ kg/m^3

$\rho_{\text{air}} = 1.20$ kg m^{-3} (sea level, 20°C)

Fahrenheit to Celsius:

([°F] − 32) ÷ 1.8 =[°C]

Celsius to Fahrenheit:

([°C] × 1.8) + 32 =[°F]

$k_B = 1.38 \times 10^{-23}$ J/K

$N_A = 6.022 \times 10^{23}$

$R = 8.314$ J mol^{-1} K^{-1}

$m_p = 1.67 \times 10^{-27}$ kg

$\sigma = 5.6696 \times 10^{-8}$ W m^{-2} K^{-4}

1 cal = 4.186 J

$I_0 = 1.00 \times 10^{-12}$ W m^{-2}

Trigonometric Identities

$\sin^2\theta + \cos^2\theta = 1$

$\sin(\alpha \pm \beta) = \sin\alpha\cos\beta \pm \cos\alpha\sin\beta$

$\cos(\alpha \pm \beta) = \cos\alpha\cos\beta \mp \sin\alpha\sin\beta$

$\sin\alpha + \sin\beta = 2\cos\left(\frac{\alpha-\beta}{2}\right)\sin\left(\frac{\alpha+\beta}{2}\right)$

$\cos\alpha + \cos\beta = 2\cos\left(\frac{\alpha-\beta}{2}\right)\cos\left(\frac{\alpha+\beta}{2}\right)$

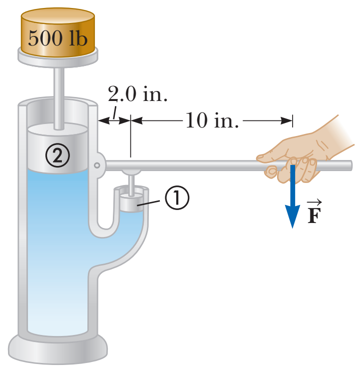
$\sin\left(\theta + \frac{\pi}{2}\right) = \cos\theta$

$\cos\left(\theta + \frac{\pi}{2}\right) = -\sin\theta$

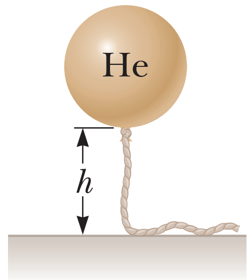
1. **[7pts]** In the diagram, piston 1 has a diameter of 0.200 cm. Piston 2 has a diameter of 1.40 cm.

   (a) Using the values given in the diagram, determine the magnitude of the force F necessary to support the 2220-N (500-lb) load in the absence of friction. [6 pts]

   (b) What is the name of the fluid principle used here? [1 pt]



2. A helium-filled balloon (whose envelope has a mass of $m_b = 0.240$kg) is tied to a uniform string of length $\ell = 2.00$ m and mass $m = 0.0650$ kg. The balloon is spherical with a radius of $r = 0.400$ m. When released in air of temperature 20°C, standard atmospheric pressure, and density $\rho_{air} = 1.20$ kg/m^3, it lifts a length h of string and then remains stationary as shown. Find the length of string lifted by the balloon. (Helium is a monatomic gas and each atom has two neutrons and two protons.) **[10 pts]**



3. **[20pts]** A sample of an ideal monatomic gas with n moles is taken through the cycle shown. The process $A \to B$ is a reversible isothermal expansion. Using the information given on the graph:

(a) What is the change in the internal energy in process $A \to B$? [1 pt]

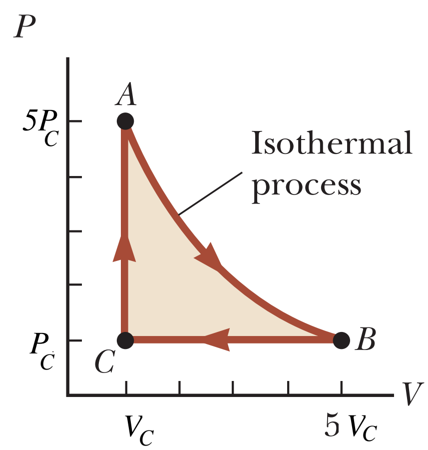
(b) What is the work done on the gas in the process $A \to B$? [4 pts]

(c) What is the entropy change in complete cycle ABCA? [1 pt]

(d) Find the entropy change for each of the three steps of the cycle. [9 pts]

(e) Explicitly confirm your answer to part (c) using your answers to part (d). [3 pts]

(f) Consider an adiabatic free expansion that starts at the state A and ends at the state B. What is the entropy change in that process and why? [2 pts]



4. [**16pts**] A transverse sinusoidal wave on a string has a period $T = 35.0$ ms and travels in the negative x direction with a speed of 30.0 m/s. At $t = 0$, an element of the string at $x = 0$ has a transverse position of 2.00 cm and is traveling upward with a speed of 200 cm/s.

   (a) What is the amplitude of the wave? [6 pts]

   (b) What is the initial phase angle? [4 pts]

   (c) What is the maximum transverse speed of an element of the string [2 pts]

   (d) Write the wave function for the wave filling in all values as appropriate. [4 pts]

5. Two train whistles have identical frequencies, f. When one train is at rest in the station and the other is moving nearby along a straight track, a commuter standing next to the track hears beats with a frequency of f_b when the whistles operate together. Let v be the speed of sound. Find expressions for the two possible speeds the moving train can have, and give the direction the train is moving in each case. [**8 pts**]

6. **[10pts]** The distance between an object and its upright image is 18.0 cm. If the magnification is 0.500,

   (a) what kind of mirror is being used to form the image? [1 pt]

   (b) what is the focal length of the mirror? [9 pts]

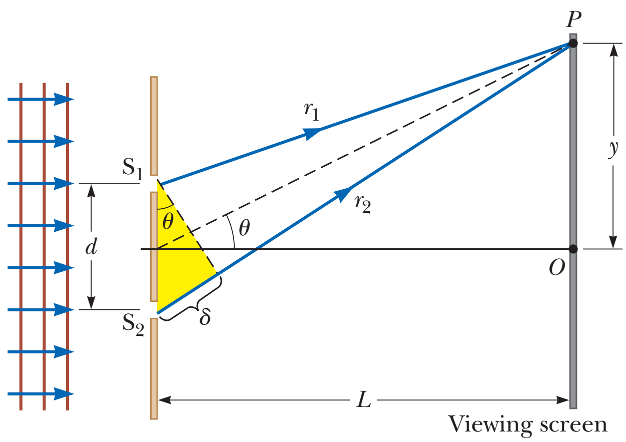
7. **[14pts]** In the double-slit arrangement shown, the slit separation is d, the distance to the screen is L, the wavelength of incident light is λ, and the distance from the center of the screen to the point P is y.

(a) What are the conditions on δ for constructive interference and for destructive interference? (If you introduce any new variable say what values it can take.) [3 pts]

(b) Find an expression for the path difference δ for the rays from the two slits arriving at P in terms of d, y, and L, assuming $y << L$. [4 pts]

(c) Suppose the width of each slit is about $\frac{d}{10}$. You notice that the 10th order bright fringes of the double-slit interference pattern are missing, but you can see more faint bright fringes beyond that. What effect is causing this? [2 pts]

(d) If a thin sheet of transparent plastic having an index of refraction n and thickness t is placed over the upper slit (S_1), the central maximum of the interference pattern moves upward a distance y'. Assuming $(n-1) << 1$ and $\frac{t}{d} < 1$, find y' in terms of n, d, t, and L. [5 pts]



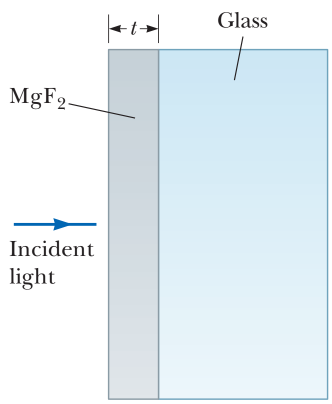
8. **[10pts]** A lens made of crown glass ($n_g = 1.52$) is coated with a thin film of MgF_2 ($n_s = 1.38$) of thickness $t = 95.1$ nm. Visible light is incident normally on the coated lens as shown.

   (a) What is the phase change for light that reflects off of the thin film back into the surrounding air? [1 pt]

   (b) For what frequency will the reflected light be missing, assuming the lens coating was made as thin as possible to achieve this effect? [4 pts]

   (c) What is the frequency of light that is closest to your answer to part (b) such that all of the incident light at that frequency is reflected? [4 pts]

   (d) Humans cannot see frequencies higher than about 7.5×10^{14} Hz, or lower than about 4.6×10^{14} Hz. Why would a thin film coating like the one in this question be put onto a lens? [1 pt]



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$P = \frac{F}{A}$

$P = P_0 + \rho g h$

$B = \rho g V$

$A_1 v_1 = A_2 v_2$

$P + \frac{1}{2}\rho v^2 + \rho g y =$const.

$\Delta L = \alpha L_i \, \Delta T$

$\Delta V = \beta V_i \, \Delta T$

$PV = nRT$

$PV = N k_B T \; (nR = N k_B)$

$n = \frac{m}{M}$

$Q = C \, \Delta T$

$Q = cm \, \Delta T$

$Q = mL$

$\Delta E_{\text{int}} = W + Q$

$W_{\text{on gas}} = -\int_{V_i}^{V_f} P \, \text{dV}$

$W = nRT \ln \left(\frac{V_i}{V_f} \right)$

$P = kA \left| \frac{\text{dT}}{\text{dx}} \right|$

$P = kA \left(\frac{T_h - T_c}{L} \right)$

$P = \sigma A e T^4$

$P = \frac{2}{3} \frac{N}{V} \bar{K}$

$\bar{K} = \frac{1}{2} m_0 \overline{v^2} = \frac{3}{2} k_B T$

$K_{\text{tot,trans}} = \frac{3}{2} N k_B T = \frac{3}{2} nRT$

$e = 1 - \frac{1}{(V_1/V_2)^(\gamma-1)}$

$Q = n C_V \, \Delta T$

$Q = n C_P \, \Delta T$

$\Delta E_{\text{int}} = n C_V \, \Delta T$

$\gamma = \frac{C_P}{C_V}$

$PV^\gamma = \text{const.}$

$TV^{\gamma-1} = \text{const.}$

$n_V(E) \propto e^{-E/k_B T}$

$N_v \propto v^2 e^{-m_0 v^2 / 2 k_B T}$

$v_{\text{rms}} = \sqrt{\frac{3 k_B T}{m_0}}$

$\Delta S = \int_i^f \frac{\text{dQ}_\text{r}}{T}$

$\Delta S = n C_v \ln \left(\frac{T_f}{T_i} \right) + nR \ln \left(\frac{V_f}{V_i} \right)$

$S = k_B \ln W$

$e = \frac{W_{\text{eng}}}{|Q_h|} = \frac{|Q_h| - |Q_c|}{|Q_h|} = 1 - \frac{|Q_c|}{|Q_h|}$

$\text{COP (cooling)} = \frac{|Q_c|}{W}$

$\text{COP (heating)} = \frac{|Q_h|}{W}$

$e = \frac{T_h - T_c}{T_h} = 1 - \frac{T_c}{T_h}$

$$\int_v^{v+\text{dv}} N_v \, \text{dv} = \int_v^{v+\text{dv}} 4\pi N \left(\frac{m_0}{2\pi k_B T} \right)^{3/2} v^2 e^{-m_0 v^2 / 2 k_B T} \, \text{dv}$$

$f = \frac{1}{T}$

$k = \frac{2\pi}{\lambda}$

$\omega = 2\pi f$

$T = 2\pi \sqrt{\frac{m}{k}}$

$T = 2\pi \sqrt{\frac{L}{g}}$

$\frac{\partial^2 y}{\partial x^2} = \frac{1}{v^2}\frac{\partial^2 y}{\partial t^2}$

$y(x,t) = f(x \mp vt)$

$v = f\lambda = \frac{\omega}{k}$

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

$y(x,t) = A\sin\left(kx - \omega t + \phi\right)$

$v_y = \frac{\partial y}{\partial t}$

$a_y = \frac{\partial^2 y}{\partial t^2}$

$P = \frac{1}{2}\mu\omega^2 A^2 v$

$y(x,t) = [2A\sin(kx)]\ \cos(\omega t)$

$v = (331 \text{ m/s})\sqrt{1 + \frac{T_{\text{Cel}}}{273}}$

$B = -\frac{\Delta P}{\Delta V/V_i}$

$y(t) = \sum_{n=1}^{\infty}\left(A_n \sin(2\pi n f t) + B_n \cos(2\pi n f t)\right)$

$v = \sqrt{\frac{B}{\rho}}$

$s(x,t) = s_{\max}\cos(kx - \omega t)$

$\Delta P(x,t) = (\Delta P_{\max})\sin(kx - \omega t)$

$\Delta P_{\max} = B\, s_{\max} k = \rho v \omega s_{\max}$

$I = \frac{P_{\text{avg}}}{A}$

$P_{\text{avg}} = \frac{1}{2}\rho v \omega^2 A\, s_{\max}^2$

$\lambda_n = \frac{2L}{n}$

$f_n = \frac{nv}{2L}$

$\lambda_{2n+1} = \frac{4L}{(2n+1)}$

$f_{2n+1} = \frac{(2n+1)v}{4L}$

$|L_2 - L_1| = n\lambda$

$|L_2 - L_1| = \frac{(2n+1)\lambda}{2}$

$f_{\text{beat}} = |f_1 - f_2|$

$\beta = 10\log_{10}\left(\frac{I}{I_0}\right)$

$f' = \left(\frac{v \pm v_0}{v \mp v_s}\right) f$

$\sin\theta = \frac{v}{v_s}$

$\text{Mach number} = \frac{v_s}{v}$

$E = hf$

$n = \frac{c}{v}$

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\sin\theta_c = \frac{n_2}{n_1}$

$M = \frac{h'}{h}$

$f = \frac{R}{2}$

$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$

$\frac{n_1}{p} + \frac{n_2}{q} = \frac{n_2 - n_1}{R}$

$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

$I \propto E^2$

$d\sin\theta = m\lambda$

$d\sin\theta = (m + \frac{1}{2})\lambda$

$I = I_{\max}\cos^2\left(\frac{\pi d \sin\theta}{\lambda}\right)$

$2nt = (m + \frac{1}{2})\lambda$

$2nt = m\lambda$

$r \approx \sqrt{\frac{m\lambda R}{n}}$

$\sin\theta = m\frac{\lambda}{a}$

$I = I_{\max}\left(\frac{\sin(\pi a \sin\theta/\lambda)}{\pi a \sin\theta/\lambda}\right)^2$

$\theta_{\min} = 1.22\,\frac{\lambda}{D}$

$I = I_{\max}\cos^2\theta$

$\tan\theta_p = \frac{n_2}{n_1}$