PHYSICS 2C FINAL EXAM WINTER QUARTER 2018
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Formulas:

$T_3 = 273.16K = 0.01^o C$; water freezes/boils at $T = 0^o C = 32^o F \,/\, T = 100^o C = 212^o F$

$1cal = 4.1868J$; $N_A = 6.02\times10^{23}$

Thermal expansion: $\Delta L = L\alpha\Delta T$; $\Delta V = V\beta\Delta T$; $\beta = 3\alpha$

Heat capacity and specific heat: $Q = C\Delta T$; $Q = cm\Delta T$

Heat of vaporization, fusion: $Q = L_V m$; $Q = L_F m$

First law of thermodynamics: $\Delta E_{\text{int}} = Q - W$; $\text{d}E_{\text{int}} = dQ - dW$; $\text{W}=\int_{V_i}^{V_f} p\,dV$ work

Conduction: $\text{P}_{cond} = \frac{Q}{t} = kA\frac{T_H - T_L}{L}$; $R = \frac{L}{k}$ k,R=thermal conductivity, resistance

Radiation: $P_{rad} = \sigma\varepsilon AT^4$; $\sigma = 5.67\times10^{-8} W/m^2K^4$ $\varepsilon = 1$ for black body

Ideal gas: $PV = nRT = NkT = nN_A kT$; R=8.31J/molK ; $k = 1.38\times10^{-23} J/K$

Pressure: $P = \frac{Nm}{3V}(v^2)_{avg}$ Kinetic energy: $K_{avg} = \frac{1}{2}m(v^2)_{avg} = \frac{3}{2}kT$

Internal energy: $E_{\text{int}} = NK_{avg}$; $C_V = \frac{3}{2}R$ for monoatomic gas; $C_P = C_V + R$

C_V, C_P = molar heat capacity at constant volume, pressure

$C_V = \frac{f}{2}R$ for polyatomic gases with f degrees of freedom per molecule

Adiabatic expansion of ideal gas: $PV^\gamma = const$, $TV^{\gamma-1} = const$; $\gamma = C_P / C_V$

Distribution of molecular speeds: $P(v) = 4\pi(\frac{m}{2\pi kT})^{3/2} v^2 e^{-mv^2/(2kT)}$

Velocity distribution: $F(v_x,v_y,v_z) = f(v_x)f(v_y)f(v_z)$, $f(v_x) = (\frac{m}{2\pi kT})^{1/2} e^{-mv_x^2/(2kT)}$

Mean free path: $\lambda = 1/(\sqrt{2}\pi d^2 N/V)$, d=diameter ; $v_{rms} = \sqrt{(v^2)_{avg}}$

Entropy: $dS = dQ/T$ in a reversible process. S is a function of state. $\Delta S = \int_i^f dQ/T$

$\Delta S \geq 0$ for a closed system. = if reversible process, > if irreversible process

Ideal gas: $S(T,V) = nR\ln V + nC_v \ln T + const$

Heat engine: $\varepsilon = \frac{|W|}{|Q_H|}$; Carnot engine: $\varepsilon = 1 - \frac{|Q_L|}{|Q_H|} = 1 - \frac{T_L}{T_H}$

Refrigerator coefficient of performance $K = \frac{|Q_L|}{|W|}$; Carnot refrigerator $K_C = \frac{T_L}{T_H - T_L}$

Statistical view of entropy: $S = k\ln W$; $W = N!/(n_1!\; n_2!\; ....)$; $N! \approx N(\ln N) - N$

Fluids: $\rho = m/V$, $p = F/A$, $1atm = 1.01x10^5 Pa = 760 torr$

Fluid at rest: $p_2 + \rho g y_2 = p_1 + \rho g y_1$; gauge pressure=p-$p_{atmospheric}$

Pascal's principle: $\Delta p = F_1 / A_1 = F_2 / A_2$

Archimedes principle: buoyant force $F_b = m_{fluid} g$

Continuity equation: volume flow rate = $R_V = Av$ = a constant

Bernoulli equation: $p + \frac{1}{2}\rho v^2 + \rho g y$ = a constant

Oscillations: simple harmonic motion: $x(t) = x_m \cos(\omega t + \phi)$; $\omega = 2\pi f = 2\pi / T$

spring: $F = -kx$, $\omega = \sqrt{k/m}$, energy: $E = U + K = \frac{1}{2}kx_m^2$; $U = \frac{1}{2}kx^2$, $K = \frac{1}{2}mv^2$

torsion pendulum: $\tau = -\kappa\theta$, $\omega = \sqrt{\kappa / I}$; simple pendulum: $\omega = \sqrt{g/L}$

physical pendulum: $\omega = \sqrt{mgh/I}$; $I = I_{CM} + mh^2 = \int r^2 dm$

Damped shm: $F_d = -bv$, $x(t) = x_m e^{-bt/2m}\cos(\omega' t + \phi)$, $\omega' = \sqrt{\omega^2 - (b/2m)^2}$

Forced oscillations: $F_f = f\cos(\omega_d t)$, $x(t) = x_m \cos(\omega_d t + \phi)$; resonance: $\omega_d = \omega$

$$x_m = (f/m)/\sqrt{(\omega_d^2 - \omega^2) + b^2\omega_d^2/m^2}, \quad \tan\phi = (b/m)\omega_d/(\omega_d^2 - \omega^2)$$

Waves:

$y(x,t) = y_m \sin(kx - \omega t)$; $\omega = 2\pi f = 2\pi / T$; $k = 2\pi/\lambda$; $v = \omega/k = \lambda f = \lambda / T$

string: $v = \sqrt{\tau/\mu}$; power: $P_{avg} = \frac{1}{2}\mu v \omega^2 y_m^2$

interference: $y'(x,t) = [2y_m \cos\frac{1}{2}\phi]\sin(kx - \omega t + \frac{1}{2}\phi)$

standing waves: $y'(x,t) = [2y_m \sin(kx)]\cos\omega t$; resonance: $f = \frac{v}{\lambda} = n\frac{v}{2L}$

speed of sound: $v = \sqrt{\frac{B}{\rho}}$; $B = -V\frac{\partial P}{\partial V})_S$; ideal gas: $B = \gamma P$

$s = s_m \cos(kx - \omega t)$; $\Delta p = \Delta p_m \sin(kx - \omega t)$; $\Delta p_m = v\rho\omega s_m$

interference: $\phi = \frac{\Delta L}{\lambda}2\pi$; constructive $\phi = 2\pi m$, destructive $\phi = \pi(2m+1)$

sound intensity $I = \frac{P}{A} = \frac{1}{2}\rho v \omega^2 s_m^2 = \frac{P_s}{4\pi r^2}$; decibels $\beta = (10\text{dB})\log\frac{I}{I_0}$, $I_0 = 10^{-12} W/m^2$

pipes: $f = \frac{nv}{2L},\ n = 1,2,3$ or $f = \frac{nv}{4L},\ n = 1,3,5$; beats $f_{beat} = f_1 - f_2$

Doppler: $f' = f\frac{v \pm v_D}{v \pm v_s}$; shock wave $\sin\theta = \frac{v}{v_S}$

Electromagnetic waves and optics:

$E = E_m \sin(kx - \omega t)$; $c = E/B = 1/\sqrt{\mu_0\varepsilon_0} = 2.998\times 10^8 m/s \approx 3\times 10^8 m/s$

$B = B_m \sin(kx - \omega t)$; $\mu_0 = 4\pi\times 10^{-7} Tm/A$; $\varepsilon_0 = 8.85\times 10^{-12} C^2/Nm^2$

Energy flow: $\vec{S} = (1/\mu_0)\vec{E}\times\vec{B}$; $S_{av} = I = 1/(c\mu_0)E_{rms}^2 = P_s/(4\pi r^2)$

Energy density: $u = u_E + u_B$; $u_E = (1/2)\varepsilon_0 E^2 = 1/(2\mu_0)B^2 = u_B$; $S = cu$

Radiation pressure: $p_r = I/c$ (absorption), $p_r = 2I/c$ (reflection)

Polarization: $I = (1/2)I_0$ if unpolarized, or $I = I_0\cos^2\theta$ if polarized

Reflection, refraction: $\theta_1 = \theta_1'$, $n_1\sin\theta_1 = n_2\sin\theta_2$

Total internal reflection $\theta_c = \sin^{-1}(n_2/n_1)$; Brewster angle $\theta_B = \tan^{-1}(n_2/n_1)$

Spherical mirror: $1/p + 1/i = 1/f = 2/r$; thin lens: $1/p + 1/i = 1/f$

lateral magnification (spherical mirror or thin lens) $m = -i/p$, $|m| = h'/h$

Index of refraction $n = c/v$, $\lambda_n = \lambda/n$

Young slits: $\Delta L = d\sin\theta = m\lambda$ (bright), $d\sin\theta = (m+1/2)\lambda$ (dark); $\phi = 2\pi\Delta L/\lambda$

Intensity: $I = 4I_0\cos^2(\phi/2)$; thin film $2L = (m+1/2)(\lambda/n_2)$(bright), (m) (dark)

Single slit diffraction: $a\sin\theta = m\lambda$ (minima), $I(\theta) = I_m(\sin\alpha/\alpha)^2$, $\alpha = (\pi a/\lambda)\sin\theta$

Circular aperture diffraction first minimum $\sin\theta = 1.22\lambda/d$, Raleigh criterion $\theta_R = 1.22\lambda/d$

Double slit diffraction: $I(\theta) = I_m\cos^2\beta(\sin\alpha/\alpha)^2$, $\beta = (\pi d/\lambda)\sin\theta$, $\alpha = (\pi a/\lambda)\sin\theta$

Diffraction gratings: $d\sin\theta = m\lambda$ (maxima), half widths $\Delta\theta_{hw} = \lambda/(Nd\cos\theta)$

Dispersion and resolving power: $D = \Delta\theta/\Delta\lambda = m/(d\cos\theta)$; $R = \lambda_{av}/\Delta\lambda = Nm$

X-ray diffraction: $2d\sin\theta = m\lambda$ (Bragg's law)

The exam has 16 problems counting 1 point each, and 4 “extra credit problems” counting 0.5 points each.
Pick the answers closest to the ones you find even if it is not the same.

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Problem 1 (1 point)
10g of steam at 100ºC are added to 200g of a mixture of water and ice in equal proportions that are in thermal equilibrium in a thermally insulated container. How much water is there when the system reaches again thermal equilibrium?
Heat of vaporization of water: 539 cal/g, heat of fusion of ice: 79.7 cal/g; specific heat of water: 1cal/g ºC
A: 210g; B: 200g; C: 190g; D: 180g; E: 170g

Problem 2 (1point)
A cylindrical glass bottle of height much larger than its radius is filled with water at 50ºC. The glass has thickness 0.2cm, and its thermal conductivity is 10^{-4}cal/(s cm ºC). The environment temperature is 20ºC. It takes 3 minutes for the temperature of the water to decrease by 1ºC. What is approximately the radius of the bottle?
Specific heat of water: 1cal/g ºC. Density of water: 1g/cm^3
A: 2cm; B: 2.4cm; C: 2.8cm; D: 3.2cm; E: 3.6cm

Problem 3 (1 point)
In an adiabatic expansion, a monatomic ideal gas does 10J of work in expanding from volume V to volume 2V. How much work does it approximately do in expanding adiabatically from volume 2V to volume 4V?
A: 6.3J; B: 8.5J; C: 9.4J; D: 10.7J; E: 13.6J

Problem 4 (1 point)
A gas has molecular weight 29g/mol. In a container, for every 1000 molecules of this gas that have speed 300m/s there are 500 molecules with speed 600m/s. What is the temperature of this gas?
A: 227K; B: 284K; C: 318K; D: 346K; E: 380K

Problem 5 (1 point)
You are ice skating while drinking a cup of coffee, and spill your coffee on the ice. The coffee freezes. What is approximately the change in entropy of the coffee in this process? Assume: (1) coffee=water; (2) your cup has 300g of coffee at 50ºC; (3) specific heat of water = 1cal/gºC; (4) heat of fusion of ice = 79.5 cal/g; (5) ice in ice skating rink is at temperature infinitesimally below 0ºC .
A: 0cal/K; B: -138cal/K; C: -87cal/K; D: -44cal/K; E: +68cal/K

Problem 6 (1 point)
n moles of a monatomic ideal gas initially at temperature T and volume V undergo free expansion to volume 2V. Then, the gas is compressed isothermally from volume 2V back to volume V. The change in the entropy of the environment in this entire process is:

A: $-nR\ln 2$; **B:** $\frac{3}{2}nR\ln 2$; **C:** $-\frac{3}{2}nR\ln 2$; **D:** $nR\ln 2$; **E:** 0

Problem 7 (extra credit problem) (0.5 points)
n moles of a monatomic ideal gas initially at temperature T and volume V undergo free expansion to volume 2V. Then, the gas is compressed adiabatically from volume 2V back to volume V. The change in the entropy of the environment in this entire process is**:**

A: $-nR\ln 2$ **; B:** $\frac{3}{2}nR\ln 2$ **; C:** $-\frac{3}{2}nR\ln 2$ **; D:** $nR\ln 2$ **; E:** 0

Problem 8 (1 point)
A Carnot engine operates reversibly at 20% efficiency producing 40J of work per cycle and releasing heat to the environment at room temperature (300K). What is the temperature of the heat reservoir from which it is absorbing heat?
A: 350K B: 375K; C: 400K; D: 425K; E: 450K

Problem 9 (1 point)
You are standing on a 2000kg block of ice that is floating on water and is 95% submerged. What is your mass?
Ice density: 0.92 g/cm^3*. Water density 1 g/cm*^{3}*. Your density 1.05 g/cm*^{3}*.*
A: 50 kg; B: 55 kg; C: 60 kg; D: 65 kg; E: 70 kg

Problem 10 (1 point)
Assume the ice you are standing on in Problem 9 has the shape of a cube. You jump off the ice into the water, and the ice starts oscillating up and down, with angular frequency:
A: 1.04rad/s; B: 1.96rad/s; C: 2.87rad/s; D: 3.62rad/s; E: 4.48rad/s

Problem 11 (1 point)
Water flows vertically down out of a circular faucet of diameter 2cm at speed 1m/s. You want to fill a bottle which has a circular opening of diameter 1.5 cm. What is the minimum distance below the faucet that you should put your bottle so that the water goes in without spilling over the sides?
A: 7cm; B: 8cm; C: 9cm; D: 10cm; E: 11cm

Problem 12 (1 point)
An aluminum sphere is suspended by a string above a tank of water. You pluck the string and hear its fundamental frequency at f=300Hz. Then the sphere is partially submerged so that half its volume is under water. What frequency will you hear if you pluck the string now? The density of aluminum is 2.7 g/cm^3.
A: 280Hz; B: 270Hz; C: 260Hz; D: 250Hz; E: 240Hz

Problem 13 (1 point)
A violin string has mass 4g and is under 216N tension. In its fundamental mode it emits sound of wavelength 227cm. What is the string's length?
V_{sound}=340m/s
A: 40cm; B: 45cm; C: 50cm; D: 55cm; E: 60cm

Problem 14 (1point)
You look at yourself in a concave spherical mirror and appear upright and twice as tall. If the mirror radius is R, how far from the mirror are you standing?
A: R/2 B: R/4; C: 3R/4; D: 5R/4; E: 3R/2

Problem 15 (extra credit problem) (0.5 points)
Radiation with electric field E_{rms}=100V/m is incident from all directions on a black body floating in outer space. In thermal equilibrium, what is the temperature of the black body?
A: 2660K B: 1420K; C: 612K; D: 147K; E: 84K

Problem 16 (1 point)
What is the minimum number of polarizing sheets that you need if you want to rotate the polarization direction of linearly polarized light by 90 degrees and keep at least 75% of its intensity?
A: 6; B: 7; C: 8; D: 9; E: 10

Problem 17 (1 point)
Instead of a double slit assume there are three pinholes arranged in an equilateral triangle of side length 1.5 mm through which coherent light goes through. On a screen that is 2m away you see three dark spots that are exactly aligned with the pinholes. What is the wavelength of the light?
A: 450nm; B: 530nm C: 600nm; D: 646nm; E: 695nm

Problem 18 (extra credit problem) (0.5 points)
For the interference-diffraction pattern from 2 slits of width 0.3mm each that are at distance 1mm from each other (center to center), what is the intensity of the first maximum off-center compared to the intensity at the center?
A: 99%; B: 98%; C: 97%; D: 96%; E: 95%

Problem 19 (1 point)
For a diffraction grating with 1000 slits and distance between adjacent slits 0.1mm, what is the half-width of the peak at 10cm from the central axis on a screen that is 2m away from the grating, for light of wavelength 500nm?
A: 1mm; B: .1mm C: .01mm; D: .001mm; E: .0001mm

Problem 20 (extra credit problem) (0.5 points)
For the diffraction grating of problem 19, how many other peaks are there between that peak and the peak at the central axis?
A: 4; B: 8; C: 12; D: 16; E: 20