PHYSICS 215 - Thermodynamics and Modern Physics

Practice Final Exam

Name: ______________________________

PID: ______________________________

Problem #1 _____

Problem #2 _____

Problem #3 _____

Problem #4 _____

Problem #5 _____

Problem #6 _____

Problem #7 _____

Problem #8 _____

Total _____/48

I will attempt to avoid multiple jeopardy. Please help me by giving an algebraic symbol for the answer to each part if you use it in subsequent parts.

Useful Constants: 1 calorie = 4.186 J
Latent heat of vaporization of water = 539 cal/g = 2256 kJ/kg
Latent heat of fusion of water = 79.5 cal/g = 333 kJ/kg
Specific heat of water = 1 cal/g = 4.19 kJ/kg
1 atmosphere = 1.01E5 Pa
Universal Gas Constant, R = 8.31 J/mol.K
Boltzmann's constant, k = 1.38E-23 J/K
Stefan-Boltzmann constant, σ = 5.67E-8 W/m^2K^4
Avogadro's number, N_A = 6.02E23 mol^{-1}
Coulomb's constant, $(1/4\pi\varepsilon_0)$ = 8.99E9 $N.m^2/C^2$
Speed of light, c = 3.00E8 m/s
Charge of an electron, -e = -1.6E-19 C
Mass of the electron, m_e = 9.1E-31 kg = 511 keV/c^2 = 5.49E-4 u
Mass of the proton, m_p = 1.67E-27 kg = 938.3 MeV/c^2 = 1.00728 u
Mass of the neutron, m_n = 1.675E-27 kg = 939.6 MeV/c^2 = 1.00866 u
Mass of the α particle, m_α = 3727.4 MeV/c^2 = 4.00151 u
Planck's constant, h = 6.63E-34 J.s = 4.14E-15 eV.s
Planck's reduced constant, $\hbar = h/2\pi$ = 1.05E-34 J.s = 6.58E-16 eV.s
Compton Wavelength of the electron, $\lambda_c = h/m_ec$ = 2.4263E-12 m
The Bohr Magneton, μ_B = 5.79E-5 eV/T
Atomic mass unit, u = 1.66E-27 kg = 931.5 MeV/c^2
1 Curie = 3.7E10 Bq

Useful Formulae

$\Delta Q = mc\Delta T$ where m = mass, c = specific heat.
Heat conduction, $I = \Delta T/R$ in Watts where R = thermal resistance = $\Delta x/kA$ and Δx = thickness, A = area and k = thermal conductivity of the material.
$P_{RAD} = \sigma\varepsilon AT^4$ where ε = emissivity and A = area.
1st Law of Thermodynamics: $\Delta Q = \Delta W + \Delta U$

Ideal gas law: $PV = nRT$ Work done, $\Delta W = \int PdV$ $v_{rms} = \sqrt{(3RT/M)}$

Molar specific heats: $C_V = \Delta U/n\Delta T$ $C_P = \Delta Q/n\Delta T$ $C_P = C_V + R$ $\gamma = C_P/C_V$

Adiabatic ==> $\Delta Q = 0$, and PV^γ = constant.
Carnot engine efficiency, $\varepsilon_C = 1 - Q_C/Q_H = 1 - T_C/T_H$
Potential energy lost by a charge q in traversing a potential difference of V is U = qV
Wave relation: $v = \nu\lambda$ where v = velocity, ν = frequency, λ = wavelength.

$\beta = v/c$ $\gamma = 1/\sqrt{(1-\beta^2)}$ Length Contraction: $L' = L/\gamma$ Time Dilation, $T' = \gamma T$

Addition of Velocities: $v' = (v + u)/(1 + vu/c^2)$ Relativistic Doppler Effect: $\nu' = \frac{\sqrt{(1-\beta)}}{\sqrt{(1+\beta)}}\nu$

Momentum – Energy relations: $E^2 = p^2c^2 + m^2c^4$
$E = \gamma mc^2$ $p = \gamma mv$ $K = E - mc^2$

Planck's Relation: $E = h\nu$ Einstein's Photoelectric Law: $h\nu = K + \phi$

Compton Effect: $\Delta\lambda = \lambda' - \lambda = (1 - \cos\theta)h/m_ec$

Electrostatic potential at a distance R from a charge Q: $V = (1/4\pi\varepsilon_0)Q/R$

Bohr Quantization Relation: $L = mvr = n\hbar$

Atomic Radii: $r_n = n^2 a_0/Z$ where $a_0 = 5.29E\text{-}11$ m

Atomic Energies: $E_n = -Z^2E_0/n^2$ where $E_0 = 13.6$ eV

Impact parameter: $b = \frac{Z_1 Z_2 e^2}{8\pi\varepsilon_0 K}\cot(\theta/2)$ $n = \rho N_A/A$

Fraction of α's scattered through θ or greater: $f = \pi b^2 nt$

Rutherford Scattering: $N(\theta) = \frac{N_i\, n\, t\, e^4 Z_1^2 Z_2^2}{16(4\pi\varepsilon_0)^2 r^2 K^2 \sin^4(\theta/2)}$

de Broglie wavelength: $\lambda = h/p$ Bragg's Law: $n\lambda = 2d\sin\theta$

Heisenberg Uncertainty Principle: $\Delta p_x \Delta x \geq \hbar/2$ $\Delta E \Delta t \geq \hbar/2$

Probability $= \psi^2$ Normalization condition: $\int \psi^2 dx = 1$

Infinite Square Well Potential in 1-dim: $\psi = \sqrt{2/L}\,\sin(n\pi x/L)$ $E_n = n^2\pi^2\hbar^2/2mL^2$

Infinite Square Well Potential in 3-dims: $E = \frac{\pi^2\hbar^2}{2m}(n_1^2/L_1^2 + n_2^2/L_2^2 + n_3^2/L_3^2)$

Simple Harmonic Oscillator: $V = \frac{1}{2}kx^2$ $\omega^2 = k/m$ $E_n = (n+\frac{1}{2})\hbar\omega$

Quantum number relations: $n > 0$ $l < n$ $\mathbf{L} = \sqrt{l(l+1)}\,\hbar$ $|m_l| \leq l$ $L_z = m_l\hbar$

$s = \pm\frac{1}{2}$ $\mathbf{S} = \sqrt{s(s+1)}\,\hbar$ $\mathbf{J} = \mathbf{L} + \mathbf{S}$ $j = l \pm s$

	S	P	D	F	G
L =	0	1	2	3	4

Spectroscopic Notation: $n^{2s+1}L_j$

Zeeman Effect: $V_B = -\boldsymbol{\mu}\cdot\mathbf{B} = \mu_B B m_l$ or $2\mu_B B m_s$

Anomalous Zeeman Effect: $V_B = \mu_B B g m_j$ where g = Landé g-factor $= 1 + \frac{J(J+1)+S(S+1)-L(L+1)}{2J(J+1)}$

Radioactive decay law: $N = N_0 e^{-\lambda t}$ with $t_{1/2} = 0.693/\lambda$

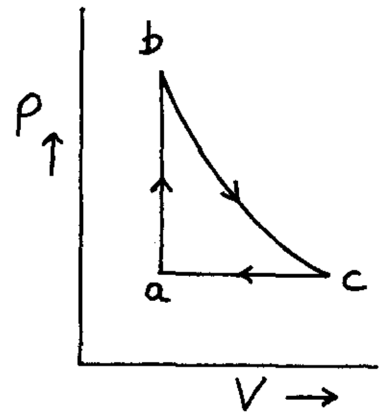
Activity: $R = \lambda N$ 1 Becquerel (Bq) = 1 decay/s

Q-value: $Q = (M_x + M_X - M_y - M_Y)c^2$

1. [6 points] **(a)** What is the rate of energy loss in Watts per square meter through a glass window of thickness 0.5 cm if the outside temperature is –25 ^{0}C and the inside temperature is +20 ^{0}C? [The thermal conductivity of glass is 1.0 W/m.K.]

(b) A storm window having the same thickness of glass is installed parallel to the first window with an air gap of 3.0 cm between the two windows. What now is the rate of energy loss? [The thermal conductivity of air is 0.026 W/m.K.]

2. [6 points] One mole of a monatomic ideal gas (C_V = 3/2 R) is taken through the reversible cycle shown in the figure. Process ab is at constant volume, process bc is adiabatic, and process ca is at constant pressure. T_a = 0 ^{0}C, T_b = 100 ^{0}C, T_c = 30 ^{0}C.



(a) What is the heat added to the gas in the process ab?

(b) What is the heat lost by the gas in the process ca?

(c) What is the heat change during process bc?

(d) What is the net work done by the gas in the cycle abca?

(e) What is the efficiency of an engine operating in this cycle?

3. [6 points] An intergalactic armada of spaceships that is 1.00 light years long (in its own rest frame) is moving away from Earth with a speed of 0.8c (relative to the Earth). A messenger spaceship travels from the rear of the armada to the front with a speed of 0.625c (relative to the armada).

(a) What is the speed of the messenger relative to the Earth?

(b) What is the length of the armada as measured by the messenger?

(c) What is the length of the armada as measured by the earth?

(d) How long does the messenger's trip take as measured in the messenger's rest frame?

(e) How long does the messenger's trip take as measured in the armada's rest frame?

(f) How long does the messenger's trip take as measured in the Earth's rest frame?

[Helpful(?) hint: **The answers to (d), (e) and (f) are all different, are all greater than 1 year, and are in increasing order of time.]**

4. [6 points] **(a)** What is the maximum wavelength of incident light that can produce photoelectrons from silver (work function, $\phi = 4.7$ eV)?

(b) What will be the maximum kinetic energy of the photoelectrons if the wavelength is halved?

5. [6 points] Consider an electron trapped in a three dimensional rectangular infinite potential well with sides of length $L_1 = L$, $L_2 = 2L$ and $L_3 = 2L$. **[Note: this is different from practice Midterm #3!]**

(a) What is the ratio of the energy of the **first excited state** relative to the **ground state**?

(b) What is the ratio of the energy of the **second excited state** relative to the **ground state**?

(c) What is the ratio of the energy of the **third excited state** relative to the **ground state**?

(d) Which of these energy levels are degenerate?

(e) If L = 1 nm, what is the energy of the **ground state** in electron volts?

6. [6 points] Consider Cockcroft and Walton's successful experiment (1931) to use an accelerator to cause the nuclear reaction:- $^{7}Li_{3}(p,\alpha)\alpha$

(a) If the mass of the Lithium nucleus is 7.01436u, what is the Q value for this reaction?

(b) Is this process exothermic or endothermic?

(c) In order to initiate this nuclear reaction, the proton has to be accelerated (by an electric field) to a kinetic energy, **K**, sufficient to overcome the Coulomb repulsion caused by the proton and the Li nucleus being separated by a distance of only 3 fm. What is this necessary kinetic energy, **K**?

(d) When the proton has this kinetic energy, **K**, what will be the total kinetic energy of the two α particles? (Assume that the Lithium nucleus is at rest.)

7. [6 points] A radioactive sample of ^{92}Sr initially has an activity of 2E9 Bq. After 1 day, the activity is observed to have dropped to 2E6 Bq.

(a) What is the half life, $t_{1/2}$, of the sample?

(b) What will be the activity after 2 days?

(c) How many grams of Strontium-92 were initially in the sample?

8. [6 points] Classify the following particles into one **or more** of the following categories:- Lepton, Hadron, Baryon, Meson, Nucleon, Antiparticle, Quark

(a) The electron ____________________

(b) The neutron ____________________

(c) The pion ____________________

(d) The muon ____________________

(e) The neutrino ____________________

(f) The positron ____________________