Thermo, Optics, Experimental – Problem Set # 1

TABLE OF INFORMATION

Rest mass of the electron	$m_e = 9.11 \times 10^{-31}$ kilogram $= 9.11 \times 10^{-28}$ gram
Magnitude of the electron charge	$e = 1.60 \times 10^{-19}$ coulomb $= 4.80 \times 10^{-10}$ statcoulomb (esu)
Avogadro's number	$N_0 = 6.02 \times 10^{23}$ per mole
Universal gas constant	$R = 8.31$ joules/(mole · K)
Boltzmann's constant	$k = 1.38 \times 10^{-23}$ joule/K $= 1.38 \times 10^{-16}$ erg/K
Speed of light	$c = 3.00 \times 10^{8}$ m/s $= 3.00 \times 10^{10}$ cm/s
Planck's constant	$h = 6.63 \times 10^{-34}$ joule · second $= 4.14 \times 10^{-15}$ eV · second
	$\hbar = h/2\pi$
Vacuum permittivity	$\epsilon_0 = 8.85 \times 10^{-12}$ coulomb²/(newton · meter²)
Vacuum permeability	$\mu_0 = 4\pi \times 10^{-7}$ weber/(ampere · meter)
Universal gravitational constant	$G = 6.67 \times 10^{-11}$ meter³/(kilogram · second²)
Acceleration due to gravity	$g = 9.80$ m/s² $= 980$ cm/s²
1 atmosphere pressure	1 atm $= 1.0 \times 10^{5}$ newton/meter² $= 1.0 \times 10^{5}$ pascals (Pa)
1 angstrom	1 Å $= 1 \times 10^{-10}$ meter
	1 weber/m² = 1 tesla = 10^4 gauss

Moments of inertia about center of mass

Rod	$\frac{1}{12}M\ell^2$
Disc	$\frac{1}{2}MR^2$
Sphere	$\frac{2}{5}MR^2$

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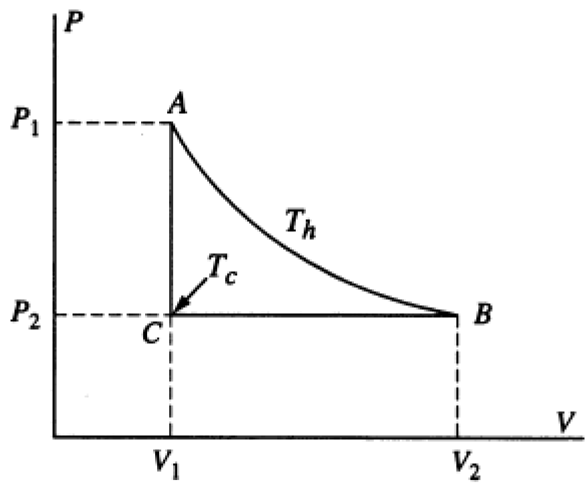
13. A 100-watt electric heating element is placed in a pan containing one liter of water. Although the heating element is on for a long time, the water, though close to boiling, does not boil. When the heating element is removed, approximately how long will it take the water to cool by 1° C ? (Assume that the specific heat for water is 4.2 kilojoules/kilogram °C.)

(A) 20 s
(B) 40 s
(C) 60 s
(D) 130 s
(E) 200 s

14. Two identical 1.0-kilogram blocks of copper metal, one initially at a temperature $T_1 = 0°$ C and the other initially at a temperature $T_2 = 100°$ C, are enclosed in a perfectly insulating container. The two blocks are initially separated. When the blocks are placed in contact, they come to equilibrium at a final temperature T_f. The amount of heat exchanged between the two blocks in this process is equal to which of the following? (The specific heat of copper metal is equal to 0.1 kilocalorie/kilogram °K.)

(A) 50 kcal
(B) 25 kcal
(C) 10 kcal
(D) 5 kcal
(E) 1 kcal



15. Suppose one mole of an ideal gas undergoes the reversible cycle $ABCA$ shown in the P-V diagram above, where AB is an isotherm. The molar heat capacities are C_p at constant pressure and C_v at constant volume. The net heat added to the gas during the cycle is equal to

(A) $RT_h V_2/V_1$

(B) $-C_p(T_h - T_c)$

(C) $C_v(T_h - T_c)$

(D) $RT_h \ln V_2/V_1 - C_p(T_h - T_c)$

(E) $RT_h \ln V_2/V_1 - R(T_h - T_c)$

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16. The mean free path for the molecules of a gas is approximately given by $\frac{1}{\eta\sigma}$, where η is the number density and σ is the collision cross section. The mean free path for air molecules at room conditions is approximately

(A) 10^{-4} m
(B) 10^{-7} m
(C) 10^{-10} m
(D) 10^{-13} m
(E) 10^{-16} m

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73. The adiabatic expansion of an ideal gas is described by the equation $PV^{\gamma} = C$, where γ and C are constants. The work done by the gas in expanding adiabatically from the state (V_i, P_i) to (V_f, P_f) is equal to

(A) $P_f V_f$

(B) $\frac{(P_i + P_f)}{2}(V_f - V_i)$

(C) $\frac{P_f V_f - P_i V_i}{1 - \gamma}$

(D) $\frac{P_i (V_f^{1+\gamma} - V_i^{1+\gamma})}{1 + \gamma}$

(E) $\frac{P_f (V_f^{1-\gamma} - V_i^{1-\gamma})}{1 + \gamma}$

Questions 54-55 concern a plane electromagnetic wave that is a superposition of two independent orthogonal plane waves and can be written as the real part of $\mathbf{E} = \hat{\mathbf{x}}E_1 \exp(i[kz - \omega t]) + \hat{\mathbf{y}}E_2 \exp(i[kz - \omega t + \pi])$, where k, ω, E_1, and E_2 are real.

54. If $E_2 = E_1$, the tip of the electric field vector will describe a trajectory that, as viewed along the z-axis from positive z and looking toward the origin, is a

(A) line at 45° to the $+x$-axis
(B) line at 135° to the $+x$-axis
(C) clockwise circle
(D) counterclockwise circle
(E) random path

55. If the plane wave is split and recombined on a screen after the two portions, which are polarized in the x- and y-directions, have traveled an optical path difference of $2\pi/k$, the observed average intensity will be proportional to

(A) $E_1^2 + E_2^2$
(B) $E_1^2 - E_2^2$
(C) $(E_1 + E_2)^2$
(D) $(E_1 - E_2)^2$
(E) 0

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56. A light source is at the bottom of a pool of water (the index of refraction of water is 1.33). At what minimum angle of incidence will a ray be totally reflected at the surface?

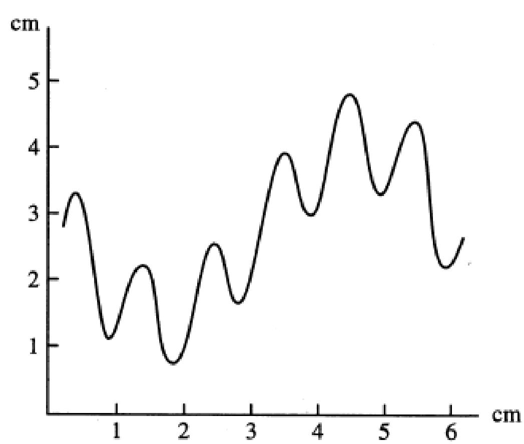
(A) 0°
(B) 25°
(C) 50°
(D) 75°
(E) 90°

57. Consider a single-slit diffraction pattern for a slit of width d. It is observed that for light of wavelength 400 nanometers, the angle between the first minimum and the central maximum is 4×10^{-3} radians. The value of d is

(A) 1×10^{-5} m
(B) 5×10^{-5} m
(C) 1×10^{-4} m
(D) 2×10^{-4} m
(E) 1×10^{-3} m

27. In laboratory experiments, graphs are employed to determine how one measured variable depends on another. These graphs generally fall into three categories: linear, semilog (logarithmic *versus* linear), and log-log. Which type of graph listed in the third column below would NOT be the best for plotting data to test the relationship given in the first and second columns?

	Relation	Variables Plotted	Type of Graph
(A)	$dN/dt \propto e^{-2t}$	Activity *vs.* time for a radioactive isotope	Semilog
(B)	$eV_S = hf - W$	Stopping potential *vs.* frequency for the photoelectric effect	Linear
(C)	$s \propto t^2$	Distance *vs.* time for an object undergoing constant acceleration	Log-log
(D)	$V_{out}/V_{in} \propto 1/\omega$	Gain *vs.* frequency for a low-pass filter	Linear
(E)	$P \propto T^4$	Power radiated *vs.* temperature for blackbody radiation	Log-log



28. The figure above represents the trace on the screen of a cathode ray oscilloscope. The screen is graduated in centimeters. The spot on the screen moves horizontally with a constant speed of 0.5 centimeter/millisecond, and the vertical scale is 2 volts/centimeter. The signal is a superposition of two oscillations. Which of the following are most nearly the observed amplitude and frequency of these two oscillations?

	Oscillation 1	Oscillation 2
(A)	5V, 250Hz	2.5V, 1000Hz
(B)	1.5V, 250Hz	3V, 1500Hz
(C)	5V, 6Hz	2V, 2Hz
(D)	2.5V, 83Hz	1.25V, 500Hz
(E)	6.14V, 98Hz	1.35V, 257Hz

29. The characteristic distance at which quantum gravitational effects are significant, the Planck length, can be determined from a suitable combination of the physical constants G, $\hbar$, and c. Which of the following correctly gives the Planck length?

(A) $G\hbar c$

(B) $G\hbar^2 c^3$

(C) $G^2\hbar c$

(D) $G^{\frac{1}{2}}\hbar^2 c$

(E) $(G\hbar/c^3)^{\frac{1}{2}}$

85. A free electron (rest mass $m_e = 0.5$ MeV/c^2) has a total energy of 1.5 MeV. Its momentum p in units of MeV/c is about

(A) 0.86
(B) 1.0
(C) 1.4
(D) 1.5
(E) 2.0