Modern Physics – Problem Set # 2

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	$R = 8.32$ 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

---

48. The magnitude of the force F on an object can be determined by measuring both the mass m of an object and the magnitude of its acceleration a, where $F = ma$. Assume that these measurements are uncorrelated and normally distributed. If the standard deviations of the measurements of the mass and the acceleration are σ_m and σ_a, respectively, then σ_F/F is

(A) $\left(\frac{\sigma_m}{m}\right)^2 + \left(\frac{\sigma_a}{a}\right)^2$

(B) $\left(\frac{\sigma_m}{m} + \frac{\sigma_a}{a}\right)^{\frac{1}{2}}$

(C) $\left[\left(\frac{\sigma_m}{m}\right)^2 + \left(\frac{\sigma_a}{a}\right)^2\right]^{\frac{1}{2}}$

(D) $\frac{\sigma_m \sigma_a}{ma}$

(E) $\frac{\sigma_m}{m} + \frac{\sigma_a}{a}$

49. Two horizontal scintillation counters are located near the Earth's surface. One is 3.0 meters directly above the other. Of the following, which is the largest scintillator resolving time that can be used to distinguish downward-going relativistic muons from upward-going relativistic muons using the relative time of the scintillator signals?

(A) 1 picosecond
(B) 1 nanosecond
(C) 1 microsecond
(D) 1 millisecond
(E) 1 second

58. The ground state configuration of a neutral sodium atom ($Z = 11$) is

(A) $1s^2 2s^2 2p^5 3s^2$

(B) $1s^2 2s^3 2p^6$

(C) $1s^2 2s^2 2p^6 3s$

(D) $1s^2 2s^2 2p^6 3p$

(E) $1s^2 2s^2 2p^5$

59. The ground state of the helium atom is a spin

(A) singlet
(B) doublet
(C) triplet
(D) quartet
(E) quintuplet

60. An electron in a metal has an effective mass $m^* = 0.1 m_e$. If this metal is placed in a magnetic field of magnitude 1 tesla, the cyclotron resonance frequency, ω_c, is most nearly

(A) 930 rad/s

(B) 8.5×10^6 rad/s

(C) 2.8×10^{11} rad/s

(D) 1.8×10^{12} rad/s

(E) 7.7×10^{20} rad/s

69. A fast charged particle passes perpendicularly through a thin glass sheet of index of refraction 1.5. The particle emits light in the glass. The minimum speed of the particle is

(A) $\frac{1}{3}c$

(B) $\frac{4}{9}c$

(C) $\frac{5}{9}c$

(D) $\frac{2}{3}c$

(E) c

70. A monoenergetic beam consists of unstable particles with total energies 100 times their rest energy. If the particles have rest mass m, their momentum is most nearly

(A) mc
(B) $10\ mc$
(C) $70\ mc$
(D) $100\ mc$
(E) $10^4\ mc$

Questions 71-73

A system in thermal equilibrium at temperature T consists of a large number N_0 of subsystems, each of which can exist only in two states of energy E_1 and E_2, where $E_2 - E_1 = \epsilon > 0$. In the expressions that follow, k is the Boltzmann constant.

71. For a system at temperature T, the average number of subsystems in the state of energy E_1 is given by

(A) $\frac{N_0}{2}$

(B) $\frac{N_0}{1 + e^{-\epsilon/kT}}$

(C) $N_0 e^{-\epsilon/kT}$

(D) $\frac{N_0}{1 + e^{\epsilon/kT}}$

(E) $\frac{N_0 e^{\epsilon/kT}}{2}$

72. The internal energy of this system at any temperature T is given by $E_1 N_0 + \frac{N_0 \epsilon}{1 + e^{\epsilon/kT}}$. The heat capacity of the system is given by which of the following expressions?

(A) $N_0 k\left(\frac{\epsilon}{kT}\right)^2 \frac{e^{\epsilon/kT}}{(1 + e^{\epsilon/kT})^2}$

(B) $N_0 k\left(\frac{\epsilon}{kT}\right)^2 \frac{1}{(1 + e^{\epsilon/kT})^2}$

(C) $N_0 k\left(\frac{\epsilon}{kT}\right)^2 e^{-\epsilon/kT}$

(D) $\frac{N_0 k}{2}\left(\frac{\epsilon}{kT}\right)^2$

(E) $\frac{3}{2} N_0 k$

73. Which of the following is true of the entropy of the system?

(A) It increases without limit with T from zero at $T = 0$.
(B) It decreases with increasing T.
(C) It increases from zero at $T = 0$ to $N_0 k \ln 2$ at arbitrarily high temperatures.
(D) It is given by $N_0 k\left[\frac{5}{2} \ln T - \ln p + \text{constant}\right]$.
(E) It cannot be calculated from the information given.

75. A uranium nucleus decays at rest into a thorium nucleus and a helium nucleus, as shown above. Which of the following is true?

(A) Each decay product has the same kinetic energy.
(B) Each decay product has the same speed.
(C) The decay products tend to go in the same direction.
(D) The thorium nucleus has more momentum than the helium nucleus.
(E) The helium nucleus has more kinetic energy than the thorium nucleus.