1. One mole of a monatomic ideal gas in a perfectly insulated cylinder is compressed from initial volume V to $\frac{V}{2}$. If the temperature and pressure of the gas before this compression are T and P, what are their values after the compression?
   (A) T and $2P$
   (B) T and $2^{5/3}P$
   (C) $2^{1/3}T$ and $2^{2/3}P$
   (D) $2^{2/3}T$ and $2^{5/3}P$
   (E) $2^{5/3}T$ and $2^{5/3}P$

2. A table-tennis ball is thrown at a stationary bowling ball. The table-tennis ball makes a one-dimensional elastic collision and bounces back along the same line. Compared with the bowling ball after the collision, does the table-tennis ball have
   (A**)** a larger magnitude of momentum and more kinetic energy,
   (B**)** a smaller magnitude of momentum and more kinetic energy,
   (C**)** a larger magnitude of momentum and less kinetic energy,
   (D**)** a smaller magnitude of momentum and less kinetic energy, or
   (E**)** the same magnitude of momentum and the same kinetic energy?

3. A charged particle is released from rest in a region where there is constant electric field and a constant magnetic field. If the two fields are parallel to each other, the path of the particle is a
   (A) Circle
   (B) Helix
   (C) Straight line
   (D) parabola
   (E) cycloid

4. For blue light, a transparent material has relative permittivity (dielectric constant) of 2.1 and a relative permeability of 1.0. If the speed of light in vacuum is c, the phase velocity of blue light in an unbounded medium of this material is

(A) $\sqrt{3.1}c$

(B) $\sqrt{2.1}c$

(C) $\frac{c}{\sqrt{1.1}}$

(D) $\frac{c}{\sqrt{2.1}}$

(E) $\frac{c}{\sqrt{3.1}}$

5. The equation $y = A\,Sin[2\pi(t/T - x/\lambda)]$, where A, T and λ are positive constants, represents a wave whose

A) amplitude is $2A$
B) velocity is in the negative x-direction
C) period is $\frac{T}{\lambda}$
D) speed is $\frac{x}{t}$
E) speed is $\frac{\lambda}{T}$

6. Suppose that 1Kg. of ice melts to water that changes its entropy by α. The same process changes the entropy of the environment by β. What is the relationship between α and β?

(A) $\alpha = \beta$
(B) $\alpha = -\beta$
(C) $|\alpha| > |\beta|$
(D) $|\alpha| < |\beta|$
(E) None of the above

7. The state $\left|\Psi>=\frac{1}{\sqrt{6}}\right|\Psi_{-1}>+\frac{1}{\sqrt{2}}|\Psi_1>+\frac{1}{\sqrt{3}}|\Psi_2>$ is a linear combination of three orthonormal eigenstates of the operator $\hat{O}$ corresponding to eigenvalues -1, 1 and 2. What is the expectation value of $\hat{O}$ for this state?

(A) $\frac{1}{7}$
(B) $\frac{2}{3}$
(C) 1
(D) $\frac{4}{3}$
(E) $\frac{5}{3}$

8. Which of the following functions could represent the radial wave function of an electron in an atom? (r is the distance of the electron from the nucleus and A, b are constants.)

$$I. \quad Ae^{-br}$$
$$II. \quad A\,Sin(br)$$
$$III. \quad \frac{A}{r}$$

A) I only
B) II only
C) I *and* II only
D) I *and* III only
E) I, II *and* III

9. The wave functions of a particle of mass m in an infinite potential well of width L are $\phi_n(x)=\sqrt{\frac{2}{L}}\,\mathrm{Sin}\left(\frac{n\pi x}{L}\right)$ and energy eigenvalues $E_n=\frac{n^2\pi^2\hbar^2}{2mL^2}$ where $n=1,2,3$ .... At time $t=0$, the particle is in a state given by $\Psi(t=0)=\frac{1}{\sqrt{14}}[\phi_1+2\phi_2+3\phi_3]$. Which of the following is a possible result of measurement of energy for the state Ψ?

(A) $2E_1$
(B) $5E_1$
(C) $7E_1$
(D) $9E_1$
(E) $14E_1$

10. A free particle with initial kinetic energy E and de Broglie wavelength λ enters a region in which its potential energy is V. What is the particle's new de Broglie wavelength?
    (A) $\lambda(1+E/V)$
    (B) $\lambda(1-E/V)$
    (C) $\lambda(1+E/V)^{-1}$
    (D) $\lambda(1+V/E)^{1/2}$
    (E) $\lambda(1-V/E)^{-1/2}$

11. In a Maxwell-Boltzmann system with two states of energy ε and 2ε, respectively, with degeneracy of 2 for each state, the partition function is
    (A) $e^{-\varepsilon/kT}$
    (B) $2e^{-2\varepsilon/kT}$
    (C) $2e^{-3\varepsilon/kT}$
    (D) $e^{-\varepsilon/kT}+e^{-2\varepsilon/kT}$
    (E) $2\left[e^{-\varepsilon/kT}+e^{-2\varepsilon/kT}\right]$

12. The mean kinetic energy of electrons in metals at room temperature is many times the thermal energy kT. Which of the following can best be used to explain this fact?
    A) The energy-time uncertainty relation
    B) The Pauli exclusion principle
    C) The degeneracy of the energy levels
    D) The Born approximation
    E) The wave-particle duality

13. Which statement is true about thermodynamic processes? P, V, S, T have usual meanings i.e., pressure, volume, entropy and temperature
    (A) A reversible process is the same as a cyclic process
    (B) Entropy of a system increases in an irreversible cyclic process
    (C) An irreversible process cannot be drawn in $PV - ST$ space
    (D) Efficiency of some modern hybrid engines is higher than Carnot engine
    (E) None of the above

14. How many ten letter words can you make using the letters in a ten letter word "RAWALPINDI"?

    A) $10!$
    B) $180 \times 7!$
    C) $\frac{10!}{2!}$
    D) $7!$
    E) None of the above

15. A system has three energy levels at $E_1 = 1, E_2 = 2, E_3 = 3$ that have degeneracies $10^1, 10^2, 10^3$, respectively. Suppose P_1, P_2, P_3 are the occupation probabilities of these levels when the system is in thermal equilibrium with a reservoir at temperature T. Taking $k_B T = 1$ where k_B is the Boltzmann constant, which statement is true?

    A) $P_1 > P_2 > P_3$
    B) $P_1 > P_2 = P_3$
    C) $P_1 = P_2 = P_3$
    D) $P_1 < P_2 < P_3$
    E) $P_1 = P_2 > P_3$

16. Which of the following is an eigenfunction of the linear momentum operator $-i\hbar\frac{\partial}{\partial x}$ with a positive eigenvalue $\hbar k$

(A) $Cos(kx)$
(B) $Sin(kx)$
(C) e^{-ikx}
(D) e^{ikx}
(E) e^{-kx}

17. In a given orthonormal basis, an operator A has the values $A|e_1\rangle = 2|e_1\rangle + |e_2\rangle$ and $A|e_2\rangle = 2|e_2\rangle + |e_1\rangle$. The matrix form of A in this basis is

A) $\begin{pmatrix} 2 & 1 \\ 1 & 2 \end{pmatrix}$
(B) $\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$
(C) $\begin{pmatrix} 1 & 2 \\ 1 & 2 \end{pmatrix}$
(D) $\begin{pmatrix} 1 & 2 \\ 1 & 0 \end{pmatrix}$
(E) $\begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$

18. Fourier transform of $f(x) = e^{-x^2/\sigma^2}$ in momentum space is the following function

(A) $f(k) = \sigma k$
(B) $f(k) = \sqrt{\pi}e^{-\sigma^2 k}$
(C) $f(k) = \sigma\sqrt{\pi}e^{-\sigma^2 k}$
(D) $f(k) = \sigma\sqrt{\pi}e^{-\sigma^2 k^2/4}$
(E) $f(k) = \sqrt{\pi}e^{-\sigma^2 kx}$

19. The function xe^x expressed as a sum of an even and an odd function is

(A) $x + e^x$
(B) $Sin(x) + Cos(x)$
(C) $Sinh(x)$
(D) $Sinh(x) + Cosh(x)$
(E) $xSinh(x) + xCosh(x)$

20 . The complex conjugate of the complex number $z = w^{(4y+i7x)}$ where $w = 2x - 7i$ is

A) $(2x - 7i)^{4y-i7x}$

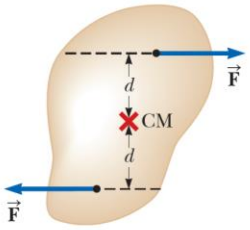
B) $(2x + 7i)^{4y-i7x}$

C) $(2x - 7i)^{4y+i7x}$

D) $(2x + 7i)^{4y+i7x}$

E) $(4y + i7x)$

21. Consider the object subject to two forces of equal magnitude, as shown in Figure. Choose the correct statement with regard to this situation



(A**)** The object is in force equilibrium but not torque equilibrium.
(B**)** The object is in torque equilibrium but not force equilibrium.
(C**)** The object is in both force equilibrium and torque equilibrium.
(D**)** The object is in neither force equilibrium nor torque equilibrium.
(E) Impossible to determine

22. A solid sphere and a hollow sphere have the same mass and radius. They are rotating with the same angular speed. Which one has the higher angular momentum?

(A**)** the solid sphere
(B) the hollow sphere
(C**)** both have the same angular momentum
(D**)** impossible to determine
(E**)** They have no angular momentum

23. A rock of mass *m* is dropped to the ground from a height *h*. A second rock, with mass 2*m*, is dropped from the same height. When the second rock strikes the ground, what is its kinetic energy?

A) twice that of the first rock
B) four times that of the first rock
C) the same as that of the first rock
D) half as much as that of the first rock
E) impossible to determine

24. A cube has a constant electric potential V on its surface. If there are no charges inside the cube, the potential at the center of the cube is

A) $\frac{V}{8}$
B) $\frac{V}{6}$
C) 0
D) V
E) $\frac{V}{2}$

25. A particle moves in a circular path of radius *r* with speed *v*. It then increases its speed to 2*v* while traveling along the same circular path. The centripetal acceleration of the particle has changed by what factor? Choose one:

A) 0.25
B) 0.5
C) 2
D) 4
E) 8