1. A block of mass m on a horizontal surface is attached to a spring having spring constant k. We pull the mass a distance $x = A$ to the right of $x = 0$, which is the equilibrium position, and let it go. How far to the left of the equilibrium position $x = 0$ will it reach, assuming that the kinetic coefficient of friction between the mass and the surface is μ_k?

(A) $\frac{-A}{2}$
(B) $-2A + \frac{2\mu_k mg}{k}$
(C) $\frac{\mu_k mg}{k}$
(D) $-2A$
(E) $-A + \frac{2\mu_k mg}{k}$

2. A completely inelastic collision occurs between a mass m_1 moving upward with velocity v_1 and a mass m_2 moving downward at velocity v_2. How high does the combined mass rise above the point of collision? The collision occurs close to the surface of earth; ignore air resistance.

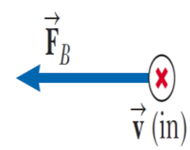
(A) $\frac{1}{2g}\left(\frac{m_1v_1 - m_2v_2}{m_1+m_2}\right)$
(B) $\frac{m_1v_1}{g}$
(C) $\frac{1}{g}\left(\frac{m_1v_1 + m_2v_2}{m_1+m_2}\right)$
(D) $\frac{1}{g}\left(\frac{m_1v_1}{m_1+m_2}\right)$
(E) $\frac{1}{g}\left(\frac{m_2v_2}{m_1+m_2}\right)$

3. A girl of mass M stands on the rim of a frictionless merry-go-round of radius R and rotational inertia I that is not moving. She throws a rock of mass m horizontally in a direction that is tangent to the outer edge of the merry-go-round. The speed of the rock, relative to the ground, is v. Afterwards what is the angular speed of the merry-go-round?

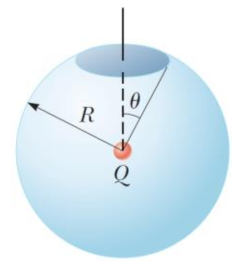
(A) $\frac{mvR}{I}$
(B) $\frac{MvR}{mR^2+I}$
(C) $\frac{mvR}{MR^2+I}$
(D) $\frac{mv}{MR}$
(E) $\frac{v}{R}$

4. A spherical charge distribution has charge density ρ that is constant from $r = 0$ to $r = R$ and zero beyond. What is the electric field for all values of r less than R?
   A) $E = \frac{\rho r}{3\varepsilon_0}$
   B) $E = \frac{\rho}{3\varepsilon_0 r}$
   C) $E = \frac{\rho r^2}{3\varepsilon_0}$
   D) $E = \frac{\rho}{3\varepsilon_0 r^2}$
   E) $E = \frac{\rho}{3\varepsilon_0}$

5. Find the direction of the magnetic field acting on a positively charged particle moving in the direction which is into the page, as shown in the figure. The direction of the magnetic force acting on it is:
   (A) Into the page
   (B) To the right
   (C) To the left
   (D) Towards the bottom of the page
   (E) Towards the top of the page



6. A sphere of radius R surrounds a particle with charge Q located at its center as shown in the figure. The electric flux through a circular cap of half-angle θ is
   A) Q/ε_0
   B) $Q/2\varepsilon_0$
   C) $\left(\frac{Q}{\varepsilon_0}\right) cos\theta$
   D) $\left(\frac{Q}{2\varepsilon_0}\right)(1 - cos\theta)$
   E) $\left(\frac{Q}{\varepsilon_0}\right)(cos\theta - 1)$



7. The expression for free energy of a system, connected to a heat bath at temperature T and with two non-degenerate states, one at energy 0 and other at ε, is

A) $F = -kT\log(1+e^{-\varepsilon/kT})$

B) $F = -kT\log(1-e^{-\varepsilon/kT})$

(C) $F = -kT\log(1-e^{\varepsilon/kT})$

(D) $F = -kT\log(1+e^{\varepsilon/kT})$

(E) $F = kT\log(1+e^{-\varepsilon/kT})$

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

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

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

9. If we consider the spin of an electron, the maximal occupation number of an energy level in an ideal electron gas is

(A) Zero
(B) One
(C) Two
(D) Three
(E) Four

10. For an isolated quantum mechanical system originally in the state $\Psi = a\phi_n + b\phi_m$ which on measurement is found to be in state ϕ_m at time t. What state will it be found in if a second experimental measurement is made at a time t' later than t?

A) ϕ_m
B) ϕ_n
C) $a\phi_n + b\phi_m$
D) Both ϕ_n and ϕ_m will have equal chance to be found
E) None of the above

11. At a given instant of time, a rigid rotator is in the state $\psi(\vartheta, \phi) = \sqrt{(3/4\pi)} \sin\vartheta \sin\phi$, where ϑ is the polar angle relative to the *z*-axis and ϕ is the azimuthal angle. Measurement will find which of the following possible values of the *z*-component of the angular momentum L_z?

(A) 0
(B) $\hbar/2, -\hbar/2$
(C) $\hbar, -\hbar$
(D) $2\hbar, -2\hbar$
(E) $\hbar, 0, -\hbar$

12. What is the expectation value of positon for a free particle of mass *m* moving in one dimension having momentum p_x?

(A) 0
(B) *x*
(C) 2*x*
(D) ∞
(E) *x/2*

13. A three-dimensional Harmonic Oscillator is in state $E_n = \frac{9\hbar\omega}{2}$, what is the degeneracy of this state?
(A) 0
(B) 3
(C) 5
(D) 7
(E) 9

14. Consider a physical system associated with a three dimensional state space. An orthonormal basis for this system is given by $|1\rangle, |2\rangle, |3\rangle$ and the Hamiltonian of this system in this basis is given by the matrix: $\begin{pmatrix} 2 & 1 & 0 \\ 1 & 2 & 0 \\ 0 & 0 & 3 \end{pmatrix}$. What are the possible results if a measurement of energy is made, in appropriate units?
(A) 1,2,3
(B) 2,2,2
(C) 1,1,1
(D) 3 and 3
(E) 1 and 3

15. You must have seen that one can obtain the classical Maxwell-Boltzmann distribution from the quantum Fermi-Dirac and Bose-Einstein distributions: $\frac{1}{e^{\beta(E_i-\mu)}\pm 1}$ where $\beta = \frac{1}{kT}$. This is obtained when
A) $e^{\beta(E_i-\mu)} \gg 1$
B) $e^{\beta(E_i-\mu)} \ll 1$
C) $e^{\beta(E_i-\mu)} = 1$
D) $e^{\beta E_i} = 1$
E) $e^{\beta\mu} \gg 1$

16. Consider an ideal gas having N particles in a container attached to a piston. The system is at temperature T. We let the gas expand isothermally in a quasi-static process from initial volume V_i to final volume V_f. If the workdone by the gas during the process is $NkTln\left(\frac{V_f}{V_i}\right)$, what is the heat input?

A) kT
B) NkT
C) $NkTln\left(\frac{V_f}{V_i}\right)$
D) $\frac{3}{2}\ NkT$
E) $\frac{1}{2}\ NkT$

17. The real and imaginary parts of $z\ = \frac{1+\mathrm{i}}{1-\mathrm{i}}$ are

(A) $(\mathrm{Re(z)}, \mathrm{Im(z)})\ = (0,1)$

(B) $(\mathrm{Re(z)}, \mathrm{Im(z)})\ = (1,1)$

(C) $(\mathrm{Re(z)}, \mathrm{Im(z)})\ = (-1,1)$

(D) $(\mathrm{Re(z)}, \mathrm{Im(z)})\ = (1,-1)$

(E) $(\mathrm{Re(z)}, \mathrm{Im(z)})\ = (0,0)$

18. Eigenvalues of the matrix $\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$ are

A) (0,0)
B) (0,1)
C) (1,0)
D) (1,-1)
E) (-1,-1)

19. Expansion of $\sin^2 x$ about $x = 0$ is

A) $x^2 - \frac{x^4}{3} + \frac{2x^6}{45} + \ldots$

B) $x^2 + \frac{x^4}{3} - \frac{2x^6}{45} + \ldots$

C) $x - \frac{x^3}{3} + \frac{2x^5}{15} + \ldots$

D) $1 + x^2 - \frac{x^4}{3} + \ldots$

E) $1 - x^2 + \frac{x^4}{3} + \ldots$

20. Consider the function $f(x, y) = Sinx + Siny$. Which of the following points (x, y) is the stationary point of $f(x, y)$?

A) $(\frac{\pi}{2}, \frac{\pi}{2})$

B) (0,0)

C) $(\frac{\pi}{2}, 0)$

D) $\left(0, \frac{\pi}{2}\right)$

E) (π, π)

21. For $\boldsymbol{v} = (y, a\,x, b\,z)$ to be a divergence-less and curl-less vector, the values of *a* and *b* are

A) $(a, b) = (0,0)$

B) $(a, b) = (0,1)$

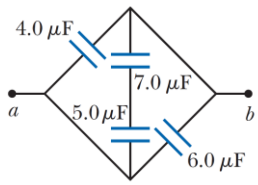
C) $(a, b) = (1,0)$

D) $(a, b) = (-1,0)$

E) $(a, b) = (0, -1)$

22. A classical system with one degree of freedom has a Hamiltonian $H(q,p) = \frac{p^2}{2m} + A(q)p + B(q)$, where A and B are functions of the coordinate q and p is the momentum conjugate to q. The velocity $\dot{q}$ is
   A) $\frac{p}{m}$
   B) $A(q)$
   C) $\frac{p}{m} + B(q)$
   D) $B(q)$
   E) $\frac{p}{m} + A(q)$

23. The equivalent capacitance between points a and b in the combination of capacitors shown in Figure, is:
   A) 12.9 μF
   B) 11.9 μF
   C) 14.9 μF
   D) 10.8 μF
   E) 9.9 μF



24. The position vector of a particle moving in a circle of radius R with angular velocity ω at time t is $\vec{r}(t) = R(\cos(\omega t)\,\hat{\imath} + \sin(\omega t)\hat{\jmath})$. Its velocity at time $t = 0$ is
   A) 0
   B) $2\omega R\hat{\jmath}$
   C) $\omega R\hat{\imath}$
   D) $\omega R\hat{\jmath}$
   E) $-\omega R\hat{\jmath}$

25. Two point charges are located on the x-axis, $q_1 = -e$ at $x = 0$ and $q_2 = +e$ at $x = a$. The work that must be done by an external force to bring a third point charge $q_3 = +e$ to $x = 2a$ from infinity is
   A) $\frac{+e^2}{8\pi\varepsilon_0 a}$
   B) $\frac{+e^2}{4\pi\varepsilon_0 a}$
   C) $\frac{-e^2}{8\pi\varepsilon_0 a}$
   D) $\frac{+e^2}{a}$
   E) $\frac{+e}{8\pi\varepsilon_0 a}$