Multiple Choice (60 points). Circle the one best answer for each question.

1. Which among moment of inertia $I$, angular velocity $\omega$, and angular momentum $\ell$ increase when a diver brings his arms and legs inward, close to the axis of rotation, while spinning in the air?
   (a) all three increase  (b) $I$ and $\omega$ only  (c) $\omega$ and $\ell$ only  
   (d) $\omega$ only  (e) $\ell$ only

2. For angular momentum of a system to be conserved, we must have ________________ .
   (a) no net external torque acting on the system 
   (b) no net external force acting on the system 
   (c) no net external torque and no net external force acting on the system

3. A spinning star suddenly contracts (collapses) inward so that its moment of inertia $I$ decreases to one fourth its original value. The rotational speed will ________________ .
   (a) decrease to one fourth its original amount  (b) decrease to half its original amount  
   (c) increase to 4 times its original amount  (d) increase to 16 times its original amount  
   (e) remain the same

4. A horizontal disk is rotating in a clockwise direction as seen from the top. A mouse sits on the edge of the disk as it rotates. The mouse begins running along the edge of the disk in the counterclockwise direction. Compared with the situation before the mouse began to run, the angular momentum of the mouse-disk system __________, and the angular speed of the disk __________.
   (a) did not change; decreased  (b) did not change; increased  
   (c) did not change; did not change  (d) decreased; increased  
   (e) increased; decreased

5. Consider the situation in the previous question, except here the mouse runs in the clockwise direction, while the disk still rotates in the clockwise direction. Compared with the situation before the mouse began to run, the angular momentum of the clockwise disk __________, and the angular momentum of the mouse __________.
   (a) did not change; decreased  (b) did not change; increased  
   (c) did not change; did not change  (d) decreased; increased  
   (e) increased; decreased

6. An airborne helicopter has its main blades spinning counterclockwise as shown in the diagram. If the back rotor suddenly breaks off, what will happen to the body of the helicopter when the pilot tries to increase the rotational speed of the main blades?
   (a) It will rotate cw  (b) It will rotate ccw  
   (c) It will not rotate
For Questions 7-9, consider the following three objects, a uniform solid disk $D$, a hoop $H$, and a wheel $W$ as shown below. All three have the exact same mass and radii. The mass distribution of the disk is uniform, and the mass of wheel is concentrated in the center where the dark circle is.

7. Which object has the smallest moment of inertia about its center?
(a) $D$ only  (b) $H$ only  (c) $W$ only  
(d) tie with $D$ and $H$  (e) all three are the same

8. Suppose these three objects are allowed to roll down a ramp. Arrange them according to the translational velocity they would have at the bottom of a ramp, from slowest to fastest.
(a) $D, H, W$  (b) $D, W, H$  (c) $H, D, W$  
(d) $W, D, H$  (e) $W, H, D$

9. Again, consider that these objects are allowed to roll down a ramp. Arrange them according to the amount of rotational kinetic energy they would have at the bottom of a ramp, from least to most.
(a) $D, H, W$  (b) $D, W, H$  (c) $H, D, W$  
(d) $W, D, H$  (e) $W, H, D$

10. The diagram shows views of a uniform rod on which three or more forces act perpendicular to the rod. If the magnitudes of the forces are adjusted properly (but not set to zero), for which case(s) would it not be possible that the rod is in static equilibrium?
(a) A only  (b) B only  (c) C only  
(d) D only  (e) B and D

11. The diagram shows three forces acting on a disk that is free to rotate about a pivot at its center. The disk _________ in equilibrium.
(a) is  (b) is not

12. The diagram shows a mobile of decorative stars hanging from the ceiling. Each crossbar has negligible mass and extends four times as far to the left of the supporting wire as to the right. Given that Star 1 has a mass of 80 g, what must be the mass of Stars 3?
(a) 60 g  (b) 20 g  (c) 16 g  (d) 8 g  (e) 4 g
13. The diagram illustrates the effect of a ______________ stress.
   (a) tensile       (b) compressive
   (c) shear        (d) hydraulic

14. The ______ modulus is a material property that relates hydraulic stresses to changes in volume.
   (a) Young’s       (b) shear         (c) bulk

15. The table shows the areas of three surfaces and the magnitude of force that is applied uniformly to
the surface. Rank the surfaces according to the stress on them, from least to greatest.

<table>
<thead>
<tr>
<th>Surface</th>
<th>Area</th>
<th>Force</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface A</td>
<td>$A_0$</td>
<td>$0.5F_0$</td>
</tr>
<tr>
<td>Surface B</td>
<td>$0.5A_0$</td>
<td>$F_0$</td>
</tr>
<tr>
<td>Surface C</td>
<td>$A_0$</td>
<td>$F_0$</td>
</tr>
</tbody>
</table>

   (a) A, B, C       (b) A, C, B       (c) C, B, A
   (d) B, C, A       (e) C, A and B tie

16. Two objects attract each other with a gravitational force of 4.0 N. If the mass of one object were to
increase to twice its original mass and the distance between the two objects were increased to twice
its original distance, what would the gravitational attraction between the two objects then be?
   (a) 0.5 N       (b) 1.0 N       (c) 2.0 N
   (d) 3.0 N       (e) 4.0 N

17. Two objects of mass 1.0 kg and 2.0 kg attract each other with a gravitational force of 10.0 N. If
these masses were to increase to 3.0 kg and 6.0 kg, while the distance between them was cut in half,
what would the gravitational attraction between the two objects then be?
   (a) 23 N       (b) 45 N       (c) 90 N
   (d) 180 N      (e) 360 N

18. The diagram shows three rings (shells) of mass distributed uniformly along the ring. The total mass
of each ring is $M$. Which gives the order, from least to most, of the gravitational attraction of $m$ by
the ring, when $m$ is placed a distance $d$ from the center of the ring in each case?

   (a) $R_1$, $R_2$, $R_3$     (b) $R_1$, $R_3$, $R_2$
   (c) $R_3$, $R_2$, $R_1$
   (d) $R_3$, $R_1$ and $R_2$ tie  (e) all three are the same
For Questions 19-20, refer to the diagram below that shows the arrangement of several masses around a central 2.0-kg mass. The sides of the dashed square are 2.0 m each. The 4.0-kg and 1.0-kg masses are midway between the corners; the 6.0-kg masses are halfway between the 1.0-kg masses and the corner.

19. What is the direction of the net gravitational force on the 2.0-kg mass at the center?
   (a) towards upper right corner   (b) towards lower left corner   (c) horizontal, to the right
   (d) towards 6.0-kg mass at left   (e) towards 6.0-kg mass at right

20. What is the magnitude of the net gravitational force on the 2.0-kg mass at the center? \( G \) is the universal gravitational constant; SI units are implied.
   (a) \( \frac{G}{2} \)   (b) \( G \)   (c) \( 2G \)
   (d) \( 3G \)   (e) \( 6G \)

Extra Credit

21. Newton’s Universal law of Gravity applies to:
   (a) Any two masses
   (b) Charged particles only
   (c) Planet size objects only
   (d) Microscopic size particles only
   (e) Masses near Earth’s surface only

22. The diagram shows three solid spheres of uniform mass distribution. The total mass of each sphere is \( M \). Which gives the order, from least to most, of the gravitational attraction on \( m \) by the sphere, when \( m \) is placed a distance \( d \) from the center of the sphere in each case?

   (a) \( S_1, S_2, S_3 \)   (b) \( S_2, S_3, S_1 \)   (c) \( S_3, S_2, S_1 \)
   (d) \( S_2 \) and \( S_3 \) tie, \( S_1 \)   (e) all three are the same
Problem Solving (50 points). Solve any two of the three problem sets on a separate piece of paper.

1. (a) A solid ball \((I = 0.40MR^2)\) is released at the top of a smooth ramp that is 2.0 m high. What is its translational speed at the bottom of the ramp if it rolls down without slipping and without any frictional energy losses?

(b) A merry-go-round at a park is a uniform disk \((I = 0.50MR^2)\) of mass \(M = 200.0\) kg and radius \(R = 3.00\) m. Two physics students, with masses of 70.0 kg and 120.0 kg, are standing on the disk at \((1/2)R\) while it rotates at 0.250 rev/sec. What is the new rotational speed if the 70.0-kg persons moves to \((1/4)R\) and the 120.0-kg person moves to the outer edge?

2. A uniform strut weighing 200.0 N is attached to the floor at one end by a hinge. The strut is held up at an angle of \(30^\circ\) from the floor, as shown in the diagram, by a horizontal wire attached to the wall at one side and \(1/3\) of the way up the strut at the other side. A 100.0-N package is attached to the strut \(3/4\) of the way up the strut. Determine the (a) tension in the wire, (b) horizontal force on the strut at the hinge, and (c) vertical force on the strut at the hinge.

![Diagram of strut and wire](image)

3. Two masses, \(m_1 = 20.0\) kg and \(m_2 = 10.0\) kg, are connected by a string (string has negligible mass) as shown in the diagram. There is negligible friction between \(m_2\) and incline surface. The string does not slip on the wheel; instead, the wheel turns with the movement of the string along its rim. The wheel has mass 60.0 kg which is all concentrated along its rim, and the wheel turns with negligible friction in the bearing. (a) Write out three equations from which \(T_1\) (tension in string pulling \(m_1\)), \(T_2\) (tension in string pulling \(m_2\)), and acceleration \(a\) of the system can be found. Clearly mark/label the three equations. (b) Solve these three equations for \(T_1\), \(T_2\), and \(a\). (Hint: The leftward direction should be taken as positive.)

![Diagram of masses and string](image)