Your name sticker
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1. Use a #2 pencil to make entries on the answer sheet. Enter the following ID information now, before the exam starts.
2. In the section labeled NAME (Last, First, M.I.) enter your last name, then fill in the empty circle for a blank, then enter your first name, another blank, and finally your middle initial.
3. Under STUDENT # enter your 9-digit RUID Number.
4. Under CODE enter the exam code given above.
5. Enter 124 under COURSE. You do not need to write anything else on the answer sheet. You should continue to read the instructions.
6. During the exam, you are allowed one 8.5 x 11 inch sheet of paper handwritten, both sides.
7. The exam consists of 15 multiple-choice questions. For each multiple-choice question mark only one answer. There is no deduction of points for an incorrect answer; if you cannot work out the answer to a question, you should make an educated guess.
8. If you have questions or problems during the exam, you may raise your hand and a proctor will assist you. We will provide the value of physical constants that are needed. It is your responsibility to know the relevant equations.
9. A proctor will check your name sticker and your student ID sometime during the exam. Please have them ready.
10. You are not allowed to help any other student, ask for help from anyone but a proctor, change your seat without permission from a proctor or use any electronic device other than a scientific calculator. Doing so will result in a zero score for the exam.
11. When you are done with the exam, hand in only this cover sheet and your answer sheet.
12. Please sign above by the name sticker to indicate that you have read and understood these instructions.
Possibly useful constants:

\[ G = 6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2 \]
\[ g = 9.8 \text{ m/s}^2 \]

Radius of Earth = 6.4 \times 10^6 \text{ m}, mass of Earth = 6.0 \times 10^{24} \text{ kg}

Moments of inertia for uniform density objects:

\[ I_{\text{disk}} = I_{\text{solid cylinder}} = \frac{1}{2} MR^2 \]
\[ I_{\text{thin walled hollow cylinder}} = I_{\text{ring}} = MR^2 \]
\[ I_{\text{solid sphere}} = \frac{2}{5} MR^2, \ I_{\text{thin walled hollow sphere}} = \frac{2}{3} MR^2 \]
\[ I_{\text{slender rod, axis through center}} = \frac{1}{12} ML^2 \]
\[ I_{\text{slender rod, axis through one end}} = \frac{1}{3} ML^2 \]

Circumference of a circle = 2\pi r; area of a circle = \pi r^2

Surface area of a sphere = 4\pi r^2; Volume of a sphere = \frac{4}{3} \pi r^3

Surface area of a cylinder = 2\pi rh + 2\pi r^2; Volume of cylinder = \pi r^2h

\[
\begin{align*}
\sin(0^\circ) &= \cos(90^\circ) = 0 \\
\sin(90^\circ) &= \cos(0^\circ) = 1 \\
\sin(30^\circ) &= \cos(60^\circ) = 1/2 \\
\sin(60^\circ) &= \cos(30^\circ) = \sqrt{3}/2 \\
\sin(45^\circ) &= \cos(45^\circ) = \sqrt{2}/2 \\
\end{align*}
\]

Some metric prefixes:

f = femto = 10^{-15}
p = pico = 10^{-12}

n = nano = 10^{-9}

\mu = micro = 10^{-6}
m = milli = 10^{-3}

k = kilo = 10^{3}

M = mega = 10^{6}
G = giga = 10^{9}
1. Four small cylinders are identical in shape. They rest on a circular horizontal turntable as shown in the top-view diagram, where the distances from the center are $d_P = d_S = d_T = d$ and $d_R = d/2$. The masses are $M_P = M_S = M$, and $M_R = M_T = 2M$. The turntable is rotating clockwise around a vertical axis through the center of the turntable at a constant angular speed. Rank the magnitudes of the angular momenta $L$ of the cylinders about the axis of rotation of the turntable.

   a) $L_P = L_R = L_S = L_T$
   b) $L_P = L_R = L_S < L_T$
   c) $L_R < L_P = L_S < L_T$
   d) $L_R = L_P < L_S < L_T$
   e) $L_R < L_P < L_S < L_T$

2. A seesaw of negligible mass is broken so it extends 1.5 m to one side, but only 1.0 m to the other side. If a 50-kg student sits at the end of the long side, what force $F$ is needed at the end of the short side to balance the seesaw?

   a) $F = 75$ N
   b) $F = 33$ N
   c) $F = 330$ N
   d) $F = 740$ N
   e) $F = 1200$ N

3. On a certain planet, the escape speed for an empty space vehicle with mass $m$ is $v_m = 1.12 \times 10^4$ m/s. What is the corresponding escape speed $v_M$ for the fully loaded vehicle which has triple the mass $M = 3m$ of the empty one? Neglect air resistance.

   a) $v_M = 3.73 \times 10^3$ m/s
   b) $v_M = 1.94 \times 10^4$ m/s
   c) $v_M = 1.12 \times 10^4$ m/s
   d) $v_M = 6.47 \times 10^3$ m/s
   e) $v_M = 3.36 \times 10^4$ m/s
4. A bicycle wheel is rotating on an axle through its center such that the magnitude of its angular momentum is \( L = 10 \text{ kg} \cdot \text{m}^2/\text{s} \). Two constant forces begin acting on the wheel. One force has a magnitude of \( F_1 = 30 \text{ N} \), is acting a distance of \( r_1 = 0.80 \text{ m} \) from the center of the wheel, and is acting to rotate the wheel counter-clockwise. The other force has a magnitude of \( F_2 = 120 \text{ N} \), is acting at \( r_2 = 0.20 \text{ m} \) from the center of the wheel, and is acting to rotate the wheel clockwise. Both of the forces \( F_1 \) and \( F_2 \) are perpendicular to the radius vector at the point of action. What is the magnitude of the angular momentum \( L \) of the wheel after the forces have been acting for \( t = 10 \text{ seconds} \)? Note: Counter-clockwise rotation is defined as positive.
   a) \( L = 0 \)
   b) \( L = 10 \text{ kg} \cdot \text{m}^2/\text{s} \)
   c) \( L = 48 \text{ kg} \cdot \text{m}^2/\text{s} \)
   d) \( L = 58 \text{ kg} \cdot \text{m}^2/\text{s} \)
   e) \( L = 38 \text{ kg} \cdot \text{m}^2/\text{s} \)

5. The radius of the moon is \( R \). A satellite orbiting the moon in a circular orbit has an acceleration due to the moon’s gravity of \( a_h \). The acceleration due to gravity at the moon’s surface is \( a_m = 16a_h \). What is the height \( h \) of the satellite above the moon’s surface?
   a) \( h = 4R \)
   b) \( h = R \)
   c) \( h = 15R \)
   d) \( h = 3R \)
   e) \( h = 16R \)

6. A solid sphere is rolling at a constant angular velocity without slipping along a straight line on a horizontal surface. The axis of rotation is parallel to the horizontal surface. Which of the following is TRUE for the sphere with this motion?
   a) Non-zero net torque is applied to the sphere, but the net force on it is zero.
   b) Non-zero net force is applied on the sphere, but the net torque on it is zero.
   c) Both the net torque and force applied to the sphere are zero.
   d) The amount of net torque applied on the sphere depends on its moment of inertia.
   e) The amount of net force applied on the sphere depends on its mass.
7. The planet Plunox has mass \( M_P = 2M_{\text{earth}} \). Plunox orbits a distant star with mass \( M = 2M_{\text{sun}} \). The orbit of Plunox about this star has radius \( O_P = O_{\text{earth}} \), i.e., the same as the radius of the orbit of the earth around the sun. Assume the orbits of Plunox and the earth are circular. What is the length of a year \( Y_P \) on this distant planet, in units of earth years \( Y_E \)?
   a) \( Y_P = \frac{1}{\sqrt{2}} Y_E \)
   b) \( Y_P = \frac{1}{2} Y_E \)
   c) \( Y_P = Y_E \)
   d) \( Y_P = \sqrt{2} Y_E \)
   e) \( Y_P = 2Y_E \)

8. A student working on a physics problem is absentmindedly twirling her pen in her fingers. The mass of the pen is \( M \) and its length is \( \ell \). The pen is rotating fully once every second about a line through the center of and perpendicular to the pen. What is the magnitude of its angular momentum \( L \)?
   a) \( L = M\ell^2 \)
   b) \( L = 2\pi M\ell^2 \)
   c) \( L = 2\pi M\ell^2 / 3 \)
   d) \( L = \pi M\ell^2 / 12 \)
   e) \( L = \pi M\ell^2 / 6 \)

9. A wire of uniform density and cross sectional area is bent at its midpoint through a right angle, as shown in the figure. Which arrow best shows the location of the center of mass of the system?
   a) Arrow 3
   b) Arrow 2
   c) Arrow 4
   d) Arrow 5
   e) Arrow 1
10. Three objects are in space, away from any star or other massive objects. Object $O_1$ has mass $m_1 = M$, object $O_2$ has mass $m_2 = 5M$ and object $O_3$ has mass $m_3 = 50M$. The average distance between the centers of $O_1$ and $O_2$ is $r_{12}$ and the average distance between the centers of $O_2$ and $O_3$ is $r_{23} = 10r_{12}$. What is the net force $F_{net}$ on $O_2$ when the objects are aligned as displayed in the figure? Note: Figure not drawn to scale.

a) $F_{net} = 0$
b) $F_{net} = 7.5M^2G/(r_{12}^2)$
c) $F_{net} = 5M^2G/(r_{12}^2)$
d) $F_{net} = 2.5M^2G/(r_{12}^2)$
e) $F_{net} = M^2G/(r_{12}^2)$

11. A horizontal turntable with a moment of inertia $2I$ is freely spinning with an angular velocity $\omega_0$. A stationary disk with a moment of inertia $I$ around its vertical symmetry axis is dropped onto this turntable. If the axis of rotation of the turntable passes through the center of the disk, the final angular velocity $\omega_f$ of the turntable will be

a) $\omega_f = (1/4)\omega_0$
b) $\omega_f = (1/2)\omega_0$
c) $\omega_f = (1/3)\omega_0$
d) $\omega_f = (2/3)\omega_0$
e) $\omega_f = (3/4)\omega_0$
12. A nail is hammered into a board so that it would take a force $F_{\text{nail}}$, applied straight upward on the head of the nail, to pull it out. (Take an upward force to be positive.) A carpenter uses a crowbar to try to pry it out. The length of the handle of the crowbar is $L_h$ and the length of the forked portion of the crowbar (which fits around the nail) is $L_n$. Assume that the forked portion of the crowbar is perfectly horizontal. As displayed in the figure, the handle of the crowbar makes an angle $\theta = 30^\circ$ with the horizontal, and the carpenter pulls directly along the horizontal. With what force $F_{\text{pull}}$ must the carpenter pull on the crowbar to remove the nail?

![Diagram of a nail and crowbar]

a) $F_{\text{pull}} = F_{\text{nail}}$

b) $F_{\text{pull}} = F_{\text{nail}}L_n/L_h$

c) $F_{\text{pull}} = 2F_{\text{nail}}L_n/L_h$

d) $F_{\text{pull}} = 2F_{\text{nail}}L_n/(\sqrt{3}L_h)$

e) $F_{\text{pull}} = F_{\text{nail}}L_n/(2L_h)$

13. Planet A has a gravitational acceleration $g_A$ at its surface. For planet B the gravitational acceleration at its surface is $g_B = 2g_A$. The radius of planet B $R_B = 3R_A$, where $R_A$ is the radius of planet A. What is the mass of planet B, $M_B$, in terms of the mass of planet A, $M_A$?

a) $M_B = M_A$

b) $M_B = 18M_A$

c) $M_B = 9M_A$

d) $M_B = (2/9)M_A$

e) $M_B = 6M_A$
14. A stick of length $\ell$ lies on a frictionless horizontal table and pivots about its left end at the origin. The picture shows a view of the stick looking down on the table. A force $F$ is applied at the middle of the stick at an angle $\theta = 30^\circ$. If the magnitude of the torque due to the force is $\tau$, what is the magnitude of the applied force $F$?

a) $F = 4\tau/\ell$
b) $F = 2\tau/\ell$
c) $F = \tau/(2\ell)$
d) $F = 4\tau/(\sqrt{3}\ell)$
e) $F = 2\tau/(\sqrt{3}\ell)$

15. Four forces $F_A = F_B = F_C = F_D = 4$ N act on a 3-m by 4-m piece of wood as shown in the figure. Rank the magnitudes of the torques $\tau$ about point P.

a) $\tau_B > \tau_C > \tau_D > \tau_A$
b) $\tau_B > \tau_C = \tau_D > \tau_A$
c) $\tau_D > \tau_C > \tau_B > \tau_A$
d) $\tau_A = \tau_B > \tau_C > \tau_D$
e) $\tau_C > \tau_D = \tau_A > \tau_B$