Physics 101	Hour Exam II	Fall 2012

Last Name:_______________First Name_________________Network-ID____________
Discussion Section:________Discussion TA Name:______________________________
Exam Room__________________________Seat Number____________

Instructions—Turn off your cell phone and put it away.
Calculators cannot be shared. Please keep yours on your own desk.

This is a closed book exam. You have 1.5 hours (90 minutes) to complete it.
This is a multiple choice exam. Use the bubble sheet to record your answers.

1. Use a #2 pencil; do **not** use a mechanical pencil or a pen. Fill in completely (until there is no white space visible) the circle for each intended input – both on the identification side of your answer sheet and on the side on which you mark your answers. If you decide to change an answer, erase vigorously; the scanner sometimes registers incompletely erased marks as intended answers; this can adversely affect your grade. Light marks or marks extending outside the circle may be read improperly by the scanner.

2. Print your last name in the **YOUR LAST NAME** boxes on your answer sheet and print the first letter of your first name in the **FIRST NAME INI** box. Mark (as described above) the corresponding circle below each of these letters.

3. Print your NetID in the **NETWORK ID** boxes, and then mark the corresponding circle below each of the letters or numerals. Note that there are different circles for the letter "I" and the numeral "1" and for the letter "O" and the numeral "0". **Do not** mark the hyphen circle at the bottom of any of these columns.

4. You may find the version of **this Exam Booklet at the top of page 2**. Mark the version circle in the **TEST FORM** box in the bottom right on the front side of your answer sheet. **DO THIS NOW!**

5. Stop **now** and double-check that you have bubbled-in all the information requested in 2 through 4 above and that your marks meet the criteria in 1 above. Check that you do not have more than one circle marked in any of the columns.

6. Print your UIN# in the **STUDENT NUMBER** designated spaces and mark the corresponding circles. You need not write in or mark the circles in the SECTION box.

7. Write in your course on the **COURSE LINE** and on the **SECTION** *line*, print your **DISCUSSION SECTION**. (You need not fill in the INSTRUCTOR line.)

8. Sign **(DO NOT PRINT)** your name on the **STUDENT SIGNATURE** *line*.

Before starting work, check to make sure that your test booklet is complete. You should have 17 ***numbered pages*** *which include 2 Formula Sheets.*

On the test booklet:
Write your **NAME**, your **Discussion TA's NAME**, your **DISCUSSION SECTION** and your **NETWORK-ID**. Also, write your **EXAM ROOM** and **SEAT NUMBER**.

When you are finished, you must hand in BOTH the exam booklet AND the answer sheet. Your exam will not be graded unless both are present.

Academic Integrity—**Giving assistance to or receiving assistance from another student or using unauthorized materials during a University Examination can be grounds for disciplinary action, up to and including expulsion.**

This Exam Booklet is Version A. Mark the **A** circle in the **TEST FORM** box in the bottom right on the front side of your answer sheet. **DO THIS NOW!**

Exam Format & Instructions:

This exam is a mixture of
* Two-Answer Multiple Choice (2 points each)
* Three-Answer Multiple Choice (3 points each)
* Five-Answer Multiple Choice (6 points each)

There are 24 problems for a maximum possible raw score of 112 points.

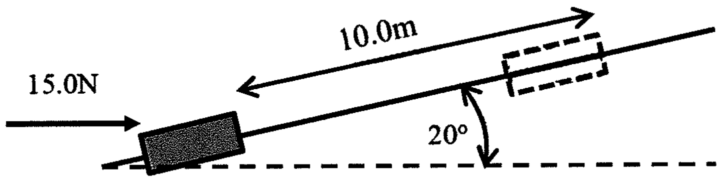
<u>Instructions for Two-Answer Multiple Choice Problems:</u>
Indicate on the answer sheet the correct answer to the question (*a* or *b*).
Each question is worth 2 points. If you mark the wrong answer, or mark more than one answer, you receive 0 points.

<u>Instructions for Three-Answer Multiple Choice Problems:</u>
Indicate on the answer sheet the correct answer to the question (*a, b* or *c*).
Each question is worth 3 points. If you mark the wrong answer, or mark more than one answer, you receive 0 points.

<u>Instructions for Five-Answer Multiple Choice Problems:</u>
Indicate on the answer sheet the correct answer to each question (*a, b, c, d* or *e*).
<u>Credit is awarded in the following way:</u>
- If you mark one answer and it is correct, you will receive 6 points;
- If you mark two answers, and one of them is correct, you will receive 3 points;
- If you mark three answers and one of them is correct, you will receive 2 points.
- If you mark no answer or more than three answers, you will receive 0 points.

Unless otherwise stated, ignore air resistance. Assume the acceleration of gravity is $g = 9.8\ m/s^2$ vertically downward. Assume that all fluids are ideal, and that all gases are ideal.

1. A small bead slides along a frictionless wire as shown. A 15.0 N force acts on the bead as it slides upwards along the wire. The wire is oriented at 20° above horizontal. During the time it takes for the bead to move 10.0 m, how much work does the force do?



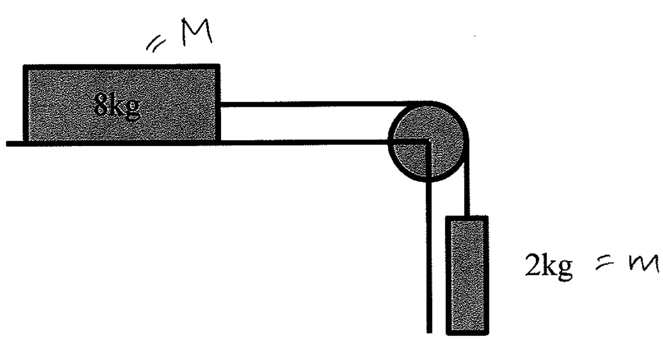
$W = Fd\cos\theta$

$= 15\text{ N} \times 10\text{ m} \times \cos 20°$

$= 141\text{ J}$

A. 1.5 J
(B.) 141 J
C. 150 J
D. 51 J
E. 14.1 J

2. The masses shown begin from rest and then move downwards a distance of 2.0 m. How fast are they moving now? There is no friction and the pulley has no mass.



A. 19.60 m/s
B. 11.20 m/s
C. 5.60 m/s
D. 6.26 m/s
(E.) 2.80 m/s

$KE = mgh$

$\frac{1}{2}Mv^2 + \frac{1}{2}mv^2 = mgh$

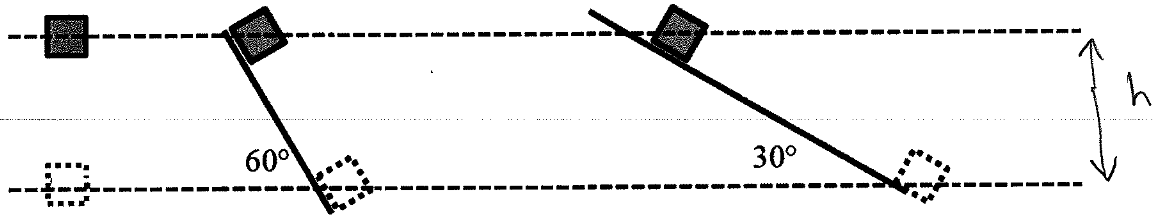
$\frac{1}{2}(M+m)v^2 = mgh$

$v = \sqrt{\frac{2mgh}{M+m}}$

$= \sqrt{\frac{2 \times 2\text{kg} \times 9.8\text{ m/s}^2 \times 2\text{ m}}{(8+2)\text{ kg}}}$

$= 2.8\text{ m/s}$

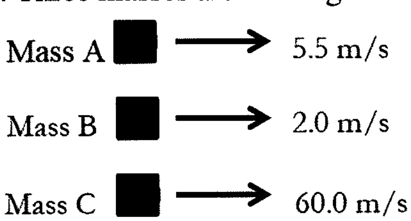
3. A small metal block (shaded block) is released from rest at the level of the top dashed line. It either falls or slides on a *frictionless* incline to the level of the bottom dashed line (dotted block). For which choice is the speed of the block greatest at the bottom dashed line?



$\frac{1}{2}mv^2 = mgh$

A. Falling
B. Sliding on the 30° incline
C. Sliding on the 60° incline
D. Sliding on either incline
(E.) All three choices result in the same speed

4. Three masses are moving to the right, as shown.



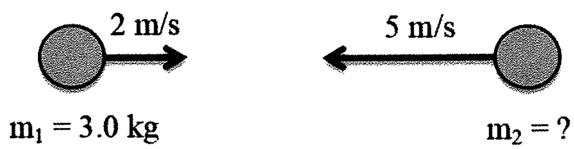
$mv = 10\text{ kg} \times 5.5\text{ m/s} = 55\text{ kg m/s}$
$mv = 30\text{ kg} \times 2\text{ m/s} = 60$
$mv = 1\text{ kg} \times 60\text{ m/s} = 60$

Mass A is 10.0 kg moving at 5.5 m/s. Mass B is 30.0 kg moving at 2.0 m/s. Mass C is 1.0 kg moving at 60.0 m/s. Which mass has the greatest momentum?

A. Mass A
B. Mass B
C. Mass C
D. Masses A and B are tied for greatest momentum.
(E.) Masses B and C are tied for greatest momentum.

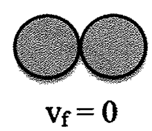
5. A 3.0 kg mass moves at 2 m/s to the right. A second mass moves at 5 m/s to the left. They collide and stick together. If the final velocity is zero, what is the mass of the second mass?

Before Collision:



A. 2.5 kg
(B) 1.2 kg
C. 15 kg
D. 3.3 kg
E. 7.5 kg

After Collision:



$m_1 V_1 - m_2 V_2 = 0$

$m_2 = m_1 \frac{V_1}{V_2}$

$= 3 \text{ kg} \times \frac{2}{5}$

$= 1.2 \text{ kg}$

6. A bat hits a 0.35 kg ball. The ball was moving at 20 m/s to the right before being hit; it moves at 30 m/s to the left after being hit. What is the change in momentum of the ball?

(A) 17.5 kg m/s to the left
B. 17.5 kg m/s to the right
C. 10.5 kg m/s to the left.

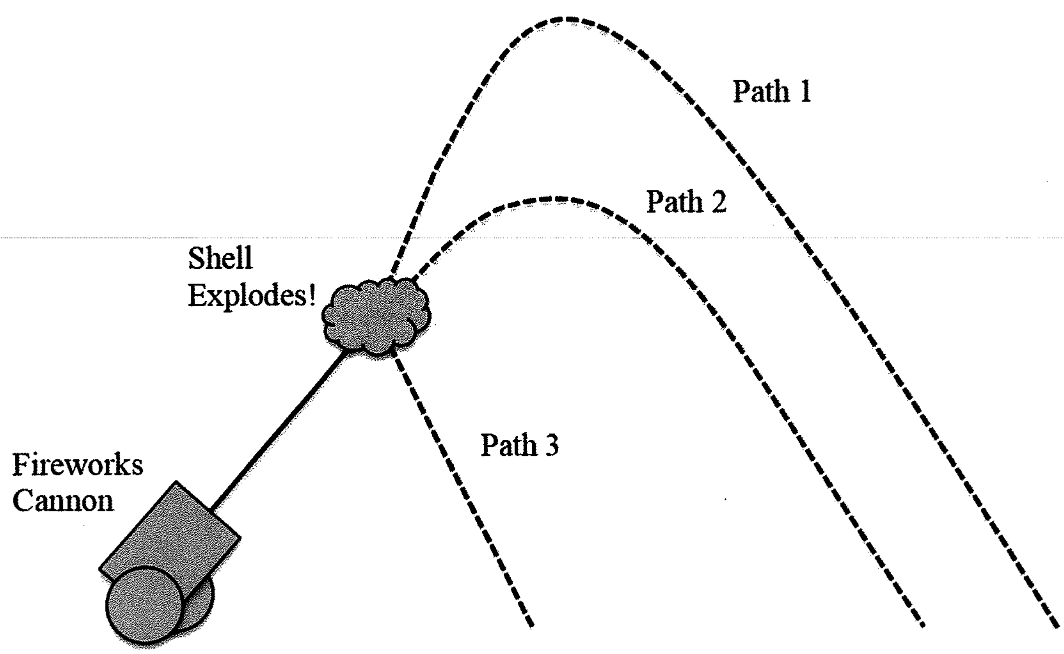
$- \leftarrow \quad \rightarrow +$

$\Delta p = m(v_f - v_i)$

$= 0.35 \text{ kg} (-30 \text{ m/s} - 20 \text{ m/s})$

$= -17.5 \text{ kg m/s}$

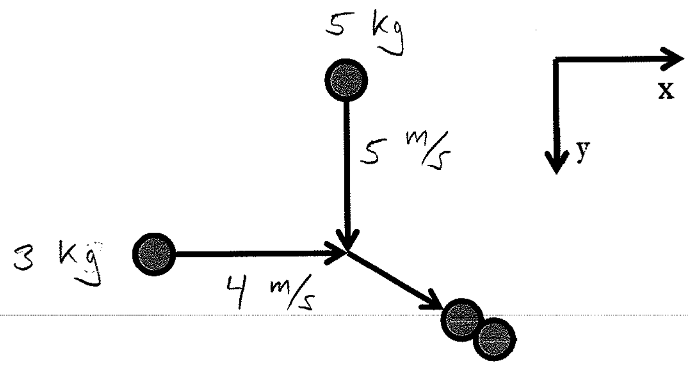
The following diagram refers to the following one problem.



7. It's July 4th and time for some fireworks. A shell is fired, and at 100 meters high while still going at a 75° slant, but still going up, the shell suddenly explodes, releasing fireworks. Does the path of the center-of-mass look like:

A. Path 1
(B.) Path 2
C. Path 3
D. The center of mass stops when the shell exploded.
E. The center of mass vanishes.

The following diagram refers to the following one problem.



8. There is no gravity in this problem; it takes place on a spaceship in deep space. Two clay balls are thrown. Ball #1 has mass 3.0 kg and velocity 4 m/s in what is called the x direction. Ball #2 has a mass 5.0 kg and is thrown at 5.0 m/s in what is called the y direction (perpendicular to the x direction). They hit and stick. What is the x component of the velocity of the combined mass of clay after the collision?

(A.) 1.50 m/s
B. -1.50 m/s
C. 12.0 m/s
D. 25.0 m.s
E. 27.7 m/s

$p_x = 3\text{ kg} \times 4\text{ m/s} = (3+5)\text{ kg} \times V_x$

$V_x = \frac{3}{3+5} \times 4\text{ m/s}$

$= 1.5\text{ m/s}$

9. A roller coaster car has a mass of 500.0 kg. It is moving at 25.0 m/s coming toward the end of the ride. Special brakes slow the car to a stop over a distance of 30.0 m. How much work did the brakes do?

A. $-1.25 \cdot 10^3$ J
(B.) $-1.56 \cdot 10^5$ J
C. $-3.75 \cdot 10^3$ J

$W = \Delta KE$

$= -\frac{1}{2} mv^2$

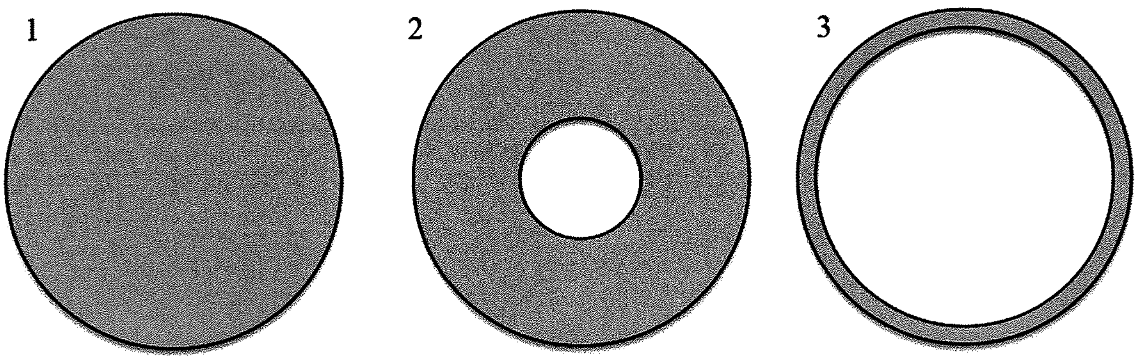
$= -\frac{1}{2}\, 500\text{ kg} \times (25\text{ m/s})^2$

$= -156{,}250\text{ J}$

10. Torque is a kind of vector: it has both magnitude and direction.

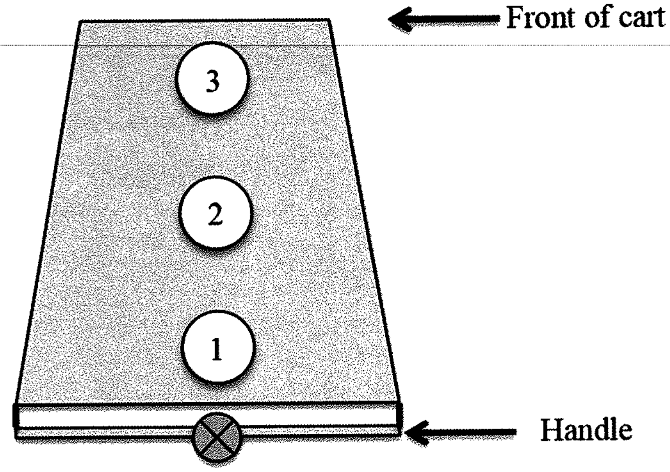
A. True
B. False

11. The objects below all have the same total mass and the same outer radius. Place them in order of *decreasing* magnitude of the moment of inertia, I.



A. $I_1 > I_2 > I_3$
B. $I_3 > I_2 > I_1$
C. $I_2 > I_3 > I_2$

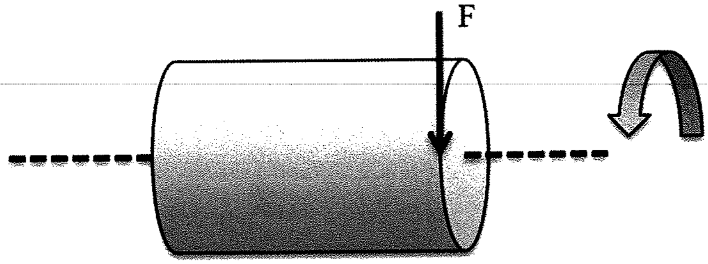
12. At the grocery store, you steer your cart by applying torques in order to rotate the cart either left or right about the axis of rotation; the axis of rotation is indicated as a circled X in the drawing of the top view of the cart below, and the axis points perpendicularly to the plane of the paper. While shopping, you purchase three identical and large, extremely heavy cases of bottled water. You can place each of the cases of water into three possible positions in your cart, as indicated on the diagram. Where should you place the cases of water in order to make your cart easiest to turn?



(A.) All cases in Position 1 smallest I
B. All cases in Position 3
C. One case in each of Positions 1, 2, and 3

The next two questions relate to the following situation

A constant force of F = 2.50 N acts tangentially on a cylinder of radius 12.5 cm and mass 10 kg ($I_{cylinder} = MR^2/2$). The cylinder is initially at rest, and comes to a final angular speed of 12.6 rad/s.



13. What is the magnitude of the torque acting on the cylinder?

A. 1.75 N m
B. 1.52 N m
C. 1.21 N m
D. 0.524 N m
(E.) 0.313 N m

$\tau = FR$
$= 2.5\ N \times 0.125\ m$
$= 0.3125\ Nm$

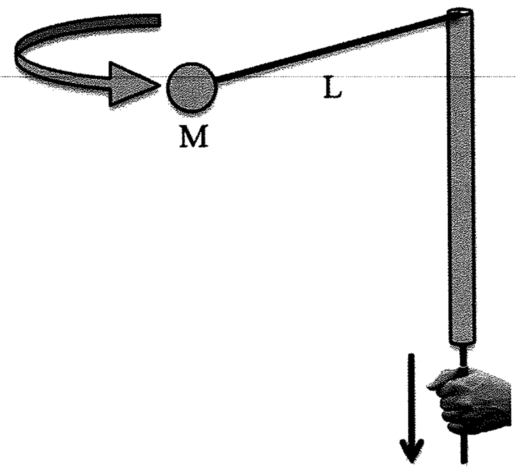
14. How much work is done in bringing the cylinder up to the final angular speed of 12.6 rad/s? ($I_{cylinder} = MR^2/2$)

A. 5.1 J
(B.) 6.2 J
C. 7.0 J
D. 7.4 J
E. 8.0 J

$W = \Delta KE$
$= \frac{1}{2} I \omega^2$
$= \frac{1}{2} \frac{1}{2} MR^2 \omega^2$
$= \frac{1}{4} 10\ kg \times (0.125\ m)^2 (12.6\ rad/s)^2$
$= 6.2\ J$

The following diagram applies to the net two problems.

A ball of mass M is connected to a massless string of length L, which passes through a hollow central support, about which it spins with angular speed ω_0. In this problem, you can ignore the effect of gravity.
If the length of the string is suddenly halved by pulling on the string:



15. The object's moment of inertia:

A. Becomes larger
(B) Becomes smaller
C. Stays the same.

16. How does the new angular speed, ω_f, compare to the initial angular speed?

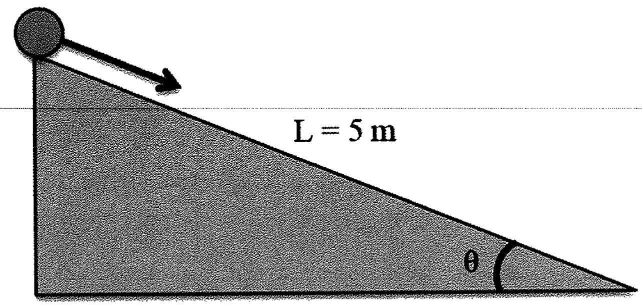
A. $\omega_f = \omega_0$
B. $\omega_f = 2\,\omega_0$
(C.) $\omega_f = 4\,\omega_0$
D. $\omega_f = \omega_0/2$
E. $\omega_f = \omega_0/4$

$I_0 \omega_0 = I_f \omega_f$

$M L^2 \omega_0 = M (L/2)^2 \omega_f$

$\omega_f = 4\omega_0$

17. A ball ($I_{ball} = 2MR^2/5$) starts from rest at the top of an inclined plane. The length of the hypotenuse of the plane is L = 5 m, and it is inclined at an angle $\theta = 30^o$ from the horizontal. The ball then rolls down the incline without slipping. What is its linear speed at the bottom of the incline?



A. 3.2 m/s
B. 4.7 m/s
C. 5.0 m/s
(D.) 5.9 m/s
E. 6.5 m/s

$KE = mgh$

$\frac{1}{2} m v^2 + \frac{1}{2} I \omega^2 = mg L \sin\theta$

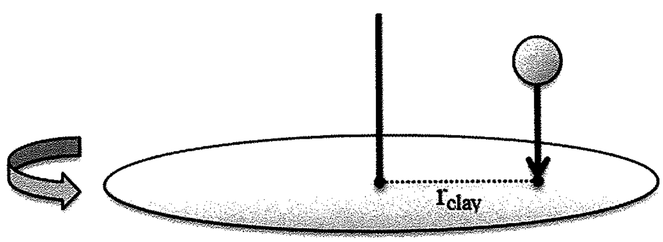
$\frac{1}{2} m v^2 + \frac{1}{2}\frac{2}{5} m R^2 \left(\frac{V}{R}\right)^2 = mg L \sin\theta$

$\frac{7}{10} v^2 = g L \sin\theta \Rightarrow v = \sqrt{\frac{10}{7} g L \sin\theta}$

$= \sqrt{\frac{10}{7} 9.8 \, m/s^2 \, 5m \sin 30}$

$= 5.9 \, m/s$

18. A 0.5 kg disk ($I_{disk} = MR^2/2$) of 0.500 m radius is rotating freely at an angular velocity of 2.00 rad/s. A 100 gram ball of clay is dropped and sticks at a radius of $r_{clay} = 0.375$ meters. What is the final angular speed of the system?



(A.) 1.63 rad/s
B. 2.00 rad/s
C. 2.37 rad/s

$I_o \omega_o = I \omega$

$\frac{1}{2} MR^2 \omega_o = \left(\frac{1}{2} MR^2 + m r_{clay}^2\right)\omega$

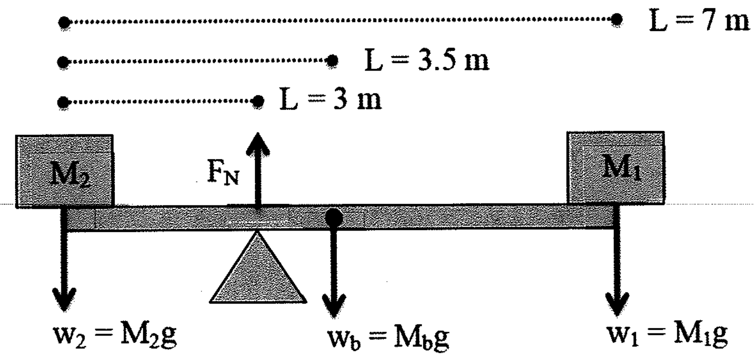
$\omega = \frac{1}{2} MR^2 \omega_o / \left(\frac{1}{2} MR^2 + m r_{clay}^2\right)$

$= \frac{1}{2} 0.5 \, kg \times (0.5 m)^2 \times 2 \, rad/s$

$/ \left[\frac{1}{2} 0.5 \, kg \times (0.5 m)^2 + 0.1 \, kg \times (0.375 m)^2\right]$

$= 1.63 \, rad/s$

19. A mass of $M_1 = 5$ kg is placed on the far right end of a uniform beam of length $L = 7$ m and mass $M_b = 25$ kg. A fulcrum is placed at 3 meters from the left hand side. The fulcrum holds the beam up. What is the magnitude of the mass M_2 that should be placed at the far left end in order to balance the beam?

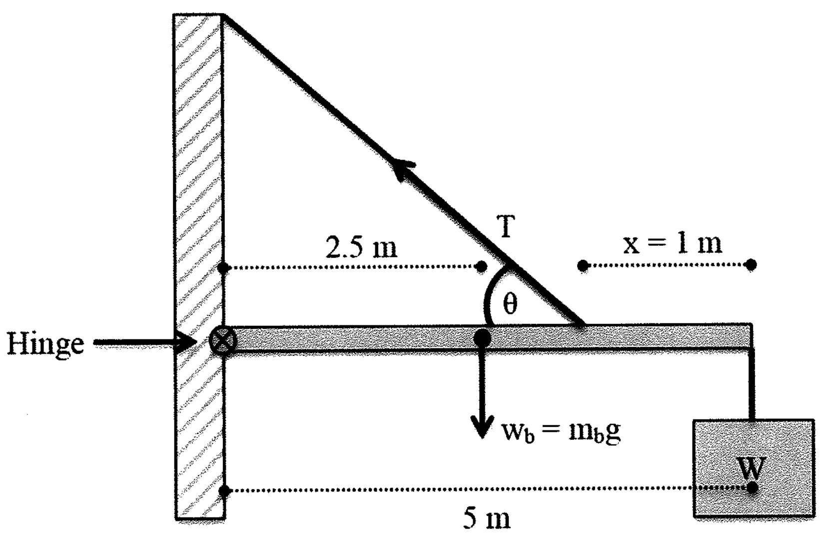


$M_2 g \times 3\,m = M_b g \times 0.5\,m + M_1 g \times 4\,m$

A. 3 kg
B. 7 kg
(C.) 11 kg

$M_2 = \frac{1}{3}(25\,kg \times 0.5 + 5\,kg \times 4) = 10.83\,kg$

20. A sign of weight W = 100 N is hung from the end of a uniform horizontal boom of length L = 5 m and mass $m_b = 25$ kg. The boom is affixed to the side of a building through a hinge, indicated by a circled x on the diagram below. The boom is additionally supported by a cable attached at point x = 1 m from the free end of the boom and inclined at an angle of $\theta = 45^{\circ}$ to the boom. What is the tension, T, in the cable?



Torque about hinge = 0

$-m_b g \times 2.5\,m + W \times 5\,m + T \times 4\,m \times \sin\theta = 0$

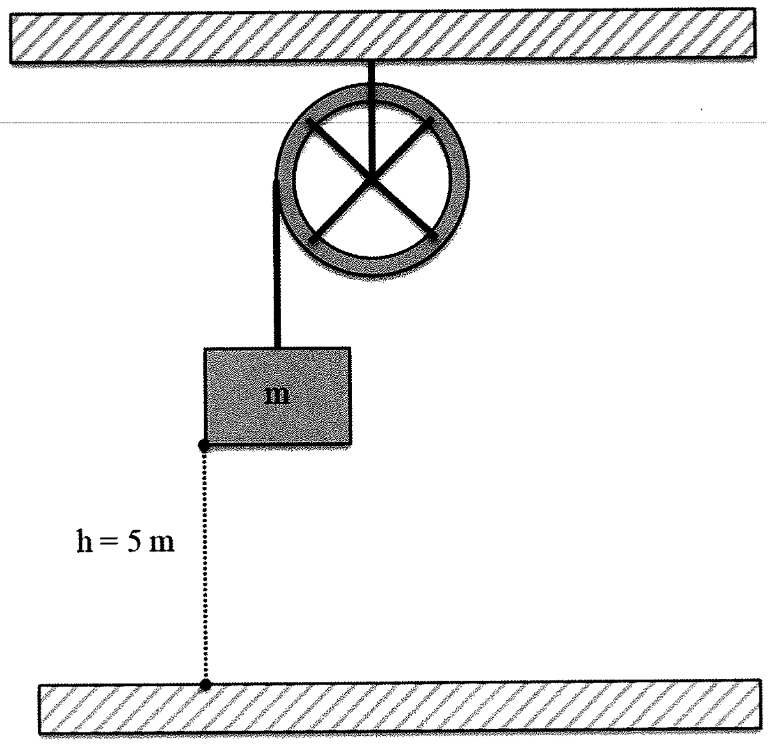
A. 243 N
(B.) 393 N
C. 413 N
D. 475 N
E. 513 N

$T = (25\,kg \times 9.8\frac{m}{s^2} \times 2.5\,m + 100\,N \times 5\,m) / 4\,m \times \sin 45$

$= 393\,N$

The next two questions relate to the following situation

A hoop of mass M = 2.5 kg and radius R = 1 m is acting as a pulley ($I_{hoop} = MR^2$). A rope is wrapped around the hoop and is connected to a mass of m = 15 kg, which is suspended a height h = 5 m above the floor. The system is initially at rest, and the mass is released and allowed to fall.



21. What is the speed of the mass just before it hits the ground?

(A.) 9.2 m/s
B. 8.7 m/s
C. 7.4 m/s
D. 6.2 m/s
E. 5.1 m/s

$\frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 = mgh$

$\frac{1}{2}mv^2 + \frac{1}{2}MR^2\left(\frac{v}{R}\right)^2 = mgh$

$\frac{1}{2}(m+M)v^2 = mgh$

$v = \sqrt{2mgh/(m+M)} = \sqrt{\frac{2 \times 15\ kg \times 9.8\ m/s^2 \times 5\ m}{(15+2.5)\ kg}}$

$= 9.16\ m/s$

22. What is the work done on the mass m by gravity?

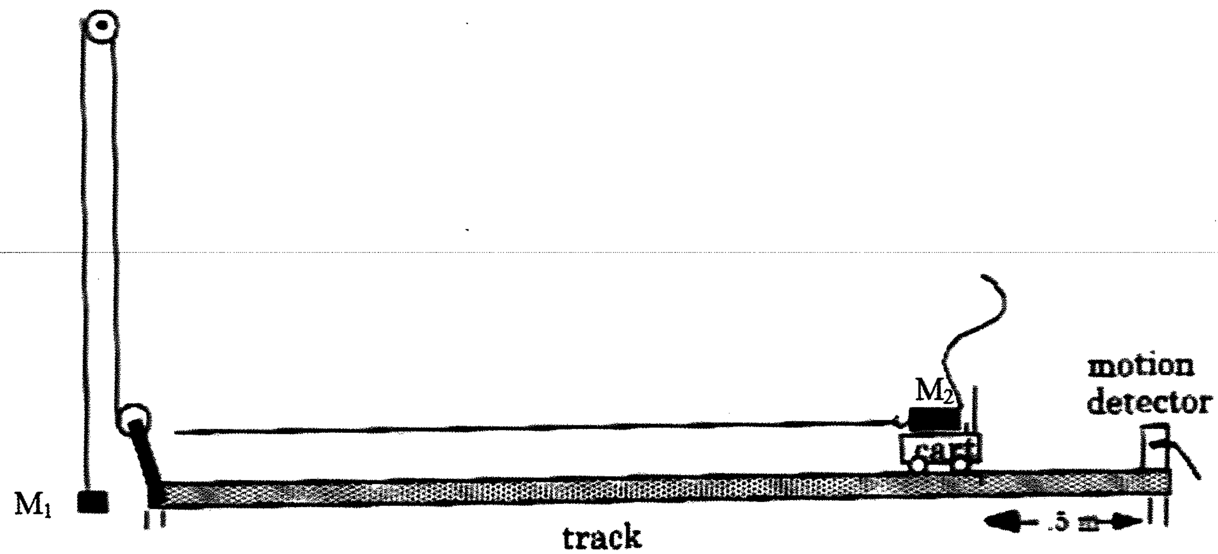
A. 273 J
B. 310 J
C. 442 J
D. 543 J
(E.) 735 J

$W = Fd$

$= mgh$

$= 15\ kg \times 9.8\ m/s^2 \times 5\ m$

$= 735\ J$



23. In the diagram above, a mass M_1 is pulling a cart of mass M_2, on a system that has <u>no</u> friction. Depending on whether M_1 is larger or smaller than M_2, the acceleration of M_2 can be larger or smaller than g.

A. True
(B.) False

24. In the laboratory, you dropped a basketball, letting it bounce off of the floor several times. In between the bounces, when the ball is in the air, the basketball:

(A.) Had approximately the same acceleration, both amplitude and direction. $a = g$ downwards
B. Had an negative acceleration going down, but positive acceleration going up.
C. Had the velocity always negative.

Physics 101 Formulas

Kinematics
$\mathbf{v}_{ave} = \Delta\mathbf{x}/\Delta t$ $\mathbf{a}_{ave} = \Delta\mathbf{v}/\Delta t$
$v = v_0 + at$ $x = x_0 + v_0t + {}^1/_2at^2$ $v^2 = v_0^2 + 2a\Delta x$
$g = 9.8 m/s^2 = 32.2 ft/s^2$ (near Earth's surface)

Dynamics
$\Sigma\mathbf{F} = m\mathbf{a}$ $F_g = Gm_1m_2 / R^2$ $F_g = mg$ (near Earth's surface)
$f_{s,max} = \mu_sF_N$ Gravitational constant, $G = 6.7 \times 10^{-11}\ N{\cdot}m^2/kg^2$
$f_k = \mu_kF_N$ $a_c = v^2 / R = \omega^2R$

Work & Energy
$W_F = FS\cos(\theta)$ $K (\text{or } KE) = {}^1/_2mv^2$ $W_{NET} = \Delta K = K_f - K_i$ $E = K + U$
$W_{nc} = \Delta E = E_f - E_i = (K_f + U_f) - (K_i + U_i)$
$W_{grav} = -mg\Delta y$ U_{grav} (or PE_{grav}) $= mgy$

Impulse & Momentum
Impulse $\mathbf{I} = \mathbf{F}_{ave}\Delta t = \Delta\mathbf{p}$ $\mathbf{F}_{ave}\Delta t = \Delta\mathbf{p} = m\mathbf{v}_f - m\mathbf{v}_i$ $\mathbf{F}_{ave} = \Delta\mathbf{p}/\Delta t$
$\Sigma\mathbf{F}_{ext}\Delta t = \Delta\mathbf{P}_{total} = \mathbf{P}_{total,final} - \mathbf{P}_{total,initial}$ (momentum conserved if $\Sigma\mathbf{F}_{ext} = 0$)
$\mathbf{X}_{cm} = (m_1\mathbf{x}_1 + m_2\mathbf{x}_2)/(m_1 + m_2)$

Rotational Kinematics
$\omega = \omega_0 + \alpha t$ $\theta = \theta_0 + \omega_0t + {}^1/_2\alpha t^2$ $\omega^2 = \omega_0^2 + 2\alpha\Delta\theta$
$\Delta x_T = \Delta\theta R$ $v_T = \omega R$ $a_T = \alpha R$ (rolling without slipping: $\Delta x = \Delta\theta R$ $v = \omega R$ $a = \alpha R$)

Rotational Statics & Dynamics
$\tau = Fr\sin\theta$
$\Sigma\tau = 0$ and $\Sigma F=0$ (static equilibrium)
$\Sigma\tau = I\alpha$
$I = \Sigma mr^2$ (for a collection of point particles)
$I = {}^1/_2MR^2$ (solid disk or cylinder) $I = {}^2/_5MR^2$ (solid sphere) $I = {}^2/_3MR^2$ (hollow sphere)
$I = MR^2$ (hoop or hollow cylinder) $I = {}^1/_{12}ML^2$ (uniform rod about center)
$W = \tau\theta$ (work done by a torque)
$\mathbf{L} = I\omega$ $\Sigma\tau_{ext}\Delta t = \Delta\mathbf{L}$ (angular momentum conserved if $\Sigma\tau_{ext} = 0$)
$K_{rot} = {}^1/_2I\omega^2 = L^2/2I$ $K_{total} = K_{trans} + K_{rot} = {}^1/_2mv^2 + {}^1/_2I\omega^2$

Simple Harmonic Motion
Hooke's Law: $F_s = -kx$
$W_{spring} = {}^1/_2kx_i^2 - {}^1/_2kx_f^2$ $U_{spring} = {}^1/_2kx^2$
$x(t) = A\cos(\omega t)$ or $x(t) = A\sin(\omega t)$
$v(t) = -A\omega\sin(\omega t)$ or $v(t) = A\omega\cos(\omega t)$
$a(t) = -A\omega^2\cos(\omega t)$ or $a(t) = -A\omega^2\sin(\omega t)$
$\omega^2 = k/m$ $T = 2\pi/\omega = 2\pi\sqrt{m/k}$ $f = 1/T$
$x_{max} = A$ $v_{max} = \omega A$ $a_{max} = \omega^2A$ $\omega = 2\pi f$
For a simple pendulum $\omega^2 = g/L$, $T = 2\pi\sqrt{L/g}$

Fluids

$P = F/A$, $P(d) = P(0) + \rho g d$ change in pressure with depth d

Buoyant force $F_B = \rho g V_{dis}$ = weight of displaced fluid

Flow rate $Q = v_1A_1 = v_2A_2$ continuity equation (area of circle $A = \pi r^2$)

$P_1 + {}^1/_2\rho v_1^2 + \rho g y_1 = P_2 + {}^1/_2\rho v_2^2 + \rho g y_2$ Bernoulli equation

$\rho_{water} = 1000\ kg/m^3$ $1m^3 = 1000$ liters

$\rho = M/V$ 1 atmos. = 1.01×10^5 Pa 1 Pa = 1 N/m^2

Temperature and Heat

Temperature: Celsius (T_C) to Fahrenheit (T_F) conversion: $T_C = (5/9)(T_F - 32)$

Celsius (T_C) to Kelvin (T_K) conversion: $T_K = T_C + 273$

$\Delta L = \alpha L_0 \Delta T$ $\Delta V = \beta V_0 \Delta T$ thermal expansion

$Q = cM\Delta T$ specific heat capacity

$Q = L_f M$ latent heat of fusion (solid to liquid) $Q = L_v M$ latent heat of vaporization

$Q = kA\Delta Tt/L$ conduction

$Q = e\sigma T^4 At$ radiation ($\sigma = 5.67\times10^{-8}\ J/(s{\cdot}m^2{\cdot}K^4)$)

$P_{net} = e\sigma A(T^4 - T_0^4)$ (surface area of a sphere $A = 4\pi r^2$)

Ideal Gas & Kinetic Theory

$N_A = 6.022 \times 10^{23}$ molecules/mole Mass of carbon-12 = 12.000u

$PV = nRT = Nk_BT$ $R = 8.31\ J/(mol{\cdot}K)$ $k_B = R/N_A = 1.38 \times 10^{-23}\ J/K$

$KE_{ave} = {}^3/_2 k_BT = {}^1/_2 m v_{rms}^2$ $U = {}^3/_2 Nk_BT$ (internal energy of a monatomic ideal gas)

$v_{rms}^2 = 3k_BT/m = 3RT/M$ (M = molar mass = kg/mole)

Thermodynamics

$\Delta U = Q + W$ (1'st law)

$U = ({}^3/_2)nRT$ (internal energy of a monatomic ideal gas for fixed n)

$C_V = ({}^3/_2)R = 12.5\ J/(mol{\cdot}K)$ (specific heat at constant volume for a monatomic ideal gas)

$Q_H = Q_C + W$ (heat engine or refrigerator)

$e = W/Q_H = 1 - Q_C/Q_H$ $e_{max} = 1 - T_C/T_H$ (Carnot engine)

$Q_C/Q_H = T_C/T_H$ at maximum efficiency (2'nd law)

$W = -P\Delta V$ (work done by expanding gas)

Harmonic Waves

$v = \lambda / T = \lambda f$

$v^2 = F/(m/L)$ for wave on a string

$v = c = 3 \times 10^8$ m/s for electromagnetic waves (light, microwaves, etc.)

$I = P/(4\pi r^2)$ (sound intensity)

Sound Waves

Loudness: $\beta = 10 \log_{10}(I/I_0)$ (in dB), where $I_0 = 10^{-12}\ W/m^2$

$$f_{observer} = f_{source}\frac{v_{wave} - v_{observer}}{v_{wave} - v_{source}}$$ (Doppler effect)