

Please write your CID here \_\_\_\_\_

No time limit. No notes. No books. Testing Center calculators only.

Constants:

$g = 9.8 \text{ m/s}^2 \rightarrow$  **but you may use 10  $\text{m/s}^2$  in nearly all cases**  
 $G = 6.67 \times 10^{-11} \text{ N}\cdot\text{m}^2/\text{kg}^2$   
 $k_B = 1.381 \times 10^{-23} \text{ J/K}$   
 $N_A = 6.022 \times 10^{23}$   
 $R = k_B \cdot N_A = 8.314 \text{ J/mol}\cdot\text{K}$   
 $\sigma = 5.67 \times 10^{-8} \text{ W/m}^2\cdot\text{K}^4$   
 Mass of Sun =  $1.991 \times 10^{30} \text{ kg}$   
 Mass of Earth =  $5.98 \times 10^{24} \text{ kg}$

Radius of Earth =  $6.38 \times 10^6 \text{ m}$   
 Radius of Earth's orbit =  $1.496 \times 10^{11} \text{ m}$   
 Density of water:  $1000 \text{ kg/m}^3$   
 Density of air:  $1.29 \text{ kg/m}^3$   
 Young's modulus of steel:  $20 \times 10^{10} \text{ N/m}^2$   
 Linear exp. coeff. of copper:  $17 \times 10^{-6} /^\circ\text{C}$   
 Linear exp. coeff. of steel:  $11 \times 10^{-6} /^\circ\text{C}$   
 Specific heat of water:  $4186 \text{ J/kg}\cdot^\circ\text{C}$   
 Specific heat of ice:  $2090 \text{ J/kg}\cdot^\circ\text{C}$   
 Specific heat of steam:  $2010 \text{ J/kg}\cdot^\circ\text{C}$

Specific heat of aluminum:  $900 \text{ J/kg}\cdot^\circ\text{C}$   
 Latent heat of melting (water):  $33 \times 10^5 \text{ J/kg}$   
 Latent heat of boiling (water):  $2.26 \times 10^6 \text{ J/kg}$   
 Thermal conduct. of aluminum:  $238 \text{ J/s}\cdot\text{m}\cdot^\circ\text{C}$   
 $\sin(30^\circ) = 0.5$   
 $\cos(30^\circ) \approx 0.866$   
 $\tan(30^\circ) \approx 0.577$   
 $\pi \approx 3.14$

Conversion factors

1 inch = 2.54 cm  
 1  $\text{m}^3 = 1000 \text{ L}$

1 atm =  $1.013 \times 10^5 \text{ Pa} = 14.7 \text{ psi}$   
 $T_F = \frac{9}{5}T_C + 32$

$T_K = T_C + 273.15$

Other equations

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Surface area of sphere =  $4\pi r^2$

Volume of sphere =  $(4/3)\pi r^3$

$$v_{ave} = \frac{v_i + v_f}{2}$$

$$v = v_o + at$$

$$x = x_o + v_o t + \frac{1}{2}at^2$$

$$v_f^2 = v_o^2 + 2a\Delta x$$

$$w = mg, PE_g = mgy$$

$$F = -kx, PE_s = \frac{1}{2}kx^2$$

$$f = \mu_k N \text{ (or } f \leq \mu_s N)$$

$$P = F_{\parallel} v = Fv \cos \theta$$

$$\vec{F}\Delta t = \Delta\vec{p}$$

Elastic:  $(v_1 - v_2)_{\text{bef}} = (v_2 - v_1)_{\text{after}}$

arc length:  $s = r\theta$

$$v = r\omega$$

$$a_{\text{tan}} = r\alpha$$

$$a_c = v^2/r$$

$$F_g = \frac{GMm}{r^2}, PE_g = -\frac{GMm}{r}$$

$$I_{\text{pt mass}} = mR^2$$

$$I_{\text{sphere}} = (2/5)mR^2$$

$$I_{\text{hoop}} = mR^2$$

$$I_{\text{disk}} = (1/2)mR^2$$

$$I_{\text{rod (center)}} = (1/12)mL^2$$

$$I_{\text{rod (end)}} = (1/3)mL^2$$

$$L = r_{\perp} p = rp_{\perp} = rp \sin \theta$$

stress =  $F/A$ ; strain =  $\Delta L/L$

$Y = \text{stress/strain}$

$$P = P_0 + \rho gh$$

$$VFR = A_1 v_1 = A_2 v_2$$

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho gy_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho gy_2$$

$$\Delta L = \alpha L_0 \Delta T$$

$$\Delta V = \beta V_0 \Delta T; \beta = 3\alpha$$

$$KE_{ave} = \frac{1}{2}mv_{ave}^2 = \frac{3}{2}k_B T$$

$$Q = mc\Delta T; Q = mL$$

$$\frac{\Delta Q}{\Delta T} = kA \frac{T_2 - T_1}{L}$$

$$P = e\sigma AT^4$$

$|W_{\text{on gas}}| = \text{area under P-V curve}$

=  $P\Delta V$  (constant pressure)

=  $nRT \ln(V_2/V_1)$  (isothermal)

=  $\Delta U$  (adiabatic)

$$U = \frac{3}{2}Nk_B T = \frac{3}{2}nRT \text{ (monatomic)}$$

$$Q_h = |W_{\text{net}}| + Q_c$$

$$e = \frac{|W_{\text{net}}|}{Q_{\text{added}}} = 1 - \frac{Q_c}{Q_h}$$

$$e_{\text{max}} = 1 - \frac{T_c}{T_h}$$

$$\omega = \sqrt{\frac{k}{m}}, T = 2\pi\sqrt{\frac{m}{k}}$$

$$\omega = \sqrt{\frac{g}{L}}, T = 2\pi\sqrt{\frac{L}{g}}$$

$$v = \sqrt{\frac{T}{\mu}}, \mu = m/L$$

$$v = \sqrt{\frac{Y}{\rho}}, v = \sqrt{\frac{B}{\rho}}$$

$v_{\text{air}} = 343 \text{ m/s at } 20^\circ\text{C}$

$$\beta = 10 \log\left(\frac{I}{I_0}\right) \quad I_0 = 10^{-12} \text{ W/m}^2$$

$$f' = f \frac{v \pm v_0}{v \pm v_s}$$

$$f_n = n \frac{v}{2L} \quad n = 1, 2, 3, \dots$$

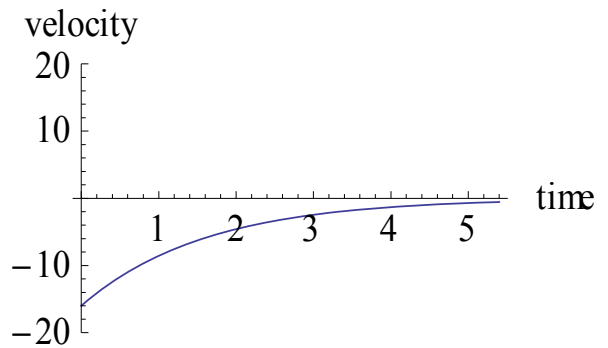
$$f_n = n \frac{v}{4L} \quad n = 1, 3, 5, \dots$$

Did you write down your CID at the top of the page? \_\_\_\_\_ If not, you may not get this test booklet back.

**Instructions:**

- Record your answers on the bubble sheet.
- The Testing Center no longer allows students to see which problems they got right & wrong, so I strongly encourage you to **mark your answers in this test booklet**. You will get this test booklet back (but only if you **write your CID at the top of the first page**).
- You may write on this exam booklet, and are strongly encouraged to do so.
- In all problems, **ignore friction, air resistance, and the mass of all springs, pulleys, ropes, cables, strings etc.**, unless specifically stated otherwise.
- Use  $g = 9.8 \text{ m/s}^2$  only if there are "9.8" numbers in the answer choices; **otherwise use  $g = 10 \text{ m/s}^2$** .
- Problems 1-28 will be scaled to be worth 92 total points; problems 29 and 30 are worth 4 points each.

Problem 1. The figure shows a velocity vs time graph of a car moving along a road, and positive means "to the right". According to the graph, what is the car doing from 0 to 5 seconds?

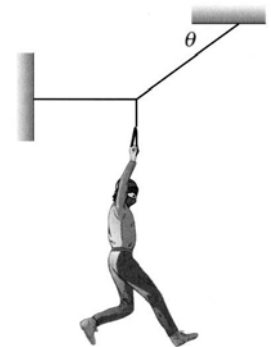


- a. moving to the left, slowing down, and stopping
- b. moving to the left and speeding up
- c. moving to the right, slowing down, and stopping
- d. moving to the right and speeding up
- e. first moving right, then moving left
- f. first moving left, then moving right

Problem 2. A box slides down a smooth ramp. The work done on the box by the normal force is:

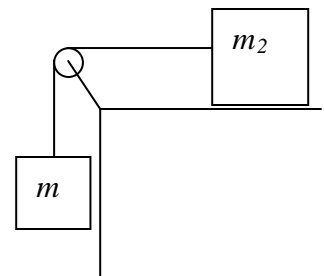
- a. positive
- b. negative
- c. zero

Problem 3. Two cables support a cat burglar of mass 75 kg. One cable is at an angle as shown in the figure, with  $\theta = 36.87^\circ$ . What is the tension in the cable connected to the left wall. *Note:*  $\sin(36.9^\circ) = 0.60$ ,  $\cos(36.9^\circ) = 0.80$ ,  $\tan(36.9^\circ) = 0.75$ .



- a. Less than 550 N
- b. 550 - 650
- c. 650 - 750
- d. 750 - 850
- e. 850 - 950
- f. 950 - 1050
- g. 1050 - 1150
- h. More than 1150 N

Problem 4. A hanging mass, 3 kg, is attached via a pulley to another mass, 15 kg, which is resting on a horizontal table as shown in the figure. There is enough friction on the table ( $\mu = 0.8$ ) to prevent the masses from moving. What is the tension in the line connecting the two masses?



- a. Less than 19 N
- b. 19 - 27
- c. 27 - 35
- d. 35 - 43
- e. 43 - 51
- f. 51 - 59
- g. More than 59 N

Problem 5. William, initially floating in outer space with no forces acting on him, throws a ball. The ball goes one way, and he goes the other way. Before the collision, there was no momentum, and after the collision, both he and the ball have momentum. It doesn't look like momentum was conserved. What's the best explanation for this situation?

- Both William and the ball get half of the original momentum.
- Momentum is a vector, so two momentums can "cancel out".
- Momentum was created because of the "explosion".
- Momentum wasn't conserved in this situation, but *energy* was conserved.
- There was an outside force, so we shouldn't expect momentum to be conserved.
- William's momentum is very small, since his mass is much larger than the ball.

Problem 6. A railroad car of mass 20,000 kg moving to the right at 2 m/s collides and couples with another railroad car that has a mass of 30,000 and is moving to the right at 1 m/s (before the collision). What is the speed of the two coupled cars after the collision?

- 0.2 m/s
- 0.4
- 0.6
- 0.8
- 1.0
- 1.2
- 1.4
- 1.6 m/s

Problem 7. In a collision between two objects with no outside forces, the total momentum of the system is conserved:

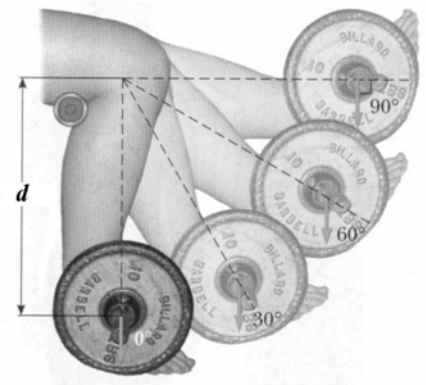
- Always
- Only when the collision is elastic

Problem 8. The *escape velocity* of the Earth is the speed needed for an object to go from the surface of the Earth into a "near Earth" orbit.

- True
- False

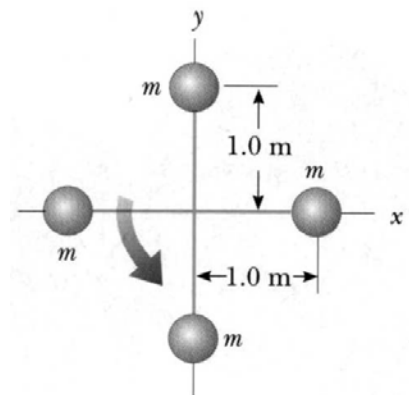
Problem 9. A weight (mass  $m$ ) is attached to an ankle, and leg lifts are done as shown in the figure. What is the torque about the knee due to this weight for the position labeled  $60^\circ$ ?

- $mgd$
- $mgd \cos(30^\circ)$
- $mgd \cos(60^\circ)$
- $mgd \sin(30^\circ)$
- $mgd \sin(60^\circ)$
- $mgd \tan(30^\circ)$
- $mgd \tan(60^\circ)$



Problem 10. The four balls in the figure, each with mass 2 kg, are connected by rods. They are rotating together (as shown by the arrow) in outer space with an angular speed of 40 rad/s. The light, flexible rods can be lengthened or shortened through internal motors. What is the new angular velocity if the spokes are shortened from 1 m to 0.50 m?

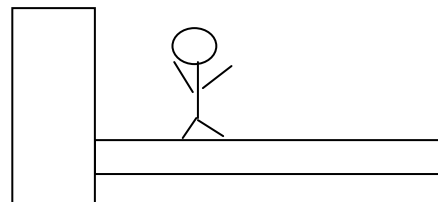
- 10 rad/s
- 20
- 40
- 80
- 160 rad/s



Problem 11. Suppose an alien astronaut in a circular orbit around the alien homeworld, 10000 km from the planet's center, has an orbital speed of 20 km/s. How long would it take the alien to make one complete orbit?

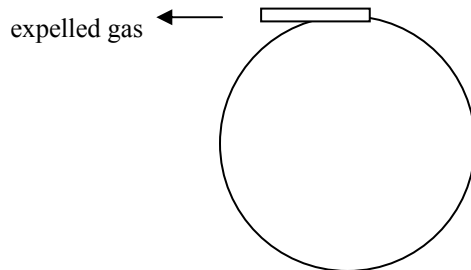
- Less than 700 seconds
- 700 – 1400
- 1400 – 2100
- 2100 – 2800
- 2800 – 3500
- 3500 – 4200
- More than 4200 seconds

Problem 12. A man stands 2 m from the left end of a very light plank (essentially zero mass) that is 6 m long. A vertical cable is attached to the right end of the plank, as shown. Calling the left end of the plank the “pivot point”, how does the torque from the man compare to the torque from the cable? Just compare magnitudes.



- The torque from the man is equal to the torque from the cable.
- The torque from the man is greater than the torque from the cable.
- The torque from the man is less than the torque from the cable.

Problem 13. A satellite in the shape of a solid cylinder (end view shown in figure) of mass 20 kg and radius 2 m has a very small jet at the edge that provides a force of 30 N on the gasses it expels—and via Newton's 3<sup>rd</sup> Law causes a force of 30 N to occur on the satellite. What is the torque about the center of the cylinder due to the jet?



- 0 N·m
- 3
- 30
- 40
- 60
- 600
- 1200 N·m

Problem 14. Same situation. What will be the angular acceleration of the satellite?

- 0 rad/s<sup>2</sup>
- 0.5
- 0.75
- 1
- 1.5
- 2
- 2.5
- 3 rad/s<sup>2</sup>

Problem 15. Which has greater linear speed (m/s), a horse near the outside rail of a merry-go-round or a horse near the inside rail?

- outside horse
- inside horse
- both the same

Problem 16. Which has greater angular speed (rad/s), a horse near the outside rail of a merry-go-round or a horse near the inside rail?

- outside horse
- inside horse
- both the same

Problem 17. An 80 kg man stands in the middle of a frozen pond of radius 5 m. He is unable to get to the other side because of lack of friction between his shoes and the ice. To overcome this difficulty, he throws his 2 kg physics textbook horizontally towards the north shore, at a speed of 10 m/s. How long does it take him to reach the south shore?

- a. Less than 16 seconds
- b. 16 – 19
- c. 19 – 22
- d. 22 – 25
- e. 25 – 28
- f. 28 – 31
- g. More than 31 seconds

Problem 18. A ping-pong ball moves forward with a momentum  $p$ . It strikes a heavier tennis ball and bounces off backwards with a momentum (magnitude) of  $0.8p$ . The tennis ball is initially at rest but free to move. Ignore outside forces. The momentum of the tennis ball after the collision will be:

- a. greater than  $p$
- b. less than  $p$
- c. equal to  $p$

Problem 19. A dentist's drill starts from rest. After 3 s of constant angular acceleration, it turns at a rate of 150 rev/min. What was the drill's angular acceleration?

- a.  $\pi/3$  rad/s<sup>2</sup>
- b.  $\pi$
- c.  $5\pi/3$
- d.  $7\pi/3$
- e.  $3\pi$
- f.  $11\pi/3$  rad/s<sup>2</sup>

Problem 20. The reason the moon does not fall into the Earth is that:

- a. the gravitational pull of the Earth on the moon is weak
- b. the gravitational pull of the sun keeps the moon up
- c. the moon has a sufficiently large orbital speed
- d. the moon has less mass than Earth
- e. none of the above

Problem 21. Two cylinders are the same size and have the same mass. However, cylinder A has most of its weight concentrated at its rim, whereas cylinder B has most of its weight concentrated at its center. The two are rolled down a ramp. Which one will reach the bottom first?

- a. A
- b. B
- c. Both will reach the bottom at the same time.

Problem 22. A 1 kg mass moving east at 4 m/s on a frictionless horizontal surface collides with a 2 kg mass that is initially at rest. After the collision, the first mass moves south at 3 m/s. What is the magnitude of the velocity of the second mass after the collision?

- a. Less than 1.3 m/s
- b. 1.3 – 1.8
- c. 1.8 – 2.3
- d. 2.3 – 2.8
- e. 2.8 – 3.1
- f. 3.1 – 3.4
- g. More than 3.4 m/s

Problem 23. In the “velocity amplifier” demo, the disk at the top (“disk 1”) obtained a very fast speed due to a series of elastic collisions. Considering just the final collision, suppose disk 2 is moving upwards at speed  $v$  and collides elastically with disk 1, which is stationary. If the mass of disk 2 is much larger than the mass of disk 1, what will the speed of disk 1 be after the collision?

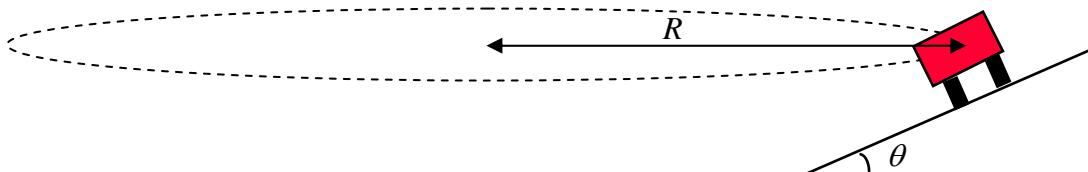
- 0
- $0.5 v$
- $v$
- $1.5 v$
- $2 v$

Problem 24. A 0.5 kg pendulum bob passes through the lowest part of its path at a speed of 3 m/s. What is the tension in the pendulum cable at this point if the pendulum is 90 cm long?

- Less than 3 N
- 3 – 4.5
- 4.5 – 6
- 6 – 7.5
- 7.5 – 9
- 9 – 10.5
- More than 10.5 N

Problem 25. In class, a student in the rotating chair was rotating with his arms extended, holding weights. Then, he brought his arms closer towards his body and rotated faster. Did the student do work on the rotating system during this process?

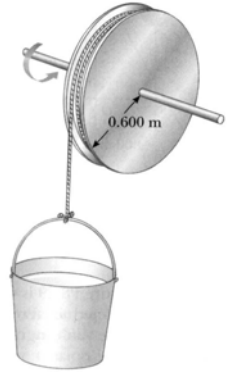
- No, because the student had the same kinetic energy at the end
- No, because the student had the same kinetic energy at the end
- Yes, because the student had more angular momentum at the end
- Yes, because the student had more kinetic energy at the end



Problem 26. A curved exit ramp (radius of curvature  $R = 10$  m) is banked at a  $36.87^\circ$  angle. It is designed so that a car (end view shown) will not have to rely on friction to round the curve without slipping off; instead the centripetal acceleration will arise from a component of the normal force. What speed is this particular curve designed for? *Note:*  $\sin(36.9^\circ) = 0.60$ ,  $\cos(36.9^\circ) = 0.80$ ,  $\tan(36.9^\circ) = 0.75$ . *Another note:* A free body diagram and equations will be required for this situation, for Problem 29.

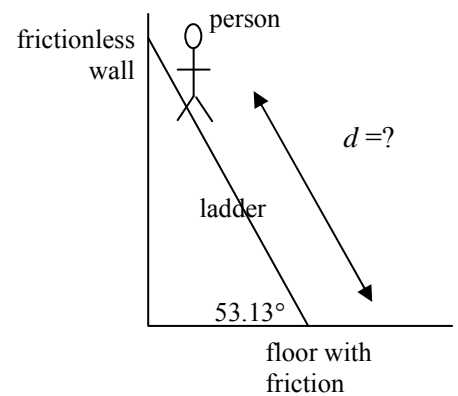
- $\sqrt{60}$  m/s
- $\sqrt{75}$
- $\sqrt{80}$
- $\sqrt{125}$
- $\sqrt{133.3}$
- $\sqrt{166.7}$  m/s

Problem 27. A string attached to a bucket (mass 6 kg) is wound over a large pulley having a mass of 12 kg (not zero mass!). The pulley can be considered to be a solid cylinder of radius 0.6 m. The pulley turns as the block is allowed to fall from rest. No energy is lost to friction. If the bucket falls 1 m, how fast will it be going?



- $\sqrt{8}$  m/s
- $\sqrt{9}$
- $\sqrt{10}$
- $\sqrt{11}$
- $\sqrt{12}$
- $\sqrt{13}$  m/s

Problem 28. A 10 m, 10 kg ladder rests against a smooth, frictionless wall. The floor has friction, however, with  $\mu_s = 0.5$ . The ladder makes a  $53.13^\circ$  angle with the horizontal. A 50 kg person climbs up the ladder. How far up the ladder (distance  $d$ ) can the person climb before the ladder begins to slip? *Note:*  $\sin(53.13^\circ) = 0.8$ ;  $\cos(53.13^\circ) = 0.6$ ;  $\tan(53.13^\circ) = 1.33$ . *Note:* A FBD and equations will be required for this situation, for Problem 30.



- 1 m
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9 m

Write your CID separately here to make sure this page doesn't get lost. CID: \_\_\_\_\_

**Problem 29.** (4 pts) (a) Draw a FBD for the car in Problem 26. Be sure to label all forces.



(b) Based on your FBD, write down and fill in the N2 “blueprint equations” for the x- and the y-directions. Don't solve the equations, just take them one step past the blueprint. Be sure to fill in the acceleration(s) if known. Do divide the forces into components as appropriate.

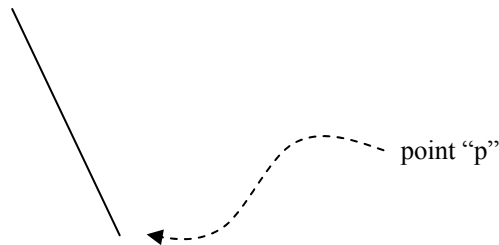
(b1) N2 x-direction blueprint:

N2 x-direction filled in:

(b2) N2 y-direction blueprint:

N2 y-direction filled in:

**Problem 30.** (4 pts) (a) Draw a FBD for the ladder in Problem 28. Be sure to label all forces.



(b) Based on your FBD, write down and fill in the N2 “blueprint equations” for the x- and the y-directions, as well as the torque blueprint equation for torques around point “p” at the base of the ladder. Don't solve the equations, just take them one step past the blueprint. Be sure to fill in the acceleration(s) if known. Do plug in  $F_{friction} = \mu N$  when appropriate, along with appropriate components for any perpendicular distances that arise.

(b1) N2 x-direction blueprint:

N2 x-direction filled in:

(b2) N2 y-direction blueprint:

N2 y-direction filled in:

(b3) Torques about “p” blueprint:

Torques about “p” filled in: