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I. Multiple Choice [5 pts each] Bubble in the most correct answer on your bubble sheet and circle the correct answer here.

Use the following situation to answer the next two questions:
A box of mass 20 kg is placed on a rough, flat, horizontal table. The coefficient of static friction between the box and the table is 0.2 and that of kinetic friction is 0.1.

1. [5 pts] A person acts with a horizontal force of 30 N on the box. Does the box move due to that applied force?
   - A. Yes, it moves with a constant velocity.
   - B. Yes, it moves with a constant acceleration.
   - C. No, it does not move.
   - D. The information provided is not enough to answer.

67%

Is $F_{app} > f_{s,max}$?

$f_{s,max} = (0.2)(20)(9.8) = 39\text{N}$

$\Rightarrow f_{s,max} > F_{app} \Rightarrow$ no motion

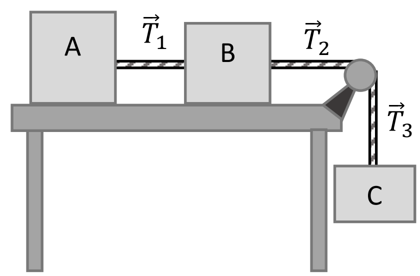
2. [5 pts] Now the person is pushing with a different force from question 1. The box accelerates on the rough table at $1.1\ \text{m/s}^2$, calculate the applied force.
   - A. 20 N
   - B. 22 N
   - C. 39 N
   - D. 42 N
   - E. 61 N

45%

$F_{net} = ma = F_{app} - f_k \Rightarrow F_{app} = ma + f_k$; $f_k = \mu_k n = \mu_k mg$

$\Rightarrow F_{app} = (20\ \text{kg})(1.1\ \text{m/s}^2) + (0.1)(20\ \text{kg})(9.8\ \text{m/s}^2)$
$= 42\text{N}$

Use the following situation to answer the next two questions:
Three boxes are connected with ropes, as shown at right. Boxes A and B are placed on a frictionless table, while box C hangs over the edge. The ropes are massless and inextensible, and the pulley is massless and frictionless.



3. [5 pts] Choose the correct ranking of the tension forces T_1, T_2 and T_3. Assume that $m_A > m_B > m_C$.
   - A. $T_1 < T_2 = T_3$
   - B. $T_1 < T_2 < T_3$
   - C. $T_3 < T_2 < T_1$
   - D. $T_1 = T_2 = T_3$
   - E. $T_3 = T_2 < T_1$

24%

No friction with pulley $\Rightarrow T_2 = T_3$

B accelerates to the right $\Rightarrow F_{net,B}$ to the right $\Rightarrow T_2 > T_1$

4. [5 pts] Which of the following describes the acceleration of the system a_{sys} made of the blocks and ropes?
   - A. $a_{sys} = g$
   - B. $a_{sys} < g$
   - C. $a_{sys} > g$
   - D. $a_{sys} = 0$
   - E. The information provided is not enough to answer.

31%

For C the net force is

$F_{net,c} = T_3 - m_c g = -m_c a$

$\Rightarrow a = g - \frac{T_3}{m_c}$

$\Rightarrow a < g$

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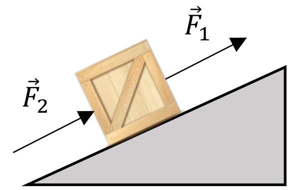
5. [5 pts] You and your friend are trying to move a 200 kg crate up a ramp that makes an angle of 10° with the horizontal. Fortunately, the surface of the ramp is very smooth that you don't have to worry about friction. You pull using a rope with a force $F_1 = 160$ N. What is the magnitude of the force that you friend needs to push with F_2 to ensure the crate moves at constant speed? Assume both forces are parallel to the ramp.



61%

A. 1800 N
B. 500 N
C. 120 N
D. 280 N
E. 180 N

$v = \text{const} \Rightarrow F_{net} = 0 = F_1 + F_2 - mg\sin\theta$

$\Rightarrow F_2 = mg\sin\theta - F_1$

$= (200\,kg)(9.8\,\frac{m}{s^2})\sin 10° - 160N = 180N$

6. [5 pts] Two identical balls are dropped straight down. Ball 1 is dropped in air and ball 2 is dropped in water. Both balls reach their terminal speeds. The density of water is approximately 1000 times the density of air. What is the ratio of terminal speed of ball 1 to that of ball 2, $v_{1,\text{term}}/v_{2,\text{term}}$? Assume a high Reynold's number.

26%

A. 1000
B. 31
C. 1
D. 0.031
E. 0.001

Identical balls $\Rightarrow m_1 = m_2$; $C_{D_1} = C_{D_2}$; $A_1 = A_2$

when $v = v_{term}$: $\Sigma F = 0 \Rightarrow D = mg \Rightarrow D_1 = D_2$

$\Rightarrow \cancel{\tfrac{1}{2}} \cancel{C_D} \cancel{A} \rho_{air} v_1^2 = \cancel{\tfrac{1}{2}} \cancel{C_D} \cancel{A} \rho_w v_2^2 \Rightarrow \frac{v_1}{v_2} = \sqrt{\frac{\rho_w}{\rho_{air}}} = \sqrt{1000} = 31$

7. [5 pts] A 24-kg kid is on a merry-go-round standing a distance of 0.85 m from the center. What is the fastest the merry-go-round can go without the kid's shoes slipping if the maximum possible static friction between their shoes and the merry-go-round is 94 N?

54%

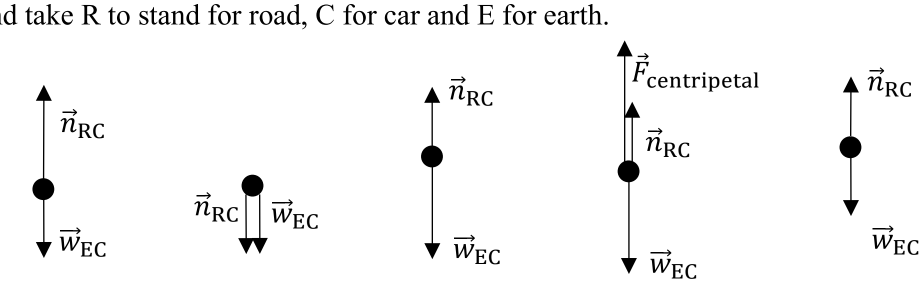
A. 1.8 m/s
B. 2.6 m/s
C. 1.2 m/s
D. 2.9 m/s
E. 3.1 m/s

$F_{net} = \frac{m v_{max}^2}{r} = f_{s,max} \Rightarrow v_{max} = \sqrt{\frac{r f_{s,max}}{m}}$

$\Rightarrow v_{max} = \sqrt{\frac{(0.85m)(94N)}{24\,kg}} = 1.8\ m/s$

8. [5 pts] A car drives over a dip in the road at constant speed, as shown at right. Choose the correct free-body diagram representing the car when it is at the lowest point in the dip. Neglect friction and take R to stand for road, C for car and E for earth.

40%



A. B. C. D. E.

F_{net} must be centripetal $\Rightarrow n > w$

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9. [5 pts] A bike wheel is spinning at ω = 400 rpm (revolutions per minute). If it takes the bike 5.5 seconds to come to a complete stop from that speed, what is the angular acceleration α of the wheel during that time, assuming it was constant? Recall: 1 revolution = 2π rad.

59%

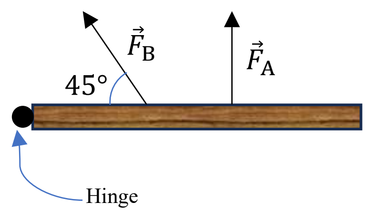
   A. 12 rad/s^2
   B. 72 rev/s^2
   C. 24 rad/s^2
   D. $\boxed{7.6 \text{ rad/s}^2}$
   E. 2.9 rad/s^2

$\alpha = \frac{\Delta\omega}{\Delta t}$; $\Delta\omega = 0 - 400 \text{ rpm} = \frac{-400\,(2\pi \text{ rad})}{60 \text{ s}}$

$= -42 \text{ rad/s}$

$\Rightarrow \alpha = \frac{-42 \text{ rad/s}}{5.5\text{s}} = -7.6 \text{ rad/s}^2$

10. [5 pts] Two students are trying to open a stuck door by pushing on it. Student A pushes with a force $\vec{F}_A$ of 30 N at a distance of 0.8 m from the hinge, at an angle of 90° to the door. Student B pushes with a force $\vec{F}_B$ of 80 N at a distance of 0.5 m from the hinge, but at an angle of 45° to the door. The figure at right shows a top view of the situation. Who applies the greater torque, and why?



69%

   A. Student A, because the force is applied farther from the hinge.
   B. Student B, because acting at an angle less than 90° is more effective.
   C. Student A, because acting at an angle of 90° is more effective.
   D. $\boxed{\text{Student B, because the product of force and lever arm } (r_\perp) \text{ is greater.}}$
   E. Both apply the same torque.

$\tau_A = (0.8\text{m})(30\text{N}) \sin 90°$
$= 24 \text{ N}\cdot\text{m}$
$\tau_B = (0.5\text{m})(80\text{N}) \sin 45°$
$= 28 \text{ N}\cdot\text{m}$

11. [5 pts] Three masses are arranged along the *x*-axis: a mass of 2.0 kg at *x* = – 1.0 m, a second of 2.0 kg at *x* = 1.0 m, and the last 1.0 kg at *x* = 5.0 m. What is the location of the center of gravity of this system?

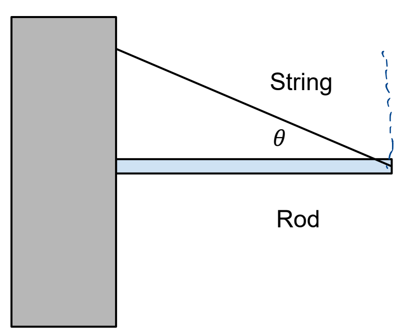
76%

   A. $\boxed{x_{CG} = 1.0 \text{ m}}$
   B. $x_{CG} = 1.5$ m
   C. $x_{CG} = 2.5$ m
   D. $x_{CG} = 5.0$ m
   E. None of these are correct.

$x_{CG} = \frac{\sum x_i m_i}{\sum m_i} = \frac{(-1.0\text{m})(2.0\text{kg}) + (1.0\text{m})(2.0\text{ kg}) + (1.0\text{ kg})(5.0\text{m})}{(2.0 + 2.0 + 1.0)\text{ kg}}$

$= 1.0 \text{ m}$

12. [5 pts] A uniform horizontal rod of mass 10.0 kg and length 5.0 m has a massless string attached to the far end at an angle of θ = 25°, holding it up. What is the tension in the string?



$T_\perp = T \sin\theta$

40%

   A. *T* = 98 N
   B. $\boxed{T = 116 \text{ N}}$
   C. *T* = 226 N
   D. *T* = 456 N
   E. None of these could be the tension

$\sum \tau = 0 = \tau_{wall} + \tau_w + \tau_T$

$= 0 - (\tfrac{1}{2}\, 5.0\text{m})(10.0\text{ kg})(9.8\tfrac{\text{m}}{\text{s}}) + (5.0\text{ m})T \sin 25° = 0$

$= -245\text{N}\cdot\text{m} + (2.11\text{ m})T \Rightarrow T = \frac{245\text{N}\cdot\text{m}}{2.11\text{m}} = 116 \text{ N}$

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II. Lecture Free Response [20 pts total]: Show work and/or explain reasoning where indicated.

For problems 13-16 the following situation applies:
Two blocks are connected by massless strings and are being pulled to the right by a constant force on string A, on frictionless ground, as seen in the diagram below. They have been moving for some time. Block 2 has more mass than block 1.

13. [5 pts] Which is *greater*, the tension on block 2 from string *B*, or the tension on block 1 from string *A*? Explain your answer.

74%

String A has the greatest tension, as it is accelerating both blocks.

From Newton's second law, using the system as the combined masses, we see the force acting is the tension from A, as the tension from B cancels as it acts on blocks 1 and 2. So the force from string A is $(m_1+m_2)\,a$.

14. [5 pts] On which object is the *net force* greater? If they are the same state so explicitly. Explain your answer.

The net force on 2 is greater than the net force on 1, since the mass of 2 is greater. Using Newton's second law the net force is ma.

48%

15. [4 pts] Draw the *direction* of the net force on block 1 and the *direction* of the acceleration on block 1 in the boxes below.

$\boldsymbol{F}_{\text{net}}$ on 1 $\qquad$ $\boldsymbol{a}$ on 1

83%

Both to the right.

16. [6 pts] Block 1 has a mass of 3.0 kg, and block 2 has a mass of 5.0 kg. If they are accelerating at 2.5 m/s^2, what is the tension in string *A*? *Show work* for full credit.

Sum forces on both objects, set equal to ma of each. Then solve for combined equations:

72%

$$\Sigma F_1 = m_1 a = T_A - T_B \text{ and } \Sigma F_2 = m_2 a = T_B$$

$$T_A = (m_1 + m_2)\,a = 20\text{ N}$$

$T_A =$

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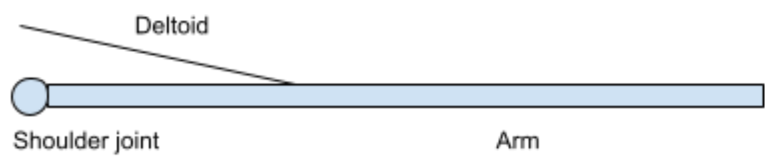
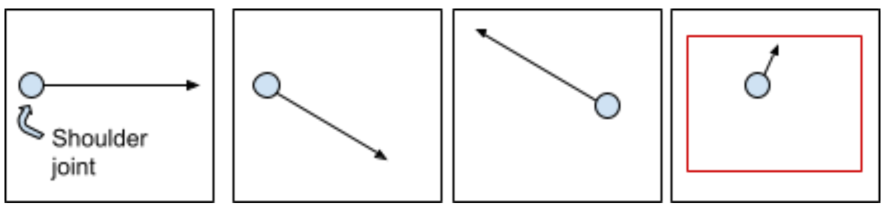
III. Tutorial Free Response [20 pts total]: Problems 17-20. Show work and/or explain reasoning where indicated.

For 17. and 18. use the diagram below. The deltoid muscle and tendon attach to the arm as shown in the diagram. The arm is horizontal and outstretched in this diagram.

66%

17. [5 pts] Which of the following can represent the moment arm (lever arm) for the deltoid muscle if the pivot point (axis) is at the shoulder, on the far left in this diagram? Circle the most correct box.





Explain your answer:

*The box on the **far right** gives the correct moment (lever) arm.*

The moment arm is the line from the axis of rotation (pivot point) perpendicular to the line of action. The deltoid's attachment point and angle determines the line of action here.

18. [5 pts] If the arm lowers, what happens to the *length* of the moment arm? Does it increase, decrease, or remain the same? Explain and/or draw diagrams. Assume the attachment points of the deltoid remain the same as shown in the diagram, on both ends. (Since the torque equals the force times the moment arm, this gives an idea of the strength of the arm at different positions)

62%

*The length of the moment arm **shortens** as the arm lowers.*

As the arm drops, the distance between the line of action of the deltoid and the shoulder joint decreases, and the angle of the deltoid relative to the shoulder shrinks, this causes the moment art to shrink as well.

The angle of the lever arm changes, to maintain the 90 degree angle from the line of action it will have to rotate clockwise.

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19. [5 pts] A dwarf siren salamander grows in such a way that it increases its size equally in all dimensions. An adult salamander is three times larger in every dimension than an infant salamander.

What is the ratio of the adult's mass to the infant's mass? Explain your reasoning.

80%

Since mass is proportional to volume via $m = \rho V$ we find the volume scaling and that equals the mass scaling.

For isometric scaling $V_f = f^3 V_o$ so it will scale as 3 cubed, or 27 times more mass..

20. [5 pts] A contractor builds a swimming pool (pool A) that has length l, a width w, and a depth d. The contractor then tiles the walls and floor of the pool. It takes 20 boxes of tiles to complete the work.

In a different project, the contractor needs to build a swimming pool (pool B) that has a length $2l$, a width $2w$, and a depth $2d$. If the contractor also needs to tile the walls and floor of pool B, how many boxes of tiles will they need? Assume the tiles used are identical for both pools. Show your work.

65%

This is also isometric scaling, by a factor of 2. In this case it is an area, so the scaling goes as $A_f = f^2 A_o$ and f=2. So we will need 2 squared more boxes, or 4x as many.

This will be 80 boxes of tiles.