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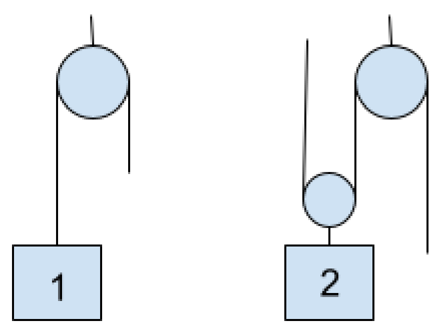
I. Multiple Choice [5 pts each] Bubble in the most correct answer on your bubble sheet and circle the correct answer here.

1. [5 pts] A stubborn elephant of mass 4,200 kg refuses to move. You push the elephant with a force of 890 N. The elephant still doesn't move. What is the frictional force on the elephant from the ground while you push on it?
   A. You need μ_s to solve for friction.
   B. 890 N
   C. 41 kN
   D. You need your mass to solve for friction.
   E. None of these.

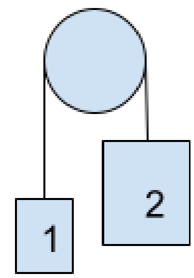
2. [5 pts] From the previous problem, assume the elephant is now sliding on a horizontal surface under a horizontal push of $F = 9,232$ N. Assume $\mu_s = 0.3$, $\mu_k = 0.2$ and $m = 4,200$ kg. What is the acceleration of the elephant?
   A. 0.24 m/s^2
   B. 2.4 m/s^2
   C. 3.4 m/s^2
   D. 2.0 m/s^2
   E. No acceleration.

3. [5 pts] In the figure at right all blocks are stationary and of equal mass, all ropes are massless and inextensible, and all pulleys are massless and frictionless. The ropes are free to move around the pulleys.

   Choose the correct ranking of the magnitudes of the tension forces T_1 and T_2
   A. $T_1 = T_2$
   B. $T_1 < T_2$
   C. $T_1 > T_2$
   D. The ropes need to have mass to have tension.
   E. None of these.



4. [5 pts] Block 1 of mass 3.0 kg is attached to a massless string over a massless pulley and connected with a massless inextensible string to block 2 of 5.0 kg. They start at rest in the orientation shown. When released, what direction do they start to move?
   A. Block 2 falls and block 1 rises.
   B. Block 1 falls and block 2 rises.
   C. Stay in equilibrium, at rest.
   D. Depends on the relative heights.
   E. None of these



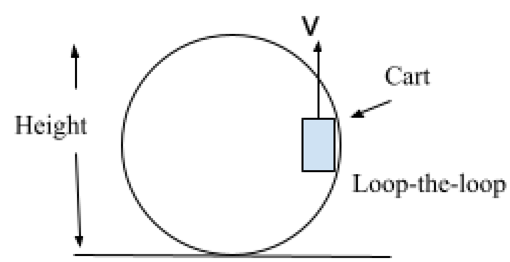
5. [5 pts] From question 4., what is the acceleration of the blocks?
   A. 1.45 m/s^2
   B. 12.5 m/s^2
   C. 3.60 m/s^2
   D. 2.45 m/s^2
   E. Not enough information was given to solve.

6. [5 pts] A bacterium of radius 10^{-6} m and mass of 4.0×10^{-15} kg falls in water at the surface of the earth; assume it is approximately spherical for calculations. It falls very slowly due to the viscosity of water. What is the terminal velocity as it does so? If needed the density of water is 1000 kg per cubic meter and the viscosity of water is about 1.0×10^{-3} Pa s.
   A. 0.21×10^{-12} m/s
   B. 2.1×10^{-6} m/s
   C. 2.1 m/s
   D. 1.2×10^{-16} m/s
   E. None of these.

7. [5 pts] A merry-go-round of radius 2.5 m spins in a circle. It is found it moves through 1.5 rotations in 3.0 s. What is the angular speed of the merry-go-round?
   A. 0.51 rad/s
   B. 1.6 rad/s
   C. 2.0 rad/s
   D. 3.1 rad/s
   E. None of these are correct

8. [5 pts] A person in an elevator is moving down and *speeding up*. Which is greater, the normal force on the person from the elevator or the weight of the person?
   A. Normal force on the person is greater
   B. The weight of the person is greater
   C. They are both equal
   D. It depends on the initial velocity.
   E. None of the above.

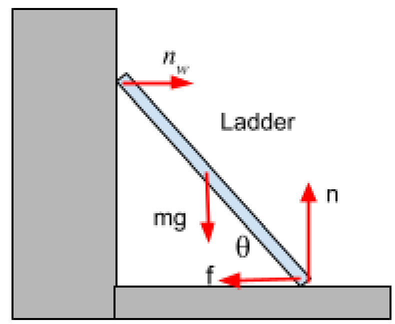
9. [5 pts] A cart moves around a loop-the-loop as shown at right. At the instant shown it is on the right side ascending the track. At that moment, what is the force that supplies the "centripetal force" and centripetal acceleration, allowing it to move in a circle?
   A. Weight force
   B. Frictional force
   C. Normal force
   D. Tension force
   E. None of these.



10. [5 pts] A see-saw has a person of mass 45 kg at a distance of 1.8 m from the fulcrum. If a dog of mass 20 kg runs on to the see-saw, what distance would it need to be from the fulcrum (axis) to have the system in static equilibrium?
    A. 4.1 m
    B. 2.2 m
    C. 1.8 m
    D. 0.82 m
    E. None of these are correct.

11. [5 pts] An outstretched arm has a center of gravity about ⅓ the total length of the arm, closest to the shoulder. Let us assume that location is about 25 cm from the shoulder joint, with the total length of the arm being 75 cm. If the mass of this arm is about 4.0 kg, what is the torque applied by gravity to the arm and shoulder?
    A. 4.9 Nm
    B. 9.8 Nm
    C. 11.2 Nm
    D. 19.6 Nm
    E. The total length of the arm is the key, so none of these solutions is correct.

12. [5 pts] A stationary ladder of mass 20 kg makes an angle of 55 degrees from the horizontal as seen at right. The ladder has a length of 5.0 m. The wall has no friction, but the floor has friction. What is the magnitude of the frictional force from the *floor* on the ladder?
    A. $f = 198$ N
    B. $f = 120$ N
    C. $f = 105$ N
    D. $f = 68.6$ N
    E. None of these could be the frictional force; you need the coefficient of friction.



Solution: By using Newton's second law and the fact that the ladder is in static equilibrium, we find that in the y-direction the normal force from the ground is equal to the weight, *mg*.

In the x-direction we find that the normal force from the wall is equal to the friction force from the ground. Thus if we find the normal force from the wall we also get the friction.

In this case we set the pivot point to the point on the ground. This makes the torque from the normal from the ground and friction zero. We can find the others:

$$\Sigma\tau = \frac{L}{2}mg\sin(90 - \theta) - Ln_w\sin(\theta) = 0$$

Solving for n_w:

$$n_w = \frac{mg\sin(90-\theta)}{2\sin(\theta)}$$

This also equals *f*.

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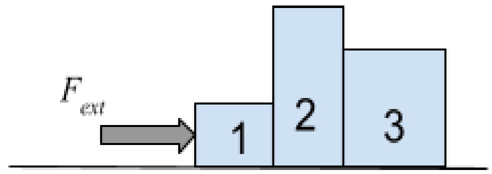
II. Lecture Free Response [20 pts total]: Show work and/or explain reasoning where indicated.

For problems 13-16 the following situation applies: Three blocks are sliding to the right on a frictionless surface. There is a force acting on the left block, 1, pushing to the right. The mass of block 3 is greater than block 2 which is greater than block 1.



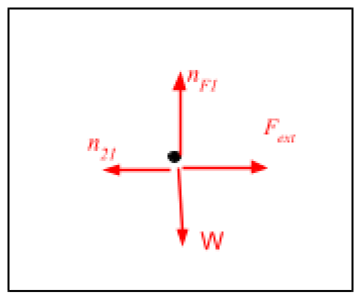
13. [5 pts] On which block is the net force greatest? If it is zero, state this explicitly. Explain your answer.

Using Newton's second law, the net force on block 3 must be greatest since all objects are accelerating the same, and it has the greatest mass.

14. [5 pts] How do the accelerations of each block compare? If they are the same, state this explicitly. Explain your answer.

Since they are connected, all accelerations are the same.

15. [4 pts] Draw the *free body diagram* for **block 1** in the box:



16. [6 pts] Block 1 has a mass of 1.0 kg, block 2 has a mass of 2.5 kg, and block 3 has a mass of 4.0 kg. If the external force applied is 15 N, what is the normal force between blocks 1 and 2? Show work for full credit.

We can find the acceleration of the system by using the net force on the system, F_{ext}:

$$\Sigma F_x = (m_1 + m_2 + m_3)a = F_{ext}$$

$$a = \frac{F_{ext}}{(m_1+m_2+m_3)}$$

For block 1 we again use Newton's second law:

$$\Sigma F_{1x} = m_1 a = F_{ext} - n_{21}$$

$$n_{21} = F_{ext} - m_1 a = F_{ext}\left(1 - \frac{m_1}{m_1+m_2+m_3}\right)$$

N_{12}= 13.0 N

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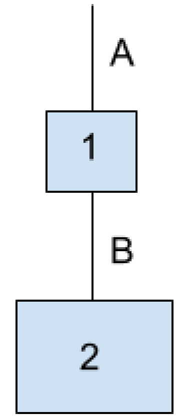
III. Free Response [20 pts total]: Problems 17-20. Show work and/or explain reasoning where indicated.

For 17 and 18 the system shown is moving down in an elevator but slowing down. Here the strings *A* and *B* are massless, and mass 2 is greater than mass 1.



17. [5 pts] Again, the system is moving down and slowing down. Rank the tensions in *A* and *B*. If they are the same state this explicitly. Explain your answer for full credit.

Tension A > Tension B

Using Newton's second law, rope A must accelerate both mass 1 and 2, so the tension is greater.

Rope B only has to accelerate mass 2, so is less.

Or, looking at mass 1, we see tension in A must be greater than tension in B in order for mass 1 to accelerate up.

18. [5 pts] Now assume mass 2 is 5.0 kg and mass 1 is 2.5 kg. If the acceleration of the system has a magnitude of 1.5 m/s^2 find the tension in string *A*.

First we note the acceleration is up, so in the +*y* direction.

Use Newton's second law on the whole system:

$$\Sigma F_y = (m_1 + m_2)a = T_A - m_1 g - m_2 g$$

$$T_A = (m_1 + m_2)a + m_1 g + m_2 g$$

$$T_A = (m_1 + m_2)(a + g)$$

T_A = 84.8 N

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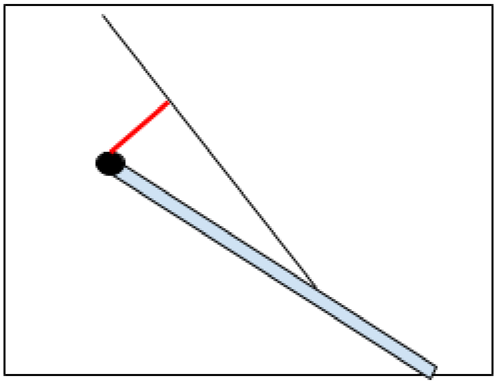
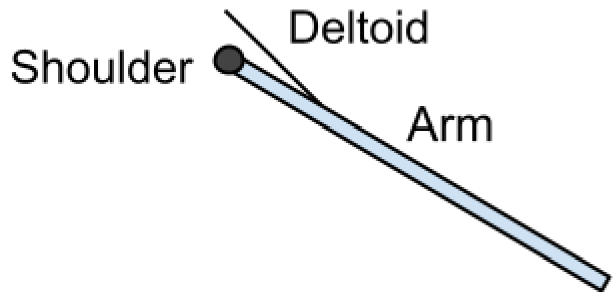
For 19. and 20. use the diagram below.

19. [5 pts] The deltoid attaches to the upper arm as shown below. On the exploded diagram to the left, draw the lever (moment) arm extending from the shoulder (our axis in this situation).





20. [5 pts] Assuming the connection point above the shoulder joint remains fixed, what happens to the lever (moment) arm as the arm is lowered from the position shown? Does it get longer or shorter, or stay the same? *Explain your reasoning or show work for full credit.*

It will get shorter. (Thus the torque will decrease for a given force from the deltoid).

As the arm drops the tendon will attach to the upper arm at a steeper and steeper angle. But the attachment point at the shoulder stays approximately the same. This means the line of action will get ever closer to the upper arm, and thus the lever arm will shorten.