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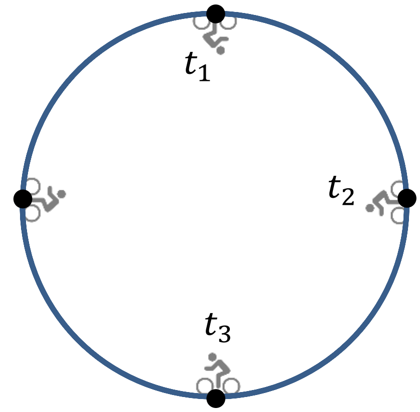
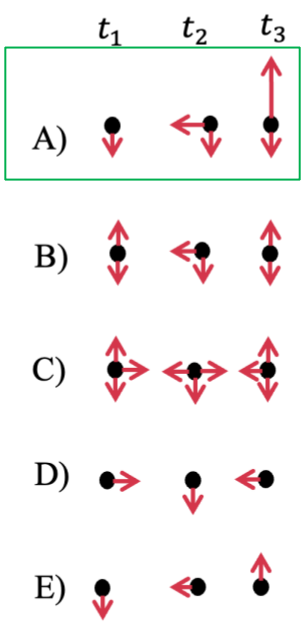
1. [5 pts] A cyclist is going clockwise around a vertical circular track (loop-the-loop). They are going just fast enough at the top to make it all the way around the track. The person is not pedaling. Ignore friction and drag. Which of the choices below (A to E) correctly shows the free-body diagrams for the cyclist at times t_1, t_2, and t_3?





The correct answer is A.

At t_1, only the gravitational force is acting on the cyclist; because they are only going just fast enough to make it around, there is no normal force at this point.

At t_2, the gravitational force is still acting, and the normal force is acting as the central force causing the circular motion.

At t_3, the gravitational force is still acting with the same magnitude, and the normal force must be larger in magnitude and in the opposite direction to provide the needed net central force to cause the circular motion.

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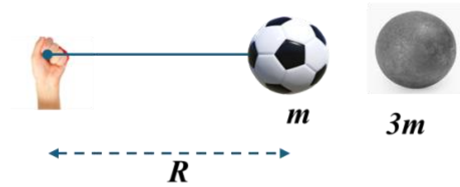
2. [5 pts] A professor swings a soccer ball around in a horizontal plane at a constant angular frequency. The mass of the ball is $m = 0.45$ kg and the distance from the hand to the center of the ball is $R = 0.75$ m. The maximum angular frequency before the string breaks is $\omega = 8.0$ rad/s. If the ball is replaced by a solid sphere 3 times the mass of the soccer ball, what is the maximum angular frequency it can be rotated before the string breaks?



A) 0.89 rad/s

B) 2.7 rad/s

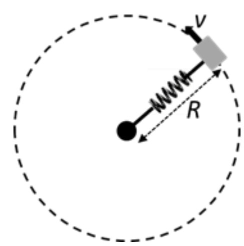
C) 4.6 rad/s

D) 8.2 rad/s

E) 24 rad/s

1) You can calculate the first case and get $T = m\omega^2 R = (0.45)(64)(0.75) = 21.6$ N and then go the other way to get $21.6 = (3m)(\omega'^2)(R) \rightarrow \omega' = 4.62$ rad/s; OR, better, 2) just take the ratio from knowing that ω is proportional to 1/sqrt(m) and compare: $\omega' = \omega$/sqrt(3) = 4.62 rad/s.

3. [5 pts] A 30-kg block is rotating on a frictionless *horizontal* surface at a constant speed of 3.0 m/s. A spring (k = 250 N/m) attaches the center pivot of the circle to the block as shown. The spring is expanded from its equilibrium length by 0.60 m. What is the length of the unstretched spring?



Top-view diagram

A) 0.6 m

B) 1.0 m

C) 1.2 m

D) 1.5 m

E) 1.8 m

First note that R is the spring's equilibrium length plus the amount it is stretched. Call the equilibrium length L, so the $R = L + \Delta S$, where ΔS is 0.6 m. The radial force to keep block on this circle is calculated from $F_r = mv^2/R$; it is also equal to the restoring force from the stretched spring, $F_s = k\Delta S$. So, equating $mv^2/R = k\Delta S$ and solving for R gives $R = (30)(3)^2/(250)(0.6) = 1.8$ m; Thus, $L = R - \Delta S = 1.8 - 0.6 = 1.2$ m

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4. [5 pts] Complete the following sentence. "The work done to accelerate a car from 0 to 30 m/s ……"

A) is more than that required to accelerate it from 30 m/s to 60 m/s.

B) is equal to that required to accelerate it from 30 m/s to 60 m/s.

C) is less than that required to accelerate it from 30 m/s to 60 m/s.

D) The sentence can be completed by any of the preceding statements, depending on the time taken.

E) None of the above statements correctly complete the sentence.

$W = \Delta KE$; Compare ΔKE_1 to ΔKE_2; drop the ½ and the m's for both and just look at difference of the squares of final vs initial velocities: $(v_{30})^2$ vs $[(v_{60})^2 - (v_{30})^2]$ and clearly ΔKE_2 is > ΔKE_1.

5. [5 pts] What is the work done by a car's braking system when it slows the 1500-kg car from an initial speed of 96.0 km/h to 56.0 km/h in a distance of 55.0 m?

A) -8.30 kJ

B) -352 kJ

C) -816 kJ

D) -1270 kJ

E) -4560 kJ

Just need ΔKE; (we do not need the distance). So, we need to calculate $W = K_f - K_i = \frac{1}{2} m (v_f^2 - v_i^2)$ and remember to get the units right (and the sign). The speeds convert from km/hour by the factor of 1000/3600 in each case, give initial and final speeds of 26.7 and 15.5 m/s, respectively. Then, computing the work we get ½ (1500) $[(15.5)^2 - (26.7)^2]$ = -354 kJ.

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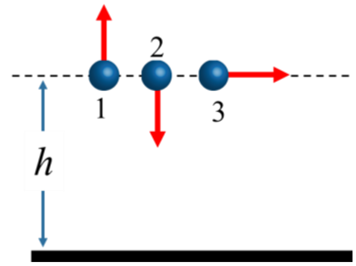
6. [5 pts] Three balls of equal mass are fired simultaneously **with equal speeds** from the same height h above the ground. Ball 1 is fired straight up, ball 2 is fired straight down, and ball 3 is fired horizontally. Rank in order from largest to smallest their speeds v_1, v_2, and v_3 just before each ball hits the ground. Ignore air resistance.



A) $v_1 > v_2 > v_3$

B) $v_3 > v_2 > v_1$

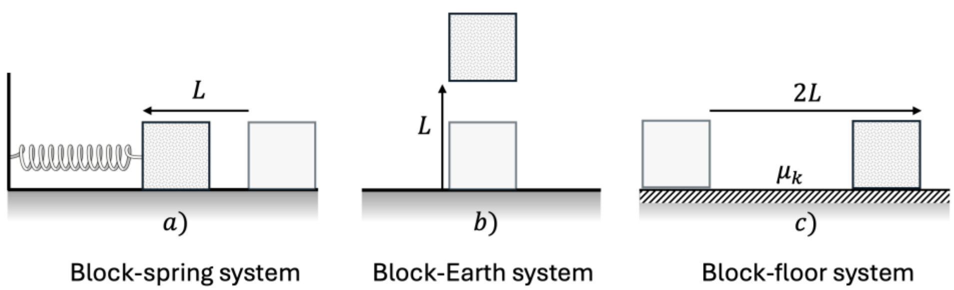
C) $v_2 > v_3 > v_1$

D) $v_1 = v_2 > v_3$

E) $v_1 = v_2 = v_3$

Consider a system that includes only the ball. The only external force on the ball is the gravitational force. The absolute value of the work done by the gravitational force is equal to mgh, and this work will be equal to the change in kinetic energy of the ball. Since all balls move through the same vertical distance, the work done on each ball by the gravitational force is the same. This also means that the balls will have the same change in kinetic energy. Since the balls begin with the same speed, they must also then end with the same speed as each other (the final speed is larger than the initial speed due to the positive work done).

7. [5 pts] Three situations are shown where a block of mass m is moved by an external force from an initial rest position to a final rest position. In a) it compresses a spring a distance L from its equilibrium length; in b) the block is raised a distance L from the ground; in c) it is pushed a distance $2L$ across a rough surface. Parameters: $\boldsymbol{m}$ **= 5 kg**; $\boldsymbol{k}$ **= 327 N/m**; μ_k**= 0.5**; and $\boldsymbol{L}$ **= 0.3 m.**



Rank the work done on the system by the external force for the three cases. The system is defined in the diagram.

A) $W_a > W_b > W_c$

B) $W_a > W_c > W_b$

C) $W_b > W_a > W_c$

D) $W_b > W_c > W_a$

E) $W_a = W_b = W_c$

a) $\frac{1}{2} k L^2 = 14.7$ J; b) $mgL = 14.7$ J; c) $mgu_k(2L) = 14.7$ J (all the same)

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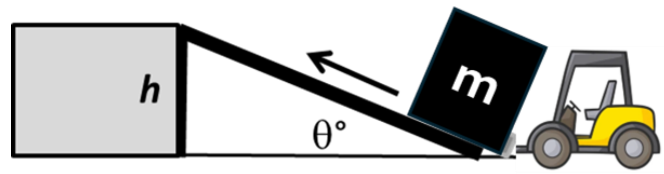
8. [5 pts] A forklift pushes a box up a ramp at a constant speed, raising it a vertical distance $\boldsymbol{h}$. The box has mass $\boldsymbol{m}$ and the coefficient of kinetic friction between the box and the ramp is $\boldsymbol{\mu_k}$. Calculate the work done by the forklift on the box-ramp-Earth system to push the box to the top of the platform. The ramp is at an incline angle of θ.



A) mgh

B) $mgh\mu_k \frac{\sin\theta}{\cos\theta}$

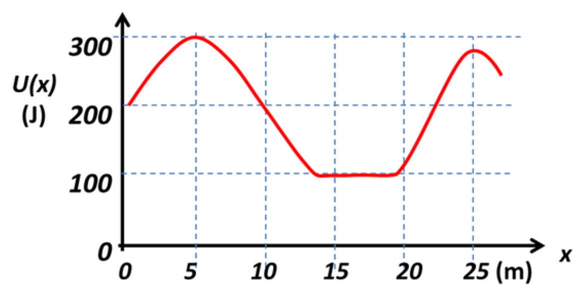
C) $mgh\mu_k \frac{\cos\theta}{\sin\theta}$

D) $mgh\left(1 + \mu_k \frac{\cos\theta}{\sin\theta}\right)$

E) $mgh \tan\theta$

Need Work to raise it distance h (mgh) plus work to push a box a distance S on the surface.
S is h/sinθ. The normal force is mg cosθ, so the increase in thermal energy is (mg cosθ) μ_k (h/sinθ).
The total is then mgh (1 + μ_k cosθ/ sinθ).

9. [5 pts] The potential energy curve for a system that contains a single particle is shown at right. Rank the force on the particle, from most negative to most positive, when the particle is **x = 5 m, 10 m, 22 m, and 25 m.**



A) $F_5 < F_{10} < F_{22} < F_{25}$

B) $F_{22} < F_5 = F_{25} < F_{10}$

C) $F_{22} < F_{10} < F_{25} < F_5$

D) $F_{10} < F_{22} < F_5 = F_{25}$

E) $F_{10} < F_5 = F_{25} < F_{22}$

The force is -dU/dx. The forces are approximately $F_5 = 0$; $F_{10} \sim 20$; $F_{22} \sim -30$; $F_{25} = 0$
So $F_{22} < F_5 = F_{25} < F_{10}$

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Lab Multiple Choice Questions

10. [5 pts] A group of students measure the time it takes a coffee filter to fall 1.5 m. The data is shown at right. They calculate the uncertainty in the three readings using the **standard deviation** of their measurements. How could they report the average time and its uncertainty correctly according to the guidelines in the Phys 121 labs?

Trial	Time (s)
1	1.13
2	1.17
3	1.11

$$\sigma = \sqrt{\frac{\sum_{i=0}^{N}(x_i - \bar{x})^2}{N-1}}$$

A) (1.14 ± 0.03) s

B) (1.14 ± 0.05) s

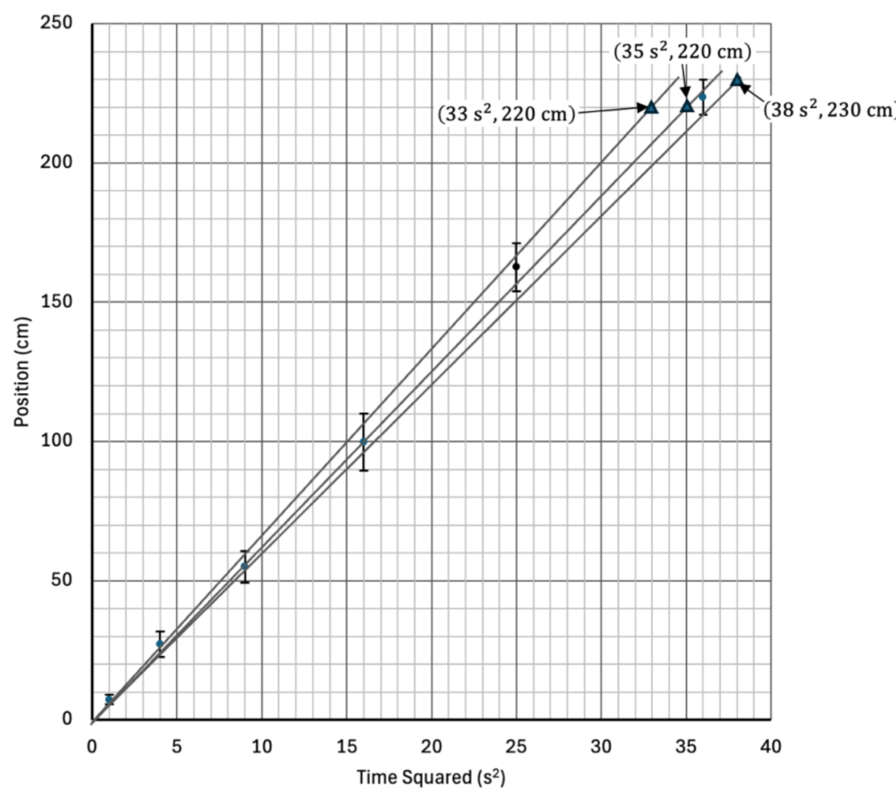
C) (1.137 ± 0.041) s

D) (1.15 ± 0.03) s

E) (1.172 ± 0.025) s

The average is 1.1367 s, so we can rule out choices D and E. The standard deviation is 0.0306 s. We can report the uncertainty to no more than two sig. figs, and the last decimal place of the uncertainty should match the last decimal place of the average value. So, the average time could be reported as (1.137 ± 0.031) *s or* (1.14 ± 0.03) *s. Only the latter is shown above, which is choice A.*

11. [5 pts] A group of students have carried out Lab B1 and B2, and they form the x vs. t^2 graph shown below. The graph also includes lines of best-fit, maximum slope and minimum slope. All lines pass through the origin and a second coordinate (triangle markers) for each line is shown on the graph. **Based on the concepts outlined in these labs**, how should the students correctly report the acceleration of the ball?



A) $(6.285 \pm 0.381)\ \text{cm/s}^2$

B) $(6.29 \pm 0.38)\ \text{cm/s}^2$

C) $(8.92 \pm 0.85)\ \text{cm/s}^2$

D) $(12.57 \pm 0.76)\ \text{cm/s}^2$

E) $(12.8 \pm 0.9)\ \text{cm/s}^2$

The slope of the best line is:

$$m_{slope} = \frac{220\ \text{cm}}{35\ \text{s}^2} = 6.286\ \text{cm/s}^2$$

The slope of the line with maximum slope is:

$$m_{max} = \frac{220 \text{ cm}}{33 \text{ s}^2} = 6.667 \text{ cm/s}^2$$

The slope of the line with minimum slope is:

$$m_{max} = \frac{230 \text{ cm}}{38 \text{ s}^2} = 6.053 \text{ cm/s}^2$$

The maximum difference between the max- and min- lines from the best fit line is 0.381 cm/s^2. The kinematics model applied in Lab B1/B2 was that the slope was equivalent to 0.5a ($x_f = \left(\frac{1}{2}a\right)t^2$). The acceleration is therefore:

$$a = 2(6.286 \pm 0.381) \text{ cm/s}^2$$

$$a = (12.57 \pm 0.762) \text{ cm/s}^2$$

Applying the rules for significant figures, the final reported answer could be $(12.6 \pm 0.8) \text{ cm/s}^2$ *or* $(12.57 \pm 0.76) \text{ cm/s}^2$. *Only the latter term is listed and is the correct answer (choice D).*

12. [5 pts] A student is trying to determine the terminal speed of a coffee filter using distance and time data. The distance the coffee filter falls through while moving at terminal speed is (1.650 ± 0.005) m, and the time taken to fall this distance is (1.12 ± 0.08) s. **Based on the guidelines from Lab C1**, how could they report the terminal speed correctly?

A) $(1.473 \pm 0.105) \text{ m/s}$

B) $(1.47 \pm 0.11) \text{ m/s}$

C) $(1.51 \pm 0.09) \text{ m/s}$

D) $(1.5 \pm 0.2) \text{ m/s}$

E) $(1.49 \pm 0.11) \text{ m/s}$

The terminal speed can be determined by using the average distance and the average time.

$$v_{term} = \frac{1.650 \text{ m}}{1.12 \text{ s}} = 1.473 \text{ m/s}$$

To find the uncertainty, we must consider the percentage uncertainties or relative uncertainties in each term.

$$distance \Rightarrow \frac{0.005 \text{ m}}{1.650 \text{ m}} = 0.00303 = 0.303\%$$

$$time \Rightarrow \frac{0.08 \text{ m}}{1.12 \text{ m}} = 0.0714 = 7.14\%$$

The percentage uncertainty in the time is ~24 times larger than the percentage uncertainty in the distance. We are thus justified in using this percentage uncertainty to find the uncertainty in terminal speed.

$$\sigma_v = (1.473 \text{ m/s})0.0714 = 0.105 \text{ m/s}$$

Following the significant figures guidelines, we could report the terminal speed as $(1.47 \pm 0.11) \text{ m/s}$ *or* $(1.5 \pm 0.1) \text{ m/s}$. *Only the former term is given as choice B.*

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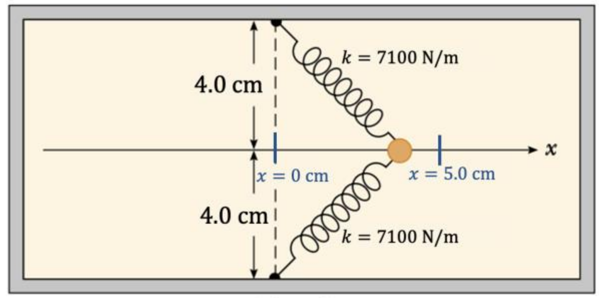
Lecture Free Response

The following two questions are about this scenario. A ball is attached between two identical springs on a horizontal frictionless table. Both springs have spring constant $k = 7100$ N/m. The ball is initially at rest at $x = 0.0$ cm and the springs each have an equilibrium length of 4.0 cm. The ball is then moved by an external force to $x = 5.0$ cm where it is held at rest. **Show your work for all questions.**



Top view

13. [5 pts] How much work do the springs do on the ball while the ball is being moved from $x = 0$ to $x = 5.0$ cm?

Calling the x displacement Δx, the amount by which each spring is stretched is $\sqrt{(\Delta x)^2 + L^2} - L$.

The energy stored in the two springs is therefore $2 * \frac{1}{2} k \left(\left(\sqrt{(\Delta x)^2 + L^2} - L\right)^2 - 0^2\right)$.

The energy stored in the springs is equal and opposite to the work the springs did on the ball.

Therefore, $W_{springs\ on\ ball} = -k\left(\left(\sqrt{(\Delta x)^2 + L^2} - L\right)^2 - 0^2\right)$

$$= -(7100\ \text{N/m})\left(\sqrt{(5.0\ \text{cm})^2 + (4.0\ \text{cm})^2} - 4.0\ \text{cm}\right)^2$$

$$= -(7100\ \text{N/m})(6.4\ \text{cm} - 4.0\ \text{cm})^2$$

$$= -(7100\ \text{N/m})(0.024\ \text{m})^2$$

$$= -4.1\ \text{J}$$

14. [5 pts] What is the net force of both springs on the ball when the ball is at $x = 5$ cm?

The y components of the forces exerted by the springs are equal and opposite, so they cancel:
$\vec{F}_{y,net} = 0$

The x component of the force of each spring is in the -x direction and with magnitude given by $\frac{|\vec{F}_{x,top\ spring}|}{|\vec{F}_{total,top\ spring}|}$ *times the total force exerted by that spring:*

$$\vec{F}_{x,top\ spring} = \left(\frac{5.0\ \text{cm}}{6.4\ \text{cm}}\right)(-k * \Delta x)$$

Adding the forces from both springs together to get the net force:

$$\vec{F}_{x,net} = \vec{F}_{x,top\ spring} + \vec{F}_{y,bottom\ spring}$$

$$= 2 * \vec{F}_{x,top\ spring}$$

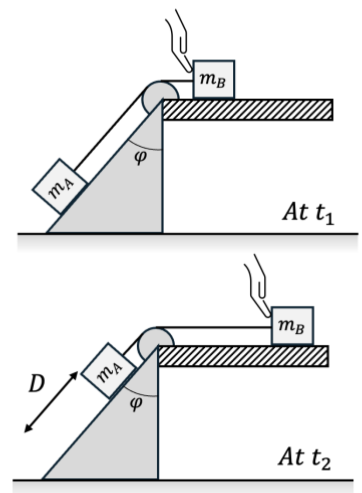
$$= -2\left(\frac{5.0\text{ cm}}{6.4\text{ cm}}\right)\left(7100\,\frac{\text{N}}{\text{m}}\right)(0.024\text{ m})$$

$$= -270\text{ N}$$

Other acceptable ways of expressing the answer would include:

$\vec{F}_x = -(270\text{ N})\hat{\imath}$ *or* $\vec{F}_x = 270\text{ N in the} - x\text{ direction}$

Q15 to Q17 refer to this scenario. Two blocks, A and B, with masses m_A and m_B are attached by a massless rope that goes around a massless and frictionless pulley. Block A is on a frictionless slope with angle φ from the vertical and block B is on a rough surface with a coefficient of kinetic friction μ_k. The blocks are initially held at rest. **Show your work for all questions.**



15. [5 pts] At t_1, a hand pushes block B to the right such that block A travels a distance D up the ramp. At t_2, both blocks are at rest. Consider a system that includes the Earth, the two blocks and all surfaces in the diagram. In terms of the given variables, what is the change in the gravitational potential energy of this system between t_1 and t_2?

    Only Block A's height changes. It moves downward by $D_{1\to2}\cos\varphi$*. Setting the zero of gravitational potential energy at its height at* t_2*, the change in gravitational potential energy is therefore*

    $$\begin{aligned}\Delta U_G &= U_{G,f} - U_{G,i}\\ &= 0 - m_A g D\cos\varphi\\ &= -m_A g D\cos\varphi\end{aligned}$$

16. [5 pts] Consider a system that includes the Earth, the two blocks and all surfaces in the diagram. In terms of the given variables, what is the change in thermal energy of this system between t_1 and t_2?

    The only dissipative force is friction between Block B and the surface that it is on. Since block A moves downward a distance D along the incline, block B must also have moved a distance D to the left. The change in thermal energy is always positive, and it is given between times t_1 *and* t_2 *by:*

    $$\Delta E_{th,1\to2} = F_{friction} * distance$$

    $$= \mu_k n D$$

    $$= \mu_k m_B g D$$

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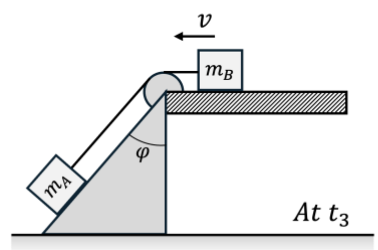
17. [5 pts] The hand then releases the blocks. At time t_3, block B has moved a distance *D* to the left and is moving at a speed v. Consider a system that includes both blocks and all surfaces shown. What is the change in the energy of this system between t_1 and t_3 (so, including both the periods from t_1 to t_2 and from t_2 to t_3)?



The system is defined as both blocks and all surfaces. This means the change in energy of the system can be determined by the change in kinetic energy of the blocks and the change thermal energy of blocks and surfaces. Since the gravitational force is external to the system, this means that there is no potential energy inside the system—work done by the gravitational force is considered external work.

$\Delta E_{sys} = \Delta K + \Delta E_{th}$

At t_1*, both blocks are at rest. At* t_3*, they are moving with the same speed,* v*. So, the change in kinetic energy of the system is:* $\Delta K = \frac{1}{2}m_A v^2 + \frac{1}{2}m_B v^2 = \frac{1}{2}v^2(m_A + m_B)$.

From t_1 *to* t_2*, the thermal energy of the system increases by* $\mu_k m_B g D$*. From* t_2 *to* t_3*, the thermal energy of the system will increase again by the same amount,* $\mu_k m_B g D$*. The change in thermal energy is therefore* $2\mu_k m_B g D$.

The change in energy of the system is given as:

$$\Delta E_{sys} = \Delta K + \Delta E_{th} = \frac{1}{2}v^2(m_A + m_B) + 2\mu_k m_B g D$$

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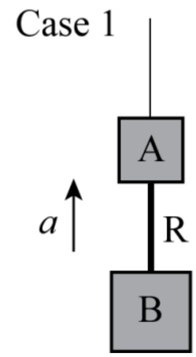
Tutorial Free Response Questions

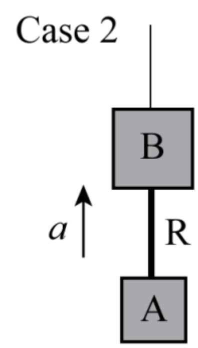
18. [5 pts] In case 1, blocks A and B ($m_A < m_B$) are connected by a rope (R) of mass *m*. A string is connected to block A, and the entire system is pulled upward such that the system accelerates upward. Is the magnitude of the tension force exerted by block A on the rope *greater than, less than,* or *equal to* the magnitude of the tension force that block B exerts on the rope? Explain.



It is given that that the rope has a mass m, and that it is accelerating upward. By Newton's second law, this means that there must be an upward net force on the rope.

There are three forces on the rope, an upward tension force by block A, a downward tension force by block B and a downward gravitational force by the Earth. The upward tension force by block A must be greater in magnitude than the sum of the two downward forces, meaning the tension force by block A is greater in magnitude than the tension force by block B

19. [5 pts] In case 2, the order of the blocks is reversed, such that the bottom of the rope is attached to block A as shown. The blocks are pulled upward with the same acceleration as in case 1. Is the magnitude of the tension force that block B exerts on the rope in case 2 *greater than, less than,* or *equal to* the magnitude of the force that block A exerts on the rope in case 1? Explain.



For case 1, consider a system that includes the rope and block B. Block A exerts an upward force on this system, and the Earth exerts a downward gravitational force on the system (equal to $(m_R + m_B)g$). Since the system is accelerating upward, the upward force by block A is larger than the gravitational force on the system and given as:

$$T_{sys,A} - F_{G,sys,E} = m_{sys}a$$

$$T_{sys,A} = T_{RA} = F_{G,sys,E} + m_{sys}a = m_{sys}(a+g) = (m_R + m_B)(a+g)$$

We can apply the same logic to case 2, however, the mass of the system of the rope and block A is less than the mass of the system consisting of the rope and block B.

$$T_{sys,B} - F_{G,sys,E} = m_{sys}a$$

$$T_{sys,B} = T_{RB} = F_{G,sys,E} + m_{sys}a = m_{sys}(a+g) = (m_R + m_A)(a+g)$$

Since the acceleration is the same in both cases, the magnitude of the force that block B exerts on the rope in case 2 is less than the magnitude of the force that block A exerts on the rope in case 1.

$$T_{RB} < T_{RB} \ \ since\ (m_R + m_A)(a+g) < (m_R + m_B)(a+g)$$

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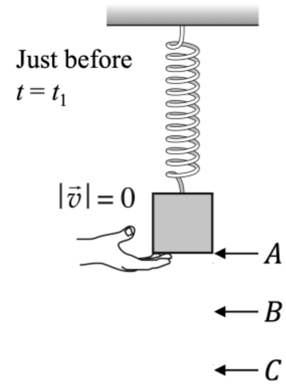
20. [5 pts] A spring and block are hung from a ceiling as shown. The block is initially held at position *A,* and the spring is neither stretched nor compressed. The block is released at time t_1. It reaches its maximum speed at point *B* at time t_2, and it turns around at point *C* at time t_3.



Over the interval from t_2 to t_3 (*i.e.,* as the block moves from *B* and *C*), is the absolute value of the work on the block by the spring *greater than, less than,* or *equal to* the absolute value of the work on the block by the Earth? Explain.

Greater than. *There are two forces exerted on the block, (1) the upward force by the spring and (2) the downward gravitational force by the Earth. The block has a downward displacement from* t_2 *to* t_3*, which means the spring force does negative work on the block and the gravitational force does positive work on the block. Since the block moves from a maximum speed at point B to rest to point C, the block undergoes a negative change in kinetic energy. The total work done on the block is equal to the change in its kinetic energy. Since the change in kinetic energy is negative, the absolute value of the negative work done by the spring must be greater than the positive work done by the Earth.*