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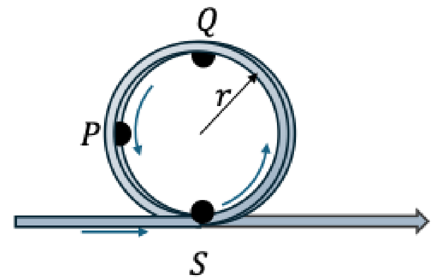
I. Lecture Multiple Choice [45 points – 9 questions]

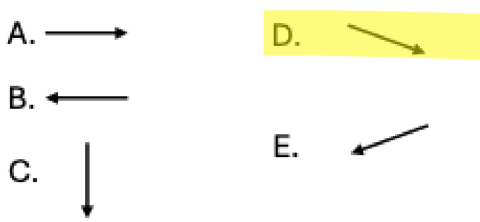
All questions have only one correct answer.

The figure at the right is for the next two questions.



An object is sliding with no friction around a circular loop of radius r. It enters at point S, travels counter-clockwise through points Q and P and then exits the loop again at point S.

1. [5 pts] At point P, the object is heading down the track and is speeding up. Which of these vectors could represent the net force on the object at point P?



2. [5 pts] What is the minimum speed that the object must have at point Q to stay on the track all the way around the loop? In the answers below,
r = radius of the loop; m = mass of the object; g = gravitational acceleration.

   A. $\sqrt{5rg}$

   B. $2\sqrt{rg}$

   C. $\sqrt{rg}$

   D. $2mgr$

   E. $\sqrt{2rg}$

---

3. [5 pts] A system has a potential energy described by: $U(r) = -B_o/r$, where r and B_o are both > 0. Which one of the following must be true:

   A. If $r_1 > r_2$, then $|U(r_1)| > |U(r_2)|$

   B. If $r_1 > r_2$, then $|F(r_1)| > |F(r_2)|$

   C. If $r_1 = 2r_2$, then $F(r_1) = 2F(r_2)$

   D. If $r_1 = 2r_2$, then $F(r_1) = ½\, F(r_2)$

   E. If $r_1 = 2r_2$, then $F(r_1) = ¼\, F(r_2)$

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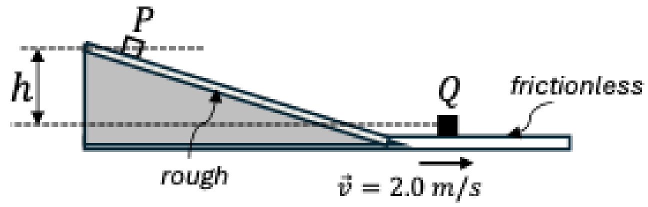
The sketch at the right is for the next two problems.

A block of mass 0.50 kg is released from rest at point P and the Earth-block-ramp system gains 4.0 J of thermal energy as the block slides from point P to point Q. The ramp is rough, and the horizontal surface at the base of the ramp is frictionless. The block has speed $v_Q = 2.0\ m/s$ as it passes through point Q.



4. [5 pts] What is h, the difference in height between points P and Q?

   A. 0.80 m

   B. 0.20 m

   C. 1.0 m

   D. 0.60 m

   E. Cannot determine without knowing the angle of the ramp.

5. [5 pts] The experiment is repeated by releasing a block of mass 1.0 kg from point P so that it slides to point Q. The 1.0 kg block and the 0.5 kg block have the same coefficients of friction (both static and kinetic). Which of the following statements is true about the experiment with the 1.0 kg block?

   A. The block's speed when it passes through Q is greater than 2.0 m/s.

   B. The block's speed when it passes through Q is less than 2.0 m/s.

   C. The block's speed when it passes through Q is equal to 2.0 m/s.

   D. We need to know the coefficient of friction and the angle of the ramp to compare the blocks' speeds when passing through Q.

---

6. [5 pts] A constant net force, $\overrightarrow{F_{net}}$, is exerted on an object over a displacement $\overrightarrow{\Delta r}$. Which one of the following sets represents a possible combination of the quantities associated with the total work done on the object: the net force $\overrightarrow{F_{net}}$, the displacement $\overrightarrow{\Delta r}$, and the total work done on the object, W_{tot}?

   A. $\overrightarrow{F_{net}} = -10\text{ N}\,\hat{\imath}$ $\overrightarrow{\Delta r} = +5\ m\,\hat{\jmath}$ $W_{tot} = -50$ J

   B. $\overrightarrow{F_{net}} = (-10\,\hat{\imath} + -5\hat{\jmath})$ N $\overrightarrow{\Delta r} = -2\ m\,\hat{\imath}$ $W_{tot} = -20$ J

   C. $\overrightarrow{F_{net}} = (-10\,\hat{\imath} + -5\hat{\jmath})$ N $\overrightarrow{\Delta r} = +4\ m\,\hat{\jmath}$ $W_{tot} = -20$ J

   D. $\overrightarrow{F_{net}} = (-10\,\hat{\imath} + -5\hat{\jmath})$ N $\overrightarrow{\Delta r} = +5\ m\,\hat{\imath}$ $W_{tot} = -25$ J

   E. $\overrightarrow{F_{net}} = (-10\,\hat{\imath} + -5\hat{\jmath})$ N $\overrightarrow{\Delta r} = +5\ m\,\hat{\imath}$ $W_{tot} = +50$ J

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7. [5 pts] An object is moving along a line and slows down during a time interval of 0.1 seconds because it experiences a force. Which one of the following combinations of the initial momentum, p_{ix}, the final momentum, p_{fx} , and of the average force, $F_{ave,x}$, are possible if it slows down?

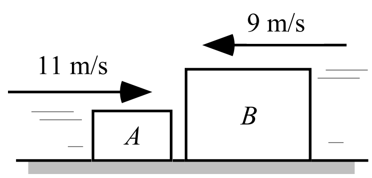
A. $p_{ix} = +3\ \frac{\text{kg·m}}{s}$ $p_{fx} = +5\ \frac{\text{kg·m}}{s}$ $F_{ave,x}$=-20 N

B. $p_{ix} = -5\ \frac{\text{kg·m}}{s}$ $p_{fx} = -3\ \frac{\text{kg·m}}{s}$ $F_{ave,x}$=+20 N

C. $p_{ix} = +5\ \frac{\text{kg·m}}{s}$ $p_{fx} = +3\ \frac{\text{kg·m}}{s}$ $F_{ave,x}$=+20 N

D. $p_{ix} = -3\ \frac{\text{kg·m}}{s}$ $p_{fx} = -5\ \frac{\text{kg·m}}{s}$ $F_{ave,x}$=-20 N

8. [5 pts] Block B has three times the mass of Block A. The two blocks move toward each other and collide head-on. Just before the collision, Block A is moving to the right at a speed of 11 m/s, and Block B is moving to the left at a speed of 9.0 m/s. If the blocks stick together after the collision, what is their velocity (magnitude and direction) immediately after impact?



A. They will move to the left with a speed of 4.0 m/s.

B. They will move to the left with a speed of 9.3 m/s.

C. They will move to the right with a speed of 4.0 m/s.

D. They will move to the right with a speed of 9.3m/s.

E. Their velocities are equal to zero because both blocks stop after the collision.

9. [5 pts] A bundle of unexploded fireworks of total mass M moves horizontally along a frictionless track in the positive direction at a speed of 4.0 m/s. A small explosion occurs, splitting the bundle into two equal pieces. One piece continues moving in the positive direction, but at a speed of 16 m/s. What is the velocity (magnitude and direction) of the other piece immediately after the explosion?

A. − 16 m/s

B. + 16 m/s

C. − 20 m/s

D. − 8 m/s

E. + 8 m/s

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II. Lab multiple choice questions [15 points, 3 questions]

10. [5 pts] A group of students dropped a paper cup from above the top of a ladder. They decided it reached its terminal speed when it was at the top of the ladder. They repeated the experiment four times and measured the time it took for the cup to fall from the top of the ladder to the floor. What is the fractional uncertainty in the elapsed time?

Trial	Elapsed time (s)
1	2.15
2	2.23
3	2.16
4	2.20
Average	2.185
Standard deviation	0.037

A. 0.037 s
B. 0.037
C. 0.017 s
D. 0.017
E. 0.074

Fractional uncertainty is the uncertainty (standard deviation in this case) / best estimate (average). Thus 0.037 s /2.185 s = 0.017. (It is unitless, since the units cancel.)

11. [5 pts] Another group of students did a similar experiment with a different paper cup. The average time, the distance and the associated uncertainties and fractional uncertainties are shown in the table. (The fractional uncertainty
is the entire value shown on their calculator.)

	Average	**Uncertainty**	**Fractional uncertainty**
Time	4.5 s	0.3 s	0.06667
Distance	3.000 m	0.005 m	0.00167

What should the students report for the terminal speed of their paper cup based on the rules developed in lab for finding the uncertainty and significant figures?

A. 1.0 ± 0.1 m/s
B. 0.7 ± 0.1 m/s
C. 0.667 ± 0.002 m/s
D. 0.67 ± 0.07 m/s
E. 0.67 ± 0.04 m/s

*The speed is 3.000 m / 4.5 s = 0.66667 m/s. The fractional uncertainty in the time is greater than that in the distance, thus we use that to find the uncertainty in the speed. So, the uncertainty in speed is 0.66667 m/s * 0.0667 = 0.04 m/s (to one digit). Thus, to one digit in the uncertainty, we obtain 0.67 ± 0.04 m/s.*

12. [5 pts] A different group conducted an experiment to find out how the terminal speed depends on mass. For each trial, they dropped a cup and started their clock when the cup was moving at constant speed and was 3 m above the ground. They recorded the distance the cup fell in 2 s and repeated this measure four times. They followed this procedure for six measurements, using six identically shaped cups with a different mass for each measurement. In their exploration of how the terminal speed depends on the mass of the cup, what are the independent and the dependent quantities?

	Independent	**Dependent**	**Control**
A.	Distance	Time	Mass
B.	Time	Distance	Mass
C.	Mass	Distance	Time
D.	Mass	Time	Distance
E.	Distance	Mass	Time

The time was controlled in this experiment. Students changed the mass (independent variable) and for each mass found the distance through which the cup fell (dependent variable) in the (controlled) time.

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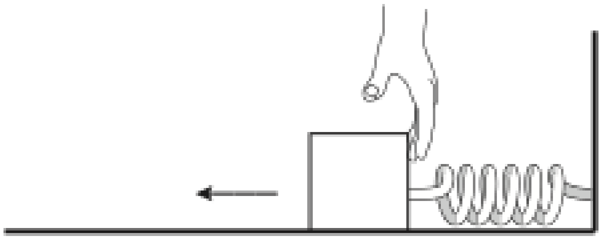
III. Lecture free-response questions [25 points]

Use the following scenario for the next two questions.

A block of mass $m = 2.0\ kg$ is attached to an ideal spring with spring constant k = 24.0 N/m, the other end of which is attached to a rigid wall. At t = 0 s, the spring is at its equilibrium length and the block has kinetic energy $K = 1.2\ J$. At that instant, a student starts pushing the block with a constant horizontal force F = 9.0 N in the direction of the block's motion.



13. [6 pts] The student assumes the friction in the block-spring-surface system is negligible. What is their prediction for the kinetic energy of the block after they have pushed it a distance d = 0.4 m?

There is no friction in the system, so there is no increase in thermal energy. Applying the principle of energy conservation to the system gives us:

$$K_i + U_{sp\ i} + W_{ext} = K_f + U_{sp\ f}$$

K_i is given. At t = 0, the spring is neither stretched nor compressed so $U_{sp\ i} = 0$. After the block has moved a distance d, $U_{sp\ f} = \frac{1}{2}kd^2 = 1.92\ J$. Over this same interval the hand does work $W_{ext} = F_{BH}d = 3.6\ J$. Therefore $K_f = W_{ext} + K_i - U_{sp\ f} = 3.6\ J + 1.2\ J - 1.92J = 2.88\ J$

Predicted final kinetic energy = 2.88 J

14. [7 pts] The student conducts the experiment and finds that the kinetic energy of the block is 0.19 J *less* than they predicted. Determine the coefficient of kinetic friction between the block and the surface.

Applying the principle of energy conservation to the system with friction gives us:

$$K_i + U_{sp\ i} + E_{th\ i} + W_{ext} = K_f + U_{sp\ f} + E_{th\ f}$$

Both W_{ext} and $U_{sp\ f}$ are the same as for the prediction, therefore the change in thermal energy is equal to the difference between the predicted and actual final kinetic energies, $\Delta E_{th} = 0.19J$.

The change in thermal energy of the system depends on the frictional force exerted by the surface on the block and on the distance the block moves d, $\Delta E_{th} = f_{SB}^k d$ where $f_{SB}^k = \mu_k N_{SB}$. Using $N_{SB} = mg$, we get $\mu_k mgd = \Delta E_{th}$ and finally $\mu_k = 0.024$.

Coefficient of friction = 0.024

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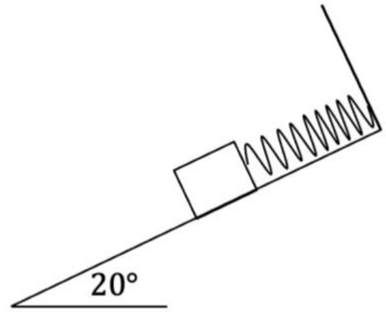
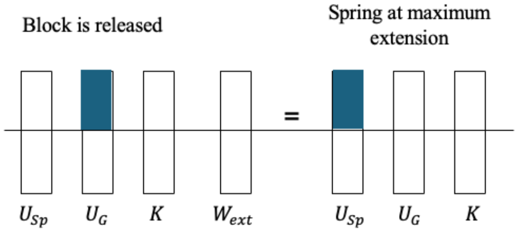
Use the following scenario for the next two questions.

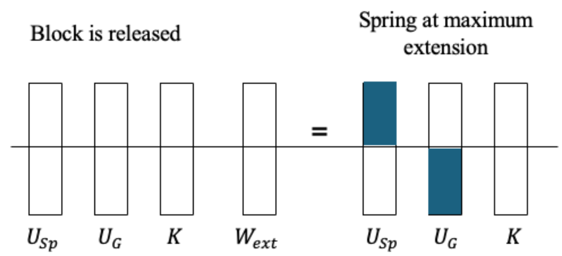


A block of mass m = 1.2 kg is attached to an ideal spring with spring constant k = 32.0 N/m. The block can slide with negligible friction along a 20-degree ramp, as shown.
At t = 0 s, the block is released from rest when the spring is neither stretched nor compressed.

15. [6 pts] Complete the energy bar charts below for the system of the block, spring and Earth for the instant the block is released, and the instant the spring reaches its maximum extension.



OR



16. [6 pts] What is the maximum distance the block travels along the ramp?

Applying the principle of energy conservation to the block-spring-Earth system and using $K_i = 0$ and $K_f = 0$ gives us:

$$U_{sp\ i} + U_{G\ i} = U_{sp\ f} + U_{G\ f} \text{ OR } \Delta U_G = -\Delta U_{Sp}$$

Letting d represent the maximum extension of the spring we get $\Delta U_{Sp} = \frac{1}{2}kd^2$ and $\Delta U_G = -mgsin\theta d$ so that $\frac{1}{2}kd^2 = mgsin\theta d$, which we can solve to find $d = 0.25m$

Maximum distance = 0.25 m

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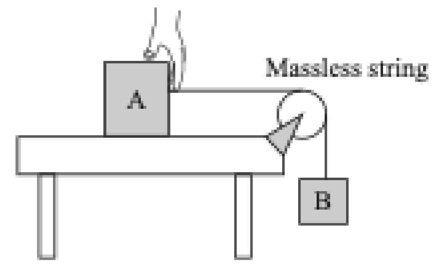
IV. Tutorial free-response questions [15 points]

The next two questions are based on the description below.



Block A, on a level, frictionless table, is attached to a massless string that passes over an ideal, frictionless pulley. The other end of the string is attached to block B. At t_o, Block A is released. The mass of block B is less than that of block A.

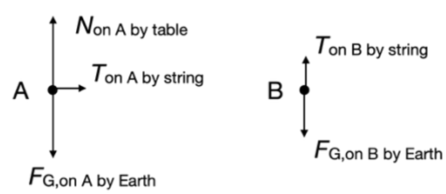
After t_o but before block B hits the ground:

17. [5 pts] Is the magnitude of the acceleration of block A *greater than, less than,* or *equal to* the magnitude of the acceleration of block B? Explain.

The accelerations are equal. The string is inextensible, so the magnitudes of the displacements of the blocks are equal for every interval of time so the velocities have equal magnitudes and thus the accelerations have equal magnitudes.

18. [5 pts] Is the magnitude of the force on block A by the string *greater than, less than,* or *equal to* the magnitude of the gravitational force on block B by the Earth? Explain.

Block B has tension up and gravitational force down. The tension is less in order for block B to accelerate downward. The string is massless so the force it exerts on block A is equal to the force it exerts on block B. Thus, the force on Block A by the string is less than the gravitational force on block B by the Earth.



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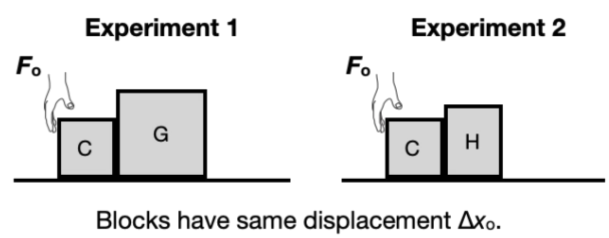
19. [5 pts] In experiment 1, blocks C and G are pushed to the right on a table by a constant force $\boldsymbol{F}_o$, as shown.

In Experiment 2, block G is replaced by a block of less mass, block H. The same constant force $\boldsymbol{F}_o$ is applied to block C. In both cases, the blocks have the same displacement, Δx_o.



Is the total external work done on the system that includes only block C in experiment 1 ($W_{\text{tot ext, C1}}$) *greater than, less than,* or *equal to* the total external work done on that system in experiment 2 ($W_{\text{tot ext, C2}}$)? Explain.

Assume that friction can be neglected. The displacements and hand forces are the same, so the hands do equal work. However, the mass of the entire system in Exp. 1 is greater so $a_1 < a_2$. Hence, from Newton's second law, $F_{net,C1} < F_{net,C2}$. Thus, the magnitude of the normal force by block G on block C ($N_{GC,1}$) must be greater than $N_{HC,2}$ and so $|W_{GC,1}| > |W_{HC,2}|$.

Now, $W_{total,ext} = \sum W_{on\ C}$. Since the works by G and by H are negative, Wtotal,ext is less in experiment 1.

Alternate solution: Since $a_1 < a_2$, $v_{final,C}$ is less in Exp. 1 and so $\Delta K_1 < \Delta K_2$. Since there is no potential energy, then $W_{total,\ ext} = \Delta K$ and $W_{total,ext}$ is less in Experiment 1.