Question 1

Part (a)
The resistor in series with the battery takes the largest current of any of the three resistors by Kirchoff’s junction rule. By Ohm’s law, $V = IR$, a resistor with both the largest current and the largest resistance will similarly take the largest voltage. So put the largest resistor $R_3$ in series with the battery, as shown.

1 point for a correct diagram.

1 point for a correct justification.

Part (b)

Yes. Consider the equivalent circuit drawn, where the second resistor is the equivalent resistor of the parallel combination. These two resistors each take the same current by Kirchoff’s junction rule; by Ohm’s law, with the same current, the larger of the two takes the larger voltage. If the equivalent resistance of the parallel combination is greater than the resistance of the resistor in series with the battery, then the parallel combination will take more voltage than the first resistor. In this case, putting $R_1$ in series with the battery and the other two resistors in the parallel combination satisfies this condition; the equivalent resistance of $R_2$ and $R_3$ in parallel is greater than 30 kW.

1 point for comparing the resistance of the parallel combination to that of the series resistor.
Part (c)
The total resistance of this circuit is the sum of the three resistors, 210 kW. The total current in the circuit is 12 V/210 kW = 57 mA (that is, 0.000057 A). Using that current in $V = IR$ for each resistor gives a voltage drop of 3.4 V, 6.9 V, and 1.7 V across each resistor in turn. So start the graph at 12 V. The voltage drops by 3.4 V after the 60 kW resistor, down to 8.6 V, as shown in the diagram. (The voltage does not change along the wire itself, which has essentially zero resistance compared to the resistors.) When we get to the 120 kW resistor, drop the voltage another 6.9 V, down to 1.7 V left. The voltage drops the rest of the way to zero after the 30 kW resistor, as required by Kirchoff’s loop rule.

1 point for any graph having three distinct voltage drops ending at 0 V.

1 point for any graph that somehow indicates the largest voltage drop across the middle resistor and the smallest voltage drop across the last resistor.

1 point for any graph with three distinct horizontal segments representing the voltage in the wires not changing.

Question 2
Part (a)
The maximum coefficient of static friction is greater than the coefficient of kinetic friction. The graph shows the maximum force of static friction, when the block starts moving, to be 1.7 N; when the block is moving, the friction force drops to 1.0 N, which is appropriate for the lower kinetic friction force.

1 point for correctly explaining the difference between static and kinetic friction in this case.

Part (b)
(i) Impulse is the area under a force-time graph. The graph has an average force of about 1.0 N, and a time interval of about 2 s (from $t = 2$ s to $t = 4$ s). That’s an impulse of 2 N-s.

1 point for using the area under the force versus time graph.

1 point for making reasonable estimates of time and force from the graph.

(ii) The student is incorrect. While it is true that the net impulse on an object is equal to the object’s change in momentum, the graph shown does not include the net force. The graph shows the force of the string only. If you were to subtract the impulse provided by the friction force, you would get zero net impulse and thus zero change in momentum.
1 point for discussing the difference between the force of the string and the net force on the cart.

1 point for including no incorrect statements.

Part (c)
The student could use a set of toy carts, each of which moves at a different constant speed. The student should connect the carts to the block via the force probe and produce force-time graphs for each cart as the cart moves across the table. The constant speed traveled by each cart can be measured by placing a sonic motion detector in front of the cart.

3 points for a complete and correct description. Of these points, 1 or 2 could be holistically awarded for a partially complete and/or partially correct description.

Part (d)
The student should make a plot of speed on the vertical axis versus the force of kinetic friction on the horizontal axis. The speed of each cart would be determined by the slope of the position-time graph produced by the sonic motion detector. The force of kinetic friction would be measured by the force probe.

The block is the same mass each time, which means it always experiences the same normal force; the coefficient of friction is the friction force divided by the normal force. So if the coefficient of friction changes, the force probe reading would change as well.

If this graph is horizontal, then the force of friction and the coefficient of friction do not change with speed. If the graph is sloped, then we can conclude that the coefficient of friction does change with speed.

1 point for using a graph with a significant number of data points, or perhaps statistical analysis of multiple trials.

1 point for correctly relating the friction coefficient to the force probe reading with constant $F_n$.

2 points for a complete and correct analysis. One of these points can be holistically awarded for a partially complete and/or partially correct analysis.

Question 3

Part (a)
1 point: As the hanging object $m$ falls, it speeds up. Its acceleration is therefore downward, and so is the net force acting on it. To get a downward net force, the downward gravitational force $mg$ must be greater than the rope’s tension.

Part (b)
4 points:

• 1 point for using an applicable fundamental relationship such as $\alpha = \frac{\tau_{net}}{I}$ (or $a=ra$).
• 1 point for a correct discussion of how to get $\tau_{net}$ (or $a$).
• 1 point for a correct discussion of how to estimate $I$ (or $a$).
• 1 point for a correct conclusion to answer the question.

The angular acceleration can be found by dividing the net torque on the device by its rotational inertia. The rotational inertia $I$ of the device can be calculated based on the assumption that the pipe and the stem do not contribute; the device consists of two pointed masses, each a distance of...
from the center of rotation. The net torque on the device is \( Tr \), where \( r \) is the radius of the support.

The only unknown information in all of this is the radius of the support \( r \). So **no, the angular acceleration cannot be calculated** with the information provided unless \( r \) is measured with calipers.

*(Alternate solution:)* The angular acceleration of the device \( \alpha \) is related to the linear acceleration \( a \) of the falling mass by \( a = r\alpha \). The radius of the support \( r \) must be measured with calipers. To get \( a \), the distance the mass falls from rest \( d \) can be measured with a meterstick, and the time \( t \) to fall that distance can be measured with a stopwatch. Then kinematics can be used to calculate \( a \). So **no, the angular acceleration cannot be calculated** with the information given here.

**Part (c)**

1 point for clearly defining and correctly using any new variables.

1 point for a correct expression for \( I \) (or \( a \)).

1 point for a correct final answer.

As described in part (b), let \( r \) be the radius of the support.

By Newton’s second law for rotation, \( \alpha = \frac{\tau_{\text{net}}}{I} \).

Using the net torque and rotational inertia explained in part (b),

\[
\alpha = \frac{Tr}{2M \left( \frac{L}{2} \right)^2}.
\]

*(Alternative solution, as described in part [b]): \( \alpha = \frac{a}{r} \).*

Falling from rest means zero initial velocity, so \( d = \frac{1}{2}at^2 \), with \( d \) and \( t \) defined as shown.

Algebraically, this makes \( a = \frac{2d}{t^2} \).

Combining these two statements gives \( \alpha = \frac{2d}{rt^2} \).

**Part (d)**

1 point for describing the quantity in the equation in (c) that would be affected by the new mass.

1 point for describing with reference to the equation how that change would affect the acceleration.

While the tension in the hanging rope is not equal to the weight of the hanging object, increasing the hanging object’s mass would increase the tension in the rope \( T \). Since \( T \) is in the numerator of the equation for angular acceleration, and since the parameters in the denominator are unchanged, the angular acceleration would increase.

*(Alternate solution:)* We would be able to measure that the hanging object falls the same distance in less time. Note that this is NOT because “heavier objects fall faster”; this is really a consequence of the reasoning already given, that the tension in the rope increases without...
changing the properties of the device. With a smaller \( t \) in the denominator and other variables unchanged, the angular acceleration would increase.)

Part (e)

2 points for a complete and correct solution. One of these points can be awarded for a partially complete or partially correct solution.

*Using a calculational approach:* You assumed that the rotational inertia of the device was wholly due to the two rocks as point objects, \( 2M(L/2)^2 \). The rotational inertia of a cylinder rotating horizontally and vertically can be looked up, and the mass of the pipe and support can be measured. You could calculate the additional rotational inertia provided by the cylinder and support. If this additional rotational inertia is substantially less than \( 2M(L/2)^2 \) such that the calculation of \( a \) would still come out approximately the same, then this additional inertia is negligible.

*Using an experimental approach:* Measure the angular acceleration of the device directly. This can be done with frame-by-frame video analysis or with a photogate set to measure the increase in angular velocity. If the angular acceleration measured matches that predicted by the equation in (c), then the assumption that the rotational inertia is due wholly to the point masses is reasonable. However, if the angular acceleration is measured to be noticeably smaller than that predicted in (c), then the rotational inertia of the pipe and support do contribute meaningfully to the calculation and are not negligible.

**Question 4**

Part (a)

(i) 1 point for calculating the spring constant.

1 point for using the calculated spring constant in a correct equation to determine the work done.

The spring constant of the spring can be determined by procedure A. The rock applies a 4 N force on the spring, compressing it 0.05 m. By \( F = kx \), that gives a spring constant \( k \) of \( (4 \text{ N})/(0.05 \text{ m}) = 80 \text{ N/m} \).

The potential energy of the spring-block-Earth system is just \( \frac{1}{2}kx^2 \), where \( x \) is the distance from the position of the block after procedure A. (If you were talking about just the spring-block system, you would use the distance from the undisturbed position, but then you would have to consider the work done on the block-Earth system separately.) So in procedure B, the block-Earth system gains \( \frac{1}{2}(80 \text{ N/m})(0.05 \text{ m})^2 \) of potential energy, which is 0.10 J. That’s how much work was done by the student.

(ii) 1 point for correctly justifying the use of data from procedure A to get the spring constant.

1 point for justifying use of \( \frac{1}{2}kx^2 \) as a change in potential energy of the correct system.

See above.

Part (b)

1 point for recognizing that the same potential energy is available to be converted to \( KE \).

1 point for words or equations showing that the mass only shows up in the denominator of an expression for the height.

1 point for using an equation or conservation of energy reasoning to get \( \frac{1}{2}h \).
The new spring-block-Earth system stores the same 0.10 J of potential energy: \( \frac{1}{2}kx^2 \), where \( x \) is the 0.05 m distance from the position of the block after procedure C. That 0.10 J is converted into kinetic energy, then to purely gravitational energy. Gravitational energy is \( mgh \); the new height is \( h_{\text{new}} = \frac{0.10 \text{ J}}{mg} \). Since this new mass is twice as much as before, and since height is in the denominator, the new height is half as much as \( h \).

**Question 5**

- 1 point for appropriate free body diagram(s) or equivalent clear descriptions of forces acting on the object.
- 1 point for relating the tension in the rope to the likelihood that the string will break.
- 1 point for using horizontal and vertical components of the strings’ tensions.
- 1 point for use of trigonometry (graphically, or with sines and cosines) relating the magnitude of the tension to the components of the tension.
- 1 point for an equivalence between the vertical tension components and the object’s weight.
- 1 point for recognizing that the vertical components of tension must be the same in either configuration.
- 1 point for connecting identical vertical tensions with different horizontal tensions to show that configuration 1 gives the larger magnitude of tension.

*Example of a good paragraph:* In each configuration, the forces acting on the object are the two equal tensions \( T \), and the object’s weight. Equilibrium demands that the vertical tension components are together equal to the object’s weight and that the horizontal tension components are equal to each other. No matter what the angle, the vertical components of tension must remain the same (because the weight of the object can’t change.) The vertical component is given by \( T\sin\theta \), with angle \( \theta \) measured from horizontal. To keep this vertical component the same no matter the angle, the tension must increase as the sine of the angle decreases. The angle \( \theta \) is smaller in configuration 1; therefore, the tension is larger and the string is more likely to break.

**Scoring the Practice Exam**

Remember that the raw percentage score necessary to obtain a 5, 4, 3, or 2 is not a fixed number. The scores are scaled each year so, regardless of whether the questions on that year’s exam are hard or easy, the meaning of each score is similar year after year after year. What you see below is merely my best educated guess at a reasonable score conversion. I’ll even use this very score conversion in my own classes. But I don’t guarantee the accuracy of the chart any more than I guarantee Arsenal to win the Premier League.

**Multiple-Choice Raw Score:** Number Correct______ (50 points maximum)

**Free Response:**

Problem 1______ (12 points maximum)
Problem 2______ (12 points maximum)
Problem 3______ (7 points maximum)
Problem 4______ (7 points maximum)
Problem 5______ (7 points maximum)

Free response total:______ (45 points maximum)
The final score is equal to \((1.11 \times \text{the free response score}) + \text{(the multiple choice score)}\)

Total score:______(100 points maximum)

Approximate Score Conversion Chart (only a guesstimate, see above)

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