Do not turn the pages of the exam until you are instructed to do so.

Exam rules: You may use **only** a writing instrument while taking this test. You may **not** consult any calculators, computers, books, nor each other.

Problems 1 and 10 must be answered on the scantron form. **Problems 11 and 12 must be answered in exam booklet 1. Problem 13 must be answered in exam booklet 2.** The answers need to be well motivated and expressed in terms of the variables used in the problem. You will receive partial credit where appropriate, but only when we can read your solution. **Answers that are not motivated will not receive any credit, even if correct.**

At the end of the exam, you must hand in your exam, the scantron form, the blue exam booklets, and the equation sheet. **All items must be clearly labeled with your name, your student ID number, and the day/time/location of your workshop. If any of these items are missing, we will not grade your exam, and you will receive a score of 0 points.**

You are required to complete the following *Honor Pledge for Exams*. Copy and sign the pledge before starting your exam.

"I affirm that I will not give or receive any unauthorized help on this exam, and that all work will be my own."

Name: _____

Signature: _____

Good Luck !

Problem 1 (2.5 points) **Answer on Scantron form**

As you hold the string, a yo-yo is released from rest so that gravity pulls it down, unwinding the string. What is the angular acceleration of the yo-yo, in terms of its string radius R, its moment of inertia I, and its mass M?

1. $\frac{g}{R+\frac{2I}{MR}}$
2. $\frac{gMR}{I}$
3. $\frac{gmR}{I+MR^2}$
4. $\frac{g}{R}$

Problem 2 (2.5 points) **Answer on Scantron form**

The moment of inertia of a uniform square plate of area $4R^2$ and mass M, with respect to an axis through its center and perpendicular to the plate, is equal to $\frac{2}{3}MR^2$. A disk of radius R is removed from the center of the plate, as shown in Fig. 1.

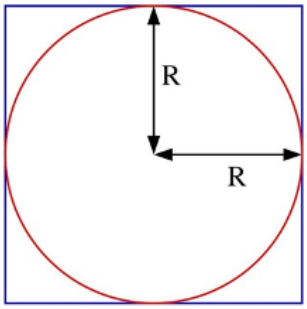

Figure 1: A square plate with a disk removed.

What is the moment of inertia of the remaining material with respect to the same axis?

1. $\frac{\pi}{8}MR^2$.
2. $\left(\frac{1}{3}-\frac{\pi}{12}\right)(MR^2$.
3. $\frac{1}{6}MR^2$.
4. $\left(\frac{2}{3}-\frac{\pi}{8}\right)(MR^2$.

Problem 3 (2.5 points) **Answer on Scantron form**

Four identical masses are connected in a flat perfect square as shown in Fig. 2.

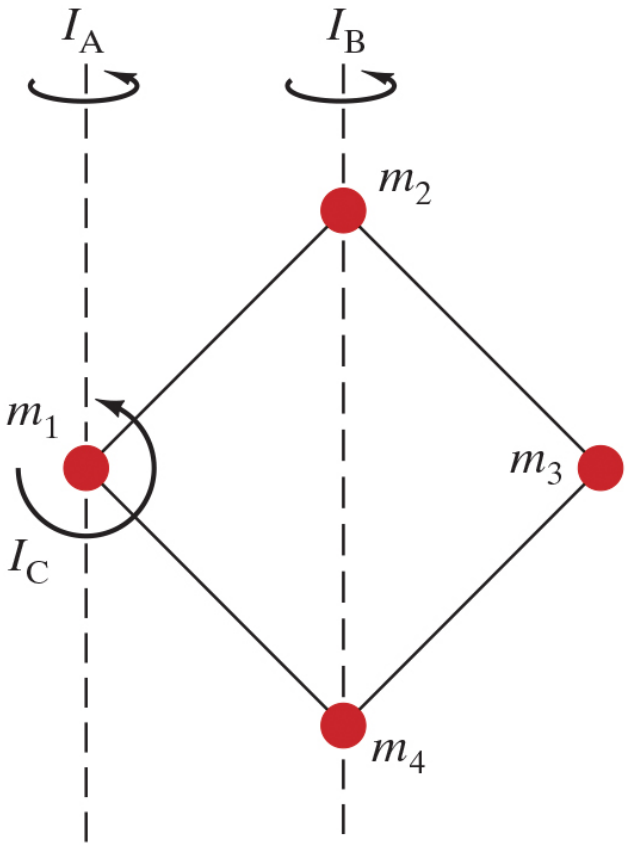

Figure 2: Mass configurations for Problem 3.

Rank the relative moments of intertia $I_A, I_B,$ and I_C about the three axes of rotation shown in Fig. 2. Axes A and B are in the plane of the square and axis C is perpendicular to the plane, through mass m_1.

1. $I_A < I_B < I_C$.
2. $I_C < I_B < I_A$.
3. $I_A = I_B = I_C$.
4. $I_B < I_A < I_C$.
5. $I_C < I_A < I_B$.

Problem 4 (2.5 points) **Answer on Scantron form**

Consider simple harmonic motion with amplitude A. At what displacement in x is the total energy shared equally between kinetic energy and potential energy?

1. A.
2. $\frac{A}{2}$.
3. $\sqrt{2}A$.
4. $\frac{A}{\sqrt{2}}$.

Problem 5 (2.5 points) **Answer on Scantron form**

A uniform meter stick, supported at the 25 cm mark, is in equilibrium when a 1-kg rock is suspended at the 0 cm end, as shown in Fig. 3.

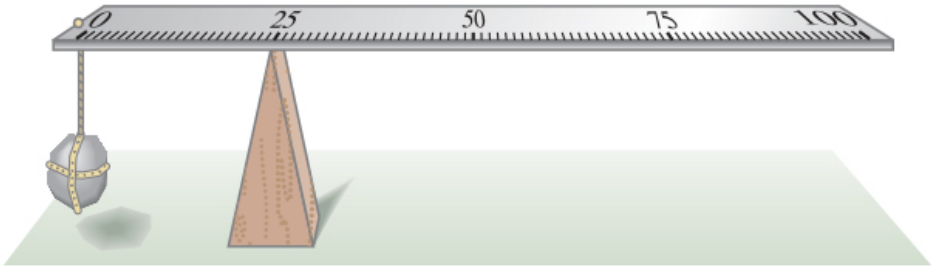

Figure 3: A meter stick in equilibrium.

What is the mass of the meter stick?

1. Greater than the mass of the rock.
2. Equal to the mass of the rock.
3. Less than the mass of the rock.
4. None of the above.

Problem 6 (2.5 points) **Answer on Scantron form**

A small mass m on a string is rotating without friction in a circle on a table, as shown in Fig. 5.

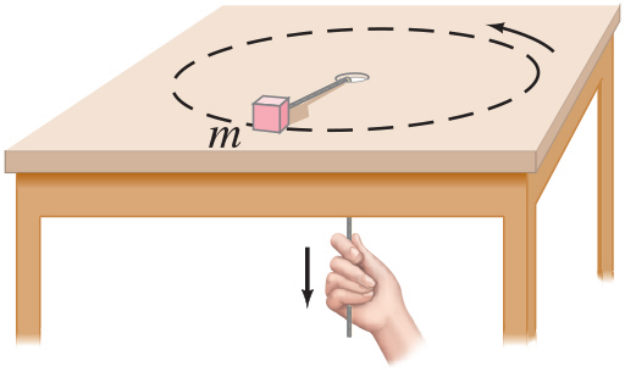

Figure 4: Rotating mass.

The string is shortened by pulling it through the axis of rotation without any external torque. What happens to the angular velocity of mass m?

1. It increases.
2. It decreases.
3. It remains the same.
4. Insufficient information provided to answer the question.

Problem 7 (2.5 points) **Answer on Scantron form**

An object of mass M oscillates at the end of a spring. To double the period, we must replace the object with one of mass

1. $2M$.
2. $\frac{M}{2}$.
3. $4M$.
4. $\frac{M}{4}$.
5. None of the above.

Problem 8 (2.5 points) **Answer on Scantron form**

Which of the graphs shown in Fig. 5 can represent the kinetic energy of simple harmonic motion as function of time?

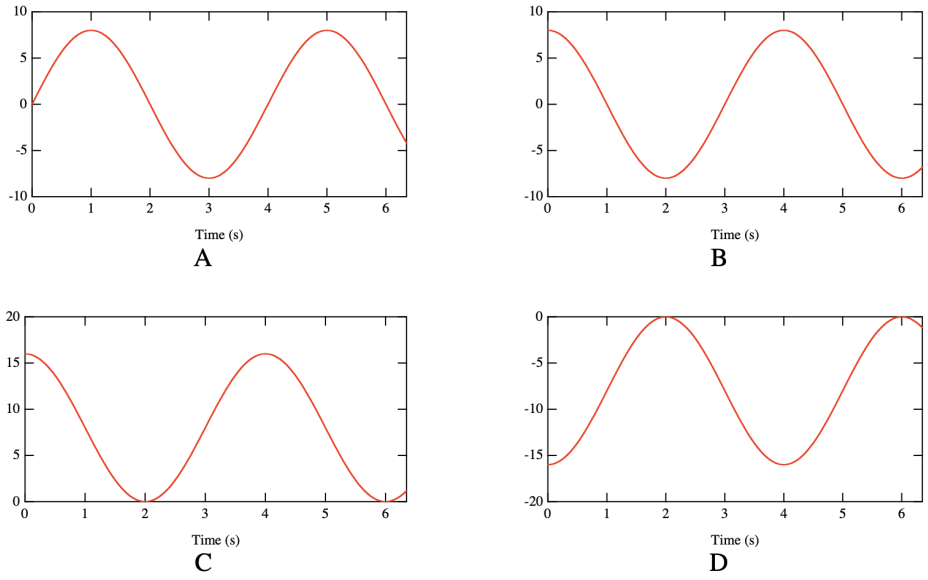

Figure 5: Graphs of parameters related to simple harmonic motion as function of time.

1. Graph A.
2. Graph B.
3. Graph C.
4. Graph D.

Problem 9 (2.5 points) **Answer on Scantron form**

Which of the following is **not** a vector?

1. Angular velocity.
2. Angular acceleration.
3. Angle.
4. Torque.

Problem 10 (2.5 points) **Answer on Scantron form**

In which country is the biggest bicycle garage in the world located?

Figure 6: The biggest bicycle garage in the world.

1. The United States.
2. Canada.
3. The United Kingdom.
4. China.
5. The Netherlands.
6. Japan.
7. Indonesia.
8. Australia.
9. South Africa.
10. Brazil

Problem 11 (25 points) **Answer in booklet 1**

A block of mass m, resting on a frictionless surface, is connected to two springs with spring constants k_1 and k_2, in two different ways, as shown in Fig. 7 and Fig. 8. Assume that $k_1 = k_2 = k$.

a) **(7.5 points)** Consider the configuration shown in Fig. 7. Both springs are in their equilibrium position.

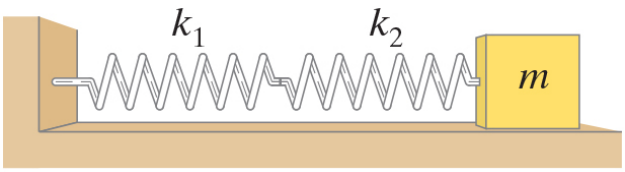

Figure 7: Mass m connected to two springs.

The block is now moved a distance x to the right. What is the force that is exerted by the springs on the block if the block is held at that position? **Specify both direction and magnitude.**

b) **(5 points)** We release the block from the position discussed in part a). What is the period of the resulting motion of mass m?

c) **(7.5 points)** Now consider the configuration shown in Fig. 8. Both springs are in their equilibrium position.

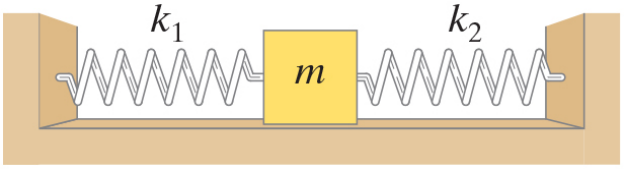

Figure 8: Mass m connected to two springs.

The block is now moved a distance x to the right. What is the force that is exerted by the springs on the block if the block is held at that position? **Specify both direction and magnitude.**

d) **(5 points)** We release the block from the position discussed in part c). What is the period of the resulting motion of mass m?

Your answers should be well motivated and expressed in terms of the variables provided.

Problem 12 (25 points) **Answer in booklet 1**

A plank, of length L and mass M, rests on the ground and on a frictionless roller at the top of a wall of height h, as shown in Fig. 9.

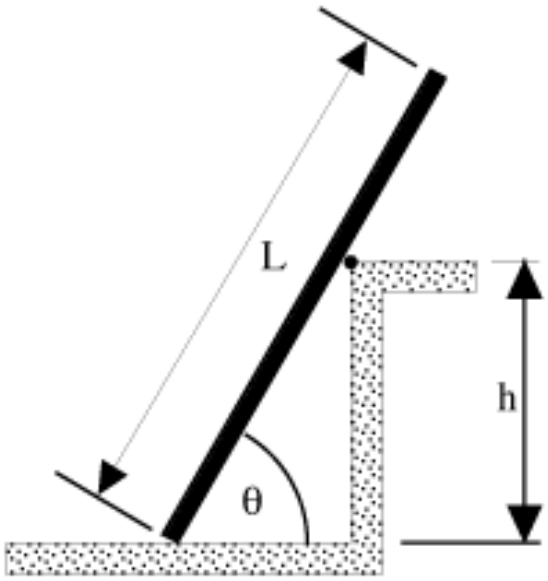

Figure 9: A plank resting on the ground and on a roller.

The center of gravity of the plank is at its center. The plank remains in equilibrium for any angle α when $\alpha > \theta$ but slips when $\alpha < \theta$.

a) **(5 points)** Draw a free-body diagram of the plank, showing all forces acting on it.

b) **(5 points)** Determine the magnitude of the force exerted by the roller on the plank when $\alpha = \theta$.

c) **(5 points)** Calculate the magnitude of the friction force between the ground and the plank when $\alpha = \theta$.

d) **(10 points)** Calculate the coefficient of static friction between the ground and the plank.

Your answers should be well motivated and expressed in terms of the variables provided.

Problem 13 (25 points) **Answer in booklet 2**

A uniform stick of length H and mass M, initially at rest, is pivoted at its center. A bullet of mass m is shot through the stick, midway between its pivot point and one end, as shown in Fig. 10.

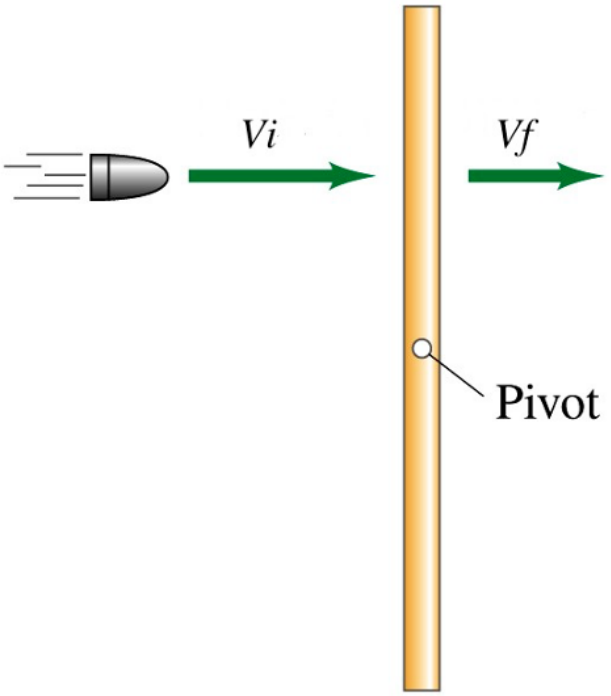

Figure 10: A bullet hitting a stick.

The bullet approaches the stick with a velocity v_i and leaves with a velocity $v_f = (1/2)v_i$. You can ignore the change in the mass and the moment of inertia of the rod as a result of the bullet passing through it. You can also ignore the effect of gravity.

a) **(2.5 points)** What is the initial angular momentum of the bullet with respect to the pivot point? Specify both its magnitude and its direction.

b) **(2.5 points)** What is the final angular momentum of the bullet with respect to the pivot point? Specify both its magnitude and its direction.

c) **(10 points)** What is the angular speed of the stick after the collision?

d) **(10 points)** How much energy is lost in the collision?

Your answers should be well motivated and expressed in terms of the variables provided.

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Figure 11: KLM houses at the KLM lounge at Schiphol. Photo made by Frank Wolfs.