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, Problems 13 and 14 must be answered in exam booklet 2, and problems 15, 16, and 17 must be answered in booklet 3** 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**

For most materials, how is the coefficient of volume expansion related to the coefficient of linear expansion?

1. The coefficient of volume expansion is equal to the coefficient of linear expansion.
2. The coefficient of volume expansion is one-third the coefficient of linear expansion.
3. The coefficient of volume expansion is three times the coefficient of linear expansion.
4. The coefficient of volume expansion is twice the coefficient of linear expansion.

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

One mole of an ideal gas in a sealed container is initially at a temperature of 100°C. The temperature is then increased to 200°C. The pressure of the gas

1. remains constant.
2. increases by about 25%.
3. doubles.
4. triples.
5. is halved.

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

Consider a mixture of oxygen (O_2, mass 32 amu) and helium (He, mass 4 amu) in equilibrium at a low temperature. Which statement is valid?

1. The helium atoms move faster than the oxygen molecules.
2. The helium atoms and the oxygen molecules move at the same average speed.
3. The oxygen molecules move faster than the helium atoms.
4. The kinetic energy of the helium atoms exceeds that of the oxygen molecules.
5. None of the above.

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

Two blocks of the same size but different masses, m_1 and m_2, are placed on a frictionless table side-by-side in contact with each other, as shown in Fig. 1. Assume that $m_1 > m_2$.

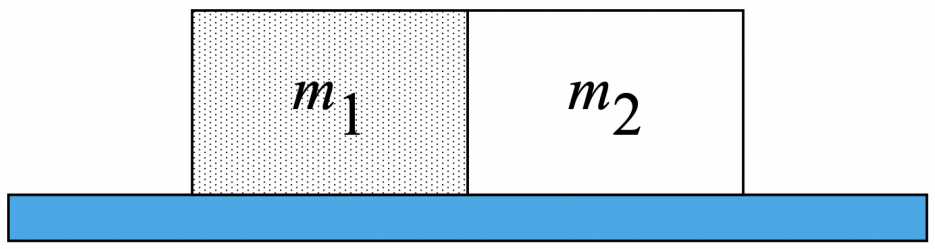

Figure 1: Masses m_1 and m_2 on a table.

Let N_1 be the magnitude of the normal force between the two blocks when you push horizontally with a force $\vec{F}$ on the free side of m_1 (towards m_2). Let N_2 be the magnitude of the normal force between the two blocks when you push horizontally with a force $-\vec{F}$ on the free side of m_2 (towards m_1). Which of the following statements is true?

1. $|N_1| = |N_2|$
2. $|N_1| < |N_2|$
3. $|N_1| > |N_2|$

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

A ball is dropped from the edge of a cliff. Soon after, a second ball is dropped. As a function of time, the separation between the two balls ...

1. stays the same.
2. increases.
3. decreases.
4. it depends on the time specified.

Problem 6 (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 7 (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. 2.

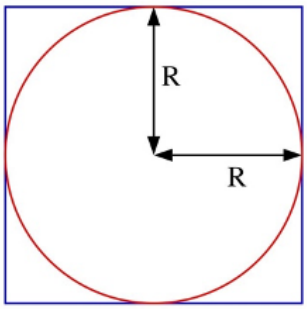

Figure 2: A square plate with a disk removed.

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

A delivery man carries a package, as shown in Fig. 3.

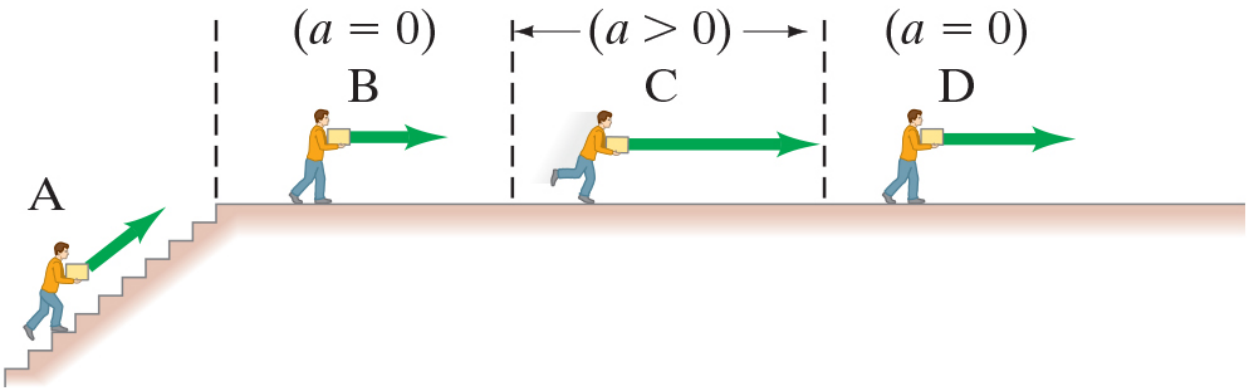

Figure 3: Delivering a package.

He walks up the stairs to the second floor at constant speed (A), and along the hall at a constant speed (B). He accelerates to a run (C) and then moves at a greater speed along the hall (D). During what parts of the motion is the delivery man doing work on the package?

1. A only.
2. B only.
3. C only.
4. D only.
5. A and C only.
6. B and C only.
7. None of these portions.
8. Work is done throughout.

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

A rocket is fired vertically upward with a constant acceleration greater than g. The rocket engine runs for several seconds and then stops. Which of the following statements is true if we plot the velocity of the rocket as a function of time after the rocket engine stops?

1. The velocity versus time graph will be parabolic.
2. The velocity versus time graph will be a straight line.
3. The velocity versus time graph will consist of two straight-line segments, both with a positive (but different) slope.
4. The velocity versus time graph will consist of two straight-line segments with slopes of opposite sign.

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

Which team is at the top of the AL East?

Figure 4: The New York Yankees vs the Boston Red Sox.

1. Baltimore Orioles.
2. Boston Red Sox.
3. Tampa Bay Rays.
4. New York Yankees.
5. Toronto Blue Jays.

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

Several planets (Jupiter, Uranus, Saturn) possess nearly circular surrounding rings, perhaps composed of material that failed to form a satellite. In addition, many galaxies contain ring-like structures.
Consider a homogeneous ring of mass M and radius R, as shown in Fig. 5.

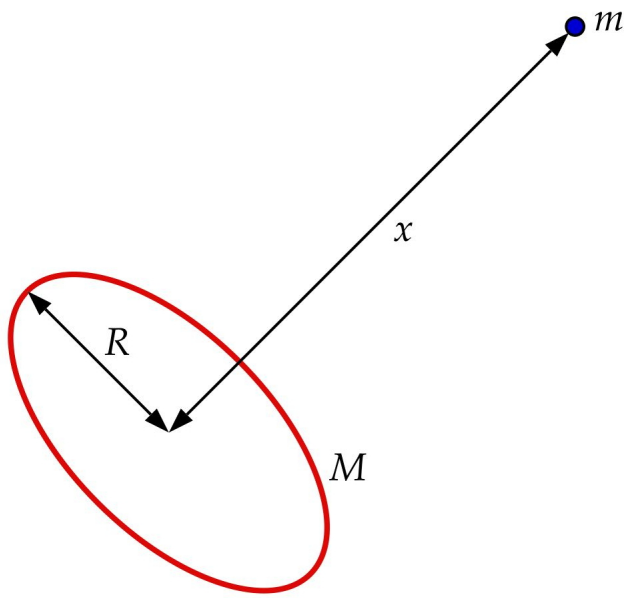

Figure 5: A homogeneous ring of matter exerting a force of particle m.

a) **(5 points)** What is the direction of the gravitational force exerted by the ring on a particle of mass m located a distance x from the center of the ring along its axis as shown in Fig. 5? **Make sure you motivate your answer!**

b) **(10 points)** What is the potential energy of mass m as a function of the distance x?

c) **(10 points)** Suppose the particle falls from rest from its current distance x as a result of the attraction of the ring of matter. Find an expression for the speed with which it passes through the center of the ring. Note: assume that the ring remains stationary at all times.

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

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

A rock of mass m is kicked horizontally with an initial speed v_0 from a hill with a 45° slope, as shown in Fig. 6.

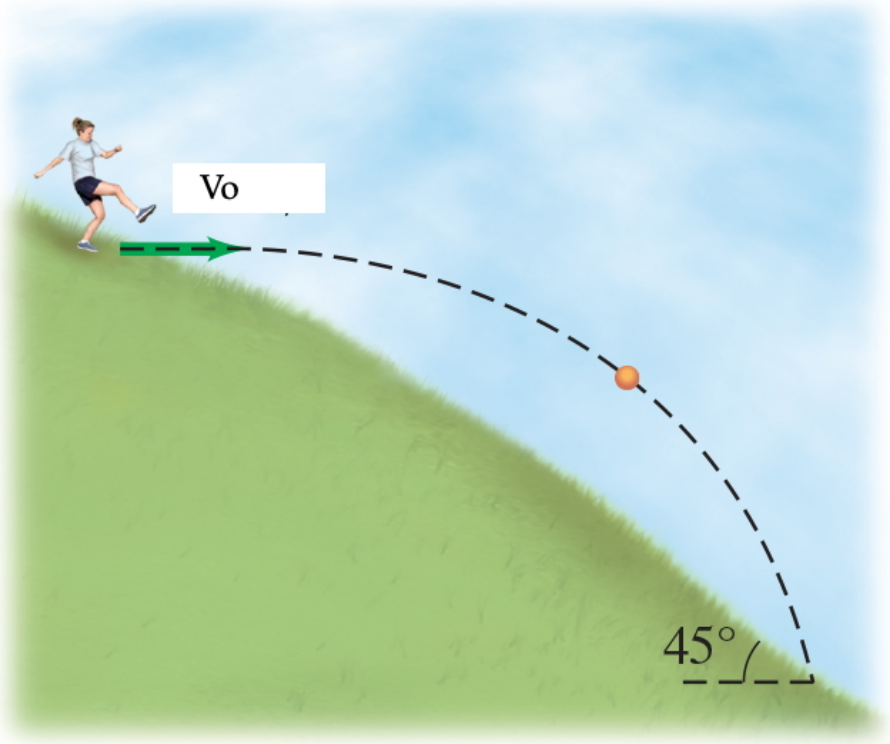

Figure 6: Kicking a rock down a hill.

1. **(15 points)** How long does it take for the rock to hit the ground?
2. **(10 points)** What is the final kinetic energy of the rock when it hits the ground?

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

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

A thin rod of mass M and length ℓ rests on a frictionless table and is struck at a point $\ell/4$ from its center of mass by a clay ball of mass m, moving with speed v, as shown in Fig. 7. The ball sticks to the rod.

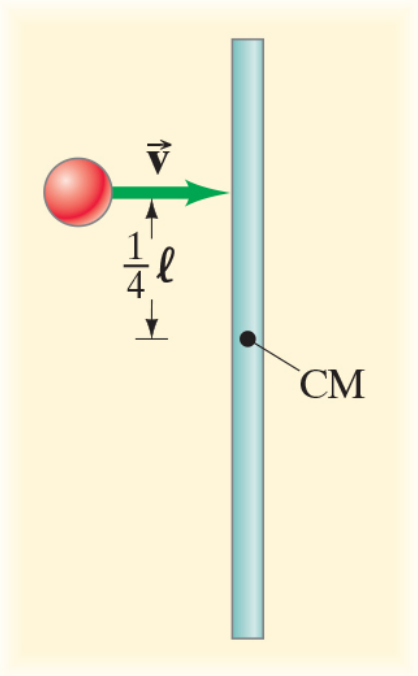

Figure 7: Clay hitting a rod.

a) **(10 points)** What is the linear velocity of the center of mass after the collision. Specify both magnitude and direction.

b) **(15 points)** What is the angular velocity of the rod after the collision? Specify both magnitude and direction.

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

Problem 14 (25 points) **Answer in booklet 2**

The operation of an automobile internal combustion engine can be approximated by a reversible cycle known as the Otto cycle, whose PV diagram is shown in the Fig. 8. The gas in cylinder at point a is compressed adiabatically to point b. Between point b and point c, heat is added to the gas, and the pressure increases at constant volume. During the power stroke, between point c and point d, the gas expands adiabatically. Between point d and point a, heat is removed from the system, and the pressure decreases at constant volume. Assume that there are n moles of gas in the engines and that the gas is an ideal monatomic gas. The heat capacity of the gas at constant volume is C_V.

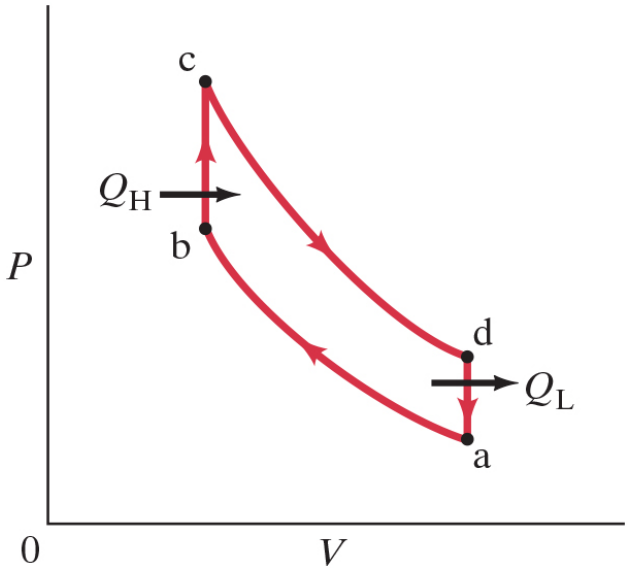

Figure 8: The Otto cycle.

a) **(5 points)** What is the amount of heat added to the system when it transitions from point b to point c. You can express your answers in terms of the temperatures T_a, T_b, T_c, and T_d.

b) **(5 points)** What is the amount of heat removed from the system when it transitions from point d to point a. You can express your answers in terms of the temperatures T_a, T_b, T_c, and T_d.

c) **(10 points)** What is the efficiency of the Otto cycle? You can express your answers in terms of the temperatures T_a, T_b, T_c, and T_d.

d) **(5 points)** The compression stroke (point a to point b) and the exhaust stroke (point c to point d) are adiabatic processes. During an adiabatic process, pV^γ is constant (γ is a constant). Use this relation to rewrite the answer you obtained in part c) in terms of the compression ratio V_a/V_b.

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

Problem 15 (25 points) **Answer in booklet 3**

A uniform solid sphere of mass M and radius r_0 rolls down a hill, as shown in Fig. 9. The sphere starts from a height H. Assume that the sphere rolls without slipping since there is plenty of static friction.

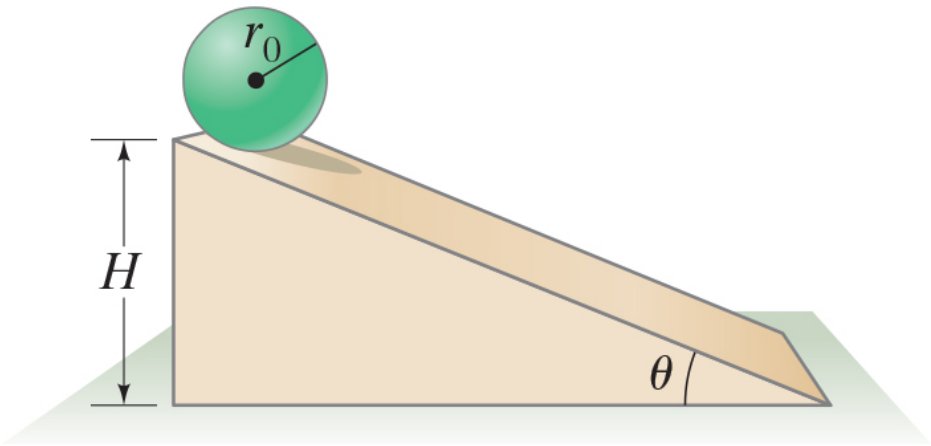

Figure 9: A uniform sphere rolling down a hill.

a) **(20 points)** What is the translational velocity when the sphere reaches the bottom of the hill?

b) **(5 points)** What is the angular velocity when the sphere reaches the bottom of the hill?

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

Problem 16 (25 points) **Answer in booklet 3**

a) **(10 points)** A car of mass m moves at a constant speed v_0 on a curved unbanked roadway whose radius of curvature is equal to R, as shown in Fig. 10. The car is able to make the turn without skidding of the road. What must be the minimum coefficient of static friction μ_s between the tires and the roadway?

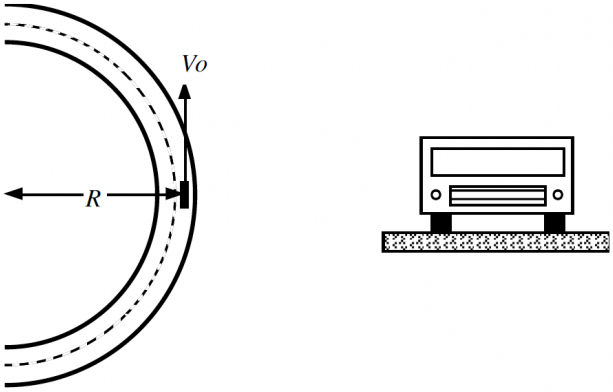

Figure 10: A car rounding an unbanked corner.

b) **(15 points)** You cannot count on a sideways frictional force to get your car around a curve if the road is icy or wet. That is why highways are banked. Suppose a car of mass m moves at a constant speed v on a curved banked highway whose radius of curvature is equal to R and whose angle of bank is equal to θ. There is no friction between the tires and the roadway. What must be the speed of the car to be able to round the curve without skidding of the road?

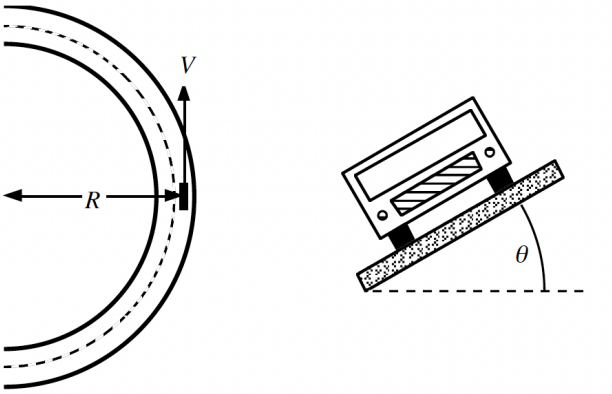

Figure 11: A car rounding an banked corner.

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

Problem 17 (25 points) **Answer in booklet 3**

A block of mass M slides on a frictionless surface with a velocity v toward a second block (at rest) of the same mass M, as shown in Fig. 12. A spring with spring constant k is attached to the second block in such a way that it will be compressed when struck by the moving block.

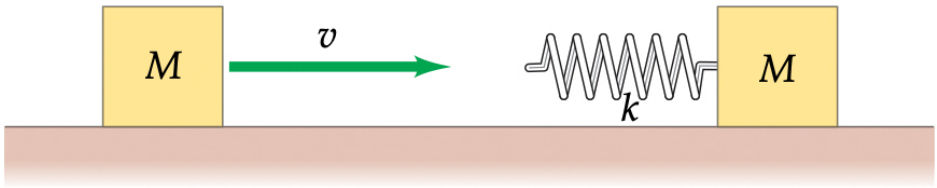

Figure 12: Two blocks on a frictionless surface.

a) **(15 points)** What will be the maximum compression of the spring?

b) **(10 points)** What will be the final velocities of the blocks after the collision?

You can ignore the mass of the spring.

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

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Figure 13: The Thunderbirds airshow in Rochester on August 23, 2023. Photo made by Frank Wolfs.