Physics 121, Final Exam

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

You are responsible for reading the following rules carefully before beginning.

Exam rules: You may use *only* a writing instrument while taking this test.

You may *not* consult any calculators, computers, books, notes, or each other.

Procedure:

1. Answer the multiple-choice questions (problems 1 – 10) by marking your answer on the scantron form. For each multiple-choice question (problems 1 – 10), select only one answer. **Questions with more than one answer selected will be considered incorrect.**
2. The analytical problems (11 – 17) must be answered in the blue exam booklets. You **must** answer problems 11, 12, 13, and 14 in one of the blue booklets, and problems 15, 16, and 17 in the other blue booklet. **If you do not follow this convention there is no guarantee that the problems that appear in the wrong booklet will be graded.**
3. The answer to each analytical problem must 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.**
4. At the end of the exam, you must hand in the blue exam booklets, the scantron form, the exam, and the formula sheets. All items must be clearly labeled with your name and student ID number. **If any of these items is missing, we will not grade your exam, and you will receive a score of 0 points.**

Note: You are not allowed to use a cheat sheet on this exam. Please refer to the formula sheet at the end of this package for important equations.

Note: If you do not answer a question in terms of the variables provided, you will not receive credit for that question.

Note: You will get 2.5 extra points if you put your student ID correctly on your scantron form and answer the analytical questions in the correct exam booklet.

Problem 1 (1.25 points)

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?

☐ The velocity versus time graph will be parabolic.

☐ The velocity versus time graph will be a straight line.

☐ The velocity versus time graph will consist of two straight-line segments, both with a positive (but different) slope.

☐ The velocity versus time graph will consist of two straight-line segments with slopes of opposite sign.

Problem 2 (1.25 points)

Which of the following units may be used to describe linear momentum?

☐ Ns

☐ N/s

☐ Nm

☐ N/m

Problem 3 (1.25 points)

Suppose Newton's Law of Universal Gravitation were modified to read: $F = GmM/r^3$, rather than the observed inverse-square law force. Kepler's third law would then read

☐ $(T_1/T_2)^2 = (r_1/r_2)$

☐ $(T_1/T_2)^2 = (r_1/r_2)^3$

☐ $(T_1/T_2)^2 = (r_1/r_2)^4$

☐ $(T_1/T_2)^2 = (r_1/r_2)^2$

Problem 4 (1.25 points)

Two masses m_1 and m_2 sit on a table connected by a rope. A second rope is attached to the opposite side of m_2. Both masses are pulled along the table with the tension in the second rope equal to T_2. Let T_1 denote the tension in the first rope connecting the two masses. Which of the following statements is true?

☐ $T_1 = T_2$

☐ $T_1 > T_2$

☐ $T_1 < T_2$

☐ We need to know the relative values of m_1 and m_2 to answer this question.

Problem 5 (1.25 points)

The linear density of a long thin rod, of length L, decreases from a value of d at the left end to zero at the right end. How far from the left end is the rod's center-of-mass located?

☐ $L/5$

☐ $L/3$

☐ $(2/3)\,L$

☐ $(4/5)\,L$

Problem 6 (1.25 points)

A sphere rolling on a horizontal flat surface slows down because of

☐ the friction force.

☐ the deformation of the surface.

☐ the ball and the surface are essentially rigid.

☐ the gravitational force.

Problem 7 (1.25 points)

Three balls start at the same vertical position but follow different frictionless paths as they descent from a height h. Which of the following statements is true?

- ☐ The balls all reach the lower level at the same time.
- ☐ The balls all reach the lower level with the same speed but at possibly different times.
- ☐ The ball that takes the longer path reaches the bottom with the lowest velocity.
- ☐ The balls all reach the lower level with the same speed and at the same time.

Problem 8 (1.25 points)

Suppose you are holding a bicycle wheel by a handle connected to the axle in front of you. The axle points horizontally away from you and the wheel is spinning clockwise from your perspective. Now try to tilt the axle to your left (center of mass moves leftward). The wheel will swerve

- ☐ upward.
- ☐ downward.
- ☐ to your left.
- ☐ to your right.

Problem 9 (1.25 points)

An ideal gas undergoing a "free expansion"

- ☐ does positive work.
- ☐ increases its internal energy.
- ☐ decreases its internal energy.
- ☐ does not change its internal energy.

Problem 10 (1.25 points)

The coefficient of performance of a Carnot engine operated as a heat pump is

☐ $1 - T_L/T_H$

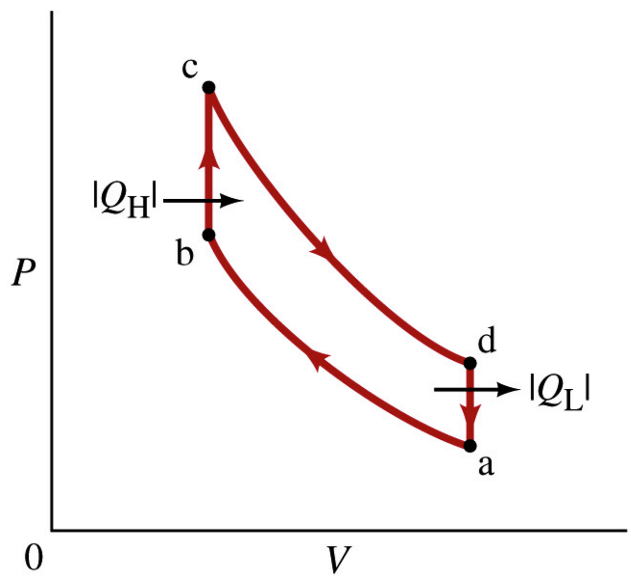
☐ $(1 - T_L/T_H)^{-1}$

☐ $(T_H/T_L - 1)^{-1}$

☐ $T_H/T_L - 1$

Problem 11 (12.5 points)

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 Figure below. 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 the gas is an ideal monatomic gas.



(a) Assuming there are n moles of gas in system, what are the heats $|Q_H|$ and $|Q_L|$? Express your answer in terms of n, R, T_a, T_b, T_c, and T_d.

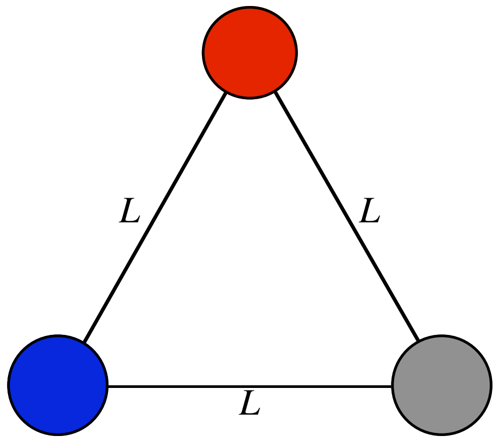
(b) What is the efficiency of the Otto cycle? Express your answer in terms of T_a, T_b, T_c, and T_d.

(c) Express the efficiency of the Otto cycle in terms of just the compression ratio V_a/V_b and γ. Hint: use the fact that during an adiabatic process PV^γ = constant.

(d) How does the efficiency change when we replace the monatomic gas with a diatomic gas?

Problem 12 (12.5 points)

Three bodies of identical mass M form the vertices of an equilateral triangle of side L (see Figure) and rotate in circular orbits around the center of the triangle. The system is held together by their mutual gravitation.



(a) Using a diagram, indicate the direction of the net force acting on each body.

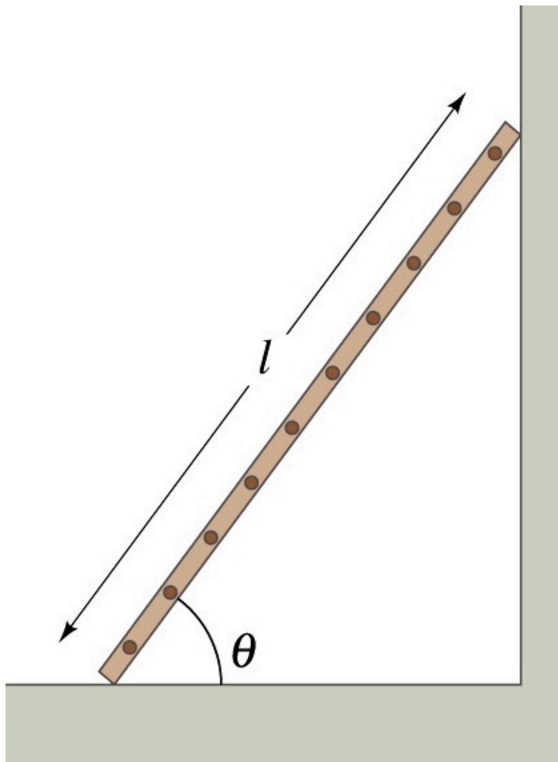
(b) What is the magnitude of the net force acting on each body?

(c) What is the speed of each body?

Express all your answers in terms of M and L.

Problem 13 (12.5 points)

A uniform ladder of mass m and length l leans at an angle θ against a frictionless wall (see Figure). The coefficient of static friction between the ladder and the ground is μ_s.



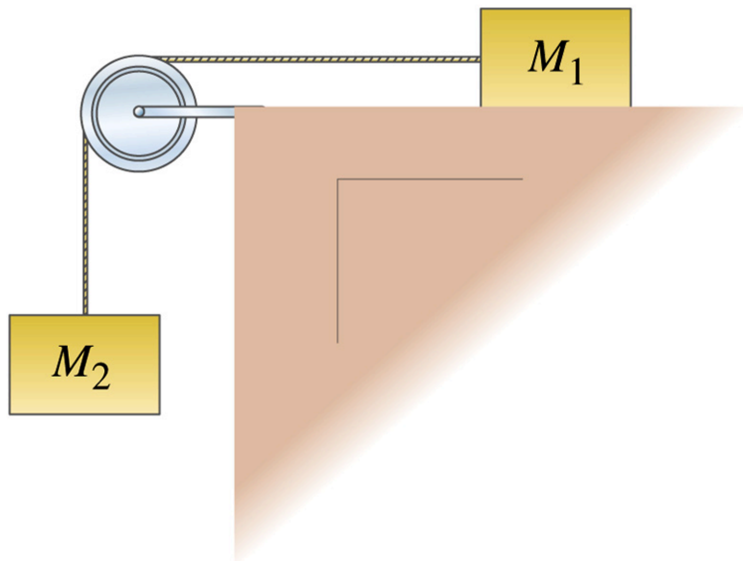
(a) Draw a free-body diagram of the ladder and include ALL the forces that act on it.

(b) What is the magnitude of the force exerted by the wall on the ladder? Express your answer in terms of m, l, μ_s and θ.

(c) What is the minimum angle θ at which the ladder will not slip? Express your answer in terms of m, l, and μ_s.

Problem 14 (12.5 points)

Consider the system shown in the Figure below. The two masses M_1 and M_2 are connected by a cord passing over a pulley of radius R_0 and moment of inertia I. Mass M_1 slides over a frictionless surface and mass M_2 hangs freely.



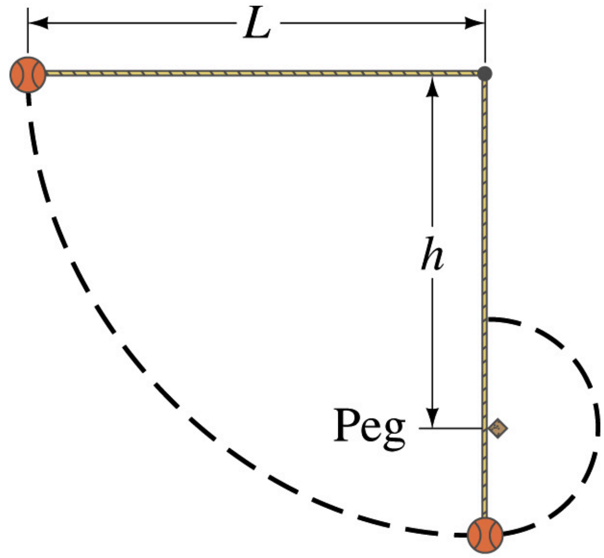
(a) What is the angular momentum of the system about the pulley axis as function of the velocity v of mass M_1 and M_2?

(b) What is the acceleration of the system?

Express your answers in terms of v, M_1, M_2, R_0, and I.

Problem 15 (12.5 points)

A ball of mass M is attached to a horizontal cord of length L whose other end is fixed, as shown in the Figure below. A peg is located a distance h directly below the point of attachment of the cord.



(a) If the ball is released from rest, what will be its speed at the lowest point of its path?

(b) What is the tension in the cord when the ball is at the lowest point of its path?

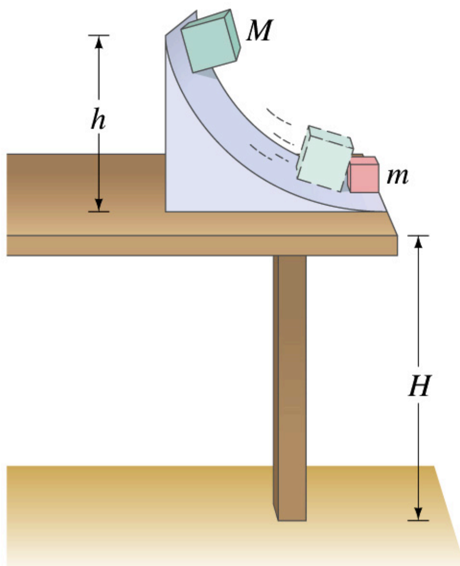
(c) What will be the speed of the ball when it reaches the top of its circular path about the peg?

(d) What will be the tension in the cord when the ball reaches the top of its circular path about the peg?

Express all your answers in terms of M, L, and h.

Problem 16 (12.5 points)

In a physics lab, a small cube of mass M slides down a frictionless incline of height h, as shown in the Figure below. The cube collides elastically at the bottom of the incline with a smaller cube of mass $m = M/2$.



(a) What is the speed of the larger cube after the collision?

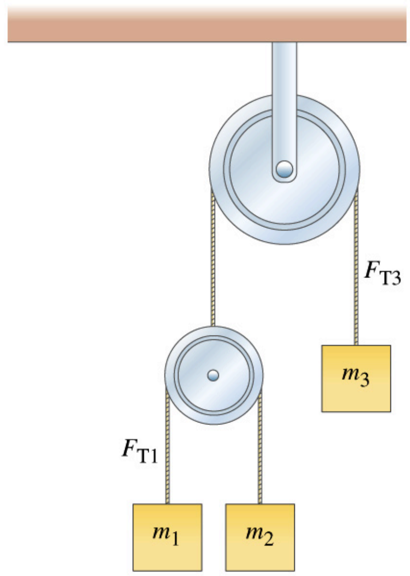
(b) What is the speed of smaller cube after the collision?

(c) After leaving the bottom of the incline, the two cubes will hit the ground. If the vertical distance between the bottom of the incline and the ground is H, what will be the horizontal distance between the positions where the two cubes hit the ground?

Express your answers in terms of M, H, and h.

Problem 17 (12.5 points)

The double Atwood machine, shown in the Figure below, has frictionless and massless pulleys and cords.



(a) What is the magnitude of the acceleration of mass m_3?

(b) What is the magnitude of the acceleration of mass m_2?

(c) What is the magnitude of the acceleration of mass m_1?

(d) What is the magnitude of the tension F_{T3}?

(e) What is the magnitude of the tension F_{T1}?

Express all your answers in terms of m_1, m_2, and m_3.