AAPT | UNITED STATES PHYSICS TEAM
AIP | 2003

Preliminary Exam
Open Response Questions

4 Questions, 60 minutes

INSTRUCTIONS
DO NOT OPEN THIS TEST UNTIL YOU ARE TOLD TO BEGIN

- Show all your work. Partial credit will be given.
- Start each question on a new sheet of paper. Be sure to put your name in the upper right-hand corner of each page, along with the question number and the page number/total pages for this problem. For example,

  Doe, Jamie
  Q1 – 1/3
- A hand-held calculator may be used. Its memory must be cleared of data and programs. You may use only the basic functions found on a simple scientific calculator. Calculators may not be shared. You may not use any tables, books, or collections of formulas.
- Each of the four questions is worth 25 points. The questions are not necessarily of the same difficulty.
- Good luck!

Possibly Useful Information

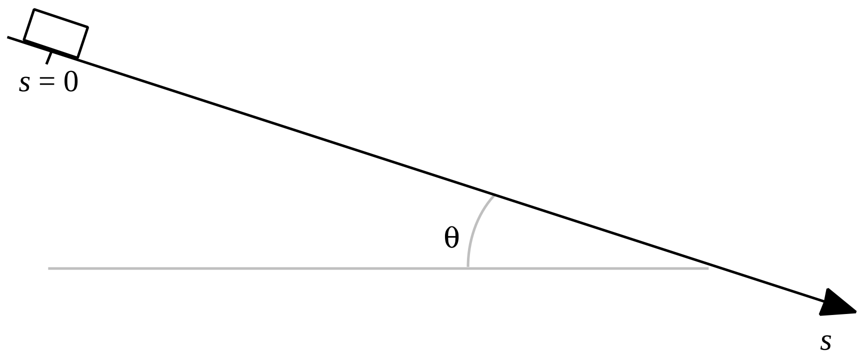
Gravitational field at the Earth's surface	$g = 9.8\ \text{N/kg}$
Newton's gravitational constant	$G = 6.67\times10^{-11}\ \text{N m}^2/\text{kg}^2$
Binomial expansion	$(1+x)^n \approx 1 + nx$ for $\lvert x\rvert << 1$

Moment of Inertia about Center of Mass – Uniform Object
(will not be provided on the second screening exam)

Disk	$\frac{1}{2} MR^2$
Sphere	$\frac{2}{5} MR^2$
Rod	$\frac{1}{12} ML^2$

Preliminary Exam

Four Open Response Questions



1. A small block of weight mg is initially at rest at the starting point $s = 0$ shown above. It slides down an increasingly rough incline at an angle of θ to the horizontal. The coefficient of kinetic friction is

$$\mu = \alpha s,$$

where α is a constant and s is measured down along the incline from the starting point $s = 0$. The magnitude of the work done by a non-constant force can be found from the area under a force versus displacement graph.

(9) a. Draw a diagram which shows all the forces acting on the block (free body diagram). Clearly label each force. Write down the magnitude of each force in terms of only the quantities given above.

(3) b. Sketch a graph of the magnitude of the frictional force versus displacement.

(3) c. Find the area under the graph and use it to determine the magnitude of the work done by the frictional force as a function of s.

(10) d. How far down the plane does the block slide before coming to rest?

2. Suppose that Galileo is in the Leaning Tower of Pisa. He throws a cannonball straight down from height H above the ground. The ball leaves his hands with an initial speed v_o. At the same instant, his friend throws a cannonball straight up from ground level with an initial speed of $2v_o$. When the cannonballs collide, they are traveling in the same direction and Galileo's cannonball is traveling with 7 times the speed of his friend's. Ignore air resistance.

(10) a. At what time does the collision occur? Express your answer in terms of H and v_o only.

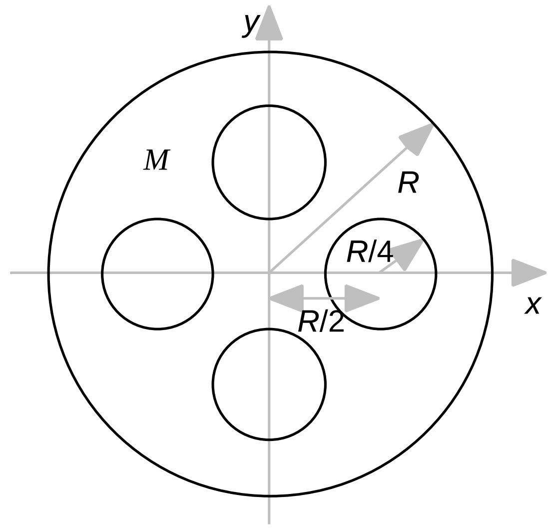
(15) b. At what height above the ground does the collision occur? Express your answer in terms of H only.

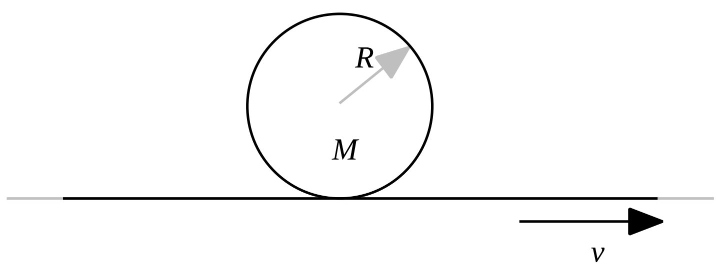
3. A disk of radius *R* is located in the *x*-*y* plane with its center at the origin. The disk has four disk-shaped holes of radius *R*/4 which are centered at (*R*/2, 0), (0, *R* /2), (-*R* /2, 0), and (0, -*R* /2), as shown in the accompanying diagram. The disk has mass *M* and uniform density. The moment of inertia (rotational inertia) of this disk about the *z* axis is CMR^2 where *C* is a constant.

(8) a. The disk starts from rest at the top of an incline of height *H* and rolls without slipping to the bottom. What is the speed of its center of mass at the bottom? Express your answer in terms of *H*, *C*, and fundamental constants.

(7) b. A nail of negligible mass is glued to the top of the disk at (0, *R*). The nail points in the *z* direction and is mounted in a frictionless pivot so that the disk hangs in the vertical plane. The disk is displaced by a small angle from its equilibrium position and released from rest. What is the period of oscillation of the disk in terms of *R*, *C*, and fundamental constants?

(10) c. Find the numerical value of the constant *C*.





4. A solid, uniform cylinder with mass *M* and radius *R* is initially at rest. It is gently placed onto a conveyor belt moving at constant velocity *v* as shown above. The cylinder's axis is perpendicular to the belt's velocity. The coefficients of static and kinetic friction are nonzero constants.   (Ignore other energy losses such as rolling resistance.)

(15) a) What is the final speed of the cylinder's center of mass?

(5)   b) If a cylinder with twice the radius and four times the mass had been used in place of the original cylinder, what would have been its final speed?

(5)   c) If a ring with the same mass and radius had been used in place of the cylinder, what would have been its final speed? Assume the ring has negligible thickness.