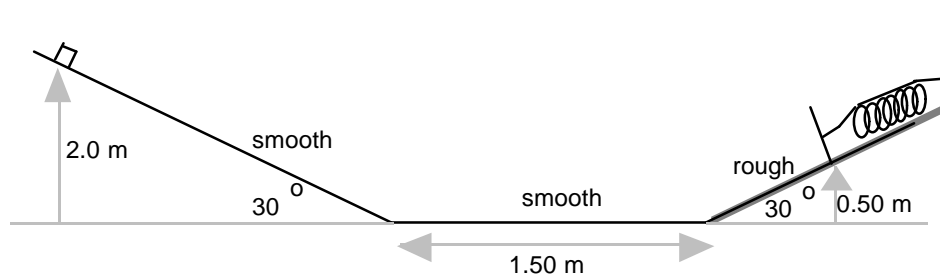


1999 Semi-Final Exam
Part A

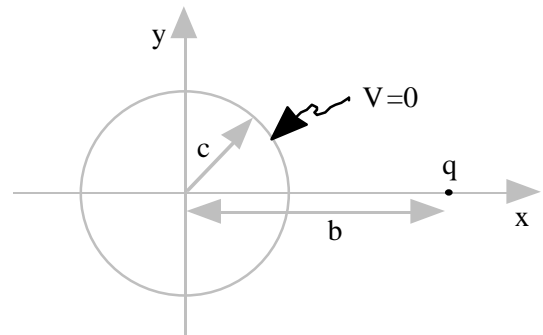


A1. A small crate of weight 5.0 N is released from rest at a height 2.0 m up a smooth inclined plane. The crate slides down the plane and across a smooth 1.50-m floor to a rough plane where a spring is located. The bottom of the spring is located at a height of 0.50 m. The spring constant is 20 N/m. The coefficient of kinetic friction between the rough plane and crate is $1/\sqrt{3}$ and the coefficient of static friction is $1/\sqrt{2}$.

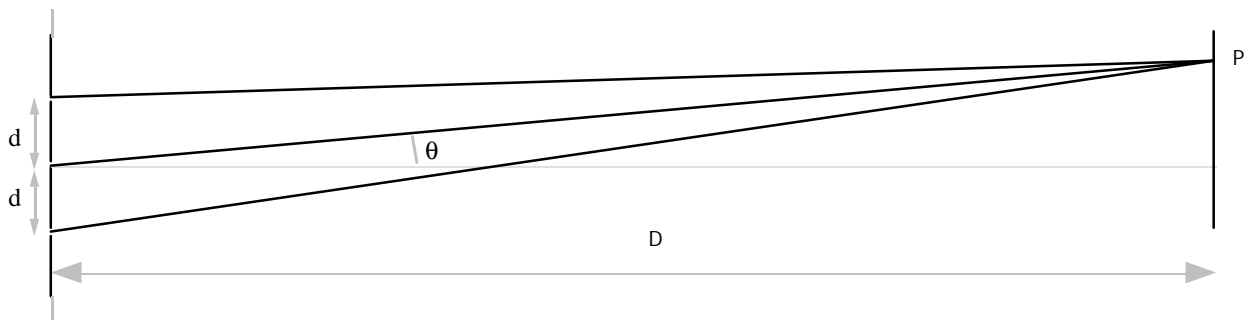
- a. (10) What is the maximum height the crate reaches on the right-hand inclined plane?
- b. (10) Where does the crate permanently come to rest? How many times does the crate travel up the rough plane?

(contributed by Mary Mogge)

A2. (20) Assume the electric potential to be zero at infinity. A charge q is located on the x-axis at $x = b$. One additional charge is placed elsewhere on the x-axis so that all points a distance c from the origin have zero total electric potential. What is that additional charge and where is it located? Express your answer in terms of q , c , and b .



(contributed by Mary Mogge)



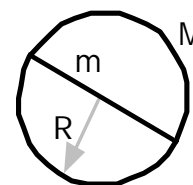
A3. Young's Triple Slit Coherent light of wavelength λ passes through three infinitesimally narrow slits with spacing d . It produces an interference pattern on screen a large distance $D \gg d$

away. (The figure above has been distorted to fit the page.) Assume the light through all three slits is in phase at the location of the slits. Further assume that a wave through any slit has amplitude A at any point P on the screen.

- a. (3) What is the phase shift between adjacent waves arriving at point P as a function of θ ?
- b. (3) Write a wave function for each of the three waves arriving at point P . Specify which wave is which by using the subscripts “t”, “m”, and “b” to denote the wave through the top, middle, and bottom slit, respectively. Define any quantities you introduce.
- c. (7) What is the amplitude of the resultant wave at point P ?
- d. (3) Write an expression for the intensity on the screen as a function of angle θ . Let I_0 be the intensity at $\theta = 0$.
- e. (4) What is the position of the first minimum, that is, what is the smallest angle at which the intensity is zero?

(contributed by Mary Mogge)

A4. A pendulum bob is constructed by taking a thin, uniform-density circular ring of mass M and radius R and affixing a straight, thin, uniform density rod of mass m and length $2R$ across its diameter as shown in the diagram. The pendulum hangs in a vertical plane from a frictionless pivot that can be attached to the ring at any point. The pivot allows the bob to swing either in the plane of the bob or in the plane perpendicular to the bob. Assume the angular amplitude is small.

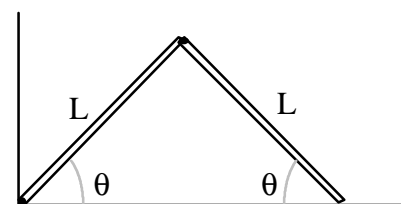


- a. (5) What swinging configurations give the maximum period?
- b. (5) What swinging configurations give the minimum period?
- c. (10) Find the ratio of the maximum period to the minimum period.

(contributed by Leaf Turner)

Part B

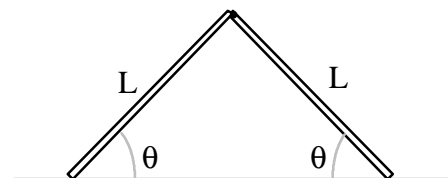
B1. Consider two uniform rods each of mass M and length L , hinged together to form an upside-down “vee” shape whose angle can vary. The rods are released from rest when their angle θ with the horizontal is 45° . All hinges are frictionless and have negligible mass.



Case 1

Case 1: The left end is also hinged at a fixed point at the bottom. The right-hand end of the configuration slides on the horizontal surface without friction.

Case 2: Both ends can slide frictionlessly along the surface.



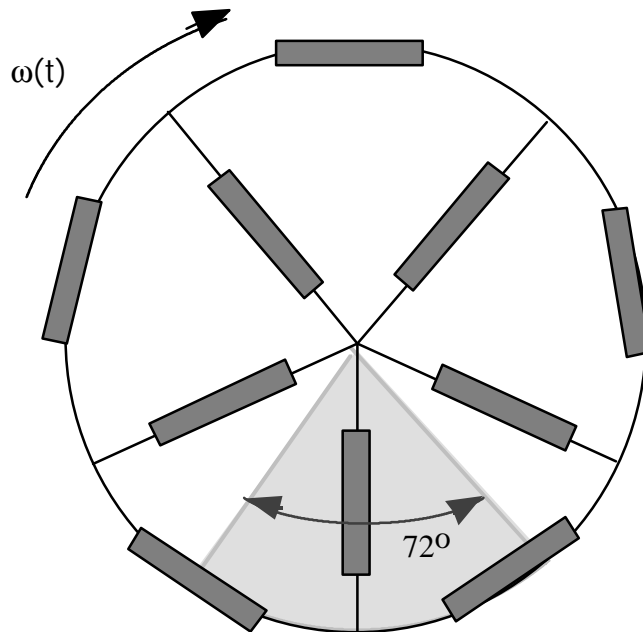
Case 2

(The sub-parts of this problem may be worked in any order.)

- (10) a. Find the upward force F_N that the horizontal surface exerts on the right hand side of the Case 1 rods just after release, when $\theta = 45^\circ$.
- (10) b. Repeat Part (a) for Case 2.
- (10) c. Find the angular velocity of the Case 1 rods as a function of θ . $0 < \theta < 45^\circ$
- (10) d. Repeat Part (c) for the configuration of Case 2.

(contributed by Leaf Turner)

B2. (40) Consider the following model of the effect of eddy currents. A rigid wheel, shown in the diagram to the right, consists of ten identical resistors each having resistance R . Five of the resistors are equally spaced around a circumference of radius r_o . The other five resistors form spokes of the wheel with an angle of $72^\circ = 2\pi/5$ radians between adjacent spokes. Assume the resistors have negligible thickness and follow the curvature of the circumference. The wheel rotates about a fixed axis through a circular-sector-wedge-shaped uniform magnetic field \mathbf{B} . The sides of the wedge have a length r_o and the angle of the wedge is 72° . The vertex of the wedge coincides with the axis of the rotating wheel. The wheel's moment of inertia about its center of mass is I_o . At time t , the wheel's angular velocity is $\omega(t)$.



A magnetic field \mathbf{B} , directed into the page, exists in the shaded region.

(15) a. Draw a diagram of the wheel which shows the direction and magnitude of the electric current in each of the ten resistors. Express all currents on the diagram as a multiple of the smallest current I . What is I ?

(5) b. Find the total power resistively dissipated by the wheel.

(10) c. Find the angular acceleration of wheel and indicate its direction.

(10) d. Now suppose there are nine equiangular $40^\circ = 2\pi/9$ radian sectors and eighteen identical resistors each having resistance R . Nine resistors are on the spokes and nine are on the circumference between each pair of spokes. The angle of the magnetic field wedge is also reduced to 40° . Repeat Part (a) for this eighteen resistor case.

(contributed by Leaf Turner)

The 1999 Semi-Final Examination questions were written by the coaches of the United States Physics Team. The coaches are: Academic Director, Dr. Mary Mogge – Professor of Physics at California State Polytechnic University, Pomona, CA; Senior Coach, Dr. Leaf Turner – Physicist in the Theoretical Division of Los Alamos National Laboratory, Los Alamos, NM; Dr. Warren Turner – Physics Teacher at St. Paul's School, Concord, NH. The coaches would also like to thank former academic director, Dr. Larry Kirkpatrick for his many helpful comments.