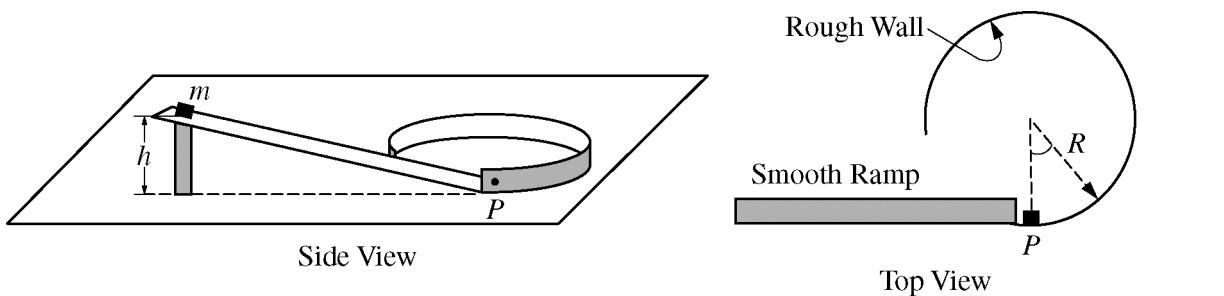


2014 AP® PHYSICS C: MECHANICS FREE-RESPONSE QUESTIONS



Mech. 2.

A small block of mass m starts from rest at the top of a frictionless ramp, which is at a height h above a horizontal tabletop, as shown in the side view above. The block slides down the smooth ramp and reaches point P with a speed v_0 . After the block reaches point P at the bottom of the ramp, it slides on the tabletop guided by a circular vertical wall with radius R , as shown in the top view. The tabletop has negligible friction, and the coefficient of kinetic friction between the block and the circular wall is μ .

- (a) Derive an expression for the height of the ramp h . Express your answer in terms of v_0 , m , and fundamental constants, as appropriate.

A short time after passing point P , the block is in contact with the wall and moves with a speed of v .

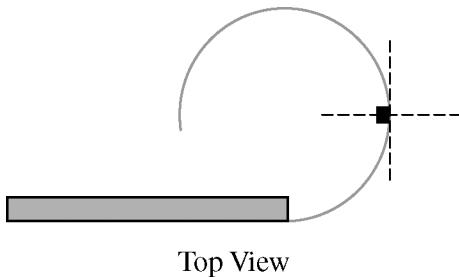
(b)

- i. Is the vertical component of the net force on the block upward, downward, or zero?

Upward Downward Zero

Justify your answer.

- ii. On the figure below, draw an arrow starting on the block to indicate the direction of the horizontal component of the net force on the moving block when it is at the position shown.



Top View

Justify your answer.

Express your answers to the following in terms of v_0 , v , m , R , μ , and fundamental constants, as appropriate.

- (c) Determine an expression for the magnitude of the normal force N exerted on the block by the circular wall as a function of v .
- (d) Derive an expression for the magnitude of the tangential acceleration of the block at the instant the block has attained a speed of v .
- (e) Derive an expression for $v(t)$, the speed of the block as a function of time t after passing point P on the track.

AP® PHYSICS C - MECHANICS
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Question 2

15 points total

**Distribution
of points**

(a) 3 points

For some correct application of conservation of energy 1 point

$$U_i = K_f$$

For substituting correct expressions for potential and kinetic energy 1 point

$$mgh_i = \frac{1}{2}mv_f^2$$

$$gh = \frac{1}{2}v_0^2$$

For a correct answer 1 point

$$h = \frac{v_0^2}{2g}$$

Alternate solution

Alternate points

For using correct kinematics and dynamics equations 1 point

$$v_f^2 = v_i^2 + 2a(s_f - s_i)$$

$$F = ma$$

For substituting correct variables 1 point

$$mg \sin \theta = ma, \sin \theta = h/L \text{ where } L \text{ is the length of the ramp, so } a = gh/L$$

$$v_0^2 = 0 + 2\left(\frac{gh}{L}\right)L$$

For a correct answer 1 point

$$h = \frac{v_0^2}{2g}$$

(b)

i. 2 points

For selecting “Zero” 1 point

For a correct explanation of why the vertical component of the net force is zero. 1 point

The explanation must be linked to the fact that there is no acceleration.

Example:

The block does not accelerate vertically, therefore the component of the net force in the vertical direction must be zero.

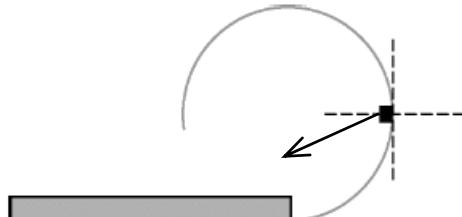
Note: No credit is earned if an incorrect choice is selected.

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Question 2 (continued)

**Distribution
of points**

- (b) (continued)
ii. 3 points



Top View

For drawing a single arrow pointing into the third quadrant

2 points

For correct justification of both components

1 point

Example:

The horizontal component of the net force must provide a centripetal force and also slow down the block. So it must point inward and against the direction of motion.

Note: If components are drawn, partial credit can be earned for the following.

For drawing an arrow pointing left (toward the center of the circle) with correct justification

1 point

For drawing an arrow pointing toward the bottom of the page with correct justification

1 point

A point is deducted for each incorrect vector drawn, with a maximum 2 point deduction

- (c) 1 point

The normal force exerted by the wall is the centripetal force.

$$F_N = F_C$$

For a correct answer

1 point

$$F_N = mv^2/R$$

Note: Since the statement of part (c) says to “determine” an expression, credit is given for just stating the correct answer.

- (d) 3 points

For correctly using the frictional force in an expression of Newton’s second law

1 point

$$-F_f = ma_t$$

$$-\mu F_N = ma_t$$

For substituting the normal force from part (c) into a correct expression

1 point

$$-\mu mv^2/R = ma_t$$

For an answer consistent with part (c)

1 point

$$a_t = -\mu v^2/R$$

Note: Since the question asks for the magnitude of the acceleration, the negative sign is not needed but students are not penalized for including it.

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Question 2 (continued)

**Distribution
of points**

(e) 3 points

For substituting dv/dt for a into the answer from part (d), or substituting dv/dt for a and the friction force for F_{net} into Newton's second law 1 point

$$\frac{dv}{dt} = -\frac{\mu v^2}{R} \quad \text{or} \quad m \frac{dv}{dt} = -F_f$$

For including the negative sign 1 point

Substituting for F_f produces the same relationship as the first equation above.

For separation of variables and using correct limits 1 point

$$\frac{1}{v^2} dv = -\frac{\mu}{R} dt$$

$$\int_{v_0}^v \frac{1}{v^2} dv = \int_0^t -\frac{\mu}{R} dt$$

Integrate the equation to solve for v .

$$\left[-\frac{1}{v} \right]_{v_0}^v = \left[-\frac{\mu t}{R} \right]_0^t$$

$$\frac{1}{v} - \frac{1}{v_0} = \frac{\mu t}{R}$$

$$v = \frac{Rv_0}{R + \mu v_0 t} \quad \text{or} \quad \frac{v_0}{1 + \mu v_0 t / R}$$