

2003 AP® PHYSICS C: MECHANICS FREE-RESPONSE QUESTIONS

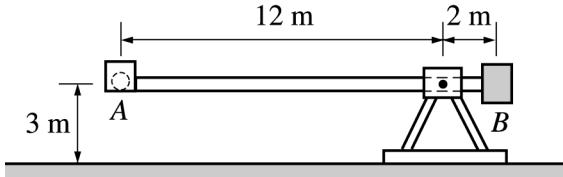


Figure 1

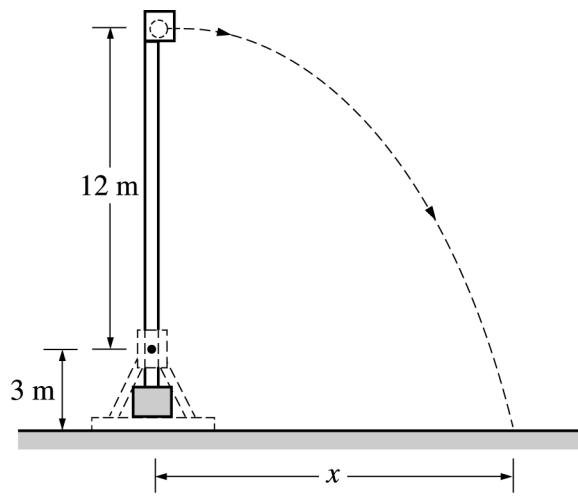


Figure 2

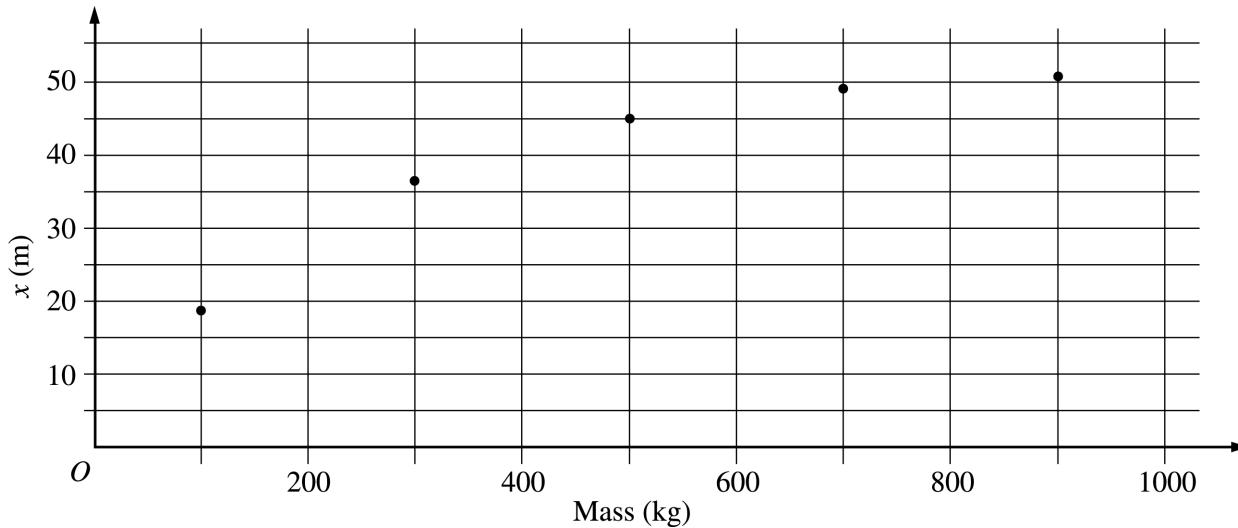
Mech. 3.

Some physics students build a catapult, as shown above. The supporting platform is fixed firmly to the ground. The projectile, of mass 10 kg, is placed in cup *A* at one end of the rotating arm. A counterweight bucket *B* that is to be loaded with various masses greater than 10 kg is located at the other end of the arm. The arm is released from the horizontal position, shown in Figure 1, and begins rotating. There is a mechanism (not shown) that stops the arm in the vertical position, allowing the projectile to be launched with a horizontal velocity as shown in Figure 2.

- (a) The students load five different masses in the counterweight bucket, release the catapult, and measure the resulting distance *x* traveled by the 10 kg projectile, recording the following data.

Mass (kg)	100	300	500	700	900
<i>x</i> (m)	18	37	45	48	51

- i. The data are plotted on the axes below. Sketch a best-fit curve for these data points.



- ii. Using your best-fit curve, determine the distance *x* traveled by the projectile if 250 kg is placed in the counterweight bucket.

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- (b) The students assume that the mass of the rotating arm, the cup, and the counterweight bucket can be neglected. With this assumption, they develop a theoretical model for x as a function of the counterweight mass using the relationship $x = v_x t$, where v_x is the horizontal velocity of the projectile as it leaves the cup and t is the time after launch.
- i. How many seconds after leaving the cup will the projectile strike the ground?
 - ii. Derive the equation that describes the gravitational potential energy of the system relative to the ground when in the position shown in Figure 1, assuming the mass in the counterweight bucket is M .
 - iii. Derive the equation for the velocity of the projectile as it leaves the cup, as shown in Figure 2.
- (c)
- i. Complete the theoretical model by writing the relationship for x as a function of the counterweight mass using the results from (b)i and (b)iii.
 - ii. Compare the experimental and theoretical values of x for a counterweight bucket mass of 300 kg. Offer a reason for any difference.

END OF SECTION II, MECHANICS

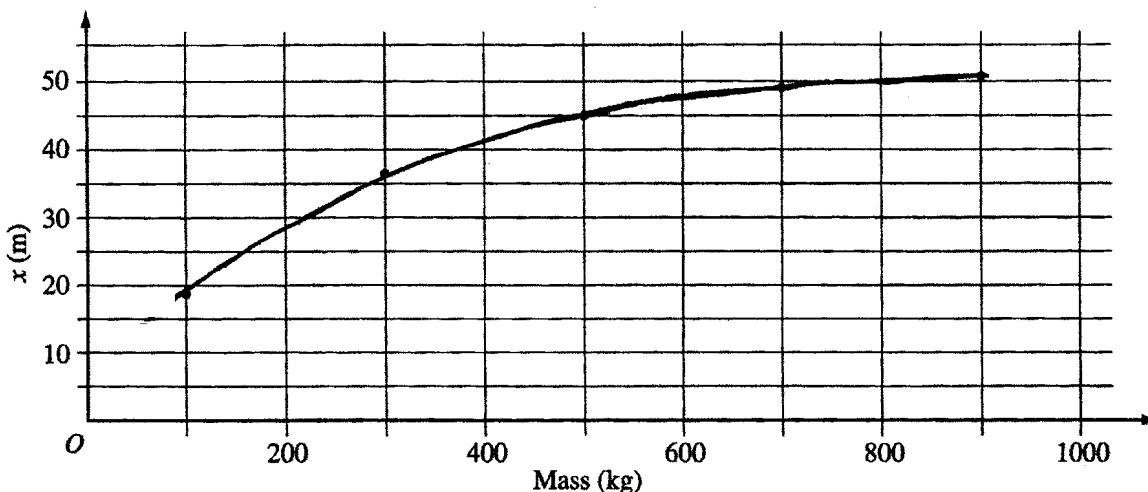
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Question 3

15 points total

**Distribution
of points**

(a) 2 points



i. (1 point)

For a smooth concave downward curve in the region between the points, that passes near all the points.

1 point

ii. (1 point)

For a reasonable interpolation of the value of x when $M = 250$ kg, based on the graph that was drawn

1 point

For example, using the above graph $x \approx 33$ m

(b) 10 points

i. (2 points)

For using correct kinematic equation(s)

1 point

For example, the equation $y = (1/2)gt^2$ can be used to directly solve for the time

$$t = \sqrt{2y/g} = \sqrt{2(15\text{ m})/9.8\text{ m/s}^2}$$

For the correct answer

1 point

$$t = 1.75\text{ s} \quad (\text{or } 1.73\text{ s using } g = 10\text{ m/s}^2)$$

ii. (3 points)

For determining the potential energy of both the load in the counterweight bucket and the projectile

1 point

For the correct value of the potential energy of the bucket load

1 point

$$U_b = mgh = M(9.8)3 = 29.4M$$

For the correct value of the potential energy of the projectile

1 point

$$U_p = mgh = (10)(9.8)3 = 294$$

$$U_{init} = U_b + U_p = 29.4M + 294 \quad (\text{or } 30M + 300 \text{ using } g = 10\text{ m/s}^2)$$

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Question 3 (cont'd.)

(b) (continued)

iii. (5 points)

For a valid statement or equation indicating conservation of energy

**Distribution
of points**

1 point

$$U_{\text{init}} = U_{\text{final}} + K$$

For the correct final potential energy of the bucket load

1 point

For the correct final potential energy of the projectile

1 point

$$U_{\text{final}} = M(9.8)(1) + (10)(9.8)(15) = 9.8M + 1470$$

For having terms for the final kinetic energy of both the bucket load and the projectile

1 point

$$K_p = (1/2)10v_x^2 \text{ and } K_b = (1/2)Mv_b^2 \text{ OR } K_p = (1/2)(1440)\omega^2 \text{ and } K_b = (1/2)(4M)\omega^2$$

For using one of the following relationships to write all expressions in terms of v_x

1 point

$$v_b = (1/6)v_x \text{ OR } \omega = v_x/12$$

Substituting into the conservation of energy equation above and solving for v_x :

$$29.4M + 294 = 9.8M + 1470 + 5v_x^2 + (M/72)v_x^2$$

$$v_x = \sqrt{(19.6M - 1176)/(5 + (M/72))}$$

$$\text{(or } \sqrt{(20M - 1200)/(5 + (M/72))} \text{ using } g = 10 \text{ m/s}^2 \text{)}$$

Alternate solution

Alternate points

For an application of the equation for torque

1 point

$$\sum \tau = I\alpha = I(d\omega/dt)$$

For determining the torque applied by the bucket load

1 point

$$\tau_b = Fr = Mgr \sin \theta = 19.6M \sin \theta$$

For determining the torque applied by the projectile

1 point

$$\tau_p = 10(9.8) \sin \theta (12) = 2940 \sin \theta$$

For determining the total rotational inertia

1 point

$$I = 10(12)^2 + M(2)^2 = 1440 + 4M$$

For using the proper relationship to change from a rotational to a linear solution

1 point

$$\omega = (1/12)v_x$$

Substituting:

1 point

$$19.6M \sin \theta - 2940 \sin \theta = (1/12)(1440 + 4M)(dv_x/dt)$$

This equation can then be solved to obtain the expression for v_x

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Question 3 (cont'd.)

**Distribution
of points**

(c) 3 points

i. (1 point)

Using the given relationship for x

$$x = v_x t$$

For substituting the answers answer from parts (b) iii. and (b) i.

1 point

$$x = 1.75 \sqrt{(19.6M - 1176)/(5 + (M/72))}$$

(or $1.73 \sqrt{(20M - 1200)/(5 + (M/72))}$ using $g = 10 \text{ m/s}^2$)

ii. (2 points)

For using the equation from part (c) i. to predict x_{theor}

1 point

$$x_{\text{theo}} = 1.75 \sqrt{(19.6(300) - 1176)/(5 + (300/72))} = 39.7 \text{ m} \quad (\text{or } 40.0 \text{ m using } g = 10 \text{ m/s}^2)$$

For a reasonable explanation for the fact that $x_{\text{exp}} < x_{\text{theor}}$

1 point

Examples: friction at the pivot, air resistance, neglected masses are not really negligible

One point was awarded if no equation is available from (c) i. to make a theoretical prediction

but the student developed the reasonable explanation for $x_{\text{exp}} < x_{\text{theor}}$

One point was awarded for a reasonable explanation if evaluation of equation in part (c)

resulted in $x_{\text{exp}} > x_{\text{theor}}$.