AP® Physics C: Mechanics
2003 Sample Student Responses

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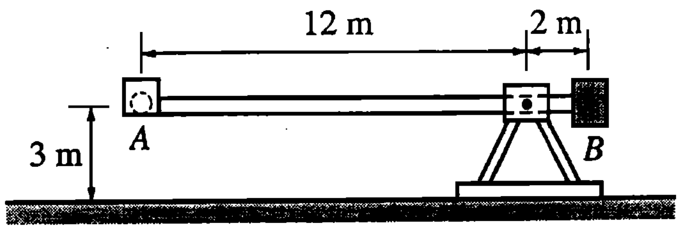


Figure 1

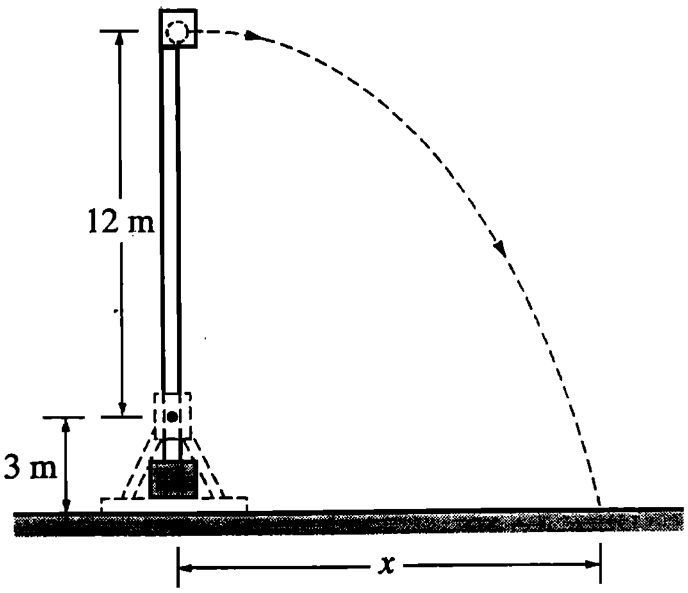


Figure 2

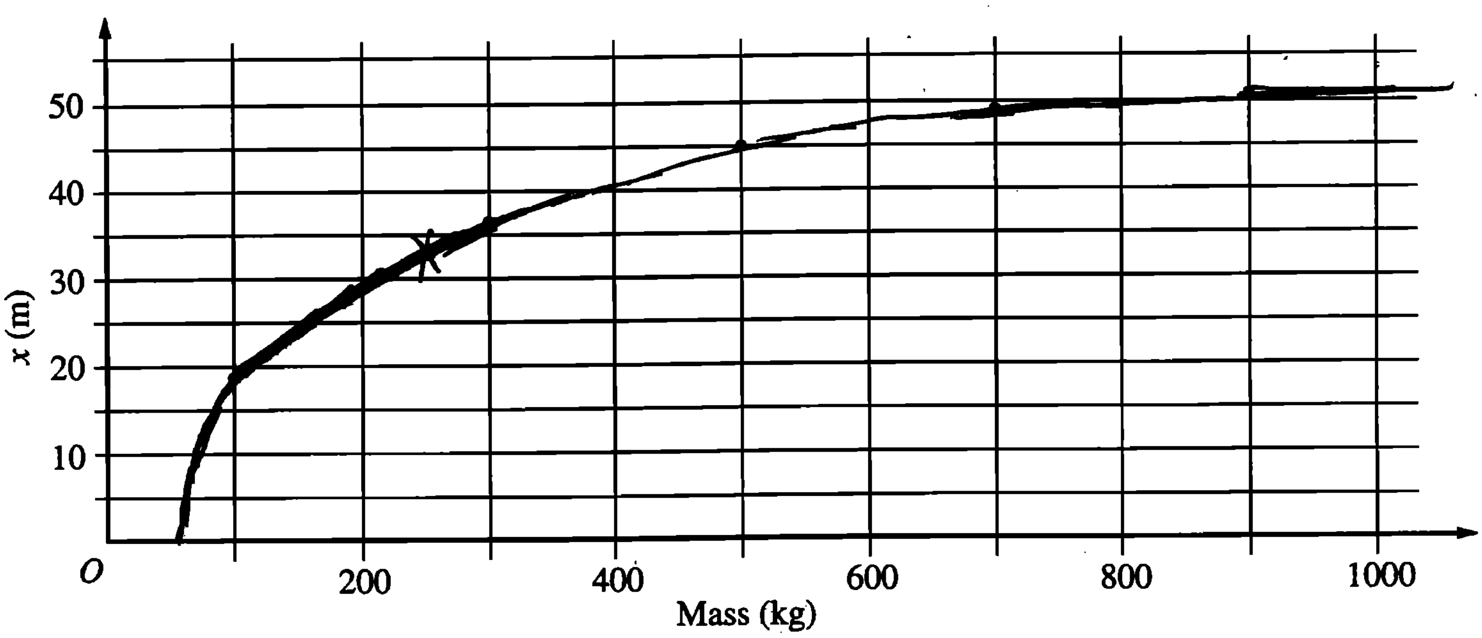
Mech. 3.

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
x (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.

From the curve, the distance X(250) is about 33m.
(marked by X)

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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?

Since the projectile is in free-fall, the equation $y_f - y_i = v_{yi}t - \frac{1}{2}gt^2$ holds; here, $y_f - y_i = 15m$ and $v_{yi} = 0$, so $15 = -\frac{1}{2}gt^2 = -\frac{1}{2}(-9.8\,m/s^2)t^2 = 4.9t^2 \Rightarrow t = 1.75\ s$ (we are only interested in the positive, post-launch value).

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.

The only masses are the projectile and the counterweight; U_g (projectile) $= mgh = (10kg)(9.8\,m/s^2)(3m) = 294\ J$, and U_g (counterweight) $= mgh = M(9.8\,m/s^2)(3m) = 29.4\ M$, so that the total gravitational potential energy, in joules, is

$294 + 29.4\ M$.

iii. Derive the equation for the velocity of the projectile as it leaves the cup, as shown in Figure 2.

In figure 2, U_g (projectile) $= mgh = (10kg)(9.8\,m/s^2)(15m) = 1470\ J$, and U_g (counterweight) $= mgh = M(1.8\,m/s^2)(1m) = 9.8M$. By conservation of energy (since only gravity, a conservative force, acts),

$K_i + U_{gi} = K_f + U_{gf}$, where K is the kinetic energy of the system. Let v be the final velocity of the ball; then the final velocity of the weight is $\frac{v}{6}$; since $K_i = 0$,

$U_{gi} = K_f + U_{gf} \Rightarrow 294 + 29.4M = \frac{1}{2}(10kg)v^2 + \frac{1}{2}M\left(\frac{v}{6}\right)^2 + 1470 + 9.8M$

$\Rightarrow v^2\left(5 + \frac{M}{72}\right) = 19.6M - 1176$

$\Rightarrow v = \sqrt{\frac{19.6M - 1176}{5 + M/72}}$.

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(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.

In flight, the ~~ball~~ projectile's x-direction or horizontal velocity is constant, so

$$x = v_0 t \Rightarrow x = 1.75\sqrt{\frac{19.6M - 1176}{5 + M/72}}.$$

ii. Compare the experimental and theoretical values of x for a counterweight bucket mass of 300 kg. Offer a reason for any difference.

In theory, $x(300) = 1.75\sqrt{\frac{19.6 \cdot 300 - 1176}{5 + 300/72}}$

$= 39.6$ m.

The experimental value of 37 m may be lower because some energy was lost to friction in the structural components.

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K4

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k g S

$\frac{1}{2}(2M)(g\frac{H}{2}) + 0 + \frac{1}{2}kD^2$

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STOP

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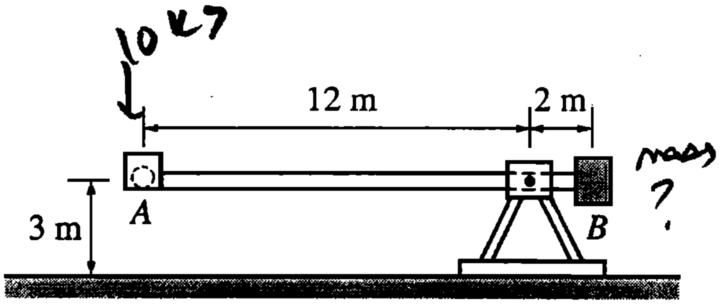

Figure 1

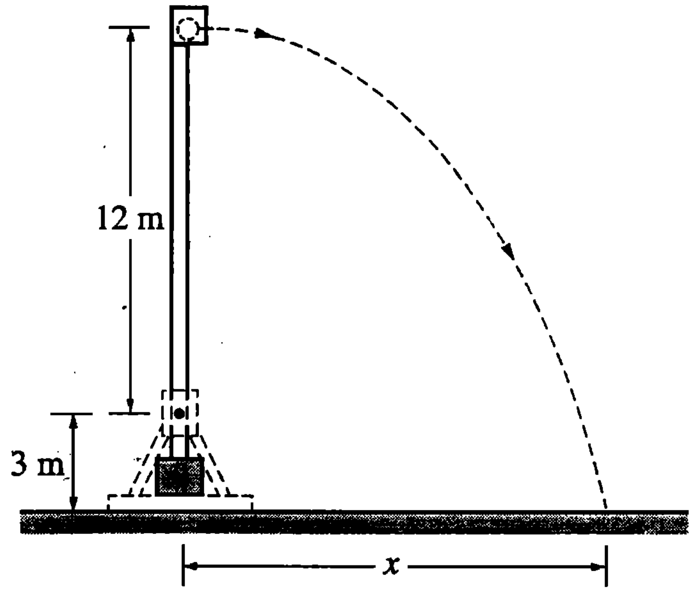

Figure 2

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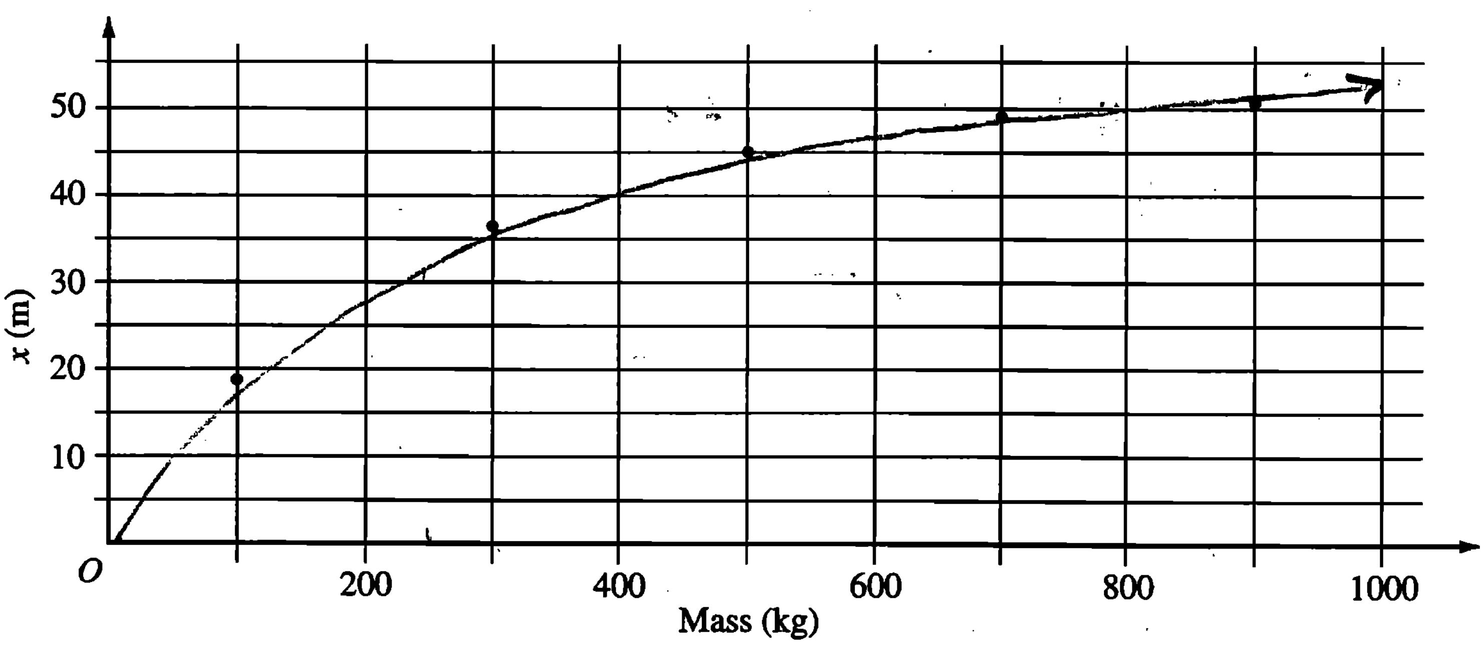
i. The data are plotted on the axes below. Sketch a best-fit curve for these data points.



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

32m

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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?

$V_y|_{t=0} = 0$ m/s

$V_y = V_y|_{t=0} - gt$

$Y = Y_0 + V_y|_{t=0} - \frac{1}{2}gt^2$

$0 = 15 + 0 - \frac{1}{2}(9.8)t^2$

$4.9t^2 = 15$

$t^2 = 3.06$

$t = 1.75$ s

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.

$U = m_A g h + Mgh$

$U = 10 \cdot 9.8 \cdot 3 + M \cdot 9.8 \cdot 3$

$U = 294 + 29.4M$

iii. Derive the equation for the velocity of the projectile as it leaves the cup, as shown in Figure 2.

$U_1 + K_1 = U_2 + K_2$

$294 + 29.4M + 0 = m_A g h + \frac{1}{2} m_A v^2$

$294 + 29.4M = 1470 + \frac{1}{2} \cdot 10 v^2$

$29.4M - 1176 = 5v^2$

$v^2 = \frac{29.4M - 1176}{5}$

$v = \sqrt{\frac{29.4M - 1176}{5}}$

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(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.

$$x = v_x t$$

$$x = \sqrt{\frac{29.4M - 1176}{5}}\, t$$

$$x = 1.75\sqrt{\frac{29.4M - 1176}{5}}$$

ii. Compare the experimental and theoretical values of x for a counterweight bucket mass of 300 kg. Offer a reason for any difference.

$$x = 1.75\sqrt{\frac{29.4(300) - 1176}{5}} = 68.4\text{m}$$

X at 300 kg in experiment is 37m

In the theoretical model, the students are neglecting the work done on M_A by non-conservative forces like friction and air-resistance. Thus, the theoretical answer is much larger than the experimental answer.

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