c 1 .A space station consists of three modules arranged in an equilateral triangle, connected by struts of length ***L*** & negligible mass. Two modules have mass ***m***, the other **2*m***. Find the center of mass.

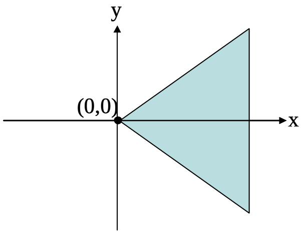
(a) (0, 0.53***L***), (b) (0, 0.33***L***), (c) (0, 0.43***L***), (d) (0, 0.23***L***)

一太空站由三個模組，以質量可忽略，長度為 ***L*** 的支柱，連成一等邊三角形。兩模組的質量為 ***m***，另一個為 **2*m*** 。求質心位置。

c 2. A supersonic aircraft wing is an isosceles triangle of length ***L***, width ***w***, and negligible thickness. It has mass ***M***, distributed uniformly [see Figure]. Where's its center of mass?

(a) (0, ***L***/3), (b) (***L***/3,0), (c) (2***L***/3,0), (d) (0,0)

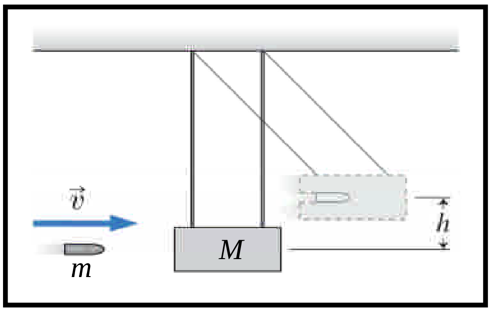
一架超音速飛機的翼是一個等腰三角形，長 ***L*** ，寬 ***w*** ，厚度則可忽略(如下圖所示)。 它的質量 ***M*** 分佈均勻。求質心位置?



c 3. A bullet of mass ***m*** strikes and embeds into a wooden block of mass ***M*** [see Figure]. The block rises a height of ***h*** above its initial position. Find a relation of the bullet's original velocity ***v*** and the height ***h***.

(a) $\frac{M}{m}\sqrt{2gh}$, (b) $\frac{M+m}{m}\sqrt{gh}$, (c) $\frac{M+m}{m}\sqrt{2gh}$, (d) $\frac{M}{m}\sqrt{gh}$

如下圖所示，一質量為 ***m*** 的子彈擊中並嵌入一質量為 ***M*** 的木塊。木塊上擺到高度為 *h*。求子彈初速率 *v* 與高度 *h* 的關係式。(15%)



b 4. A Styrofoam chest at rest on frictionless ice is loaded with sand to give it a mass of 6.4 kg. A 160-g puck strikes & gets embedded in the chest, which moves off at 1.2 m/s. What is the pucks speed?

(a) 59 m/s, (b) 49 m/s, (c) 39 m/s, (d) 29 m/s

一個保麗龍盒子放在無摩擦的冰上，盒內的砂子使它的質量達到 6.4 kg。 一枚 160-g 的球餅撞來，嵌在盒內，並使它以 1.2 m/s 移動, 球餅的速率為何？。

a 5. A firefighter directs a stream of water to break the window of a burning building. The hose delivers water at a rate of 45 kg/s, hitting the window horizontally at 32 m/s. What horizontal force does the water exert on the window?

(a) 1400 N, (b) 1300 N, (c) 1200 N, (d) 1100 N

一名消防員想用水柱把一幢着火房子的窗門打破。水管的出水速率為 45 kg/s ，水則沿水平方向以 32 m/s 打到窗門。水在水平方向施於窗門的力為何？

b 6. A 140-kg satellite collides at an altitude, where g = 8.7 m/s^2. The collision lasts 120 ms. Find the satellite's impulse.

(a) 156 N·s, (b) 146 N·s, (c) 136 N·s, (d) 126 N·s

140-kg 的人造衛星撞擊到一個高地，它的重力加速度為 8.7 m/s^2，撞擊時間延長了 120 ms。求人造衛星的衝量。

d 7. A150-g baseball is thrown at 60 km/h. It explodes into two pieces in flight, with a 38-g piece counting straight ahead at 85 km/h. How much energy do the two pieces gain in the explosion?

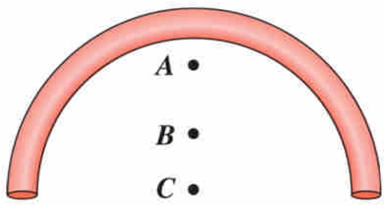
(a) 1.51 J, (b) 1.41 J, (c) 1.31 J, (d) 1.21 J

一粒 150-g 的棒球以 60 km/h 的速度被擊出，飛行中它破裂成兩碎片，其中一片質量為 38 g 並以 85 km/h 的速度繼續直線前進。求兩碎片在破裂時所得到的能量。

a 8. A thick wire is bent into a semicircle. Which of the points is the CM?

(a) A, (b) B, (c) C,

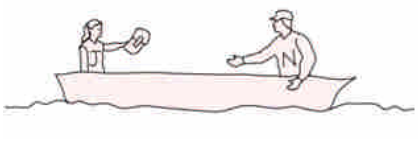
一條粗纜被扳成半圓形。那一點是質心？

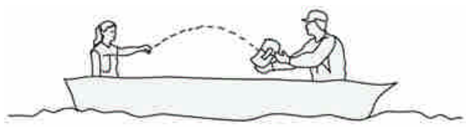


c 9. Jess (mass 53 kg) & Nick (mass 72 kg) sit in a 26-kg kayak at rest on frictionless water. Jess toss a 17-kg pack, giving it a horizontal speed of 3.1 m/s relative to the water. What's the kayak's speed while the pack is in the air & after Nick catches it?

(a) –0.55 m/s, (b) 0.45 m/s, (c) –0.35m/s, (d) 0.25 m/s

潔西 (質量 53 kg) 和尼克 (質量 72 kg) 坐在一條停在無摩擦的水上， 26-kg 的獨木舟上。潔西拋出一個 17-kg 的背包，給了它相對於水 3.1 m/s 的水平速率。當背包在空中，和在尼克接住它之後，獨木舟的速率為何？





d 10. Two skaters toss a basketball back & forth on frictionless ice.
Which of the following does not change:
(a) momentum of individual skater,
(b) momentum of basketball,
(c) momentum of the system consisting of one skater & the basketball,
(d) momentum of the system consisting of both skaters & the basketball
兩名溜冰的人在無磨擦的冰上把一個籃球互相投擲。下面那一項不會改變：
(a)個別溜冰人的動量; (b)籃球的動量; (c)包含一個溜冰人和籃球的系統的動量; (d)包含兩個溜冰人和籃球的系統的動量

d 11. Which of the following qualifies as an inelastic collision
(a) a basketball rebounds off the backboard,
(b) two magnets approach, their north poles facing; they repel,
(c) a tennis rackets against balls,
(d) a truck crushed a parked car & the two slide off together
以下何者為非彈性碰撞？
(a) 一個籃球從籃板反彈出來;
(b) 兩個磁鐵的北極互相靠近，它們互相排斥;
(c) 一個網球拍碰到網球;
(d) 一輛貨車把一輛停好的汽車壓扁，然後兩者一齊滑走。

d 12. A 4.8×10^3-kg elephant, is standing near one end of a 15×10^3-kg railcar, which is at rest on a frictionless horizontal track. The elephant walks 19 m toward the other end of the car. How far does the car move?
(a) 5.6 m, (b) –5.6 m/s, (c) 4.6 m, (d) –4.6 m
一頭 4.8×10^3-kg 的大象站在一輛 15×10^3-kg 的火車廂的一端。火車廂停在一條無摩擦的水平鐵軌上，大象朝車廂的另一端走 19 m 。車廂移動多遠？

a 13. A croquet ball strikes a stationary one of equal mass. The collision is elastic & the incident ball goes off 30° to its original direction. In what direction does the other ball move?
(a) east of north at 60°, (b) west of north at 60°, (c) east of north at 30°, (d) west of north at 30°
一個槌球撞上另一個和它質量相同的靜止槌球。碰撞是彈性的，而且入射球

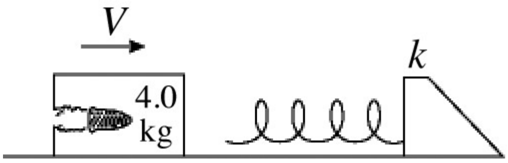
後來的方向與原來的成 30° 。另一球往那個方向走？
(a)東北 60°. (b)西北 60°. (c)東北 30°. (d)西北 30°

a 14. Moderator slows neutrons to induce fission. A common moderator is heavy water (D_2O). Find the fraction of a neutron's kinetic energy that's transferred to an initially stationary D in a head-on elastic collision.
(a) 89%, (b) 69%, (c) 49%, (d) 29%
減速子使中子慢下來以誘發核分裂。常用的減速子是重水(D_2O)。求在一迎頭彈性碰撞中，中子的動能有多少比例會轉移給一個本來是靜止的 D 。

a 15. A13.1-kg squid fires a burst of water, giving it average acceleration 19.6 m/s^2 over 100-ms. Assuming the squid starts from rest, Find its final speed.
(a) 1.96 m/s, (b) 1.86 m/s, (c) 1.76 m/s, (d) 1.66 m/s
一隻 13.1 kg 魷魚發出一陣墨水後，產生平均加速度為 19.6 m/s，經過 100 ms。假設魷魚從休息開始，求它的最終速度。

c 16. A small car has a head-on collision with a large truck. Which of the following statements concerning the magnitude of the average force due to the collision is correct?
(a) The truck experiences the greater average force.
(b) The small car experiences the greater average force.
(c) The small car and the truck experience the same average force.
(d) It is impossible to tell since the masses are not given.
一輛小型車與一輛大型卡車正面碰撞。 關於碰撞造成的平均力量大小的以下那個陳述是正確的？
(a) 卡車經歷更大的平均力量。
(b) 小型車遇到更大的平均力量。
(c) 小型車和卡車的平均力量相同。
(d) 無法知道因為沒有提供質量。

a 17. An 8.0-g bullet is shot into a 4.0-kg block, at rest on a frictionless horizontal surface (see the figure). The bullet remains lodged in the block. The block moves into an ideal massless spring and compresses it by 8.7 cm. The spring constant of the spring is 2400 N/m. What is the initial velocity of the bullet?
(a) 1100 m/s. (b) 1200 m/s. (c) 900 m/s. (d) 1300 m/s.
將一個8.0克的子彈射入一個4.0公斤的木塊靜止在無摩擦的水平面上(見圖)。子彈仍然在木塊中。 該塊移動到一個理想的無質量的彈性彈簧並壓縮8.7公分。 彈簧常數為2400N/m。 子彈的初始速度是多少？



d 18. A 60-kg skater at rest on frictionless ice, tosses 12-kg snowball with velocity $\vec{v} = 53.0\hat{i} + 14.0\hat{j}$ m/s, where the x- and y-axes are in the horizontal plane. Find the skater's subsequent velocity.

(a) $\vec{v} = 10.6\hat{i} + 2.8\hat{j}$ m/s. (b) $\vec{v} = -10.6\hat{i} + 2.8.0\hat{j}$ m/s. (c) $\vec{v} = 10.6\hat{i} - 2.8\hat{j}$ m/s. (d) $\vec{v} = -10.6\hat{i} - 2.8\hat{j}$ m/s.

靜止在無摩擦的冰上的 60 公斤滑冰運動員，以 x 和 y 軸處於水平面的速度 $\vec{v} = 53.0\hat{i} + 14.0\hat{j}$ m/s 扔出 12 公斤的雪球。 求滑冰者的後續速度。

c 19. A firecracker breaks up into several pieces, one of which has a mass of 200 g and flies off along the *x*-axis with a speed of 82.0 m/s. A second piece has a mass of 300 g and flies off along the *y*-axis with a speed of 45.0 m/s. What are the magnitude and direction of the total momentum of these two pieces?

(a) 361 kg·m/s at 56.3° from the *x*-axis.

(b) 93.5 kg·m/s at 28.8° from the *x*-axis.

(c) 21.2 kg·m/s at 39.5° from the *x*-axis.

(d) 361 kg·m/s at 0.983° from the *x*-axis.

爆竹分裂成幾塊，其中一塊質量為 200 克，沿 x 軸以速度為 82.0 m/s 飛行。 第二件具有 300 克的質量，並以 45.0 m/s 的速度沿 y 軸飛行。這兩件碎塊的總動量有多大？

(a) 離 x 軸 56.3°的 361 kg·m / s。

(b) 離 x 軸 28.8°的 93.5kg·m / s。

(c) 離 x 軸 39.5°的 21.2 kg·m / s。

(d) 離 x 軸 0.983°的 361kg·m / s。

a 20. A stationary 1.67-kg object is struck by a stick. The object experiences a horizontal force given by $F = at$ □ bt^2, where *t* is the time in milliseconds from the instant the stick first contacts the object. If a = 1500 N/ms and b = 20 N/(ms)^2, what is the speed of the object just after it comes away from the stick at t = 2.74 ms?

(a) 3.3 m/s. (b) 22 m/s. (c) 3.7 m/s. (d) 25 m/s

一個靜止的 1.67 公斤物體被一根棍子撞擊。 物體被施於一水平力 F = at □ bt^2，其中 t 是從桿最初瞬間接觸物體的計時(毫秒)。 如果 a = 1500 N /（ms），b = 20 N /(ms)^2，在 t = 2.74 ms 後，物體離開棒後的速度是多少？

b 21. During a collision with a wall, the velocity of a 0.200-kg ball changes from 20.0 m/s toward the wall to 12.0 m/s away from the wall. If the time the ball was in contact with the wall was 60.0 ms, what was the magnitude of the average force applied to the ball?

(a) 40.0 N. (b) 107 N. (c) 16.7 N. (d) 26.7 N

在與牆壁碰撞期間，0.200 公斤球的速度從 20.0 米/秒前往牆壁變化為離開牆壁的 12.0 米/秒。如果球與牆壁接觸的時間是 60.0 毫秒，施加到球的平均力的大小是多少？

d 22. In the figure, determine the character of the collision. The masses of the blocks, and the velocities before and after are given, and no other unbalanced forces act on these blocks. The collision is

(a) perfectly elastic.

(b) completely inelastic.

(c) characterized by an increase in kinetic energy.

(d) not possible because momentum is not conserved.

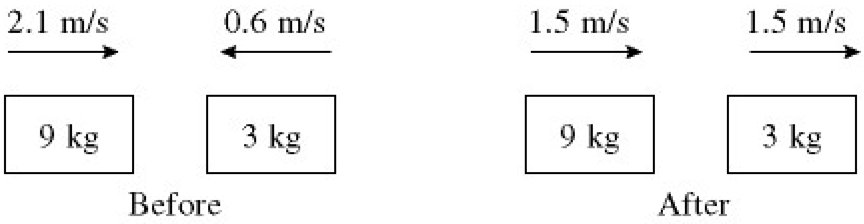
在下圖中，請確定碰撞的特徵。木塊質量和碰撞前後的速度如圖的提示，沒有其他不平衡的力對這些木塊起作用。 碰撞是

(a) 完全彈性。

(b) 完全非彈性。

(c) 其特徵在於動能的增加。

(d) 不可能，因為動量不守恆。



b 23. Two ice skaters push off against one another starting from a stationary position. The 45.0-kg skater acquires a speed of 0.375 m/s. What speed does the 60.0-kg skater acquire? Assume that any other unbalanced forces during the collision are negligible.

(a) 0.500 m/s. (b) 0.281 m/s. (c) 0.375 m/s. (d) 0.750 m/s

兩個滑冰運動員從靜止的位置相互推開。 45.0 公斤的滑冰者獲得 0.375 米/秒的速度。 求 60.0 公斤滑冰運動員獲得的速度。 假設在碰撞過程中任何其他不平衡的力都可以忽略不計。

b 24. A 2.00-kg object traveling east at 20.0 m/s collides with a 3.00-kg object traveling west at 10.0 m/s. After the collision, the 2.00-kg object has a velocity 5.00 m/s to the west. How much kinetic energy was lost during the collision?

(a) 175 J. (b) 458 J. (c) 516 J. (d) 91.7 J.

以 20.0 米/秒的速度向東移動的 2.00 公斤物體與以 10.0 米/秒的速度向西移動的 3.00 公斤物體相撞。 碰撞後，2.00 公斤物體的速度為 5.00 米/秒向西移動。 碰撞時多少動能損失？

c 25. A 5.00-kg ball is hanging from a long wire, when it is struck by a 1.50-kg stone traveling horizontally to the right at 12.0 m/s. The stone rebounds to the left with a speed of 8.50 m/s, and the ball swings to a maximum height ***h*** above its original level. Find the value of ***h***.

(a) 0.0563 m. (b) 1.10 m. (c) 1.93 m. (d) 2.20 m.

當懸掛在一條長繩末端的一個 5.00 公斤的球被一塊 1.50 公斤的石頭以水平向右的 12.0 米/秒速度撞擊後。石頭以 8.50 米/秒的速度向左反彈。求球的擺動的最大高度 ***h***。

1.

EXAMPLE 9.2 CM in Two Dimensions: A Space Station

Figure 9.2 shows a space station consisting of three modules arranged in an equilateral triangle, connected by struts of length L and of negligible mass. Two modules have mass m, the other $2m$. Find the center of mass.

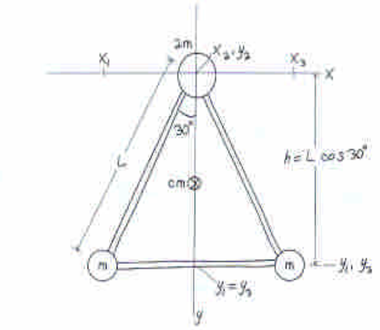


FIGURE 9.2 Our sketch of the space station.

INTERPRET We're after the center of mass of the system consisting of the three modules.

DEVELOP Figure 9.2 is our drawing. We'll use Equation 9.2, $\vec{r}_{cm} = \sum m_i\vec{r}_i/M$, to find the center-of-mass coordinates x_{cm} and y_{cm}. A sensible coordinate system has the origin at the module with mass $2m$ and the y-axis downward, as shown in Fig. 9.2.

EVALUATE Labeling the modules from left to right, we see that $x_1 = -L\sin 30° = -\frac{1}{2}L$, $y_1 = L\cos 30° = L\sqrt{3}/2$; $x_2 = y_2 = 0$; and $x_3 = -x_1 = \frac{1}{2}L$, $y_3 = y_1 = L\sqrt{3}/2$. Writing explicitly the x- and y-components of Equation 9.2 for this case gives

$$x_{cm} = \frac{mx_1 + mx_3}{4m} = \frac{m(x_1 - x_1)}{4m} = 0$$

$$y_{cm} = \frac{my_1 + my_3}{4m} = \frac{2my_1}{4m} = \frac{1}{2}y_1 = \frac{\sqrt{3}}{4}L = 0.43L$$

Although there are three "particles" here, our choice of coordinate system left only two nonzero terms in the numerator, both associated with the same mass m. The more massive module is still in the problem, though; its mass $2m$ contributes to make the total mass M in the denominator equal to $4m$.

(continued)

2.

EXAMPLE 9.3 Continuous Matter: An Aircraft Wing

A supersonic aircraft wing is an isosceles triangle of length L, width w, and negligible thickness. It has mass M, distributed uniformly over the wing. Where's its center of mass?

INTERPRET Here the matter is distributed continuously, so we need to integrate to find the center of mass. We identify an axis of symmetry through the wing, which we designate the x-axis. By symmetry, the center of mass lies along this x-axis, so $y_{cm} = 0$ and we'll need to calculate only x_{cm}.

DEVELOP Figure 9.4 shows the wing. Equation 9.4 applies, and we need only the x-component because the y-component is evident from symmetry. The x-component of Equation 9.4 is $x_{cm} = \left(\int x\,dm\right)/M$. Developing a plan for dealing with an integral like this requires some thought; we'll first do the work and then summarize the general steps involved.

Our goal is to find an appropriate mass element dm in terms of the infinitesimal coordinate interval dx. As shown in Fig. 9.4, here it's easiest to use a vertical strip of width dx. Each such strip has a different height h, depending on its position x. If we choose a coordinate system with origin at the wing apex, then, as you can see from the figure, the height grows linearly from 0 at $x = 0$ to w at $x = L$. So $h = (w/L)x$. Now the strip is infinitesimally narrow, so the sloping edges don't matter and its area is that of a very thin rectangle—namely, $h\,dx = (w/L)x\,dx$. The strip's mass dm is then the same fraction of the total wing mass M as its area is of the total wing area $\frac{1}{2}wL$; that is,

$$\frac{dm}{M} = \frac{(w/L)x\,dx}{\frac{1}{2}wL} = \frac{2x\,dx}{L^2}$$

so $dm = 2Mx\,dx/L^2$.

In the integral we weight each mass element dm by its distance x from the origin, and then sum—that is, integrate—over all mass elements. So, from Equation 9.4, we have

$$x_{cm} = \frac{1}{M}\int x\,dm = \frac{1}{M}\int_0^L x\left(\frac{2Mx}{L^2}\,dx\right) = \frac{2}{L^2}\int_0^L x^2\,dx$$

As always, constants can come outside the integral. We set the limits 0 and L to cover all the mass elements in the wing. Now we're finally ready to find x_{cm}.

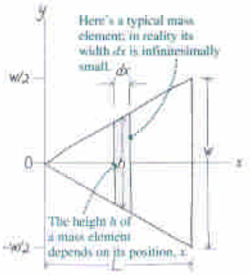


FIGURE 9.4 Our sketch of the supersonic aircraft wing.

3.

EXAMPLE 9.9 The Ballistic Pendulum

The ballistic pendulum measures the speeds of fast-moving objects like bullets. It consists of a wooden block of mass M suspended from vertical strings (Fig. 9.15). A bullet of mass m strikes and embeds itself in the block, and the block swings upward through a vertical distance h. Find an expression for the bullet's speed.

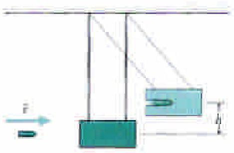


FIGURE 9.15 A ballistic pendulum (Example 9.9).

INTERPRET Interpreting this example is a bit more involved. We actually have two separate events: the bullet striking the block and the subsequent rise of the block. We can interpret the first event as a one-dimensional totally inelastic collision, as in Example 9.7. Momentum is conserved during this event but, because the collision is inelastic, energy is not. Then the block rises, and now a net external force—from string tension and gravity—acts to change the momentum. But gravity is conservative, and the string tension does no work, so now mechanical energy is conserved.

DEVELOP Figure 9.15 is our drawing. Our plan is to separate the two parts of the problem and then to combine the results to get our final answer. First is the inelastic collision; here momentum is conserved, so Equation 9.11 applies. In one dimension, that reads $mv = (m + M)V$, where v is the initial bullet speed and V is the speed of the block with embedded bullet just after the collision. Solving gives $V = mv/(m + M)$. Now the block swings upward. Momentum isn't conserved, but mechanical energy is. Setting the zero of potential energy in the block's initial position, we have $U_0 = 0$ and—using the situation just after the collision as the initial state—$K_0 = \frac{1}{2}(m + M)V^2$. At the peak of its swing the block is momentarily at rest, so $K = 0$. But it's risen a height h, so its potential energy is $U = (m + M)gh$. Conservation of mechanical energy reads $K_0 + U_0 = K + U$—in this case, $\frac{1}{2}(m + M)V^2 = (m + M)gh$.

EVALUATE Now we've got two equations describing the two parts of the problem. Using our expression for V from momentum conservation in the energy-conservation equation, we get

$$\frac{1}{2}\left(\frac{mv}{m + M}\right)^2 = gh$$

Solving for the bullet speed v then gives our answer:

$$v = \left(\frac{m + M}{m}\right)\sqrt{2gh}$$

ASSESS Make sense? Yes: The smaller the bullet mass m, the higher velocity it must have to carry a given momentum; that's reflected by the factor m alone in the denominator. The higher the rise h, obviously, the greater the bullet speed. But the speed scales not as h itself but as $\sqrt{h}$. That's because kinetic energy—which turned into potential energy of the rise—depends on velocity *squared*. ■

4.

EXAMPLE 9.7 An Inelastic Collision: Hockey

The hockey captain, a physics major, decides to measure the puck's speed. He loads a small Styrofoam chest with sand, giving a total mass of 6.4 kg. He places it at rest on frictionless ice. The 160-g puck strikes the chest and embeds itself in the Styrofoam. The chest moves off at 1.2 m/s. What was the puck's speed?

INTERPRET This is a totally inelastic collision. We identify the system as consisting of puck and chest. Initially, all the system's momentum is in the puck; after the collision, it's in the combination puck + chest. In this case of a single nonzero velocity before collision and a single velocity after, momentum conservation requires that both motions be in the same direction. Therefore, we have a one-dimensional problem.

DEVELOP Figure 9.13 is a sketch of the situation before and after the collision. With a totally inelastic collision, Equation 9.11—the statement of momentum conservation—tells it all. In our one-dimensional situation, this equation becomes $m_p v_p = (m_p + m_c)v_c$, where the subscripts p and c stand for puck and chest, respectively.

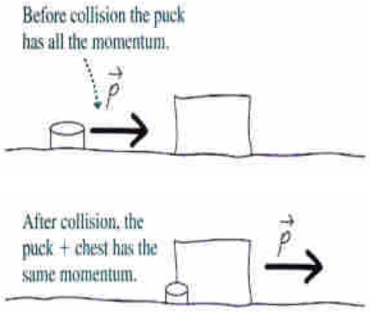


FIGURE 9.13 Our sketch for Example 9.7.

EVALUATE Here we want the initial puck velocity, so we solve for v_p:

$$v_p = \frac{(m_p + m_c)v_c}{m_p} = \frac{(0.16\ \text{kg} + 6.4\ \text{kg})(1.2\ \text{m/s})}{0.16\ \text{kg}} = 49\ \text{m/s}$$

ASSESS Make sense? Yes: The puck's mass is small, so it needs a much higher speed to carry the same momentum as the much more massive chest. Variations on this technique are often used to determine speeds that would be difficult to measure directly. ■

5.

$$\frac{dP}{dt} = \frac{dm}{dt}v = (45\ kg/s)(32\ m/s) = 1400\ N$$

6.

$$J = F\Delta t = (140kg)(8.7m/s^2)(0.12s - 0) = 146N \cdot s$$

7.

$$M\vec{v}_i = m_A\vec{v}_{A,f} + m_B\vec{v}_{B,f}$$

$$\Rightarrow (0.15kg)(60 \times 1000m/3600s)\hat{i} = (0.038kg)(85 \times 1000m/3600s)\hat{i} + (0.112kg)\vec{v}_{B,f}$$

$$\vec{v}_{B,f} = -(14.31m/s)\hat{i}$$

ΔK= K_f □ K_i

$$= \frac{1}{2}(0.038kg)(85 \times 1000m/3600s)^2 + \frac{1}{2}(0.112kg)(14.31m/s)^2 - \frac{1}{2}(0.15kg)(60 \times 1000m/3600s)^2$$

$\approx$ 1.21J

9.

CONCEPTUAL EXAMPLE 9.1 Conservation of Momentum: Kayaking

Jess (mass 53 kg) and Nick (mass 72 kg) sit in a 26-kg kayak at rest on frictionless water. Jess tosses Nick a 17-kg pack, giving it horizontal speed 3.1 m/s relative to the water. What's the kayak's speed after Nick catches the pack? Why can you answer without doing any calculations?

EVALUATE Figure 9.9 shows the kayak before Jess tosses the pack and again after Nick catches it. The water is frictionless, so there's no net external force on the system, which comprises Jess, Nick, the kayak, and the pack. Since there's no net external force, the system's momentum is conserved. Everything is initially at rest, so that momentum is zero. Therefore, it's also zero after Nick catches the pack. At that point Jess, Nick, pack, and kayak are all at rest with respect to each other.

FIGURE 9.9 Our sketch for Conceptual Example 9.1.

ASSESS We didn't need any calculations here because the powerful conservation-of-momentum principle relates the initial and final states, without our having to know what happens in between.

MAKING THE CONNECTION What's the kayak's speed while the pack is in the air?

EVALUATE Momentum conservation still applies, and the system's total momentum is still zero. Now it consists of the pack's momentum $m_p\vec{v}_p$ and the momentum $(m_J + m_N + m_k)\vec{v}_k$ of Jess, Nick, and kayak, with common velocity $\vec{v}_k$ (Fig. 9.10). Sum these momenta, set the sum to zero, and solve, using the given quantities, to get $v_k = -0.35$ m/s. Here we've dropped vector signs; the minus sign then shows that the kayak's velocity is opposite the pack's. Since kayak and passengers are much more massive than the pack, it makes sense that their speed is lower.

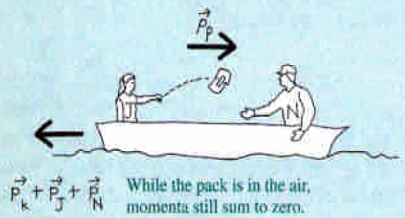


FIGURE 9.10 Our sketch for Making the Connection 9.1.

動量守恆:

$$p_1 = (m_J + m_N + m_k)v_1 + m_p v_p = p_0 = 0$$

$$v_1 = -\frac{m_p}{m_J + m_N + m_k} v_p = -0.35\ m/s$$

12.

EXAMPLE 9.4 CM Motion: Circus Train

Jumbo, a 4.8-t elephant, stands near one end of a 15-t railcar at rest on a frictionless horizontal track. (Here t is for tonne, or metric ton, equal to 1000 kg.) Jumbo walks 19 m toward the other end of the car. How far does the car move?

INTERPRET We're asked about the car's motion, but we can interpret this problem as being fundamentally about the center of mass. We identify the relevant system as comprising Jumbo and the car. Because there's no net external force acting on the system, its center of mass can't move.

DEVELOP Figure 9.8*a* shows the initial situation. The symmetric car has its CM at its center (here we care only about the *x*-component). Let's take a coordinate system with $x = 0$ at this point—that is, at the *initial* location of the car's center. After the car moves, its center will be somewhere else! Equation 9.2 applies—here in the simpler one-dimensional two-object form we used in Example 9.1: $x_{cm} = (m_J x_J + m_c x_c)/M$, where we use the subscripts J and c for Jumbo and the car, respectively, and where M is the total mass. We have a before/after situation in which the CM position can't change, so we'll write two versions of this expression, before and after Jumbo's walk. We'll then set them equal to state mathematically that the CM itself doesn't move.

We chose the coordinates so that $x_{ci} = 0$, where i designates the initial state, so our initial expression is $x_{cm} = m_J x_{Ji}/M$. After Jumbo's walk, our final expression is $x_{cm} = (m_J x_{Jf} + m_c x_{cf})/M$, with f for final. We don't know either coordinate here, but we do know that Jumbo walks 19 m *with respect to the car*. The elephant's final position x_{Jf} is therefore 19 m to the right of x_{Ji}, adjusted by the car's displacement. Therefore Jumbo ends up at $x_{Jf} = x_{Ji} + 19\ \text{m} + x_{cf}$. You might think we need a minus sign because the car moves to the left. That's true, but the sign of x_{cf} will take care of that. Trust algebra! So our final expression is

$$x_{cm} = \frac{m_J x_{Jf} + m_c x_{cf}}{M} = \frac{m_J(x_{Ji} + 19\ \text{m} + x_{cf}) + m_c x_{cf}}{M}$$

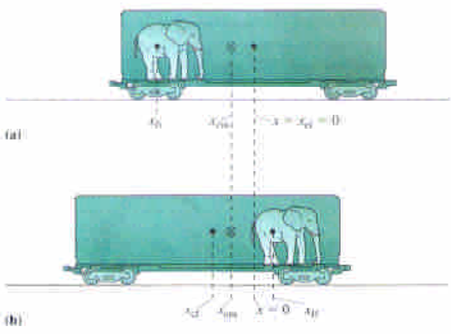


FIGURE 9.8 Jumbo walks, but the center of mass doesn't move.

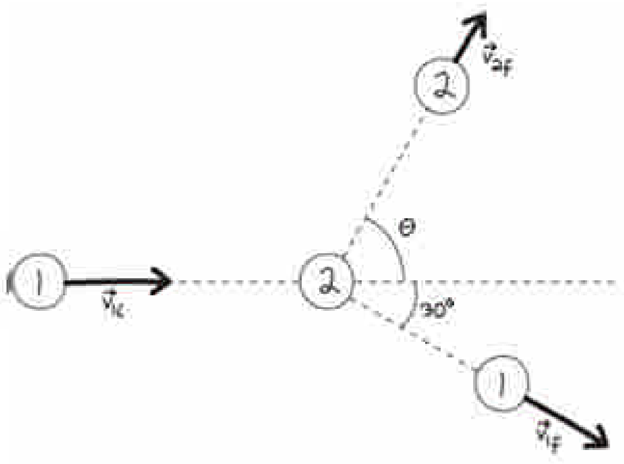
EVALUATE Finally, we execute our plan, equating the two expressions for the unchanging position of the center of mass. The total mass M cancels, and we're left with $m_J x_{Ji} = m_J(x_{Ji} + 19\ \text{m} + x_{cf}) + m_c x_{cf}$. We aren't given x_{Ji}, but the term $m_J x_{Ji}$ is on both sides of this equation, so it cancels, leaving $0 = m_J(19\ \text{m} + x_{cf}) + m_c x_{cf}$. We solve for the unknown x_{cf} to get

$$x_{cf} = -\frac{(19\ \text{m})m_J}{(m_J + m_c)} = -\frac{(19\ \text{m})(4.8\ \text{t})}{(4.8\ \text{t} + 15\ \text{t})} = -4.6\ \text{m}$$

The minus sign here indicates a displacement to the left, as we anticipated (Fig. 9.8*b*). Because the masses appear only in ratios, we didn't need to convert to kilograms.

ASSESS The car's 4.6-m displacement is quite a bit less than Jumbo's (which is 19 m − 4.6 m, or 14.4 m relative to the ground). That makes sense because Jumbo is considerably less massive than the car.

13.



動量守恆: $\mathbf{v}_{1i} = \mathbf{v}_{1f} + \mathbf{v}_{2f}$

能量守恆: $v_{1i}^2 = v_{1f}^2 + v_{2f}^2$

$$\mathbf{v}_{1i}^2 = \mathbf{v}_{1f}^2 + 2\mathbf{v}_{1f}\cdot\mathbf{v}_{2f} + \mathbf{v}_{2f}^2$$

$$v_{1i}^2 = v_{1f}^2 + 2v_{1f}v_{2f}\cos(\theta+30°) + v_{2f}^2$$

$$2v_{1f}v_{2f}\cos(\theta+30°) = 0$$

$$\theta + 30° = 90° \quad \rightarrow \quad \theta = 60°$$

14.

$$v_{1f} = \frac{(m_1-m_2)v_{1i} + 2m_2v_{2i}}{m_1+m_2} \qquad v_{2f} = \frac{2m_1v_{1i} + (m_2-m_1)v_{2i}}{m_1+m_2} \qquad v_{2i} = 0$$

$$v_{1f} = \frac{m_1-m_2}{m_1+m_2}v_{1i} = -\frac{1}{3}v_{1i} \qquad v_{2f} = \frac{2m_1}{m_1+m_2}v_{1i} = \frac{2}{3}v_{1i}$$

$$\frac{K_{2f}}{K_{1i}} = \frac{m_2\,v_{2f}^2}{m_1\,v_{1i}^2} = \frac{4\,m_1m_2}{(m_1+m_2)^2} = \frac{4(1u)(2u)}{(1u+2u)^2} = \frac{8}{9} = 89\%$$

15.

A 13.1-kg squid fires a burst of water, giving it average acceleration 2.0g (19.6 m/s²) over a 100-ms time interval. (a) Find the associated impulse. (b) Assuming the squid starts from rest, what are its momentum change and final speed?

ORGANIZE AND PLAN Given the squid's mass and acceleration, we can use Newton's law to find the force; multiplying by Δt gives the impulse. By the impulse-momentum theorem, that's the momentum change. Momentum is mass times velocity, which we can use to find the speed.

Take the x-direction to be that of the squid's motion (Figure 6.12), so the x-components of acceleration, velocity, and impulse are positive. The impulse is

$$J_x = F_x\Delta t = ma_x\Delta t$$

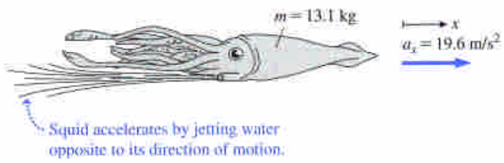


FIGURE 6.12 The squid accelerates.

Then by the impulse-momentum theorem

$$J_x = \Delta p_x = p_x$$

because the initial momentum was zero. Finally, $p_x = mv_x$, which allows you to solve for v_x which, in this one-dimensional situation, is the speed.

$$J_x = (13.1kg)(19.6m/s^2)(0.01s) = 25.7kg\cdot m/s$$

$$v_x = \frac{p_x}{m} = \frac{25.7kg\cdot m/s^2}{13.1kg} = 1.96m/s$$

17.

動量守恆: $m\vec{v}_i = (m+M)\vec{v}_f \quad \Rightarrow \quad \vec{v}_i = \dfrac{(m+M)\vec{v}_f}{m}$

能量守恆: $\frac{1}{2}(m+M)\vec{v}_f^2 = \frac{1}{2}kx^2 \Rightarrow v_f = \sqrt{\frac{kx^2}{m+M}}$

$$v_i = \frac{(m+M)}{m}\sqrt{\frac{kx^2}{m+M}} = \frac{4.008kg}{0.008kg}\sqrt{\frac{(2400N/m)(0.087m)^2}{4.008}} = 1067m/s \approx 1100m/s$$

18.

INTERPRET The object of interest is the skater. We want to find her velocity after she tosses a snowball in a certain direction.

DEVELOP On frictionless ice, momentum would be conserved in the process. Since the initial momentum of the skater-snowball system is zero, their final total momentum must also be zero:

$$0 = m_1\vec{v}_1 + m_2\vec{v}_2$$

where subscripts 1 and 2 refer to the snowball and skater, respectively.

EVALUATE By momentum conservation, the final velocity of the skater is

$$\vec{v}_2 = -\frac{m_1}{m_2}\vec{v}_1 = -\frac{12\text{ kg}}{60\text{ kg}}\left(53.0\hat{i} + 14.0\hat{j}\text{ m/s}\right) = -10.6\hat{i} - 2.8\hat{j}\text{ m/s}$$

ASSESS As expected, the skater moves in the opposite direction of the snowball. This is a consequence of momentum conservation.

19.

$\vec{p}_1 = m_1\vec{v}_1 = (0.2kg)(82.0m/s)\hat{i} = (16.4kg\cdot m/s)\hat{i}$

$\vec{p}_2 = m_2\vec{v}_2 = (0.3kg)(45.0m/s)\hat{j} = (13.5kg\cdot m/s)\hat{j}$

$\vec{p}_{total} = \vec{p}_1 + \vec{p}_2 = (16.4kg\cdot m/s)\hat{i} + (13.5kg\cdot m/s)\hat{j}$

$\left|\ \vec{p}_{total}\ \right| = \sqrt{(16.4)^2 + (13.5)^2} = 21.2$

$|\vec{p}_1| = |\vec{p}_{total}|\cdot\cos\theta$

$\theta = \cos^{-1}(\frac{16.4}{21.24}) = 39.5^o$

20.

$$J = m\Delta v = m(v_f - 0) = \int F(t)dt \Rightarrow v_f = \frac{\int F(t)dt}{m}$$

$$v_f = \frac{\int (at - bt^2)dt}{m} = \left[\frac{\frac{at^2}{2} - \frac{bt^3}{3}}{m}\right]_{t=0}^{t=0.00274} = \left[\frac{\frac{(1500N/ms)(2.74ms)^2}{2} - \frac{(20N/ms^2)(2.74ms)^3}{3}}{1{,}67kg}\right]$$

=3289 *m/ms* ≈ 3.3 *m/s*

21.

$$J = m\Delta\vec{v} = m(\vec{v}_f - \vec{v}_i) = \vec{F}_{av}\Delta t$$

$$\vec{F}_{av} = \frac{m(\vec{v}_f - \vec{v}_i)}{\Delta t} = \frac{(0.2kg)[(12m/s)\hat{i} - (-20m/s)\hat{i}]}{0.06s} = 107N$$

23.

$$\vec{p}_A + \vec{p}_B = 0 \quad \Rightarrow \quad \vec{p}_A = -\vec{p}_B$$

$$m_A\vec{v}_A = -m_B\vec{v}_B \Rightarrow \vec{v}_B = -m_A\vec{v}_A / m_B = -\frac{(45kg)(-0.375m/s)\hat{i}}{60kg} = 0.281m/s$$

24.

(1) 動量守恆: $m_A\vec{v}_{A,i} + m_B\vec{v}_{B,i} = m_A\vec{v}_{A,f} + m_B\vec{v}_{B,f}$

$$(2kg)(20m/s)\hat{i} + (3kg)(-10m/s)\hat{i} = (2kg)(-5m/s)\hat{i} + (3kg)\vec{v}_{B,f}$$

$\Rightarrow \vec{v}_{B,f}$ = (6.7m/s) $\hat{i}$

(2) $\Delta K = K_f$ □ K_i

$$= \frac{1}{2}[(2kg)(-5m/s)^2 + (3kg)(6.7m/s)^2] - \frac{1}{2}[(2kg)(20m/s)^2 + (3kg)(-10m/s)^2]$$

= □457.7 J ≈ □458 J

25.

(1) 動量守恆: $m_A\vec{v}_{A,i} + m_B\vec{v}_{B,i} = m_A\vec{v}_{A,f} + m_B\vec{v}_{B,f}$

$$(5kg)(0m/s)\hat{i} + (1.5kg)(12.0m/s)\hat{i} = (5kg)\vec{v}_{A,f} + (1.5kg)(-8.5m/s)\hat{i}$$

$\Rightarrow \vec{v}_{A,f}$ = (6.15 *m/s*) $\hat{i}$

(2) 機械能守恆: $U_i + K_i = U_f + K_f$; $U_i = 0$, $K_i = \frac{1}{2}m_A v_{A,f}^2$, $U_f = m_A gh$, $K_f = 0$

$$\Rightarrow \frac{1}{2}m_A v_{A,f}^2 = m_A gh$$

$$\frac{1}{2}(5kg)(6.15m/s)^2 = (5kg)(9.8m/s^2)h$$

$\Rightarrow h$ =1.93*m*

p.s. 因為第 8、10、11、16、及 22 題為觀念題，所以沒有計算過程。