Physics for the Life Sciences

PHYS 109 فيز

‘Selected Problems’

PART 1

Prepared by
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Preface

This manuscript is prepared by Nouf ALKATHRAN, it reports five selected problems with their solutions.

The first part (Part 1) concern the first seven chapters of the textbook, the Physical theme is Mechanics. I selected in each chapter of the textbook five problems. The solutions are done by the Female section Teaching staff, that I would like to think for their efforts to success this course PHYS 109.

The second part (Part 2) will concern all the other chapters included in the Syllabus of PHYS109. I selected the problems and the solutions will be done by the Male section Teaching staff.

Please, for any remark or correction, send an email.

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PROB. OF CHAP. 1: Physics and the Life Sciences

1.1. Express the following numbers in scientific notation:

(a) 123
(b) 1230
(c) 12300.0
(d) 0.123
(e) 0.00123
(f) 0.00000123000

1.2. How many significant figures do the following numbers have?

(a) 103.07
(b) 124.5
(c) 0.099165
(d) 5.408×10^5

1.3. Express the following products in scientific notation:

(a) 123×0.00456
(b) 1230×0.456
(c) 0.0012300×4560.0
(d) 0.01230×456.00

1.5. Express the following sums and differences in scientific notation:

(a) 123 + 456
(b) 1230 + 0.456
(c) 123.456 − 123.123
(d) 123.45678 − 123.123

1.10. Assume that you can run a 42.195 km marathon in 2 hours, 2 minutes, and 11 seconds (congratulations on setting a new world record). Use dimensional analysis to find an expression for your average speed. Express your average speed in scientific notation in units of (a) km/h; (b) m/s; (c) km/s; (d) m/h; (e) mm/ns

PROB. OF CHAP. 2: Kinematics

2.1. (a) What is the sum of the two vectors $\vec{a}$ = (5.00, 5.00) and $\vec{b}$ = (–14.00, 5.00)? (b) What is the magnitude and direction of $\vec{a}+\vec{b}$?

2.2. If vector $\vec{a}$ is added to vector $\vec{b}$, the result is the vector $\vec{c}$ = (6.00, 2.00). If $\vec{b}$ is subtracted from $\vec{a}$, the result is the vector $\vec{d}$= (–5.00, 8.00). (a) What is the magnitude of vector $\vec{a}$? (b) What is the magnitude of vector $\vec{b}$?

2.5. A competitive sprinter needs 9.90 seconds to run 100 metres. What is the average velocity in units metres per second (m/s) and in units kilometres per hour (km/h)?

2.9. A bacterium moves with a speed of 3.5 mm/s across a petri dish with radius r = 8.4 cm. How long does it take for the bacterium to traverse the petri dish along its diameter?

2.23. A ball is thrown at an angle of 60° to the horizontal with an initial speed of 10.0 m/s, as illustrated in Fig. 2.45. With its initial position taken to be the origin, find the position vector that describes the position of the ball 3.0 s later.

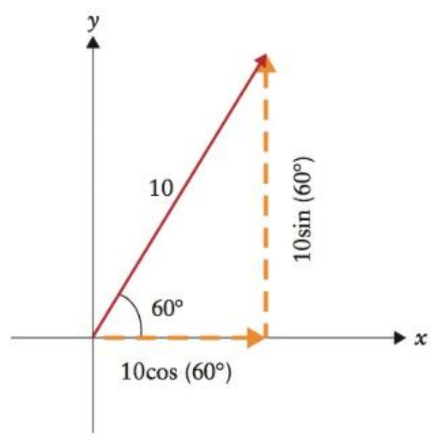

Figure 2.45 The initial velocity of the ball is broken into x- and y-components.

PROB. OF CHAP. 3: Forces

3.1. Find the force of gravity between two uniform spheres as they touch each other. Each sphere has a mass of $m = 15$ kg and a radius of $r = 0.5$ m. What is the force of gravity between them when they stand (surface to surface) 2 m from each other?

3.7. The acceleration of gravity on the surface of Mars is 3.62 m/s^2, and the mass of Mars is 6.40×10^{23} kg. Find the radius of Mars.

3.25. A 5.8 kg box is resting on an inclined surface 35° above the horizontal. Find the normal force exerted by the box on the inclined surface.

3.28. A person pushes on a 67 kg refrigerator by a horizontal force of 276 N. (a) If the coefficient of static friction is 0.55, what are the magnitude and the direction of the force of the static friction. Does the person move the refrigerator? (b) What is the magnitude of the largest push that the person can apply to the refrigerator just before it begins to move?

3.31. A box of mass 45.5 kg is at rest on a horizontal floor. If the coefficient of static friction between the box and the floor is 0.34, what is the minimum force needed for it to start to move?

4.3. A 5.0 kg block is suspended by three taut strings as shown in Fig. 4.62. Find the tension in the strings.

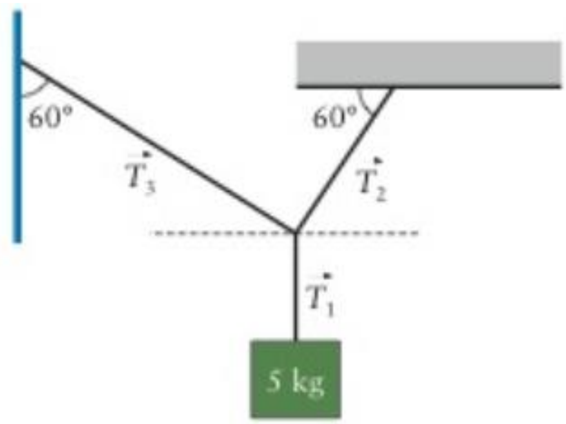

Figure 4.62

4.7. Two horizontal forces, $\vec{F}_1$ and $\vec{F}_2$, are pulling an object mass m = 1.5 kg from two opposite sides. $\vec{F}_1$ pulls to the right and $\vec{F}_2$ pulls to the left. The magnitude of $\vec{F}_1$ is 25 N. The object moves strictly along the horizontal *x*-axis, which we choose as positive to the right. Find the magnitude of $\vec{F}_2$ if the object's horizontal acceleration is (a) a=10 m/s ;(b) a=0 m/s^2 ; and (c) a = –10 m/s^2.

4.10. Fig. 4.64 shows two blocks of masses M and m. The horizontal surface allows for frictionless motion. The string tied to the two blocks is massless and passes over a massless pulley that rotates without friction. (a) What resulting motion of the two blocks do you predict? If $M = 3.0$ kg and $m = 2$ kg, (b) find the magnitude of the acceleration of the sliding block, (c) find the magnitude of the acceleration of the hanging block, and (d) find the magnitude of the tension in the massless string.

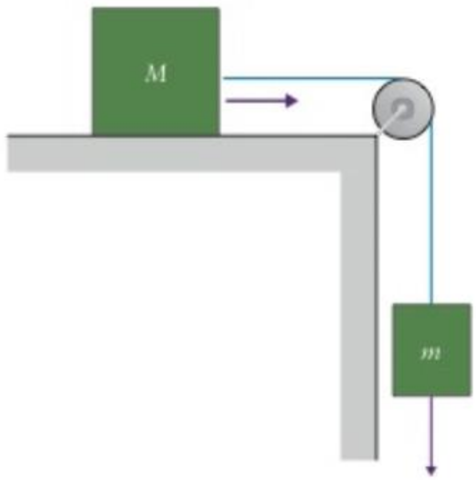

Figure 4.64

4.11. Fig. 4.65 shows two objects that are connected by a massless string. They are pulled along a frictionless surface by a horizontal external force. Using $\vec{F}_{ext}$ = 50 N, m_1 = 10 kg, and m_2 = 20 kg, calculate (a) the magnitude of the acceleration of the two objects, and (b) the magnitude of the tension ST in the string.

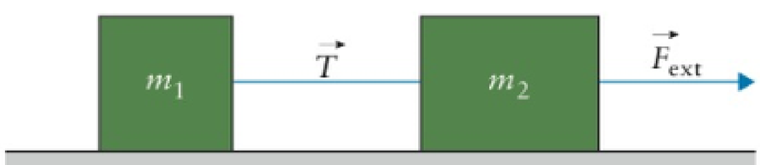

Figure 4.65

4.12. A block of mass m_1 = 14 kg, on a frictionless inclined plane with an angle of θ = 35° with the horizontal, is connected to another block of mass m_2 = 6 kg by a massless string that passes over a pulley as shown in Fig. 4.66. Take the pulley as an ideal pulley. Calculate the acceleration of the blocks and the tension in the string.

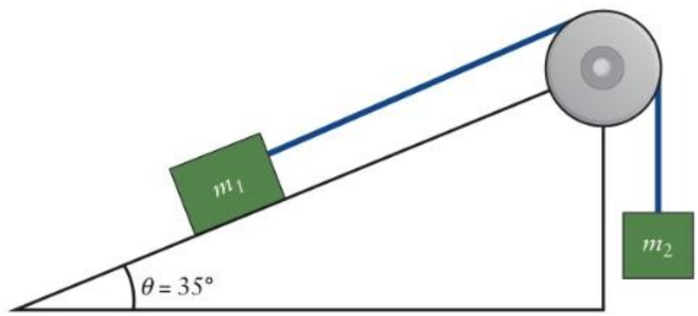

Figure 4.66

PROB. OF CHAP. 5: Center of Mass and Linear Momentum

5.5. A system is made up of point masses P_1 at position (–1 m, 5 m, 7 m), P_2 at position (3 m, 3 m, 3 m), and P_3 at position (9 m, –5 m, –2 m). Find the centre of mass of the system if (a) each of the point masses has the same mass, and (b) $m_1 = 2m_2 = 4m_3$.

5.7. A student of mass 75 kg is in a small rowboat of mass 95 kg resting on a calm lake. How far will the boat move if the student walks from the bow to the stern of the boat? The distance from the bow to the stern is 2.5 m. Ignore any horizontal force exerted by the water.

5.16. Fig. 5.21(a) shows two objects of masses m_1 and m_2 travelling with velocities $\vec{v}_1$ and $\vec{v}_2$ toward a collision point (chosen at the origin). After a perfectly inelastic collision, the combined object travels with angle f relative to the positive x-axis, as indicated in Fig. 5.21(b) (a) Derive the x- and y-component formulas for the velocity of the combined object after the collision.

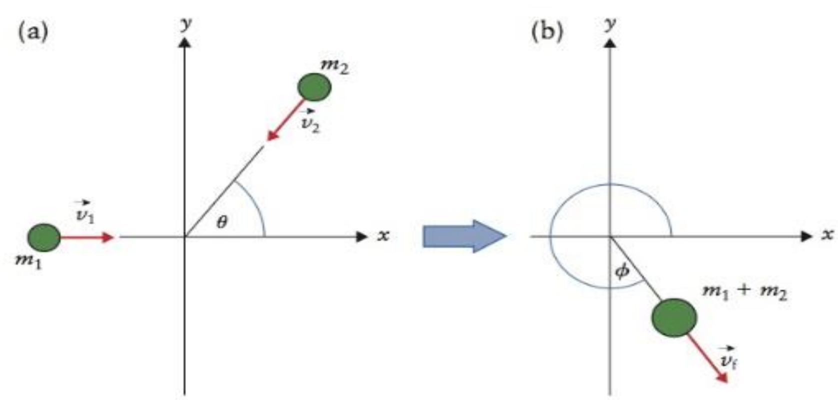

Figure 5.21 Perfectly inelastic collision of two moving objects in the *xy*-plane.

5.20. An object of mass m = 3.0 kg makes a perfectly inelastic collision with a second object that is initially at rest. The combined object moves after the collision with a speed equal to one-third of the object that was initially moving. What is the mass of the object that was initially at rest?

5.21. An object of mass m = 8 g is fired into a larger object of mass M = 250 g that was initially at rest at the edge of a table. The smaller object becomes embedded in the larger object, and the combined object lands on the floor a distance of 2.0 m away from the table. If the table top is 1.0 m above the floor, determine the initial speed of the smaller object.

PROB. OF CHAP. 6: Torque and Equilibrium

6.1. If the torque required to loosen a nut has a magnitude of τ = 40 N m, what minimum force must be exerted at the end of a 30-cm-long wrench?

6. 6. A force of 120 N in positive *x*-direction is applied perpendicularly to the middle of a 3-m-long stick standing vertically. What is the magnitude and direction of torque about each end of the stick?

6.23. Determine the torque about the knee by a hamstring tendon exerting an 80 N force on bones in the lower leg, as shown in Fig. 6.69. Assume that the knee bend is 75°, and that the tendon acts horizontally 6.0 cm below the knee, the pivot point.

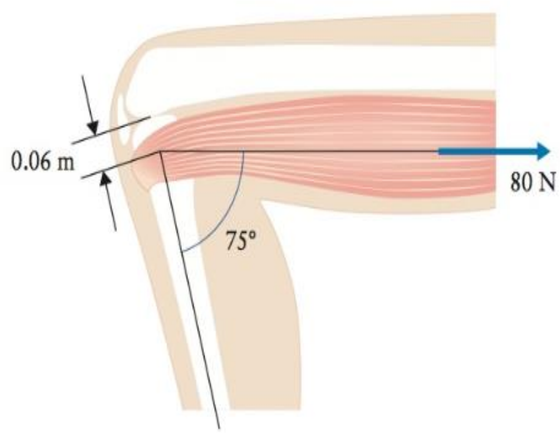

Figure 6.69

6.26. A 10 kg object rotating on a circle of 2.5 m has an angular momentum of 0.75 kg m^2/s with respect to the centre of the circle. What is its speed?

6.27. Two objects of masses m_1 =157.6 kg and m_2 = 5 4.5 kg, with speeds of $\vec{v}_1$ = 5 3.6 m/s and $\vec{v}_2$ = 5 5.2 m/s, are moving in a perpendicular direction around the origin O, as shown in Fig 6.71. If at one moment their distance from the origin O is r_1 =5 2.5 m and r_2 = 5 3.8 m, what is their total (net) angular momentum about point O?

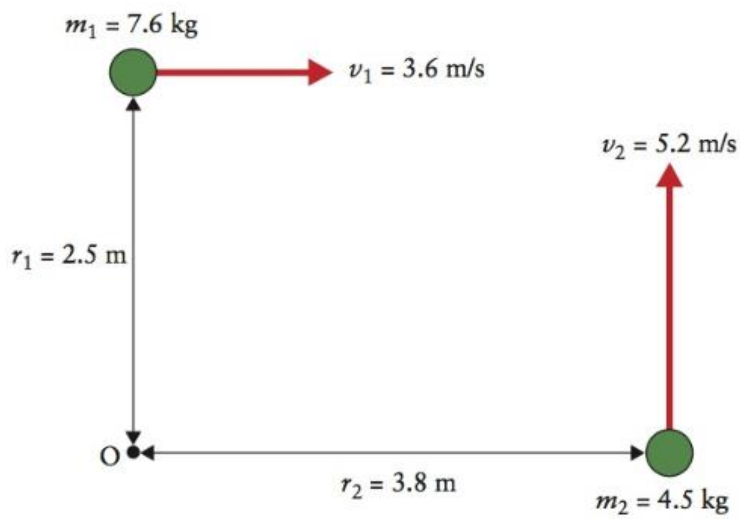

Figure 6.71

PROB. OF CHAP. 7: Energy and Its Conservation

7.3. A standard man climbs the stairs in a building. Assume that he reaches the fourth floor (16 m above the ground floor) in 15 seconds. How much work has the standard man done, and what was the power used for the climb?

7.9. A shopper in a grocery store pushes a shopping cart with a force of 40 N directed at an angle of 30° below the horizontal. What is the work the shopper does on the cart for a horizontal distance of 10 m?

7.17. A child and sled with a combined mass of 50 kg slide down a frictionless hill. If the sled starts from rest and has a speed of 3.0 m/s at the bottom, what is the height of the hill?

7.19. An object of mass 0.5 kg has a speed of 2.5 m/s at position 1 and a kinetic energy of 10.0 J at position 2. Calculate (a) its kinetic energy at position 1, (b) its speed at position 2, and (c) the total work done on the object as it moves from position 1 to position 2.

7.30. An object of mass m_1 = 7.5 g moves to the right at 25 cm/s. It makes an elastic head-on collision with a second object of mass m_2 = 12.5 g. The second object is at rest before the collision. Calculate (a) the speed of each object after the collision and (b) the fraction of the initial kinetic energy that is transferred to the second object.

Physics for the Life Sciences

PHYS 109 فيز

'Solutions for the Selected Problems'

PART 1

SOL. PROB. OF CHAP. 1: Physics and the Life Sciences

1.1. Express the following numbers in scientific notation:
(a) 123
(b)120
(c) 12300.0
(d) 0.123
(e) 0.00123
(f) 0.00000123000

Solution:

(a) $1.23x10^{2}$
(b) $1.23x10^{3}$
(c)$1.23000x10^{4}$
(d) $1.23x10^{-1}$
(e) $1.23x10^{-3}$
(f) $1.23000x10^{-6}$

Significant figures: the digits in a number that are known with certainty (except the last digit). The last significant figure has an estimated value. Trailing zeros do not count as significant figures unless the number has a decimal point. Leading zeros never count.
Multiplication and division: The result has the same number of significant figures as the number that has the least number of significant figures in the calculation.
Addition and subtraction: the result has the same precision as the least precise number used in the calculation (When numbers are added or subtracted, the number of decimal places in the result should equal the smallest number of decimal places of any term in the sum or difference).

1.2. How many significant figures do the following numbers have?
(a) 103.07
(b) 124.5
(c) 0.099165
(d) 5.408×10^{5}

Solution:

(a) 5
(b) 4
(c) 5
(d) 4

1.3. Express the following products in scientific notation:
(a) 123 × 0.00456
(b) 1230 × 0.456
(c) 0.0012300 × 4560.0
(d) 0.01230 × 456.00

Solution:

(a) $5.61x10^{-1}$
(b) $5.61x10^{2}$
(c) $5.6088x10^{0}$=5.6088
(d) $5.609x10^{0}$=5.609

1.5. Express the following sums and differences in scientific notation:
(a) 123 + 456
(b) 1230 + 0.456
(c) 123.456 − 123.123
(d) 123.45678 − 123.123

Solution:

(a) $5.79x10^{2}$
(b) $1.23x10^{3}$
(c) $3.33x10^{-1}$
(d) $3.34x10^{-1}$

1.10. Assume that you can run a 42.195 km marathon in 2 hours, 2 minutes, and 11 seconds (congratulations on setting a new world record).

Use dimensional analysis to find an expression for your average speed. Express your average speed in scientific notation in units of (a) km/h; (b) m/s; (c) km/s; (d) m/h; (e) mm/ns

Solution:

Average speed = $\frac{distance}{time} = \frac{42.195}{2+\frac{2}{60}+\frac{11}{3600}}$ = 20.721 km/h=2.0721×10^{1} km/h

$\bar{v}$ = 2.0721×10^{1} km/h = 5.7557 m/s = 5.7557×10^{-3} km/s

= 2.0721×10^{4} m/h = 5.7557×10^{-3} μm/ns

SOL. PROB. OF CHAP. 2: Kinematics

2.1. (a) What is the sum of the two vectors $\vec{a}$ = (5.00, 5.00) and $\vec{b}$ = (–14.00, 5.00)? (b) What is the magnitude and direction of $\vec{a}+\vec{b}$?

Solution:

(a) $\vec{r} = \vec{a}+\vec{b} = (5.00+(-14.00), 5.00+5.00) = (-9.00, 10.00)$

(b) The magnitude of $\vec{r}$:

$$|\vec{r}| = \sqrt{(-9.00)^2+(10.00)^2} = \sqrt{181.00} = 13.45$$

The resultant vector locate in the second quadrant at angle 132^0

As $\theta = \tan^{-1}\left(\frac{10.00}{-9.00}\right) = -48.01°$ above -x axis (A clockwise motion)

$180^0 + (-48.01^0) = 131.99° \approx 132°$

2.2. If vector $\vec{a}$ is added to vector $\vec{b}$, the result is the vector $\vec{c}$ = (6.00, 2.00). If $\vec{b}$ is subtracted from $\vec{a}$, the result is the vector $\vec{d}$= (–5.00, 8.00). (a) What is the magnitude of vector $\vec{a}$? (b) What is the magnitude of vector $\vec{b}$?

Solution:

$\vec{a} = (a_x, a_y)$, $\quad \vec{b} = (b_x, b_y)$,

$\vec{c} = (c_x, c_y) = (6.00, 2.00)$ $\quad \vec{d} = (d_x, d_y)$=(-5.00,8.00)

$a_x + b_x = 6.00$ $\quad a_y + b_y = 2.00$

$a_x - b_x = -5.00$ $\quad a_y - b_y = 8.00$

Solving these equations

$a_x = 0.50$, $b_x = 5.50$ $\quad a_y = 5.00$, $b_y = -3.00$

(a) $\vec{a} = (a_x, a_y) = (0.50, 5.00)$, $|\vec{a}| = \sqrt{(0.50)^2+(5.00)^2}$=5

(b) $\vec{b} = (b_x, b_y) = (5.50, -3.00)$, $|\vec{b}| = \sqrt{(5.50)^2+(3.00)^2}$=6.26

2.5. A competitive sprinter needs 9.90 seconds to run 100 metres. What is the average velocity in units metres per second (m/s) and in units kilometres per hour (km/h)?

Solution:

$$\boldsymbol{v}_{av} = \frac{\Delta x}{\Delta t} = \frac{100\ m}{9.90\ s} = 10.1 \text{ m/s} = 10.1\left(\frac{\times 10^{-3}\ km}{\frac{1}{3600}\ h}\right) = 36 \text{ km/h}$$

2.9. A bacterium moves with a speed of 3.5 μm/s across a petri dish with radius *r* = 8.4 cm. How long does it take for the bacterium to traverse the petri dish along its diameter?

Solution:

$$t = \frac{\Delta x}{v} = \frac{2\times 8.4\times 10^{-2} m}{3.5\times 10^{-6} m/s} = 4.8\times 10^{4} \text{ s} = 13 \text{ h } 20 \text{ min}$$

2.23. A ball is thrown at an angle of 60° to the horizontal with an initial speed of 10.0 m/s, as illustrated in Fig. 2.45. With its initial position taken to be the origin, find the position vector that describes the position of the ball 3.0 s later.

Solution:

$v_{0x} = 10\cos 60° = 5$ m/s,

$v_{0y} = 10\sin 60° = 8.66$ m/s

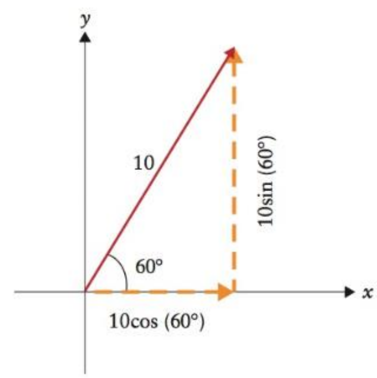

Figure 2.45 The initial velocity of the ball is broken into x- and y-components.

The final position vector $\vec{r} = (x, y)$ of the ball after 3.0 s is

$x = x_0 + v_{0x}.t = 0 + 5(3) = 15$ m

The final position vector $\vec{r} = (x, y)$ of the ball after 3.0 s is

$x = x_0 + v_{0x}.t = 0 + 5(3) = 15$ m

$$y = y_0 + v_{0y}.t - \frac{1}{2}gt^2 = 0 + 8.66\ (3) - \frac{1}{2}(9.8)(3^2) = -18 \text{ m}$$

$$\vec{r} = (x, y) = (15 \text{ m}, -18 \text{ m})$$

SOL. PROB. OF CHAP. 3: Forces

3.1. Find the force of gravity between two uniform spheres as they touch each other. Each sphere has a mass of m = 15 kg and a radius of r = 0.5 m. What is the force of gravity between them when they stand (surface to surface) 2 m from each other?

Solution:

Since they touch each other, the distance separating is D = 2xRadius, so the force is :
$F = G\, m^2/D^2 = 6.67\text{x}10^{-11}\text{x}15^2/(2\text{x}0.5)^2 = 1.5\text{x}10^{-8}$ N
Now since their surfaces are separated by 2m, the distance becomes
D = 2 × Radius + 2, so the force becomes:
$F = 6.67\text{x}10^{-11}\times 15^2/(2\times 0.5 + 2)^2 = 1.7\text{x}10^{-9}$ N

3.7. The acceleration of gravity on the surface of Mars is 3.62 m/s^2, and the mass of Mars is 6.40×10^{23} kg. Find the radius of Mars.

Solution:

$$g = G\,\frac{M}{R^2}$$

$R = \sqrt{(G.M_{Mars}/\boldsymbol{g}_{Mars})} = \sqrt{(6.67 \times 10^{-11}\ \times\ 6.40 \times 10^{23}/3.62)}$
$= 3.43\times 10^6$ m

3.25. A 5.8 kg box is resting on an inclined surface 35° above the horizontal. Find the normal force exerted by the box on the inclined surface.

Solution:

$N = mg\cos\theta = 5.8 \text{ x } 9.8 \text{ x } \cos 35^o = 47$ N

3.28. A person pushes on a 67 kg refrigerator by a horizontal force of 276 N. (a) If the coefficient of static friction is 0.55, what are the magnitude and the direction of the force of the static friction. Does the person move the refrigerator? (b) What is the magnitude of the largest push that the person can apply to the refrigerator just before it begins to move?

Solution:

a) The maximum static friction is:
$f_{smax} = \mu_s N = \mu_s mg = 0.55 \times 67 \times 9.8 = 360$ N.
Since the pushing force is smaller than the maximum static friction:
$F < f_{smax}$, The static friction in this case just equals the pushing force in magnitude and is opposite to the pushing force: $f_s = 276$ N. Thus the object does not move.
b) The largest push to make it slide should be equal to the maximum static friction, that's: F = 360 N.

3.31. A box of mass 45.5 kg is at rest on a horizontal floor. If the coefficient of static friction between the box and the floor is 0.34, what is the minimum force needed for it to start to move?

Solution:

The minimum push to make the object start moving should equal the maximum static friction, that's:
$F = f_{smax} = \mu_s N = \mu_s mg = 0.34 \times 45.5 \times 9.8 = 150$ N.

4.3. A 5.0 kg block is suspended by three taut strings as shown in Fig. 4.62.

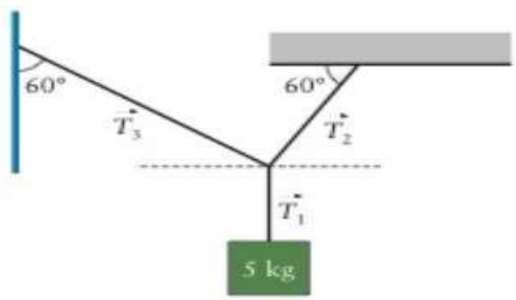

Figure 4.62

Solution:

Using the equilibrium condition in the y direction, $\sum F_y = 0 \rightarrow T_1 - F_g = 0$ This leads to $\mathrm{T_1} = \mathrm{F_g} = mg = 5 \times 9.8 = 49$ N. Thus, the upward force $\mathrm{T_1}$ exerted by the vertical string on the block balances the gravitational force.

Resolve the forces acting on the knot into their components:

Force	x Component	Y Component
$\boldsymbol{T_1}$	0	-94 N
$\boldsymbol{T_2}$	$T_2 \cos 60°$	$T_2 \sin 60°$
$\boldsymbol{T_3}$	$-T_3 \cos 30°$	$T_3 \sin 30°$

Knowing that the knot is in equilibrium (**a** = 0) allows us to write

$$\sum F_x = T_2\, cos\, 60° - T_3\, cos\, 30° = 0 \qquad (1)$$
$$\sum F_x = T_2\, sin\, 60° + T_3\, sin\, 30° + (-49\ \mathrm{N}) = 0 \qquad (2)$$

From (1) $T_3 = \frac{\cos 60°}{\cos 30°} T_2 \rightarrow T_3 = 0.577\, T_2 \quad (3)$

Substitute (3) into (2)

$$T_2\, sin\, 60° + (0.577\, T_2)\, sin\, 30° + (-49\ \mathrm{N}) = 0$$
$$T_2 = 42.6\ N$$
$$T_3 = 0.577\, T_2 = 24.6\ \mathrm{N}$$

4.7. Two horizontal forces, $\overrightarrow{F_1}$ and $\overrightarrow{F_2}$, are pulling an object mass *m* = 1.5 kg from two opposite sides. $\overrightarrow{F_1}$ pulls to the right and $\overrightarrow{F_2}$ pulls to the left. The magnitude of $\overrightarrow{F_1}$ is 25 N. The object moves strictly along the horizontal *x*-axis, which we choose as positive to the right. Find the magnitude of $\overrightarrow{F_2}$ if the object's horizontal acceleration is
(a) a=10m/s ;(b) a=0 m/s ; and (c) a = –10 m/s^2.

Solution:

$$\sum F = ma \qquad F_1 - F_2 = ma \qquad F_2 = F_1 - ma$$

a) F_2 = 25 - (1.5)(10) = 25-15 = 10 N

b) F_2 = 25 - (1.5)(0) = 25 N

c) F_2 = 25 - (1.5) (-10) =25+15 = 40 N

4.10. Fig. 4.64 shows two blocks of masses *M* and *m*. The horizontal surface allows for frictionless motion. The string tied to the two blocks is massless and passes over a massless pulley that rotates without friction. (a) What resulting motion of the two blocks do you predict? If *M* = 3.0 kg and *m* = 2 kg, (b) find the magnitude of the acceleration of the sliding block, (c) find the magnitude of the acceleration of the hanging block, and (d) find the magnitude of the tension in the massless string.

Solution:

(a) The resulting motion of the two blocks to the down due to gravity

(b) The acceleration of the two blocks *m* and *M* is the same.

Applying the Newton's second law $to\ m$

$\sum F_x$=0 , $\sum F_y = mg - T = ma$

$$(2)(9.8) - T = 2a$$

$$19.6 - T = 2a \qquad (1)$$

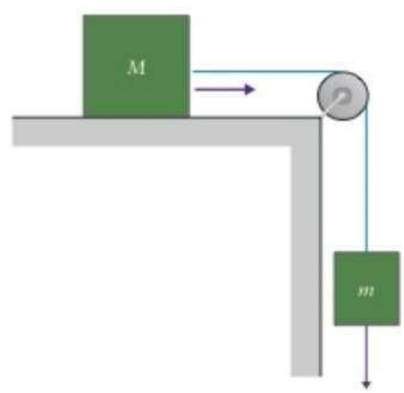

Figure 4.64

Applying the Newton's second law $to\ M$

$\sum F_y$=0 , $\sum F_x = T = Ma$

$$T = 3a \qquad (2)$$

Solving (1) and (2) to find

$a = 4\ \text{m/s}^2$

(d) Substitute a into (2) → $T = 12$ N

4.11. Fig. 4.65 shows two objects that are connected by a massless string. They are pulled along a frictionless surface by a horizontal external force. Using F_{ext} = 50 N, m_1 = 10 kg, and m_2 = 20 kg, calculate (a) the magnitude of the acceleration of the two objects, and (b) the magnitude of the tension ST in the string.

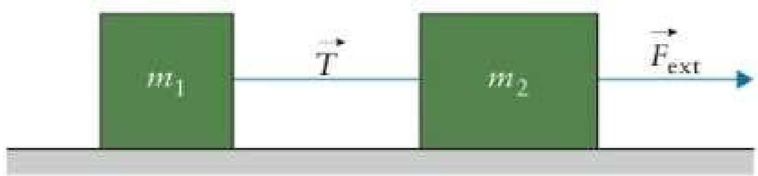

Figure 4.65

Solution:

(a) $\sum F = (m_1 + m_2)a$

$50 = 30\ a \ \rightarrow a = 1.67\ \text{m/s}^2$

(b) T=m_1a = $(10)(1.67) = 16.7$ N

4.12. A block of mass m_1 = 14 kg, on a frictionless inclined plane with an angle of θ = 35° with the horizontal, is connected to another block of mass m_2 = 6 kg by a massless string that passes over a pulley as shown in Fig.4.66. Take the pulley as an ideal pulley. Calculate the acceleration of the blocks and the tension in the string.

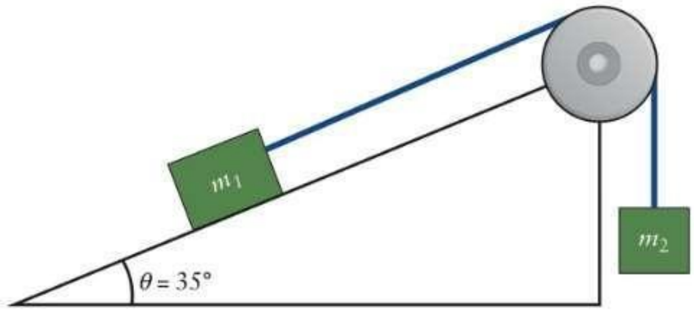

Figure 4.66

Solution:

We choose x to be parallel to the plane and y perpendicular to it. Applying the Newton's second law *to* m_2 with assuming that the motion is upward

$$\sum F_x = 0, \qquad \sum F_y = T - m_2 g = m_2 a$$
$$T - (6)(9.8) = 6a$$
$$T - 58.8 = 6a \qquad (1)$$

Applying Newton's second law *to* m_1

$$\sum F_x = m_1 g \sin(35°) - T = m_1 a$$
$$(14)(9.8)(0.57) - T = 14\,a$$
$$78.2 - T = 14\,a \qquad (2)$$

$$\sum F_y = N - m_1 g \cos(35°) = 0$$
$$N = 112.4 \text{ N}$$

Solving (1) and (2) to find

$$a = 0.97 \text{m/s}^2$$

Substituting a into either (1) or (2) to find

$$T = 64.6 \text{ N}$$

SOL. PROB. OF CHAP. 5: Center of Mass and Linear Momentum

5.5. A system is made up of point masses P_1 at position (-1 m, 5 m, 7 m), P_2 at position (3 m, 3 m, 3 m), and P_3 at position (9 m, -5 m, -2 m). Find the centre of mass of the system if (a) each of the point masses has the same mass, and (b) $m_1 = 2m_2 = 4m_3$.

Solution:

A) When $m_1 = m_2 = m_3$

$$r_{c.m.} = \frac{1}{M}\sum r_i m_i$$

$$x_{c.m.} = \frac{1}{M}\sum x_i m_i$$

$$x_{c.m.} = \frac{1}{3m}\sum(-m + 3m - 5m) = \frac{11}{3}$$

$$y_{c.m.} = \frac{1}{M}\sum y_i m_i$$

$$y_{c.m.} = \frac{1}{3m}\sum(5m + 3m - 5m) = 1$$

$$z_{c.m.} = \frac{1}{M}\sum z_i m_i$$

$$z_{c.m.} = \frac{1}{3m}\sum(7m + 3m - 2m) = \frac{8}{3}$$

$$r_{c.m.} = \left(\frac{11}{3}, 1, \frac{8}{3}\right)\text{m}$$

B) When $m_1 = 2m_2 = 4m_3$

$$r_{c.m.} = \frac{1}{M}\sum r_i m_i$$

$$M = m + \frac{1}{2}m + \frac{1}{4}m = \frac{7}{4}m$$

$$x_{c.m.} = \frac{4}{7m}\sum\left(-m + \frac{3}{2}m + \frac{9}{4}m\right) = \frac{11}{7}$$

$$y_{c.m.} = \frac{4}{7m}\sum\left(5m + \frac{3}{2}m - \frac{5}{4}m\right) = 3$$

$$z_{c.m.} = \frac{4}{7m}\sum\left(7m + \frac{3}{2}m - \frac{2}{4}m\right) = \frac{32}{7}$$

$$r_{c.m.} = \left(\frac{11}{7}, 3, \frac{32}{7}\right)\,\mathrm{m}$$

5.7. A student of mass 75 kg is in a small rowboat of mass 95 kg resting on a calm lake. How far will the boat move if the student walks from the bow to the stern of the boat? The distance from the bow to the stern is 2.5 m. Ignore any horizontal force exerted by the water.

Solution:

$$x_{c.m.} = \frac{1}{M}\sum x_i m_i$$

$$x_{c.m.} = \frac{x_1 m_1 + x_2 m_2}{m_1 + m_2}$$

$$x_{c.m.} = \frac{(L)m_1 + \left(\frac{L}{2}\right)m_2}{m_1 + m_2}$$

$$x_{c.m.} = \frac{(75)(2.5) + (59)(1.25)}{75 + 95}$$

$$x_{c.m.} = 1.8\ \mathrm{m}$$

If the student walks from the bow to the stern of the boat, boat move distance x to the right, center of the mass (gravity) will be the same

$$x_{c.m.} = \frac{1}{M}\sum x_i m_i$$

$$x_{c.m.} = \frac{x_1 m_1 + x_2 m_2}{m_1 + m_2}$$

$$x_{c.m.} = \frac{x m_1 + (x + 1.25) m_2}{m_1 + m_2}$$

$$1.8 = \frac{x(75) + (x + 1.25)(95)}{75 + 95}$$

$$x = 1.1 \text{ m}$$

5.16. Fig. 5.21(a) shows two objects of masses m_1 and m_2 travelling with velocities v_1 and v_2 toward a collision point (chosen at the origin). After a perfectly inelastic collision, the combined object travels with angle f relative to the positive x-axis, as indicated in Fig. 5.21(b). (a) Derive the x- and y-component formulas for the velocity of the combined object after the collision.

Solution:

In x axis

$$m_1 v_1 + m_2 v_{2x} \cos\theta = (m_1 + m_2) v_{fx} \cos\phi$$

$$v_{fx} = \frac{m_1 v_1 + m_2 v_{2x} \cos\theta}{(m_1 + m_2)\cos\phi}$$

In y axis

$$m_2 v_{2y} \sin\theta = (m_1 + m_2) v_{fy} \sin\phi$$

$$v_{fy} = \frac{m_2 v_{2y} \sin\theta}{(m_1 + m_2)\sin\phi}$$

5.20. An object of mass *m* = 3.0 kg makes a perfectly inelastic collision with a second object that is initially at rest. The combined object moves after the collision with a speed equal to one-third of the object that was initially moving. What is the mass of the object that was initially at rest?

Solution:

$$m_1 v_1 + m_2 v_2 = (m_1 + m_2) v_f$$

$$3v_1 = (3 + m_2)\frac{1}{3}v_1$$

$$m_2 = 6kg$$

5.21. An object of mass *m* = 8 g is fired into a larger object of mass *M* = 250 g that was initially at rest at the edge of a table. The smaller object becomes embedded in the larger object, and the combined object lands on the floor a distance of 2.0 m away from the table. If the tabletop is 1.0 m above the floor, determine the initial speed of the smaller object.

Solution:

$$m_1 v_1 + m_2 v_2 = (m_1 + m_2) v_f$$

The final velocity of the combined object landing to the floor has two dimension $v_f = (v_{fx}, v_{yf})$, $v_{fx}=v_{ox}$ and $v_{fy}=0$

Using the projectile equation

Vertically;

$$\Delta y = v_{0y}t - \frac{1}{2}gt^2$$

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

$$t = 0.45 \text{ s}$$

Horizontally;

$$\Delta x = v_{0x}t + \frac{1}{2}a_x t^2$$

$$\Delta x = v_{0x}t$$

$v_{0x} = \frac{\Delta x}{t} = \frac{2}{0.45} = 4.44\ \mathrm{m/s}$, this the final velocity of the combined object after collision.

So the initial velocity of small mass

$$m_1 v_1 + m_2 v_2 = (m_1 + m_2) v_f$$

$$(8 \times 10^{-3}) v_1 + (250 \times 10^{-3})(0) = (258 \times 10^{-3})(4.44)$$

$$v_1 = 143.2\ \mathrm{m/s}$$

SOL. PROB. OF CHAP. 6: Torque and Equilibrium

6.1. If the torque required to loosen a nut has a magnitude of τ = 40 N m, what minimum force must be exerted at the end of a 30-cm-long wrench?

Solution:

The minimum force is $F_{min} = \frac{\tau}{d}$

$$F_{min} = \frac{40\ \text{Nm}}{0.3\ \text{m}} = 133\ \text{N}$$

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6. 6. A force of 120 N in positive x-direction is applied perpendicularly to the middle of a 3-m-long stick standing vertically. What is the magnitude and direction of torque about each end of the stick?

Solution:

The force is applied at the centre of the rod. Because of this force, the rod translates and the centre of mass of rod accelerates, but the rod does not rotate and remains in rotational equilibrium. In this case, the torque about the centre of mass is zero.

6.23. Determine the torque about the knee by a hamstring tendon exerting an 80 N force on bones in the lower leg, as shown in Fig. 6.69. Assume that the knee bend is 75°, and that the tendon acts horizontally 6.0 cm below the knee, the pivot point.

Solution:

$\vec{\tau} = \vec{F} \times \vec{r}$

$$\tau = Frsin\theta = (80\ \text{N})(6.0 \times 10^{-2}\text{m})\sin 75°$$

$\tau = 4.6$ Nm

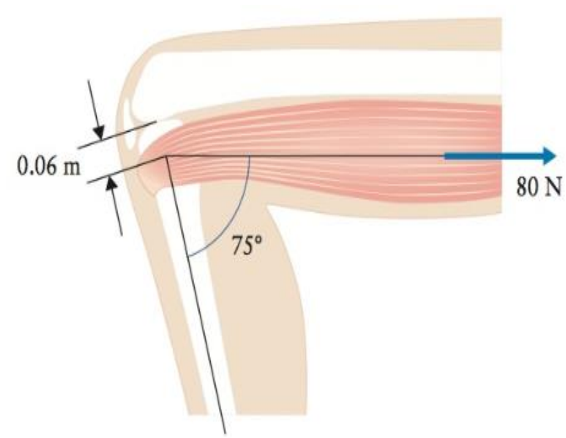

Figure 6.69

6.26. A 10 kg object rotating on a circle of 2.5 m has an angular momentum of 0.75 kg m^2/s with respect to the centre of the circle. What is its speed?

Solution:

When a particle of mass m moves with speed v on the perimeter of a circle with radius r, its angular momentum is given as:

$$L = rp = rmv$$

$$v = \frac{L}{rm} = \frac{0.75 \text{ kg m}^2/\text{s}}{(2.5 \text{ m})(10 \text{ kg})}$$

$$v = 0.03 \text{ m/s}$$

6.27. Two objects of masses m_1 =157.6 kg and m_2 = 5 4.5 kg, with speeds of v_1 = 5 3.6 m/s and v_2 = 5 5.2 m/s, are moving in a perpendicular direction around the origin O, as shown in Fig 6.71. If at one moment their distance from the origin O is r_1 =5 2.5 m and r_2 = 5 3.8 m, what is their total (net) angular momentum about point O?

Solution:

For a system of particles, the total angular momentum, $\vec{L}_{\text{tot}}$, of the system with respect to the origin is the vector sum of the angular momentum $\vec{L}_1$, of the individual particles, when the angular momentum directed with clockwise, the momentum vector (-), whereas it is (+) when directed encounter clockwise,

$$\vec{L}_{tot} = \vec{L}_1 + \vec{L}_2$$

$$\vec{L}_{tot} = -r_1 m_1 \vec{v_1} + r_2 m_2 \vec{v_2}$$

$$\|\vec{L}_{tot}\| = L_{tot} = -(2.5 \text{ m})(7.6 \text{ kg})(3.6 \text{ m/s}) + (3.8 \text{ m})(4.5 \text{ kg})(5.2 \text{ m/s})$$

$$L_{tot} = 20.5 \text{ kg m}^2/\text{s}$$

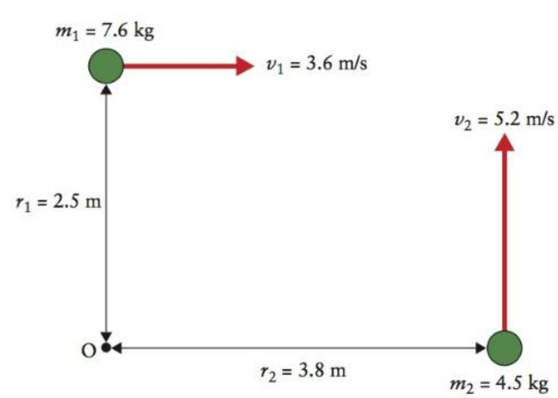

Figure 6.71

SOL. PROB. OF CHAP. 7: Energy and Its Conservation

7.3. A standard man climbs the stairs in a building. Assume that he reaches the fourth floor (16 m above the ground floor) in 15 seconds. How much work has the standard man done, and what was the power used for the climb?

Solution:

Standard man mass= 70 kg, h=16 m, t=15 s

$$W = \vec{F}.\vec{r} = Frcos\theta = mgh\,cos\theta = 70 \times 9.8 \times 16 = 10976\ \mathrm{J} = 11\ \mathrm{kJ}$$

$$P = \frac{\Delta W}{\Delta t} = \frac{11 \times 10^3}{15} = 730\ \mathrm{W}$$

7.9. A shopper in a grocery store pushes a shopping cart with a force of 40 N directed at an angle of 30° below the horizontal. What is the work the shopper does on the cart for a horizontal distance of 10 m?

Solution:

$$W = \vec{F}.\vec{r} = Frcos\theta = 40 \times 10cos(-30) = 346.4\ \mathrm{J} \cong 350\ \mathrm{J}$$

7.17. A child and sled with a combined mass of 50 kg slide down a frictionless hill. If the sled starts from rest and has a speed of 3.0 m/s at the bottom, what is the height of the hill?

Solution:

$$E_i = E_f$$

$$\frac{1}{2}mv_i^2 + mgh_i = \frac{1}{2}mv_f^2 + mgh_f$$

$$h_i = \frac{1}{2g}v_f^2 = \frac{9}{2 \times 9.8} = 0.46\ \mathrm{m} = 46\ \mathrm{cm}$$

7.19. An object of mass 0.5 kg has a speed of 2.5 m/s at position 1 and a kinetic energy of 10.0 J at position 2. Calculate (a) its kinetic energy at position 1, (b) its speed at position 2, and (c) the total work done on the object as it moves from position 1 to position 2.

Solution:

a) $K_i = \frac{1}{2} m v_i^2 = \frac{1}{2} \times 0.5 \times (2.5)^2 = 1.6$ J

b) $v_f = \sqrt{2K_f/m} = \sqrt{\frac{2\times 10}{0.5}} = 6.3$ m/s

c) $W = \Delta K = K_f - K_i = 10 - 1.6 = 8.4$ J

7.30. An object of mass m_1 = 7.5 g moves to the right at 25 cm/s. It makes an elastic head-on collision with a second object of mass m_2 = 12.5 g. The second object is at rest before the collision. Calculate (a) the speed of each object after the collision and (b) the fraction of the initial kinetic energy that is transferred to the second object.

Solution:

Because it is an elastic collision

$p_i = p_f$ (1) and $K_i = K_f$ (2)

$$m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f}$$

$$(7.5)\,(25) = (7.5\,) v_{1f} + (12.5\,) v_{2f}$$

$$187.5 = (7.5\,) v_{1f} + (12.5\,) v_{2f} \qquad (1)$$

$$\frac{1}{2} m_1 {v_{1i}}^2 + \frac{1}{2} m_2 {v_{2i}}^2 = \frac{1}{2} m_1 {v_{1f}}^2 + \frac{1}{2} m_2 {v_{2f}}^2$$

$$(7.5)(25)^2 = (7.5\,) {v_{1f}}^2 + (12.5\,) {v_{2f}}^2$$

$$4687.5 = (7.5\,) {v_{1f}}^2 + (12.5\,)\, {v_{2f}}^2 \qquad (2)$$

$$\text{From eq (1) } v_{2f} = \frac{187.5 - (7.5)v_{1f}}{(12.5)}$$

$$v_{2f} = 15 - 0.6\, v_{1f} \quad (3)$$

Applying (3) in (2)

$$(12)v_{1f}{}^2 - (225)v_{1f} - (1875) = 0$$

$$v_{1f} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} = \ 25\ c\text{m/s or} - 6.25\ c\text{m/s}$$

25 cm/s is not acceptable, thus, $v_{1f} = -6.25 \text{ cm/s}$

Substitute the value in (3)

$$v_{2f} = 18.75 \text{ cm/s}$$

b) $K_{1i} = 0.5\ (7.5 \times 10^{-3})(25 \times 10^{-2})^2 = 2.3 \times 10^{-4}$ J

$K_{2f} = 0.5\ (12.5 \times 10^{-3})(18.75 \times 10^{-2})^2 = 2.2 \times 10^{-4}$ J

$$\frac{K_{2f}}{K_{1i}} = \frac{2.2 \times 10^{-4}}{2.3 \times 10^{-4}} = 95.7\ \% \approx 96\%$$