# Chapter 5

1

## The laws of motion



1

# Lecture 03

2

## Applications



2

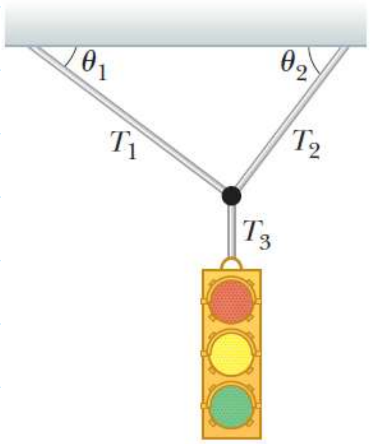
# A Traffic Light at Rest

Saturday, 30 January, 2021 12:35

Lecturer: Mustafa Al-Zyout, Philadelphia University, Jordan.


- R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.
- J. Walker, D. Halliday and R. Resnick, *Fundamentals of Physics*, 10th ed., WILEY,2014.
- H. D. Young and R. A. Freedman, *University Physics with Modern Physics*, 14th ed., PEARSON, 2016.
- H. A. Radi and J. O. Rasmussen, *Principles of Physics For Scientists and Engineers*, 1st ed., SPRINGER, 2013.


A traffic light weighing (122 N) hangs in equilibrium from a cable tied to two other cables fastened to a support as in Figure. The upper cables make angles of (37°) and (53°) with the horizontal. Find the magnitude of the tension in each cable.




SOLUTION

For the traffic light in the y direction:

$$\sum F_y = 0 \rightarrow T_3 - F_g = 0$$

$$T_3 = F_g = 122N$$

Apply the particle in equilibrium model to the knot:

(1) $\sum F_x = -T_1 \cos 37.0° + T_2 \cos 53.0° = 0$

(2) $\sum F_y = T_1 \sin 37.0° + T_2 \sin 53.0° + (-122N) = 0$

Solve Equation (1) for $T_2$ in terms of $T_1$:

(3) $T_2 = \frac{T_1 \cos 37.0°}{\cos 53.0°} = 1.33T_1$

Substitute this value for $T_2$ into Equation (2):

$$T_1 \sin 37.0° + (1.33T_1)(\sin 53.0°) - 122N = 0$$

$\Rightarrow T_1 = 73.4N$

$\Rightarrow T_2 = 1.33T_1 = 97.4N$

# The Runaway Car

Saturday, 30 January, 2021 12:36

Lecturer: Mustafa Al-Zyout, Philadelphia University, Jordan.


R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.

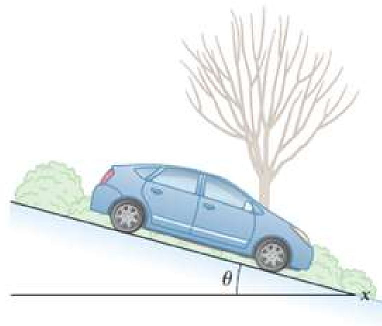
J. Walker, D. Halliday and R. Resnick, *Fundamentals of Physics*, 10th ed., WILEY,2014.

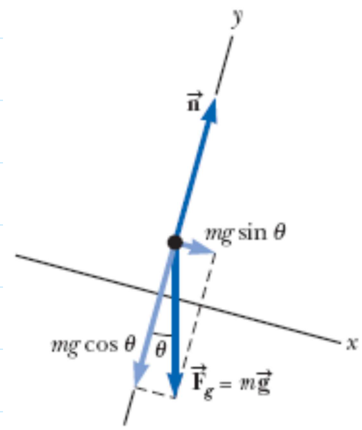
H. D. Young and R. A. Freedman, *University Physics with Modern Physics*, 14th ed., PEARSON, 2016.

H. A. Radi and J. O. Rasmussen, *Principles of Physics For Scientists and Engineers*, 1st ed., SPRINGER, 2013.


A car of mass (m) is on an icy driveway inclined at an angle $\theta$ as in the figure.

- Find the acceleration of the car, assuming the driveway is frictionless.
- what is the car's speed as it arrives there?
- Determine the normal force.




SOLUTION

The only forces acting on the car are the normal force $\vec{n}$ exerted by the inclined plane, which acts perpendicular to the plane, and the gravitational force $\vec{F}_g = m\vec{g}$, which acts vertically downward. For problems involving inclined planes, it is convenient to choose the coordinate axes with x along the incline and y perpendicular to it. With these axes, we represent the gravitational force by a component of magnitude $mg\, sin\, \theta$ along the positive x axis and one of magnitude $mg\, cos\, \theta$ along the negative y axis. Our choice of axes results in the car being modeled as a particle under a net force in the x direction and a particle in equilibrium in the y direction.

Apply these models to the car:

(1) $\sum F_x = mg\, sin\, \theta = ma_x$

(2) $\sum F_y = n - mg\, cos\, \theta = 0$

Solve Equation (1) for $a_x$:

(3) $a_x = g\, sin\, \theta$

Note that the acceleration component $a_x$ is independent of the mass of the car!

SOLUTION

To find the final velocity of the car:

$v_{xf}^2 = 2a_x d$

$v_{xf} = \sqrt{2a_x d} = \sqrt{2gd\, sin\, \theta}$

SOLUTION

From Equation (2), we conclude that the component of $\vec{F}_g$ perpendicular to the incline is balanced by the normal force; that is:

$n = mg \cos\theta$

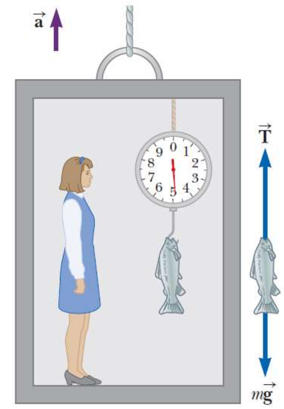
# Weighing a Fish in an Elevator

Saturday, 30 January, 2021 12:37

Lecturer: Mustafa Al-Zyout, Philadelphia University, Jordan.


R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.
J. Walker, D. Halliday and R. Resnick, *Fundamentals of Physics*, 10th ed., WILEY,2014.
H. D. Young and R. A. Freedman, *University Physics with Modern Physics*, 14th ed., PEARSON, 2016.
H. A. Radi and J. O. Rasmussen, *Principles of Physics For Scientists and Engineers*, 1st ed., SPRINGER, 2013.


A person weighs a fish of mass m on a spring scale attached to the ceiling of an elevator.




- Show that if the elevator accelerates **upward**, the spring scale gives a reading that is different from the weight of the fish.
- Show that if the elevator accelerates **downward**, the spring scale gives a reading that is different from the weight of the fish.
- Evaluate the scale readings for a (40 N) fish if the elevator moves with an acceleration $a = 2\ m/s^2$ .

SOLUTION

Inspect the diagrams of the forces acting on the fish in the figure and notice that the external forces acting on the fish are the downward gravitational force $\vec{F_g} = m\vec{g}$ and the force $\vec{T}$exerted by the string. If the elevator is either at rest or moving at constant velocity, the fish is a particle in equilibrium, so $\sum F_y = T - F_g = 0$ or $T = F_g = mg$. (Remember that the scalar $mg$ is the weight of the fish.)

Now suppose the elevator is moving with an acceleration $\vec{a}$ . The fish is now a particle under a net force.

Apply Newton's second law to the fish:

$$\sum F_y = T - mg = ma_y$$

Solve for T:

(1) $T = ma_y + mg = mg\left(\frac{a_y}{g} + 1\right) = F_g\left(\frac{a_y}{g} + 1\right)$

Where we have chosen upward as the positive y direction. We conclude from Equation (1) that the scale reading T is greater than the fish's weight mg if $\vec{a}$ is upward, so $a_y$is positive, and that the reading is less than mg if $\vec{a}$is downward, so $a_y$is negative.

SOLUTION

Evaluate the scale reading from Equation (1) if $\vec{a}$ is upward:

$$T = 40.0N\left(\frac{2.00m/s^2}{9.80m/s^2} + 1\right) = 48.2N$$

Evaluate the scale reading from Equation (1) if $\vec{a}$is downward:

$$T = 40.0N\left(\frac{-2.00m/s^2}{9.80m/s^2} + 1\right) = 31.8N$$

Suppose the elevator cable breaks and the elevator and its contents are in free fall. What happens to the reading on the scale?

Answer If the elevator falls freely, its acceleration $a_y = -g$. We see from Equation (1) that the scale reading T is zero in this case; that is, the fish appears to be weightless.

# One Block Pushes Another

Saturday, 30 January, 2021 12:36


Lecturer: Mustafa Al-Zyout, Philadelphia University, Jordan.

R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.

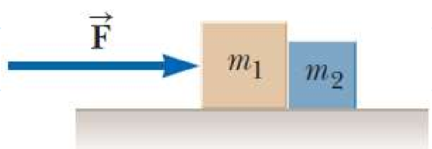
J. Walker, D. Halliday and R. Resnick, *Fundamentals of Physics*, 10th ed., WILEY,2014.

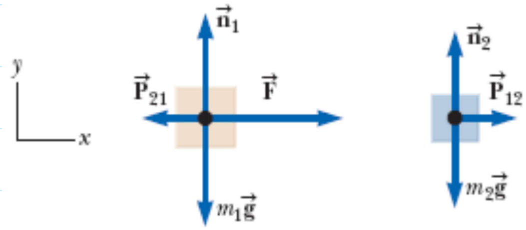
H. D. Young and R. A. Freedman, *University Physics with Modern Physics*, 14th ed., PEARSON, 2016.

H. A. Radi and J. O. Rasmussen, *Principles of Physics For Scientists and Engineers*, 1st ed., SPRINGER, 2013.


Two blocks of masses $m_1$ and $m_2$ , with $m_1 > m_2$ , are placed in contact with each other on a frictionless, horizontal surface as shown. A constant horizontal force $\vec{F}$ is applied to $m_1$ .

- Find the magnitude of the acceleration of the system.
- Determine the magnitude of the contact force between the two blocks.




SOLUTION

Both blocks must experience the same acceleration because they are in contact with each other and remain in contact throughout the motion.

Apply Newton's second law to the combination in the x direction to find the acceleration:

$$\sum F_x = F = (m_1 + m_2)a_x$$

(1) $a_x = \frac{F}{m_1+m_2}$

SOLUTION

The only horizontal force acting on $m_2$ is the contact force $\vec{P}_{12}$ (the force exerted by $m_1$ on $m_2$), which is directed to the right.

Apply Newton's second law to $m_2$:

(2) $\sum F_x = p_{12} = m_2 a_x$

Substitute the value of the acceleration $a_x$ given by Equation (1) into Equation (2):

(3)$P_{12} = m_2 a_x = \left(\frac{m_2}{m_1+m_2}\right) F$

The horizontal forces acting on $m_1$ are the applied force $\vec{F}$ to the right and the contact force $\vec{P}_{21}$ to the left (the force exerted by $m_2$ on$m_1$). From Newton's third law, $\vec{P}_{21}$ is the reaction force to$\vec{P}_{12}$, so $P_{21} = P_{12}$.

Apply Newton's second law to$m_1$:

(4) $\sum F_x = F - P_{21} = F - P_{12} = m_1 a_x$

Solve for $P_{12}$and substitute the value of $a_x$from Equation (1):

$$P_{12} = F - m_1 a_x = F - m_1\left(\frac{F}{m_1 + m_2}\right) = \left(\frac{m_2}{m_1 + m_2}\right) F$$

# The Atwood Machine

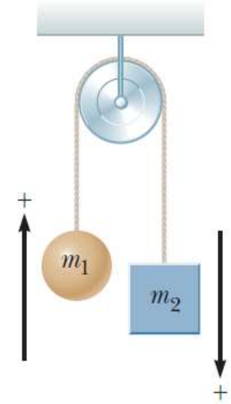
Saturday, 30 January, 2021 12:38


Lecturer: Mustafa Al-Zyout, Philadelphia University, Jordan.

- R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.
- J. Walker, D. Halliday and R. Resnick, *Fundamentals of Physics*, 10th ed., WILEY,2014.
- H. D. Young and R. A. Freedman, *University Physics with Modern Physics*, 14th ed., PEARSON, 2016.
- H. A. Radi and J. O. Rasmussen, *Principles of Physics For Scientists and Engineers*, 1st ed., SPRINGER, 2013.


When two objects of unequal mass are hung vertically over a frictionless pulley of negligible mass as in the Figure, the arrangement is called an Atwood machine. Determine:

- the magnitude of the acceleration of the two objects and
- the tension in the lightweight cord.




SOLUTION

If we define the upward direction as positive for object 1, we must define the downward direction as positive for object 2. With this sign convention, both objects accelerate in the same direction as defined by the choice of sign.

Apply Newton's second law to object 1:

$$(1)\ \sum F_y = T - m_1 g = m_1 a_y$$

Apply Newton's second law to object 2:

$$(2)\ \sum F_y = m_2 g - T = m_2 a_y$$

Add Equation (2) to Equation (1), noticing that T cancels:

$$-m_1 g + m_2 g = m_1 a_y + m_2 a_y$$

Solve for the acceleration:

$$(3)\ a_y = \left(\frac{m_2 - m_1}{m_1 + m_2}\right) g$$

Substitute Equation (3) into Equation (1) to find T:

$$(4)\ T = m_1(g + a_y) = \left(\frac{2m_1 m_2}{m_1 + m_2}\right) g$$

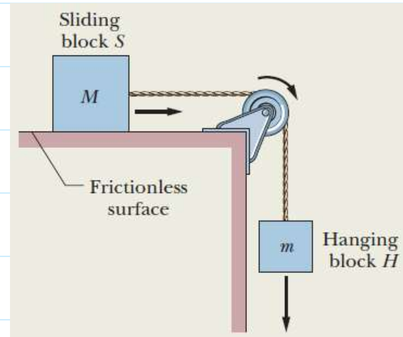
# Block on table, block hanging

Saturday, 30 January, 2021 12:39

Lecturer: Mustafa Al-Zyout, Philadelphia University, Jordan.
R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.
J. Walker, D. Halliday and R. Resnick, *Fundamentals of Physics*, 10th ed., WILEY,2014.
H. D. Young and R. A. Freedman, *University Physics with Modern Physics*, 14th ed., PEARSON, 2016.
H. A. Radi and J. O. Rasmussen, *Principles of Physics For Scientists and Engineers*, 1st ed., SPRINGER, 2013.

The figure shows a block S (the sliding block) with mass $M = 3.3\ kg$ . The block is free to move along a horizontal frictionless surface and connected, by a cord that wraps over a frictionless pulley, to a second block H (the hanging block), with mass $m = 2.1\ kg$. The cord and pulley have negligible masses compared to the blocks. The hanging block H falls as the sliding block S accelerates to the right. Find:

- the acceleration of block S or H,
- the tension in the cord.




## Solution

Apply Newton's second law to the sliding block in the x direction. There is only one force component, which is T. Thus:

$$\sum F = Ma \Rightarrow T = ma\ (1)$$

Apply Newton's second law to the hanging block in the y direction. There two forces: $m\vec{g}$acting in the same direction of the acceleration, and $\vec{T}$acting in the opposite direction of the acceleration. Thus:

$$mg - T = ma\ (2)$$

Subtracting these two equations eliminates T. Then solving for a yields

$$a = \frac{m}{M+m} g\ (3)$$

Substituting this result into equation (1) yields:

$$T = \frac{Mm}{M+m} g\ (4)$$

Putting in the numbers gives, for these two quantities:

$$a = \frac{m}{M+m} g = \frac{2.1kg}{3.3kg + 2.1kg}(9.8m/s^2) = 3.8m/s^2$$

$$T = \frac{Mm}{M+m} g = \frac{(3.3kg)(2.1kg)}{3.3kg + 2.1kg} = 13N$$