Chapter 4: Applications of Forces

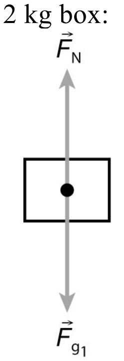
Mini Investigation: Friction from Shoes, page 161

A. Answers may vary. Sample answer:
A large or heavier shoe likely experiences a greater frictional force than a smaller size or lighter shoe. Dividing the maximum force of friction by the force of gravity of the shoe eliminates the effect of mass on the frictional force, thus making the comparison of the results fairer.

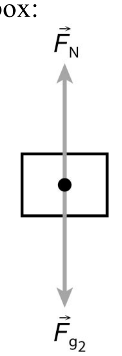
Section 4.1: Gravitational Force Near Earth

Tutorial 1 Practice, page 166

1. (a) FBD for the 12 kg box:



FBD for the 38 kg box:



(b) Choose up as positive. So down is negative.
Determine the force of gravity of the box.

$$\begin{aligned} F_{g1} &= m_1 g \\ &= (12\text{ kg})(-9.8\text{ m/s}^2) \\ F_{g1} &= -120\text{ N} \end{aligned}$$

Since the box is at rest, the net force on the box is zero.

$$\begin{aligned} F_N + F_{g1} &= 0 \\ F_N + (-120\text{ N}) &= 0 \\ F_N &= +120\text{ N} \end{aligned}$$

The normal force acting on the box is 120 N [up].

(c) Choose up as positive. So down is negative.
Determine the force of gravity of the box.

$$\begin{aligned} F_{g2} &= (m_1 + m_2)g \\ &= (12\text{ kg} + 38\text{ kg})(-9.8\text{ m/s}^2) \\ F_{g2} &= -490\text{ N} \end{aligned}$$

Since the box is at rest, the net force on the box is zero.

$$\begin{aligned} F_N + F_{g2} &= 0 \\ F_N + (-490\text{ N}) &= 0 \\ F_N &= +490\text{ N} \end{aligned}$$

The normal force acting on the box is 490 N [up].

2. (a) When the child is moving up at a constant velocity, the child is not accelerating. So the net force on the child is zero.
Choose up as positive. So down is negative.

$$\begin{aligned} F_N + F_g &= 0 \\ F_N + (36\text{ kg})(-9.8\text{ m/s}^2) &= 0 \\ F_N &= +350\text{ N} \end{aligned}$$

The normal force acting on the child is 350 N [up].

(b) When the child is moving down at a constant velocity, the child is not accelerating. So the net force on the child is zero.
Choose up as positive. So down is negative.

$$\begin{aligned} F_N + F_g &= 0 \\ F_N + (36\text{ kg})(-9.8\text{ m/s}^2) &= 0 \\ F_N &= +350\text{ N} \end{aligned}$$

The normal force acting on the child is 350 N [up].

(c) When the child is accelerating, the net force on the child is given by the equation $F_{net} = ma$.
Choose up as positive. So down is negative.

$$\begin{aligned} F_N + F_g &= F_{net} \\ F_N + mg &= ma \\ F_N &= m(a - g) \\ &= (36\text{ kg})[-1.8\text{ m/s}^2 - (-9.8\text{ m/s}^2)] \\ F_N &= +290\text{ N} \end{aligned}$$

The normal force acting on the child is 290 N [up].

3. When the person is accelerating upward, the net force on the person is given by $F_{net} = ma$.

Choose up as positive. So down is negative.

$$F_N + F_g = F_{net}$$

$$F_N + mg = ma$$

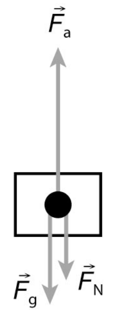
$$a = \frac{F_N + mg}{m}$$

$$= \frac{+840 \text{ N} + (72 \text{ kg})(-9.8 \text{ m/s}^2)}{72 \text{ kg}}$$

$$a = +1.9 \text{ m/s}^2$$

The acceleration of the person is 1.9 m/s^2 [up].

4. Draw a FBD of the chandelier.



The chandelier is at rest. So the net force on the chandelier is zero.

Choose up as positive. So down is negative.

$$\vec{F}_N + \vec{F}_g + \vec{F}_a = 0$$

$$F_N + (3.2 \text{ kg})(-9.8 \text{ m/s}^2) + 53 \text{ N} = 0$$

$$F_N = -22 \text{ N}$$

The normal force acting on the chandelier is 22 N [down].

Section 4.1 Questions, page 167

1. (a) According to Newton's second law, the net force acting on an object is given by the equation $\vec{F}_{net} = m\vec{a}$. In the absence of air resistance, the only force acting on a falling object is the force of gravity given by the equation $F_g = mg$.

For all objects,

$$ma = mg$$

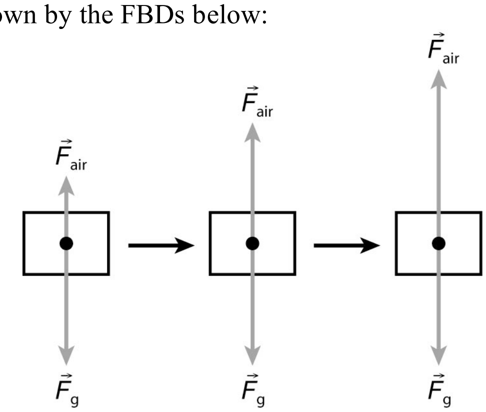
$$a = g$$

Therefore, in the absence of air resistance, all objects fall with the same acceleration *g*, which equals 9.8 m/s^2 [down].

2. Air resistance increases with the cross-sectional area and the speed of an object. A person with an open parachute has a greater cross-sectional area than the person alone, so the net upward force exerted by the air on the person with an open parachute is greater than that on the person alone. As a result, the downward acceleration of the person with an open parachute is slower and so will be the terminal speed.

3. Since air resistance, friction caused by air, increases with the cross-sectional area, an object with larger cross-sectional area experiences more air resistance than an object with smaller cross-sectional area and will fall more slowly in air. The gravitational field strength pulling an object downward, given by *mg*, increases with the mass of an object so a heavier object falls faster than a lighter object. So light objects with large cross-sectional area fall more slowly in air than heavy objects with small cross-sectional area.

4. As soon as the box leaves the plane, the box accelerates downward due to gravity. The initial acceleration is 9.8 /ms^2 and its speed increases from 0 m/s. As the speed increases, the upward force of air resistance increases. The box with the parachute has a large cross-sectional area, so the air resistance could increase to the point when its magnitude is greater than the force of gravity, as shown by the FBDs below:



When the upward force of air resistance is greater than the downward force of gravity, the net force on the box is directed upward while the box is still falling downward. The acceleration changes direction and the speed of the box decreases. When the box breaks free from the parachute, the air resistance on the box is so small that the only force acting on the box is the force of gravity. The box will be in free fall with an acceleration of 9.8 /ms^2 downward and its speed will increase.

5. (a) The mass of an object does not change with location or gravitational field strength. So the mass of the astronaut on the station is 74 kg.
(b) Weight of the astronaut on Earth's surface:

$$F_g = mg$$
$$= (74\ \cancel{\text{kg}})\left(9.8\frac{\text{N}}{\cancel{\text{kg}}}\right)$$
$$F_g = 725.2\ \text{N}$$

Weight of the astronaut on the station:

$$F_{gs} = mg_s$$
$$= (74\ \cancel{\text{kg}})\left(8.6\frac{\text{N}}{\cancel{\text{kg}}}\right)$$
$$F_{gs} = 636.4\ \text{N} \text{ (two extra digits carried)}$$

Find the difference:
725.2 N – 636.4 N = 89 N

The difference between the astronaut's weight on Earth's surface and his weight on the station is 89 N.
(c) The weight of an object is dependent on its location and the magnitude of the gravitational field strength at that location, whereas the mass of an object is the quantity of matter in the object and is independent on its location or the magnitude of the gravitational field strength at that location. So the weight of the astronaut changes but not his mass.
(d) When the station accelerates upward, the astronaut experiences a pull downward on the station due to the force of gravity and feels heavier. When the station accelerates downward, the astronaut feels lighter. As the station orbits Earth, it accelerates downward to a point where the astronaut floats in the station (both the astronaut and the station are under free fall); the astronaut will appear weightless.

6. Table 1

Latitude (°)	Weight of object (N)	$\vec{g}$ (N/kg [down])	Distance from Earth's centre (km)
0 (equator)	**195.61**	9.7805	6378
30	**195.87**	9.7934	6373
60	**196.38**	9.8192	6362
90 (North Pole)	**196.64**	9.8322	6357

(a) 196.64 N – 195.61 N = 1.03 N
The difference in weight of the object from the equator to North Pole is 1.03 N.
(b) The weight changes at different latitudes because it depends on the location and the magnitude of Earth's gravitational field strength at that latitude. The gravitational field strength is greater at the North Pole, which is closer to Earth's centre than that at the equator, which is farther away from Earth's centre.
(c) The gravitational field strength increases with latitude because the greater the latitude (at the North Pole), the closer is the location from Earth's centre. As a result, the attraction by Earth's gravitational field increases.
7. (a) The mass of the cargo box will remain unchanged because the mass of an object is unaffected by its location or the magnitude of the gravitational field strength at that location.
(b) Determine the force of gravity acting on the box. Choose up as positive. So down is negative.

$$F_g = mg$$
$$= (32.00\ \text{kg})(-9.8\ \text{N/kg})$$
$$F_g = -310\ \text{N}$$

The weight of the box on Earth's surface is 310 N.
(c) Use the equation $\vec{F}_g = m\vec{g}$ to determine the gravitational field strength, $\vec{g}_m$, on the surface of the Moon. Choose up as positive. So down is negative.

$$F_m = mg_m$$
$$g_m = \frac{F_m}{m}$$
$$= \frac{-52.06\ \text{N}}{32.00\ \text{kg}}$$
$$g_m = -1.627\ \text{N/kg}$$

The gravitational field strength on the surface of the Moon is 1.627 N/kg [down].

8. Table 2

Quantity	Definition	Symbol	SI unit	Method of measuring	Variation with location
mass	the quantity of matter in an object	m	kg	measure using a balance with standard masses	does not change due to location
weight	a measure of the force of gravity on an object	$\vec{F}_g$	N	measure the force of gravity on object using a spring scale or force sensor and divide by the mass	changes with the gravity of the location

9. Table 3

Planet	Weight (N)	$\vec{g}$ (N/kg)
Mercury	188	**3.3**
Venus	462	**8.1**
Jupiter	**150**	26

10. When an object sits on top of a scale, the reading of the scale is equal to the normal force.

(a) When the object is at rest, $F_{\text{net}} = 0$. Add all forces acting on the object. Choose up as positive. So down is negative.

$$F_{\text{N}} + F_{\text{g}} = 0$$

$$F_{\text{N}} + (24\ \cancel{\text{kg}})\left(-9.8\ \frac{\text{N}}{\cancel{\text{kg}}}\right) = 0$$

$$F_{\text{N}} = +240\ \text{N}$$

The reading on the scale is 240 N.

(b) When the object is at rest, $F_{\text{net}} = 0$. Add all forces acting on the object. Choose up as positive. So down is negative.

$$F_{\text{N}} + F_{\text{g}} + F_{\text{a}} = 0$$

$$F_{\text{N}} + (24\ \cancel{\text{kg}})\left(-9.8\ \frac{\text{N}}{\cancel{\text{kg}}}\right) + (-52\ \text{N}) = 0$$

$$F_{\text{N}} = +290\ \text{N}$$

The reading on the scale is 290 N.

(c) When the object is at rest, $F_{\text{net}} = 0$. Add all forces acting on the object. Choose up as positive. So down is negative.

$$F_{\text{N}} + F_{\text{g}} + F_{\text{a}} = 0$$

$$F_{\text{N}} + (24\ \cancel{\text{kg}})\left(-9.8\ \frac{\text{N}}{\cancel{\text{kg}}}\right) + (+74\ \text{N}) = 0$$

$$F_{\text{N}} = +160\ \text{N}$$

The reading on the scale is 160 N.