Section 3.4: Newton's Third Law of Motion

Tutorial 1 Practice, page 138

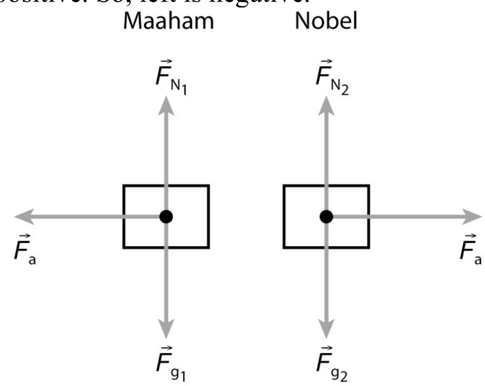
1. (a) The pressure generated by the burning rocket fuel provides an action force that causes the expanding hot gases to accelerate from the bottom of the rocket. According to Newton's third law, the expanding hot gases exert a reaction force that pushes up on the rocket. When this reaction force is greater than the force of gravity that is pulling the rocket down, the rocket can accelerate out of Earth's atmosphere.
(b) The engine at the back of the motorboat exerts an action force on the water in the direction of west. According to Newton's third law, the water exerts an equal but opposite force on the motorboat, causing the motorboat to accelerate east in the water.
(c) Football player 1 exerts an action force toward football player 2. According to Newton's third law, player 2 exerts an equal but opposite force toward player 1. The players will hold together, stopping player 2 from gaining ground toward the goal.

Mini Investigation: Demonstrating the Third Law, page 138

A. Answers may vary. Sample answers:
(a) When I sit in a chair and push my arms against a wall, the force of my arm muscles on the wall causes an equal force of the wall against my arms. I move away from the wall in the chair.
(b) When I sit in a chair not touching a wall, the force of my arm muscles on my shoulders causes an equal force of my shoulders against my arms. I do not move in the chair.
(c) When I stand on a bathroom scale and push down on the desk beside me, the force of my arms on the table causes a force of the table against my arms (or hands). I weigh less than when I do not have a table for support.
(d) When I stand on a bathroom scale and push down on my head with my hands, the force of my arms on my head causes a force of my head against my arms (or hands). I weigh the same as when I do not push down on my head.
(e) When I use a spring-loaded ballistics cart to fire a ball horizontally, the force of the spring on the ball causes a force on the ball that is pushing back on the spring. The spring pushes the ball when released.
(f) When the fan on a fan cart (without a sail) is directed to the right and then turned on, the force of the air on the fan blades causes a force of the blades on the air. The cart moves to the left.
(g) When the fan on a fan cart (with a sail) is directed toward the sail and then turned on, the force of the air on the fan blades and sail causes a force of the blades on the air and a force of the sail on the air. The cart does not move.

Tutorial 2 Practice, page 140

1. (a) The reaction force is the book pushing with 5.2 N backward on you.
(b) The reaction force is the water exerting a force of 450 N [E] on the boat.
(c) The reaction force is the boards exerting a force of 180 N [toward the hockey player]
2. (a) Draw a FBD for each person. Choose right as positive. So, left is negative.



For each person, the normal force and the force of gravity cancel each other. This means the applied force is equal to the net force.

For Maaham,

$$\vec{F}_a = \vec{F}_{net}$$
$$\vec{F}_a = m_1\vec{a}_1$$
$$F_a = (54\text{ kg})(-1.2\text{ m/s}^2) = -65\text{ N}$$
$$\vec{F}_a = 65\text{ N [left]}$$

The force that Nobel exerts on Maaham is 65 N [left].
(b) For Nobel,

$$F_{net} = F_a$$
$$m_2a_2 = +65\text{ N}$$
$$(62\text{ kg})a_2 = +65\text{ N}$$
$$a_2 = +1.0\text{ m/s}^2$$
$$\vec{a}_2 = 1.0\text{ m/s}^2\text{ [right]}$$

Nobel's acceleration is 1.0 m/s^2 [right].

3. Answers may vary. Sample answer:
The statement is not valid when the action and reaction forces are not acting on the same object. If they act on the same object, the net force will be zero and nothing will accelerate. When the horse pulls forward on the cart, the cart pulls backward on the horse. According to Newton's third law, the horse will cause a reaction force of the same magnitude on the cart in the opposite direction, making the cart accelerate forward. The action and reaction forces do not cancel because they do not act on the same object. In addition, the mass of the horse would be much greater than the mass of the cart, or vice versa.
4. (a) When the student pushes on the wall with a force of 87 N [S], the wall exerts an equal but opposite force of 87 N [N] on the student who is on the skateboard.
Choose north as positive. So, south is negative. For the student on the skateboard, the net force is equal to the reaction force exerted by the wall.

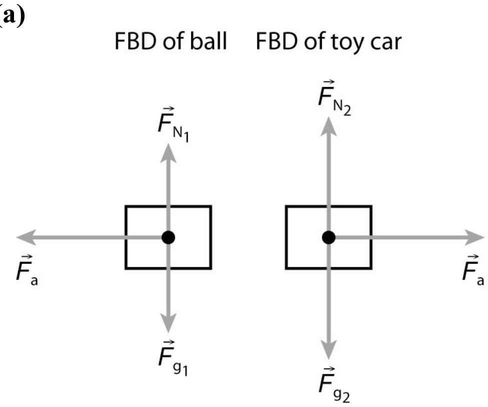
$$\begin{aligned} F_{\text{net}} &= F_{\text{a}} \\ ma &= +87\ \text{N} \\ (58\ \text{kg})a &= +87\ \text{N} \\ a &= +1.5\ \text{m/s}^2 \\ \vec{a} &= 1.5\ \text{m/s}^2\ [\text{N}] \end{aligned}$$

The acceleration of the student is 1.5 m/s^2 [N].
(b) From the equation, $a = \frac{F_{\text{net}}}{m}$, for a large value of m, the value for a will be very small. The wall does not seem to move because it is massive and anchored to the ground. The force that the student pushes on the wall is not strong enough to have any noticeable effect on the motion of the wall.

Section 3.4 Questions, page 141

1. (a) The reaction force is the road exerting a force of 240 N [forward] on the tire.
(b) The reaction force is the desk pushing with a force of 25 N [S] on you.
2. Answers may vary. Sample answers:
(a) The water expelled by the squid exerts an action force backward on the water. According to Newton's third law, the water exerts an equal but opposite force forward on the squid, causing the squid to move through the water.
(b) When you walk on a wagon, the bottoms of your feet exert a horizontal backward action force on the wagon. According to Newton's third law, the reaction force is caused by friction when the wagon pushes you to accelerate forward. You may fall off the wagon.
(c) As a helicopter hovers, its rotors cause a downward flow of air. According to Newton's third law, the air exerts an equal upward push back on the helicopter, allowing it to hover in a stationary position.
3. Answers may vary. Sample answers:
(a) As the astronaut pulls on the tether, according to Newton's third law, there is a reaction force in the opposite direction that draws her closer toward the space station.
(b) If the astronaut pulls forward on her space suit, according to Newton's third law, the space suit will cause a reaction force that pulls her backward away from the space station so she cannot push herself back to the station.
(c) The astronaut could push the tool backward. According to Newton's third law, the tool will cause an equal forward push on her toward the space station.
4. Answers may vary. Sample answer:
As a cannon forces a cannon ball out of the cannon, the cannon applies an action force on the cannon ball. According to Newton's third law, the cannon ball will cause a reaction force that pushes the cannon backward. The ropes are necessary to prevent the cannon from hitting other parts of the ship when it is pushed backward.
5. Answers may vary. Sample answers:
(a) As the fan blows to the right, it pushes the air to the right. According to Newton's third law, there is a reaction force from the air that pushes the fan and the cart back to the left. When the sail is in place, the air pushes to the right on the sail. According to Newton's third law, there is a reaction force from the sail that pushes the air back to the left. The force pushing the fan to the left is balanced by the force from the air pushing toward the sail. As a result, the cart cannot accelerate.
(b) If the sail is removed, as the fan blows to the right, it pushes the air to the right. According to Newton's third law, there is a reaction force from the air that pushes the fan and the cart back to the left. The fan cart can then accelerate because there is an external force that pushes it to the left.

6. (a)



(b) The toy car applies an action force that shoots the plastic ball horizontally out the back, causing the ball to accelerate backward. According to Newton's third law, the ball causes a reaction force on the toy car, making it accelerate forward.
For the toy car, the normal force and the force of gravity cancel each other. Since there is no friction, the applied force is equal to the net force.
Choose east as positive.
Convert 200 g to 0.2 kg.

$$\begin{aligned} F_a &= F_{net} \\ F_a &= m_1 a_1 \\ &= (0.2 \text{ kg})(+1.2 \text{ m/s}^2) \\ &= +0.24 \text{ N} \\ \vec{F}_a &= 0.24 \text{ N [E]} \end{aligned}$$

The reaction force on the toy car is 0.24 N [E].
The action force on the plastic ball is 0.24 N [W].

7. (a) Skater 2 applies an action force that pushes skater 1 west, causing skater 1 to accelerate backward. According to Newton's third law, skater 1 causes a reaction force on skater 2, making skater 2 accelerate forward. For each skater, the normal force and the force of gravity cancel each other. This means the applied force is equal to the net force.
Choose east as positive. So, west is negative.
For skater 1,

$$\begin{aligned} F_{net} &= F_a \\ m_1 a_1 &= -64 \text{ N} \\ (78 \text{ kg})a_1 &= -64 \text{ N} \\ a_1 &= -0.82 \text{ m/s}^2 \\ \vec{a}_1 &= 0.82 \text{ m/s}^2 \text{ [W]} \end{aligned}$$

The acceleration of skater 1 is 0.82 m/s^2 [W].

For skater 2,

$$\begin{aligned} F_{net} &= F_a \\ m_2 a_2 &= +64 \text{ N} \\ (56 \text{ kg})a_2 &= +64 \text{ N} \\ a_2 &= +1.1 \text{ m/s}^2 \\ \vec{a}_2 &= 1.1 \text{ m/s}^2 \text{ [E]} \end{aligned}$$

The acceleration of skater 2 is 1.1 m/s^2 [E].

(b) Since the net force acting on each skater is in a different direction and the two skaters have different masses, the skaters move in opposite directions with different accelerations.

8. Answers may vary. Sample answer:
If you punch a hole into the carton, according to Newton's third law, the inward force will cause a reaction force exerted by the water flowing out of the container. If you punch two holes in the carton at the opposite corners, you will see two jets of water coming out. The suspended carton will start to turn because as water shoots out the holes, the water also pushes back on the carton with equal force. A turbine is formed as the energy of the moving liquid is converted into rotational energy.

9. (a) The female astronaut applies an action force of 16 N [left] on the male astronaut, causing him to accelerate to the left. According to Newton's third law, the male astronaut causes a reaction force on the female astronaut, making her accelerate in the opposite direction, to the right. For each astronaut, the applied force is equal to the net force.
Choose right as positive. So, left is negative.
For the male astronaut,

$$\begin{aligned} F_{net} &= F_a \\ m_1 a_1 &= -16 \text{ N} \\ (82 \text{ kg})a_1 &= -16 \text{ N} \\ a_1 &= -0.20 \text{ m/s}^2 \\ \vec{a}_1 &= 0.20 \text{ m/s}^2 \text{ [left]} \end{aligned}$$

The acceleration of the male astronaut is 0.20 m/s^2 [left].

For the female astronaut,

$$\begin{aligned} F_{net} &= F_a \\ m_2 a_2 &= +16 \text{ N} \\ (64 \text{ kg})a_2 &= +16 \text{ N} \\ a_2 &= +0.25 \text{ m/s}^2 \\ \vec{a}_2 &= 0.25 \text{ m/s}^2 \text{ [right]} \end{aligned}$$

The acceleration of the female astronaut is 0.25 m/s^2 [right].

(b) In this situation, the action force on the female astronaut becomes the reaction force and the reaction force on the male astronaut becomes the action force. So, the answers to part (a) will not change.
(c) The magnitudes of the accelerations will double since each astronaut experiences an action as well as a reaction force of the same magnitude. So the acceleration of the male astronaut will be 0.40 m/s^2 [left] and the acceleration of the female astronaut will be 0.50 m/s^2 [right].