NAME ______________ DATE ______________ CLASS ______________

Holt Physics

Problem 4A

NET EXTERNAL FORCE

PROBLEM

The muscle responsible for closing the mouth is the strongest muscle in the human body. It can exert a force greater than that exerted by a man lifting a mass of 400 kg. Richard Hoffman of Florida recorded the force of biting at 4.33 × 10³ N. If each force shown in the diagram below has a magnitude equal to the force of Hoffman's bite, determine the net force.

SOLUTION

1. DEFINE **Define the problem, and identify the variables.**

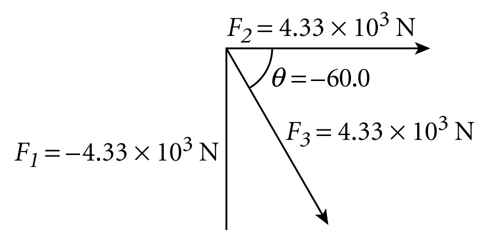
Given: $F_1 = -4.33 \times 10^3$ N

$F_2 = 4.33 \times 10^3$ N

$F_3 = 4.33 \times 10^3$ N

Unknown: $F_{net} = ?$ $\theta_{net} = ?$

Diagram:



2. PLAN **Select a coordinate system, and apply it to the free-body diagram:** Let F_1 lie along the negative y-axis and F_2 lie along the positive x-axis. Now F_3 must be resolved into x and y components.

3. CALCULATE **Find the *x* and *y* components of all vectors:** As indicated in the sketch, the angle between F_3 and the x-axis is 60.0 . Because this angle is in the quadrant bounded by the positive x and negative y axes, it has a negative value.

$$F_{3,x} = F_3(\cos\theta) = (4.33 \times 10^3 \text{ N})\,[\cos(-60.0\ )] = 2.16 \times 10^3 \text{ N}$$
$$F_{3,y} = F_3(\sin\theta) = (4.33 \times 10^3 \text{ N})\,[\sin(-60.0\ )] = -3.75 \times 10^3 \text{ N}$$

Find the net external force in both the *x* and *y* directions.

For the x direction: $\Sigma F_x = F_2 + F_{3,x} = F_{x,net}$

$$\Sigma F_x = 4.33 \times 10^3 \text{ N} + 2.16 \times 10^3 \text{ N} = 6.49 \times 10^3 \text{ N}$$

For the y direction: $\Sigma F_y = F_1 + F_{3,y} = F_{y,net}$

$$\Sigma F_y = (-4.33 \times 10^3 \text{ N}) + (-3.75 \times 10^3 \text{ N}) = -8.08 \times 10^3 \text{ N}$$

Find the net external force.

Use the Pythagorean theorem to calculate F_{net}. Use $\theta_{net} = \tan^{-1}\left(\frac{F_{y,net}}{F_{x,net}}\right)$ to find the angle between the net force and the x-axis.

$$F_{net} = \sqrt{(F_{x,net})^2 + (F_{y,net})}$$
$$F_{net} = \sqrt{(6.49 \times 10^3 \text{ N})^2 + (-8.08 \times 10^3 \text{ N})^2} = \sqrt{10.74 \times 10^7 \text{ N}^2}$$
$$F_{net} = \boxed{1.036 \times 10^4 \text{ N}}$$

$$\theta_{net} = \tan^{-1}\left(\frac{-8.08 \times 10^3 \text{ N}}{6.49 \times 10^3 \text{ N}}\right) = \boxed{-51.2}$$

4. EVALUATE The net force is larger than the individual forces, but it is not quite three times as large as any one force, which would be the case if all three forces were acting in one direction only. The angle is negative to indicate that it is in the quadrant below the positive x-axis, where the values along the y-axis are negative. The net force is 1.036×10^4 N at an angle of 51.2 below the positive x-axis.

ADDITIONAL PRACTICE

1. Joe Ponder, from North Carolina, once used his teeth to lift a pumpkin with a mass of 275 kg. Suppose Ponder has a mass of 75 kg, and he stands with each foot on a platform and lifts the pumpkin with an attached rope. If he holds the pumpkin above the ground between the platforms, what is the force exerted on his feet? (Draw a free-body diagram showing all of the forces present on Ponder.)
2. In 1994, Vladimir Kurlovich, from Belarus, set the record as the world's strongest weightlifter. He did this by lifting and holding above his head a barbell whose mass was 253 kg. Kurlovich's mass at the time was roughly 133 kg. Draw a free-body diagram showing the various forces in the problem. Calculate the normal force exerted on *each* of Kurlovich's feet during the time he was holding the barbell.
3. The net force exerted by a woodpecker's head when its beak strikes a tree can be as large as 4.90 N, assuming that the bird's head has a mass of 50.0 g. Assume that two different muscles pull the woodpecker's head forward and downward, exerting a net force of 4.90 N. If the forces exerted by the muscles are at right angles to each other and the muscle that pulls the woodpecker's head downward exerts a force of 1.70 N, what is the magnitude of the force exerted by the other muscle? Draw a free-body diagram showing the forces acting on the woodpecker's head.
4. About 50 years ago, the San Diego Zoo, in California, had the largest gorilla on Earth: its mass was about 3.10×10^2 kg. Suppose a gorilla with this mass hangs from two vines, each of which makes an angle of 30.0° with the vertical. Draw a free-body diagram showing the various forces, and find the magnitude of the force of tension in each vine. What would happen to the tensions if the upper ends of the vines were farther apart?
5. The mass of Zorba, a mastiff born in London, England, was measured in 1989 to be 155 kg. This mass is roughly the equivalent of the combined masses of two average adult male mastiffs. Suppose Zorba is placed in a harness that is suspended from the ceiling by two cables that are at right angles to each other. If the tension in one cable is twice as large as the tension in the other cable, what are the magnitudes of the two tensions? Assume the mass of the cables and harness to be negligible. Before doing the calculations, draw a free-body diagram showing the forces acting on Zorba.

Holt Physics

Problem 4B

NEWTON'S SECOND LAW

PROBLEM

A 1.5 kg ball has an acceleration of 9.0 m/s² to the left. What is the net force acting on the ball?

SOLUTION

Given: $m = 1.5$ kg

$\mathbf{a} = 9.0$ m/s² to the left

Unknown: $\mathbf{F} = ?$

Use Newton's second law, and solve for **F.**

$$\Sigma\mathbf{F} = m\mathbf{a}$$

Because there is only one force,

$$\Sigma\mathbf{F} = \mathbf{F}$$

$$\mathbf{F} = (1.5\text{ kg})(9.0\text{ m/s}^2) = 14\text{ N}$$

$$\mathbf{F} = \boxed{14\text{ N to the left}}$$

ADDITIONAL PRACTICE

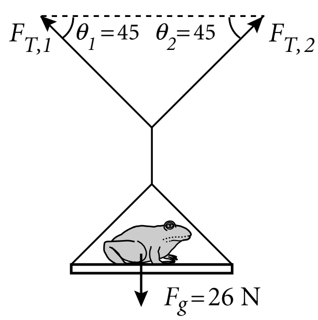
1. David Purley, a racing driver, survived deceleration from 173 km/h to 0 km/h over a distance of 0.660 m when his car crashed. Assume that Purley's mass is 70.0 kg. What is the average force acting on him during the crash? Compare this force to Purley's weight. (Hint: Calculate the average acceleration first.)
2. A giant crane in Washington, D. C. was tested by lifting a 2.232×10^6 kg load.
   - **a.** Find the magnitude of the force needed to lift the load with a net acceleration of 0 m/s².
   - **b.** If the same force is applied to pull the load up a smooth slope that makes a 30.0° angle with the horizontal, what would be the acceleration?
3. When the click beetle jumps in the air, its acceleration upward can be as large as 400.0 times the acceleration due to gravity. (An acceleration this large would instantly kill any human being.) For a beetle whose mass is 40.00 mg, calculate the magnitude of the force exerted by the beetle on the ground at the beginning of the jump with gravity taken into account. Calculate the magnitude of the force with gravity neglected. Use 9.807 m/s² as the value for free-fall acceleration.

4. In 1994, a Bulgarian athlete named Minchev lifted a mass of 157.5 kg. By comparison, his own mass was only 54.0 kg. Calculate the force acting on each of his feet at the moment he was lifting the mass with an upward acceleration of 1.00 m/s^2. Assume that the downward force on each foot is the same.

5. In 1967, one of the high school football teams in California had a tackle named Bob whose mass was 2.20×10^2 kg. Suppose that after winning a game the happy teammates throw Bob up in the air but fail to catch him. When Bob hits the ground, his average upward acceleration over the course of the collision is 75.0 m/s^2. (Note that this acceleration has a much greater magnitude than free-fall acceleration.) Find the average force that the ground exerts on Bob during the collision.

6. The whale shark is the largest type of fish in the world. Its mass can be as large as 2.00×10^4 kg, which is the equivalent mass of three average adult elephants. Suppose a crane lifts a net with a 2.00×10^4 kg whale shark off the ground. The net is steadily accelerated from rest over an interval of 2.5 s until the net reaches a speed of 1.0 m/s. Calculate the magnitude of the tension in the cable pulling the net.

7. The largest toad ever caught had a mass of 2.65 kg. Suppose a toad with this mass is placed on a metal plate that is attached to two cables, as shown in the figure below. If the plate is pulled upward so that it has a net acceleration of 2.55 m/s^2, what is magnitude of the tension in the cables? (The plate's weight can be disregarded.)



8. In 1991, a lobster with a mass of 20.0 kg was caught off the coast of Nova Scotia, Canada. Imagine this lobster involved in a friendly tug of war with several smaller lobsters on a horizontal plane at the bottom of the sea. Suppose the smaller lobsters are able to drag the large lobster, so that after the large lobster has been moved 1.55 m its speed is 0.550 m/s. If the lobster is initially at rest, what is the magnitude of the net force applied to it by the smaller lobsters? Assume that friction and resistance due to moving through water are negligible.

9. A 0.5 mm wire made of carbon and manganese can just barely support the weight of a 70.0 kg person. Suppose this wire is used to lift a 45.0 kg load. What maximum upward acceleration can be achieved without breaking the wire?

10. The largest hydraulic turbines in the world have shafts with individual masses that equal 3.18×10^5 kg. Suppose such a shaft is delivered to the assembly line on a trailer that is pulled with a horizontal force of 81.0 kN. If the force of friction opposing the motion is 62.0 kN, what is the magnitude of the trailer's net acceleration? (Disregard the mass of the trailer.)

11. An average newborn blue whale has a mass of 3.00×10^3 kg. Suppose the whale becomes stranded on the shore and a team of rescuers tries to pull it back to sea. The rescuers attach a cable to the whale and pull it at an angle of 20.0° above the horizontal with a force of 4.00 kN. There is, however, a horizontal force opposing the motion that is 12.0 percent of the whale's weight. Calculate the magnitude of the whale's net acceleration during the rescue pull.

12. One end of the cable of an elevator is attached to the elevator car, and the other end of the cable is attached to a counterweight. The counterweight consists of heavy metal blocks with a total mass almost the same as the car's. By using the counterweight, the motor used to lift and lower the car needs to exert a force that is only about equal to the total weight of the passengers in the car. Suppose the car with passengers has a mass of 1.600×10^3 kg and the counterweight has a mass of 1.200×10^3 kg. Calculate the magnitude of the car's net acceleration as it falls from rest at the top of the shaft to the ground 25.0 m below. Calculate the car's final speed.

13. The largest squash ever grown had a mass of 409 kg. Suppose you want to push a squash with this mass up a smooth ramp that is 6.00 m long and that makes a 30.0° angle with the horizontal. If you push the squash with a force of 2080 N up the incline, what is

a. the net force exerted on the squash?

b. the net acceleration of the squash?

c. the time required for the squash to reach the top of the ramp?

14. A very thin boron rod with a cross-section of 0.10 mm × 0.10 mm can sustain a force of 57 N. Assume the rod is used to pull a block along a smooth horizontal surface.

a. If the maximum force accelerates the block by 0.25 m/s^2, find the mass of the block.

b. If a second force of 24 N is applied in the direction opposite the 57 N force, what would be the magnitude of the block's new acceleration?

15. A hot-air balloon with a total mass of 2.55×10^3 kg is being pulled down by a crew tugging on a rope. The tension in the rope is 7.56×10^3 N at an angle of 72.3° below the horizontal. This force is aided in the vertical direction by the balloon's weight and is opposed by a buoyant force of 3.10×10^4 N that lifts the balloon upward. A wind blowing from behind the crew exerts a horizontal force of 920 N on the balloon.

a. What is the magnitude and direction of the net force?

b. Calculate the magnitude of the balloon's net acceleration.

c. Suppose the balloon is 45.0 m above the ground when the crew begins pulling it down. How far will the balloon travel horizontally by the time it reaches the ground if the balloon is initially at rest?

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Problem 4C

COEFFICIENTS OF FRICTION

PROBLEM

A 20.0 kg trunk is pushed across the floor of a moving van by a horizontal force. If the coefficient of kinetic friction between the trunk and the floor is 0.255, what is the magnitude of the frictional force opposing the applied force?

SOLUTION

Given: $m = 20.0$ kg

$\mu_k = 0.255$

$g = 9.81$ m/s^2

Unknown: $F_k = ?$

Use the equation for frictional force, substituting mg for the normal force F_n.

$$F_k = \mu_k F_n = \mu_k mg$$

$$F_k = (0.255)(20.0 \text{ kg})(9.81 \text{ m/s}^2)$$

$$F_k = \boxed{50.0 \text{ N}}$$

ADDITIONAL PRACTICE

1. The largest flowers in the world are the *Rafflesia arnoldii,* found in Malaysia. A single flower is almost a meter across and has a mass up to 11.0 kg. Suppose you cut off a single flower and drag it along the flat ground. If the coefficient of kinetic friction between the flower and the ground is 0.39, what is the magnitude of the frictional force that must be overcome?
2. Robert Galstyan, from Armenia, pulled two coupled railway wagons a distance of 7 m using his teeth. The total mass of the wagons was about 2.20×10^5 kg. Of course, his job was made easier by the fact that the wheels were free to roll. Suppose the wheels are blocked and the coefficient of static friction between the rails and the sliding wheels is 0.220. What would be the magnitude of the minimum force needed to move the wagons from rest? Assume that the track is horizontal.
3. The steepest street in the world is Baldwin Street in Dunedin, New Zealand. It has an inclination angle of 38.0° with respect to the horizontal. Suppose a wooden crate with a mass of 25.0 kg is placed on Baldwin Street. An additional force of 59 N must be applied to the crate perpendicular to the pavement in order to hold the crate in place. If the coefficient of static friction between the crate and the pavement is 0.599, what is the magnitude of the frictional force?

4. Now imagine that a child rides a wagon down Baldwin Street. In order to keep from moving too fast, the child has secured the wheels of the wagon so that they do not turn. The wagon and child then slide down the hill at a constant velocity. What is the coefficient of kinetic friction between the tires of the wagon and the pavement?

5. The steepest railroad track that allows trains to move using their own locomotion and the friction between their wheels and the track is located in France. The track makes an angle of 5.2° with the horizontal. Suppose the rails become greasy and the train slides down the track even though the wheels are locked and held in place with blocks. If the train slides down the tracks with a constant velocity, what is the coefficient of kinetic friction between the wheels and track?

6. Walter Arfeuille of Belgium lifted a 281.5 kg load off the ground using his teeth. Suppose Arfeuille can hold just three times that mass on a 30.0° slope using the same force. What is the coefficient of static friction between the load and the slope?

7. A blue whale with a mass of 1.90×10^5 kg was caught in 1947. What is the magnitude of the minimum force needed to move the whale along a horizontal ramp if the coefficient of static friction between the ramp's surface and the whale is 0.460?

8. Until 1979, the world's easiest driving test was administered in Egypt. To pass the test, one needed only to drive about 6 m forward, stop, and drive the same distance in reverse. Suppose that at the end of the 6 m the car's brakes are suddenly applied and the car slides to a stop. If the force required to stop the car is 6.0×10^3 N and the coefficient of kinetic friction between the tires and pavement is 0.77, what is the magnitude of the car's normal force? What is the car's mass?

9. The heaviest train ever pulled by a single engine was over 2 km long. Suppose a force of 1.13×10^8 N is needed to overcome static friction in the train's wheels. If the coefficient of static friction is 0.741, what is the train's mass?

10. In 1994, a 3.00×10^3 kg pancake was cooked and flipped in Manchester, England. If the pancake is placed on a surface that is inclined 31.0° with respect to the horizontal, what must the coefficient of kinetic friction be in order for the pancake to slide down the surface with a constant velocity? What would be the magnitude of the frictional force acting on the pancake?

Holt Physics

Problem 4D

OVERCOMING FRICTION

PROBLEM

In 1988, a very large telephone constructed by a Dutch telecommunications company was demonstrated in the Netherlands. Suppose this telephone is towed a short distance by a horizontal force equal to 8670 N, so that the telephone's net acceleration is 1.30 m/s^2. Given that the coefficient of kinetic friction between the phone and the ground is 0.120, calculate the mass of the telephone.

SOLUTION

1. DEFINE

Given:

$F_{applied} = 8670$ N
$a_{net} = 1.30$ m/s^2
$\mu_k = 0.120$
$g = 9.81$ m/s^2

Unknown: $m = ?$

2. PLAN

Choose the equation(s) or situation: Apply Newton's second law to describe the forces acting on the telephone.

$$F_{net} = ma_{net} = F_{applied} - F_k$$

The frictional force, F_k, depends on the normal force, F_n, exerted on the telephone. For a horizontal surface, the normal force equals the telephone's weight.

$$F_k = \mu_k F_n = \mu_k(mg)$$

Substituting the equation for F_k into the equation for F_{net} provides an equation with all known and unknown variables.

$$ma_{net} = F_{applied} - \mu_k mg$$

Rearrange the equation(s) to isolate the unknown(s):

$$ma_{net} + \mu_k mg = F_{applied}$$
$$m(a_{net} + \mu_k g) = F_{applied}$$
$$m = \frac{F_{applied}}{a_{net} + \mu_k g}$$

3. CALCULATE

Substitute the values into the equations and solve:

$$m = \frac{8670 \text{ N}}{1.30 \text{ m/s}^2 + (0.120)(9.81 \text{ m/s}^2)}$$

$$m = \frac{8670 \text{ N}}{1.30 \text{ m/s}^2 + 1.18 \text{ m/s}^2}$$

$$m = \frac{8670 \text{ N}}{2.48 \text{ m/s}^2} = \boxed{3.50 \times 10^3 \text{ kg}}$$

4. EVALUATE

Because the mass is constant, the sum of the acceleration terms in the denominator must be constant for a constant applied force. Therefore, the net acceleration decreases as the coefficient of friction increases.

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ADDITIONAL PRACTICE

1. Isaac Newton developed the laws of mechanics. Brian Newton put those laws into application when he ran a marathon in about 8.5 h while carrying a bag of coal. Suppose Brian Newton wants to remove the bag from the finish line. He drags the bag with an applied horizontal force of 130 N, so that the bag as a net acceleration of 1.00 m/s^2. If the coefficient of kinetic friction between the bag and the pavement is 0.158, what is the mass of the bag of coal?

2. The most massive car ever built was the official car of the General Secretary of the Communist Party in the former Soviet Union. Suppose this car is moving down a 10.0° slope when the driver suddenly applies the brakes. The net force acting on the car as it stops is -2.00×10^4 N. If the coefficient of kinetic friction between the car's tires and the pavement is 0.797, what is the car's mass? What is the magnitude of the normal force that the pavement exerts on the car?

3. Suppose a giant hamburger slides down a ramp that has a 45.0° incline. The coefficient of kinetic friction between the hamburger and the ramp is 0.597, so that the net force acting on the hamburger is 6.99×10^3 N. What is the mass of the hamburger? What is the magnitude of the normal force that the ramp exerts on the hamburger?

4. An extremely light, drivable car with a mass of only 9.50 kg was built in London. Suppose that the wheels of the car are locked, so that the car no longer rolls. If the car is pushed up a 30.0° slope by an applied force of 80.0 N, the net acceleration of the car is 1.64 m/s^2. What is the coefficient of kinetic friction between the car and the incline?

5. *Cleopatra's Needle*, an obelisk given by the Egyptian government to Great Britain in the nineteenth century, is 20+ m tall and has a mass of about 1.89×10^5 kg. Suppose the monument is lowered onto its side and dragged horizontally to a new location. An applied force of 7.6×10^5 N is exerted on the monument, so that its net acceleration is 0.11 m/s^2. What is the magnitude of the frictional force?

6. Snowfall is extremely rare in Dunedin, New Zealand. Nevertheless, suppose that Baldwin Street, which has an incline of 38.0°, is covered with snow and that children are sledding down the street. A sled and rider move downhill with a constant acceleration. What would be the magnitude of the sled's net acceleration if the coefficient of kinetic friction between the snow and the sled's runners is 0.100? Does the acceleration depend on the masses of the sled and rider?

7. The record speed for grass skiing was set in 1985 by Klaus Spinka, of Austria. Suppose it took Spinka 6.60 s to reach his top speed after he started from rest down a slope with a 34.0° incline. If the coefficient of kinetic friction between the skis and the grass was 0.198, what was the magnitude of Spinka's net acceleration? What was his speed after 6.60 s?