CHAPTER 3: FORCES CAN CHANGE VELOCITY

3.1 – The Nature of Force

EXERCISE 3.1

1. Explain the difference between kinematics and dynamics.

2. Define force. What is the SI unit for force?

3. What name is given to the force of gravity? In what direction (on earth) does this force always act?

4. Describe a free-body diagram.

5. A car with a weight of 9000 N (force of gravity – acting down) is parked on a horizontal driveway. How much force does the driveway exert on the car, and what is its direction?

The upward force described in question #5 is called a normal force. “Normal” here means perpendicular, or at right angles. Any two objects in contact have normal forces between them.

6. A student with a weight of 750 N sits on a chair. What normal force acts on the student, and where does it come from?

7. A student pushes a box with a weight of 100 N across a horizontal floor. She exerts a horizontal force of 40 N to the right. As she pushes the box, a force of friction of 20 N acts horizontally to the left. Sketch and label a free-body diagram of ALL the forces acting on the box; follow the flowchart summary on page 129.

8. What is the usual direction of a friction force?
9. Which force in question #7 would be the applied force?

10. The sketch shows a box at rest on a slanted surface, called an inclined plane. Make the sketch into a free-body diagram by drawing and labeling vectors representing the force of gravity, the normal force, and the friction force that act on the box. How do you know that there must be a friction force in this situation?

11. Repeat #10 for the box sitting on a horizontal surface (sketched at right.) Is there necessarily a friction force in this situation?

12. What is the meaning of net force? What is the magnitude and direction of the net force in question #7?

The boxes in question #10 and question #11 are said to be in equilibrium. An object is in equilibrium when the net force acting on it is zero. Objects may be in static equilibrium (like the boxes – they are static or stationary) or dynamic equilibrium, where the object is moving in a straight line at constant speed.

13. Sketch a free-body diagram and find the magnitude of the net force for each of the following.

a) A car with a weight of 8000 N accelerates along a level road. The car’s tires push horizontally on the roadway with a force of 2500 N, and friction forces of 1700 N oppose the forward motion.

(800 N)

b) Two hunters move a carcass with a weight of 3500 N across a field; one hunter uses a rope and the second pushes the carcass. The hunter with the rope pulls with a force of 400 N and the second hunter pushes with a force of 500 N; friction forces of 700 N oppose the motion.

(200 N)
c) A jet airplane with a weight of 45 kN flies horizontally at constant speed. The jet engine exerts a forward thrust of 2500 N on the airplane. There is a friction force acting against the motion of the airplane. (Hint: if the force from the engine is greater than the force of friction, what would happen to the airplane? What would happen if the force from the engine is less than the force of friction?)

14. Which of the situations in question #13 shows dynamic equilibrium? How do you know?

A particular case of static equilibrium involves inclined planes such as ramps, sloping roadways, roller coaster tracks, etc. An object at rest on an inclined is in equilibrium under the effect of three forces:

- gravity (the object’s weight) acts vertically downwards
- a perpendicular force (called a normal force shown as $F_\perp$ or $F_N$) acts from the surface of the plane onto the object
- friction (or a brake, or restraining rope, etc.) provides a parallel force (shown as $-F_{\parallel}$) along the plane.

As the object is in equilibrium, the force diagram shows a closed triangle.

EXAMPLES - INCLINED PLANES

When the brakes fail (or the rope breaks, or friction drops to zero) – what happens??

Note that the incline angle is also the angle between $F_\perp$ and $W$.

Drawing sketches in a consistent manner helps to correctly locate incline angle.
1. As sketched to the right, a roller coaster car of weight 3500 N is held at rest by a brake at the top of a 35° incline.

   a) Show as vectors all forces acting on the car.

   ![Diagram showing forces acting on the car](image)

   b) Find the perpendicular (normal) force exerted by the track on the car.

   \[ \cos 35° = \frac{|F|}{3500} \quad |F| = 2867 \text{ N} \]
   \[ |F| = 3500 \cos 35° \quad |F| = 2.9 \times 10^3 \text{ N} \]

   c) If the brake is released, find the acceleration of the car down the inclined track.

   With the brake released, the force parallel to the incline is one of the components of the weight. (The second component of the weight is opposed by the normal force.) This force component (of course) was there before – but it was opposed by the brakes, so before there was no unbalanced or net force down the incline. Now, there is – and the car will accelerate.

   \[ \sin 35° = \frac{|F|}{3500} \quad |F| = 3500 \sin 35° \]
   \[ |F| = 2008 \text{ N} \]

   Use sine to find the parallel force. Note that the force of the brakes was equal to this force – but was pointed in the opposite direction.

   The problem gave you the weight of the car – to find acceleration, you need mass in order to use the Second Law. Use \( W = mg \) to find mass.

   \[ a = 5.6 \text{ m/s}^2 \text{ down incline} \]

   Use Newton's Second Law to find the acceleration.
2. If the cyclist shown (with a mass of 72.5 kg, including bicycle) starts from rest at the top of the hill, what is his acceleration down the hill? What are his position and speed after 3.00 s?

Cyclist’s weight is: 
\[ W = mg \]
\[ W = (72.5 \text{ kg})(9.80 \text{ m/s}^2) = 710.5 \text{ N} \]

Draw a force triangle; calculate the force down the hill (parallel to the incline.)

\[ \sin 32.0^\circ = \frac{|F_\parallel|}{710.5} \]
\[ |F_\parallel| = 710.5 \sin 32.0^\circ \]
\[ |F_\parallel| = 376.51 \text{ N} \]

This is then \( F_{\text{Net}} \).

To find the position and speed after 3.00 s, use linear motion equations.

\[ V_i = 0 \]
\[ a = 5.1932 \text{ m/s}^2 \]
\[ t = 3.00 \text{ s} \]

\[ d = v_i t + \frac{1}{2} a t^2 \]
\[ d = (0)(3.00) + \frac{1}{2} (5.1932)(3.00)^2 \]
\[ d = 23.370 \text{ m} \]

\[ v_f = v_i + at \]
\[ v_f = (0) + (5.1932)(3.00) \]
\[ v_f = 15.577 \text{ m/s} \]

15. The sketches show objects at rest on inclined planes. (Note that these are not proper free-body diagrams.) Draw a properly labeled force triangle for each of the equilibrium situations shown. Then calculate the unknown forces.

a) \( F_\parallel = 4.0 \text{ N}; F_\perp = 24 \text{ N} \)

b) \( W = 7.0 \text{ N}; F_\perp = 5.7 \text{ N} \)

c) \( F_\parallel = 322 \text{ N}; W = 355 \text{ N} \)
16. A man in a wheelchair is stationary (brakes locked) on a ramp that makes an angle of 2.50° with the horizontal. The weight of the man plus his chair is 800 N.

   a) Draw a labeled vector sketch showing the forces acting on the wheelchair; give angles from horizontal for the forces.

   b) Find the force exerted by the brakes.

\[
\text{b) \quad } F_{\text{brakes}} = 34.9 \text{ N}
\]

   c) If the brakes are released, what is the wheelchair’s acceleration down the ramp?

\[
\text{c) \quad } a = 0.427 \text{ m/s}^2
\]

17. A skier pauses at the top of a steep run; the skier’s mass is 68 kg. The ski run has a slope of 24° (measured from horizontal.)

   a) What is the normal force acting from the snow onto the skier’s skis?

\[
\text{a) \quad } F_N = 6.1 \times 10^2 \text{ N}
\]

   b) What is the friction force acting parallel to the snow surface?

\[
\text{b) \quad } F_f = 2.7 \times 10^2 \text{ N}
\]
18. How much tension is needed along the rope shown at right to prevent the 200 kg crate from sliding down the ramp? The force of friction along the ramp is 120 N. (Note that the parallel force needed to maintain equilibrium will be the sum of the force from the rope plus friction.)

(387 N)

19. A 1200 kg car with brakes applied is at rest at the top of a driveway. The top of the 25.0 m long driveway is 3.00 m higher than the street below.

a) Find the angle the driveway makes with the horizontal.

(6.89˚)

b) How much force does the driveway exert on the wheels of the car, perpendicular to the driveway surface?

(1.17 x 10^3 N)

c) What force must the brakes be exerting to prevent the car from rolling?

(1.41 x 10^3 N)

d) If the brakes are released, what will be the car’s acceleration down the driveway?

(1.18 m/s^2)
20. Use techniques for adding non-collinear vectors to find the net force (magnitude and standard position direction) for each of the following. Assume the objects to be on a frictionless, horizontal surface.

a) \( (50.0 \text{ N at } 36.9^\circ) \)

b) \( (211 \text{ N at } 16.9^\circ) \)

c) \( (8.72 \text{ N at } 226^\circ) \)

SUMMARY EXAMPLE – FORCES IN EQUILIBRIUM
Most problems involving forces in equilibrium can be solved using the techniques shown for the following example.

The sketch at right shows a crane equipped with a wrecking ball of weight 9000 N. The ball is suspended from cable A and pulled away from the vertical by horizontal cable B to the position shown. If the ball is in equilibrium, find the tension in each cable.

- **Draw a free-body vector diagram** of all the forces acting on the ball.
- **Draw a vector force triangle** showing the sum of the forces as zero (object is in equilibrium.)
- **Use trigonometry to solve for unknown forces.**

Tensions in the cables are $1.4 \times 10^4$ N in cable A and $1.1 \times 10^4$ N in cable B.

21. A large speaker is suspended over a concert hall by two cables as shown. The tension in cable A is 320 N. What is the weight of the speaker, and what is the tension in cable B?

22. At a leadership camp, students are required to climb an angled suspension bridge with no handrails. Jerri (mass 76.0 kg) is halfway along the bridge as shown. Find the tension in the suspension bridge cables at A and B because of Jerri’s weight. (Assume cable at B is horizontal; use the geometric information to find the angle for cable A.)
3.2 – Newton’s First Law

EXERCISE 3.2

1. Define inertia. Name an object that has a great deal of inertia; one that has much less. Could the term mass be a synonym for inertia?

2. State Newton’s first law.

3. According to Newton’s first law, how can you change the motion of an object?

4. Does a car rounding a curve at a constant 20 m/s have a net force of zero acting on it? (Hint: consider the definition of acceleration.)

5. Explain how Newton’s first law applies to an object that is stationary and to an object that is moving. Does this explanation seem sensible for a moving object? Why do most moving objects not seem to follow the first law?

6. For each of the following, state whether or not a net (unbalanced) force exists, and if it does, give its direction. (The direction of a net force must be the same as any acceleration that occurs.)
   - a toy car moves horizontally across a table in an easterly direction at 45 cm/s
   - a ball rolls down a hill
   - a person sits in a chair
- a skydiver falls freely at a constant 35 m/s
- a car traveling north brakes to a stop
- a cyclist riding west against a strong headwind is only able to maintain a speed of 15 km/h

7. When you are riding as a front-seat passenger in a car that is traveling around a sharp left-hand curve at a constant speed, you sense a force – from the seatbelt, seat and the car door – that seems to be pushing you towards the left. Use the concept of inertia to explain why this force is needed, and what would happen to you if it were not present.

3.3 – Newton’s Second Law

EXERCISE 3.3

1. What is the relationship (as a proportionality – use the proportionality symbol, ∝) between acceleration and net force? Between acceleration and mass?

2. State Newton’s second law, including the equation that governs it. Name the units used for each variable in the equation.

3. Why is the mass in Newton’s second law referred to as inertial mass?

4. You are given an object of unknown mass, a smooth (nearly frictionless) horizontal surface that the object can slide on, an accurate spring scale calibrated in Newtons, and a motion sensor and computer. 
   a) Describe how you would use this apparatus to measure the inertial mass of the object.

   b) If the motion sensor reads an average of 35.0 cm/s² for a nearly constant scale reading of 5.00 N, what is the inertial mass of the object?

5. When you place an object on a balance, are you measuring inertial mass?
6. If you place the object from question #4 (b) on a balance, what will the readings be?

7. Find the unknown in each case, using the second law. Unless otherwise stated, assume forces are net forces. Be sure to give units and direction signs (positive is to the right) with your answers.

   a)
   \[ a = \quad \text{______________________________} \]

   b)
   \[ a = +1.50 \text{ m/s}^2 \]
   \[ F_N = \quad \text{______________________________} \]

   c)
   \[ a = -3.00 \text{ m/s}^2 \]
   \[ m = \quad \text{______________________________} \]

   d)
   \[ a = \quad \text{______________________________} \]

   e)
   \[ a = +2.30 \text{ m/s}^2 \]
   \[ F_N = \quad \text{______________________________} \]

8. A mass of \( m \) kg has an acceleration of \( a \) m/s\(^2\) when acted upon by a net force of \( F \) Newtons. What acceleration would occur in each of the following situations (in terms of \( a \))?

   Example: mass increases to \( 2m \) and force increases to \( 3F \)
   From the \( F = ma \) equation, acceleration varies directly as net force and inversely as mass. Doubling the mass and tripling the force would result in multiplying the acceleration by a factor of \( \frac{3}{2} \); the new acceleration would be \( \frac{3}{2} a \).

   a) mass increases to \( 3m \) and force remains constant _________________
b) mass decreases to 0.5\(m\) and force increases to 2\(F\)

c) mass increases to 5\(m\) and force decreases to 0.2\(F\)

d) mass decreases to 0.3\(m\) and force decreases to 0.4\(F\)

The second law applies equally well to vertical forces and acceleration. In a free body diagram, the force of gravity (weight) is always present.

**EXAMPLE – SECOND LAW FOR VERTICAL FORCES**

An object with a mass of 5.00 kg has a vertical upward force applied to it of 70.0 N. Find the acceleration of the object.

Draw a free-body diagram; remember to include the weight (force of gravity) as a downward vector. Generally, \(F_g = ma_g\), where \(a_g\) is -9.81 N/kg. Note that the units of N/kg are dimensionally equal to \(\text{m/s}^2\), based on the definition of the Newton (from Newton’s second law) as one \(\text{kg} \cdot \text{m/s}^2\).

\[
F_g = (5.00 \text{ kg}) \cdot (-9.81 \text{ N/kg}) = -49.05 \text{ N}
\]

\[
\text{F}_{\text{NET}} = F_{\text{APP}} + F_g = 70.0 + (-49.05) = +20.95 \text{ N}
\]

\[
a = \frac{\text{F}_{\text{NET}}}{m} = \frac{20.95}{5.00} = 4.19 \text{ m/s}^2
\]

The object accelerates upwards at 4.19 m/s\(^2\).

9. A flying squirrel with a mass of 120 g launches from a tree branch. After falling a short distance, air resistance (the force of air friction) on the squirrel is equal to 0.750 N. Find the squirrel’s acceleration at this point.

\[
F_g = (0.120 \text{ kg}) \cdot (-9.81 \text{ N/kg}) = -1.18 \text{ N}
\]

\[
\text{F}_{\text{NET}} = F_{\text{APP}} + F_g = 0.750 + (-1.18) = -0.43 \text{ N}
\]

\[
a = \frac{\text{F}_{\text{NET}}}{m} = \frac{-0.43}{0.120} = -3.56 \text{ m/s}^2
\]

10. After falling further, the squirrel in question #9 reaches a speed at which the force of air resistance is equal (but opposite) to the force of gravity. Describe the squirrel’s motion from this point on; use Newton’s laws to support your answer.
11. A skydiver in the spread-eagled position has a maximum speed of descent of 220 km/h; this is called
the **terminal velocity**. Use Newton’s laws to explain the terminal velocity for objects falling through
air or water.

Systems involving two objects connected by cords and pulleys can be analyzed using Newton’s second
law. It is important to identify the total mass that is accelerated and use an *equivalent dynamic system*;
often, the equation $F_{\text{Net}} = ma$ is used as a **scalar** equation.

**EXAMPLE – SECOND LAW FOR PULLEY SYSTEMS**

A mass of 1.50 kg is connected by a
cord and pulley to a cart on a horizontal
tabletop as shown in the sketch. The
cart has a mass of 3.50 kg; the system
has negligible friction. Find the
acceleration of the system if the cart is
released from rest.

The cord and pulley transfer the
weight of the mass to the cart; the
force that acts on the cart as a result
is horizontal, directed to the right. As shown at right, a free body
diagram for the cart shows an *equivalent system* with the force from the
cord and mass as a horizontal force.

Vertical forces $F_g$ and $F_{\text{Normal}}$ have a vertical sum of zero. It is customary
not to show these vertical forces if they don’t affect the problem.

The applied force is the weight of the 1.50 kg mass; note that both this
mass AND the cart’s mass are accelerated, so that the mass value for the
second law equation is the total mass: $1.50 + 3.50 = 5.00$ kg.

Find the weight of the 1.50 kg mass using $F_{\text{Net}} = ma$:$ F_{\text{Net}} = (1.50)(9.81) \quad F_{\text{Net}} = 14.72 \text{N}$

Using $a = \frac{F_{\text{Net}}}{m}$ : $a = \frac{14.72}{5.00}$ \quad a = 2.943 \text{ m/s}^2$

Note that both the weight formula and the second
law are used as **scalar** equations – direction signs would cause confusion for this question.

The acceleration of the system is 2.94 m/s$^2$.

12. Find the acceleration in the preceding example if the mass of the cart is 2.50 kg, the suspended mass is
1.00 kg, and a force of friction of 5.00 N acts horizontally to oppose the cart’s motion.
13. The sketch to the right shows an Atwood machine – two masses suspended from the ends of a cord that passes over a pulley. If mass 1 is 2.30 kg and mass 2 is 1.70 kg, find the acceleration of the system if friction is negligible. Be sure to give the direction of the acceleration.

3.4 – Newton’s Third Law

EXERCISE 3.4

1. Newton’s first two laws usually describe a different situation than does Newton’s third law. Explain; give examples. (Ref. p. 159)

2. Explain action and reaction forces, using an example involving two different objects.

3. Give Newton’s third law as a statement and as a force equation.

4. Give an example of an action-reaction pair for objects in contact; for objects some distance apart.

5. Use Newton’s third law to explain the motion of a propeller-driven airplane; of a jet airplane or rocket. Why are jet engines and rocket engines called reaction engines?
6. Two children, Ron and Edwin, tie together two toy wagons that are stationary on a level sidewalk. Ron’s mass is 35.0 kg, and each wagon has a mass of 10.0 kg. Ron sits in the second wagon (wagon B), and Edwin pulls on the first wagon (wagon A), causing both wagons and Edwin to accelerate at 1.05 m/s².

   a) If a friction force of 30.0 N acts against the motion of wagon B, find the force exerted by wagon A on wagon B.

      \((77.3 \text{ N})\)

   b) Because wagon A is empty, the friction force opposing its motion is only 10.0 N. How much force does Edwin apply to the handle of wagon A? How much force (and in what direction) does the handle of wagon A apply to Edwin’s hand?

      \((97.8 \text{ N}; -97.8 \text{ N})\)

3.5 – Friction Affects Motion

Most surfaces in contact can exert friction forces parallel to the contacting surface. Consider the series of sketches below, in which a heavy cardboard box of mass 45.0 kg is initially at rest on a smooth, horizontal tile floor. A horizontal force is applied to the box; the force is gradually increased until the box begins to move. Once the box is moving, the applied force is adjusted to keep the box moving at a constant speed. Finally, a second box is placed on top of the first, and the experiment is repeated. You’ve probably attempted this or a similar action, and would agree with the listed observations. (Note that the sketches are NOT free-body diagrams (other forces are acting, and the forces are not drawn from the centre of the box.)

I. \textit{No horizontal applied force; no motion occurs.}

a. A free-body diagram would show a zero net force; as the box is stationary, it remains at rest

II. \textit{50.0 N applied force; no motion occurs.}

This means that there is now a force of friction, equal to 50.0 N, acting against the applied force. This force is called a \textbf{static friction force}, as it is occurring without motion.
III. 75.0 N applied force; no motion occurs. This means that the force of friction has increased to 75.0 N, acting against the applied force. Generally, static friction is not a constant value; it increases as an applied force increases - up to a point!

IV. 100 N applied force; no motion occurs. The applied force is not yet sufficient to overcome static friction, which now equals 100 N.

V. 101 N applied force; the box begins to slowly move and accelerate at 0.0222 m/s$^2$ to the right. The maximum force of static friction is a bit more than 100 N; there is now a net force to the right of 1.00 N. Acting on the 45.0 kg box, the acceleration (predicted from Newton’s second law) should be 0.0222 m/s$^2$ to the right - as observed.

VI. Applied force is increased to 130 N; the box accelerates faster, at 1.50 m/s$^2$ to the right. If the friction force is still 100 N, the net force will be (130 - 100) 30.0 N to the right. From Newton’s second law, this should result in an acceleration of 0.667 m/s$^2$, but a greater acceleration is occurring. This means that the kinetic friction (which occurs for objects sliding against one another) is less than the static friction. Using the measured acceleration indicates a net force of 67.5 N is acting ($F_{\text{Net}} = (45.0)(1.50)$); the force of kinetic friction must now be (130 – 67.5) equal to 62.5 N.

VII. A second identical box is placed on top of the first box. An applied force of 202 N is needed to accelerate the box initially. For an acceleration (both boxes) of 1.50 m/s$^2$, a force of 260 N must be applied. To accelerate two boxes of total mass 90.0 kg at 1.50 m/s$^2$ requires a net force of 135 N. If the applied force is 260 N, there must now be (260 – 135) 125 N of kinetic friction acting.
The observations above are typical of systems involving friction. Use these results and observations to help answer the first five questions in Exercise 3.5.

EXERCISE 3.5

1. Does an object at rest on a horizontal surface necessarily have a friction force? Does any object have a friction force until a second applied force is added?

2. How do you suppose the numbers for friction in the example would change if the box were at rest on a rough wooden floor?

3. The force of friction can be (roughly) calculated for many surfaces in contact. When such a calculation is done for static friction, the result is given as $F_{\text{static-max}}$. Explain the “max.”

4. How does the amount of friction seem to depend on the normal force between the surfaces (of the box and the tile floor)?

5. Predict the static frictional force in the example if three boxes were pushed; predict the kinetic frictional force for three boxes.

6. The sketch shows a book with a weight of 12.5 N at rest on a wooden board; the board is propped up an angle of 15.0° to a horizontal tabletop.
   a) Draw a free-body diagram for the book; don’t forget friction, and remember that the normal force for the board must be at right angles to the board.
b) Calculate the force of static friction for the book at this angle. (Hint: the static friction force equals the component of the weight that acts parallel to the board.)

\[ (3.24 \text{ N}) \]

c) The angle of the board is increased until at 28.5° the book just begins to slide down the board. Find the value of \( F_{f\text{-static-max}} \) for the book and board.

\[ (5.96 \text{ N}) \]

d) If the angle of the board is maintained at 28.5°, would you expect the speed of the book to increase as it slides? Explain, considering the idea of kinetic friction.

Frictional forces are predicted approximately by the equations for static friction and for kinetic friction (reference p. 182-183.)

\[
\begin{align*}
F_{\text{static}} &\leq \mu_s F_N \\
F_{\text{kinetic}} & = \mu_k F_N
\end{align*}
\]

The symbol \( \mu \) is the Greek letter \( \text{mu} \), representing the coefficient of friction (static or kinetic.) Because both sides of the equation will have units of Newtons, \( \mu \) has no units – it is said to be dimensionless. \( F_N \) is the normal force between the two surfaces in contact. For an object resting on a horizontal surface, \( F_N \) is the weight of the object.

7. Summarize the points listed in your text on page 183 related to these equations.
8. For the example at the start of this section (p. 16, 17 of these notes), calculate the coefficients of static friction and kinetic friction between the cardboard box and the tile floor.

(0.227, 0.142)

9. Calculate the coefficient of static friction for the book on the board in question #6a above.

(0.268)

10. Use question #17 on page 6 of this handout for the following.

   a) Assuming the force found in part (b) to be the maximum friction force, what is the coefficient of static friction between the skis and the snow? (Remember to use the normal force - the answer to part (a) in your calculation.)

   (0.45)

   b) A second skier on the same slope also attempts to pause, but because the slope is quite icy at that point, instead she accelerates down the slope. Her mass is 52 kg. If the ice reduces the coefficient of kinetic friction to 0.10, what is the second skier’s acceleration?

   (3.1 m/s²)

10. A car with a weight of 10.0 kN starts from rest on an icy, horizontal roadway. The driver applies just enough gas to just cause one (front) tire to start spinning. Use the values from the chart on
page 183 to find the static friction force between the rubber tire and the icy roadway. (Remember that cars have four tires!)

\[(15.0 \text{ N})\]

11. Human body joints are lubricated by a fluid called synovial fluid. Many older people have hip and knee replacements; their new, artificial joints are lubricated by Teflon coatings. How does the lubrication provided by synovial fluid compare to that provided by Teflon?

\[
(15.0 \text{ N})
\]

12. According to the force of friction equations, the friction between an object and a horizontal surface depends only on the coefficient of friction and the normal force (the weight of the object.)

a) Find the maximum kinetic friction force between the tires and roadway for a 13.5 kN truck if it is moving on a dry asphalt roadway.

\[(10.8 \text{ kN})\]

b) A truck with the same weight as that in part (a) has had the standard wheels and tires replaced by larger versions; these wider profile tires have 25% more rubber in contact with the roadway than the standard tires. Such retrofits are quite expensive. Based on what you know about friction, is such a retrofit (likely) worth the money? Discuss.