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Physics 111 - Class 7B
Force Applications II

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October 20, 2021

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Class Outline

- Logistics / Announcements
- Introduction to Chapter 6
- Video Demos
- Clicker Questions

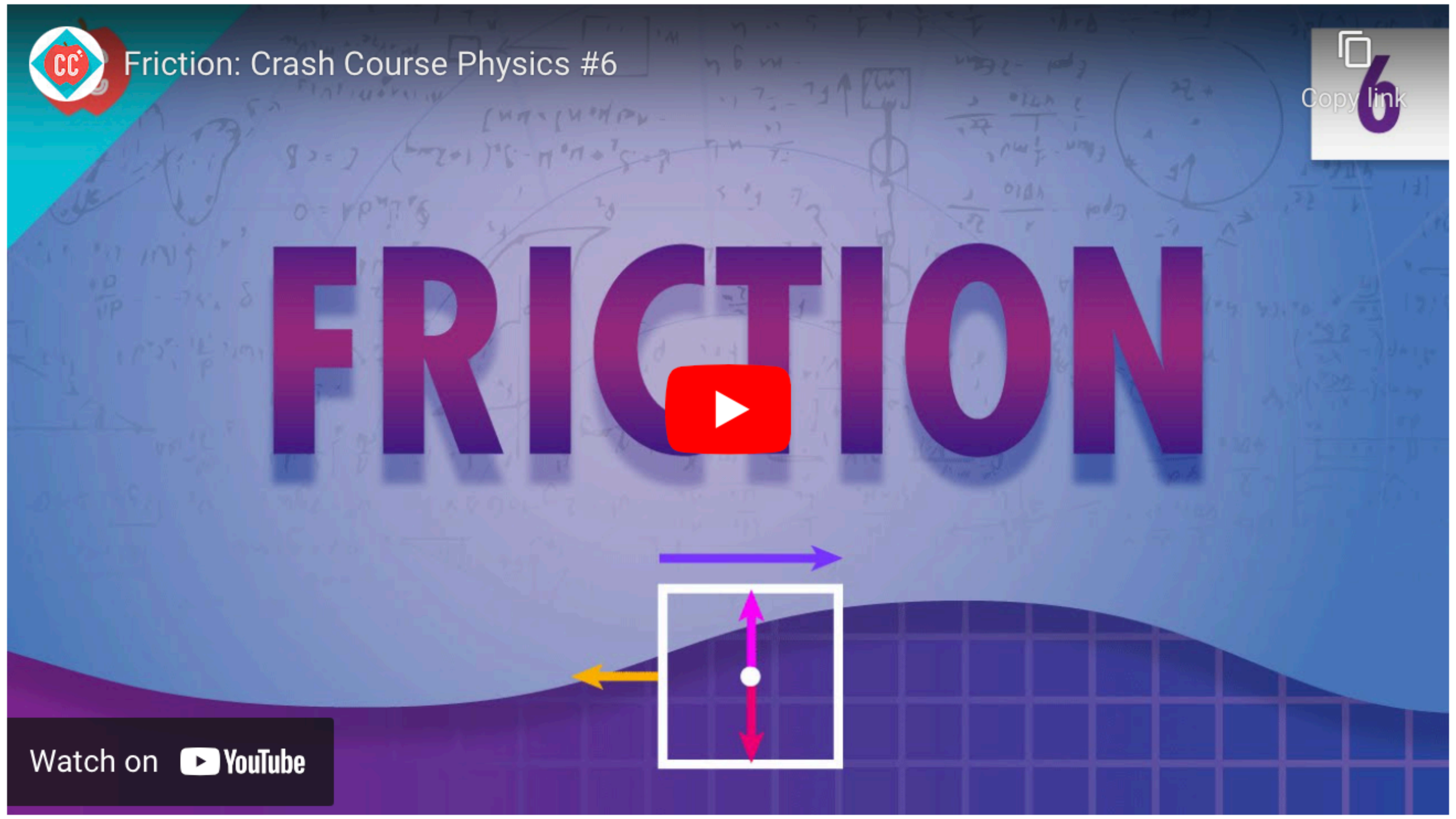
Logistics/Announcements

- Lab this week: Lab 4
- Tutorials are back this week!
- HW6 due this week on Thursday at 6 PM
- Learning Log 6 due on Saturday at 6 PM
- HW and LL deadlines have a 48 hour grace period
- Test/Bonus Test: Bonus Test 2 available this week (Chapters 3 & 4)
  - Test Window: Friday 6 PM - Sunday 6 PM

Physics 111

Search this book...

Friction



Required Videos

1. Introduction to Equilibrium

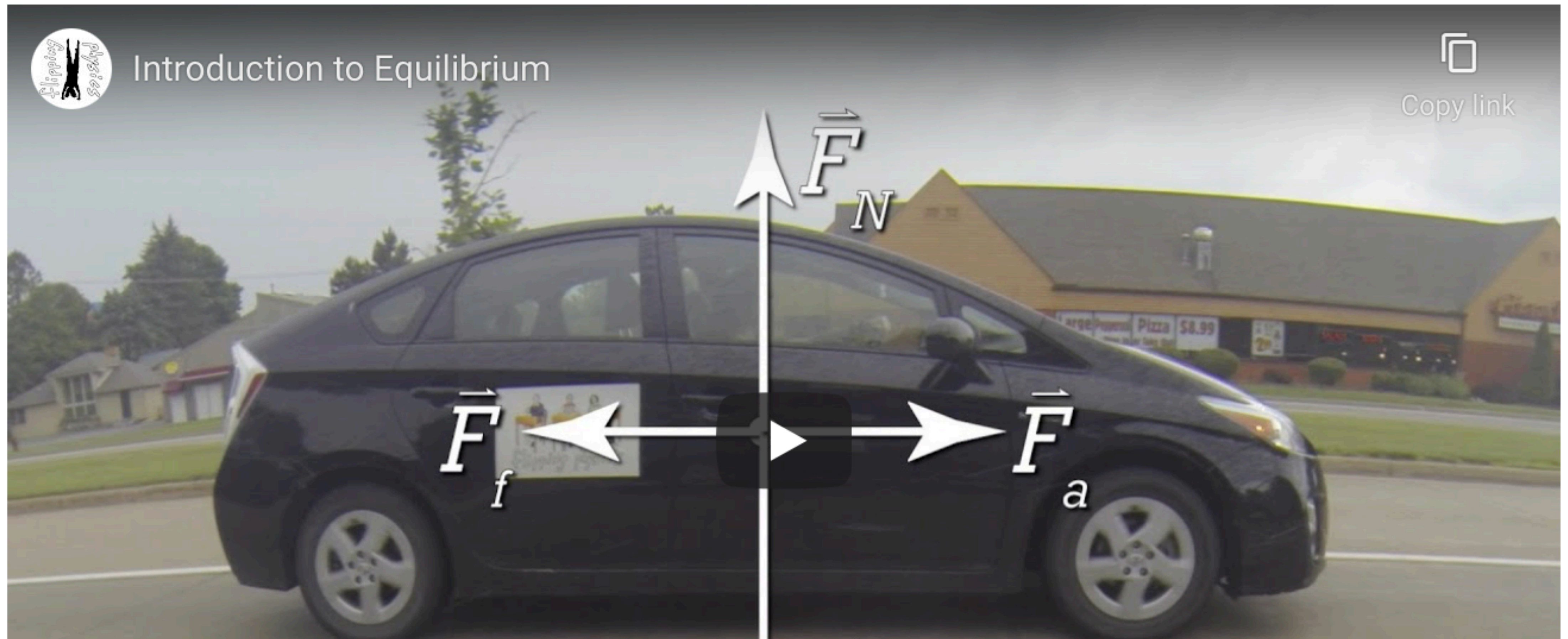


Figure 6.1 Stock cars racing in the Grand National Divisional race at Iowa Speedway in May, 2015. Cars often reach speeds of 200 mph (320 km/h). (credit: modification of work by Erik Schneider/U.S. Navy)

Chapter Outline

Car racing has grown in popularity in recent years. As each car moves in a curved path around the turn, its wheels also spin rapidly. The wheels complete many revolutions while the car makes only part of one (a circular arc). How

Figure 6.1 Stock cars racing in the Grand National Divisional race at Iowa Speedway in May, 2015. Cars often reach speeds of 200 mph (320 km/h). (credit: modification of work by Erik Schneider/U.S. Navy)

Chapter Outline

Car racing has grown in popularity in recent years. As each car moves in a curved path around the turn, its wheels also spin rapidly. The wheels complete many revolutions while the car makes only part of one (a circular arc). How

Wednesday's Class

6.2 Friction
6.3 Centripetal Force

Friction

FRICTION

Friction is a force that opposes relative motion between systems in contact.

STATIC AND KINETIC FRICTION

If two systems are in contact and stationary relative to one another, then the friction between them is called **static friction**. If two systems are in contact and moving relative to one another, then the friction between them is called **kinetic friction**.

MAGNITUDE OF STATIC FRICTION

The magnitude of static friction f_s is

$$f_s \leq \mu_s N, \tag{6.1}$$

where μ_s is the coefficient of static friction and *N* is the magnitude of the normal force.

The symbol $\leq$ means *less than or equal to*, implying that static friction can have a maximum value of $\mu_s N$. Static friction is a responsive force that increases to be equal and opposite to whatever force is exerted, up to its maximum limit. Once the applied force exceeds

$f_s(\text{max})$, the object moves. Thus,

$$f_s(\text{max}) = \mu_s N.$$

Friction

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$f_s(\text{max})$, the object moves. Thus,

$$f_s(\text{max}) = \mu_s N.$$

MAGNITUDE OF KINETIC FRICTION

The magnitude of kinetic friction f_k is given by

$$f_k = \mu_k N, \tag{6.2}$$

where μ_k is the coefficient of kinetic friction.

Friction

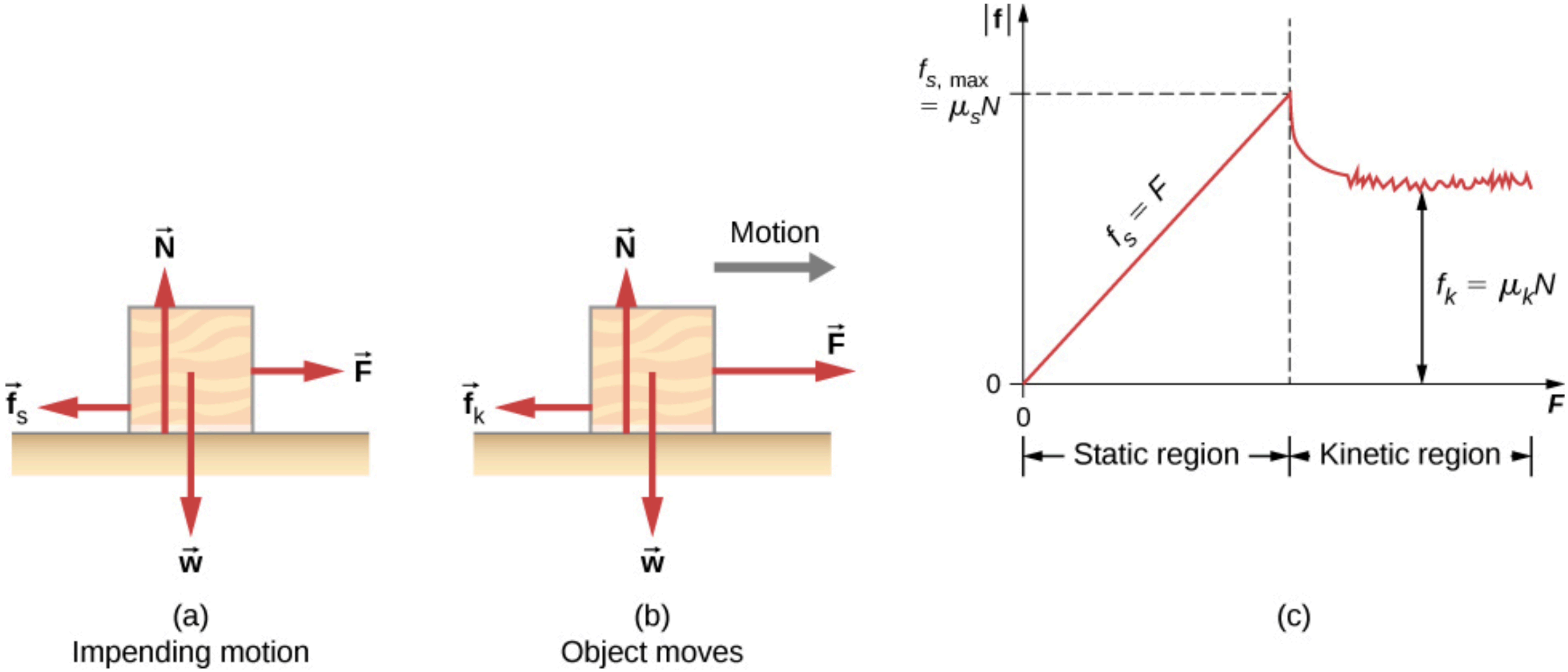


Figure 6.11 (a) The force of friction $\vec{f}$ between the block and the rough surface opposes the direction of the applied force $\vec{F}$. The magnitude of the static friction balances that of the applied force. This is shown in the left side of the graph in (c). (b) At some point, the magnitude of the applied force is greater than the force of kinetic friction, and the block moves to the right. This is shown in the right side of the graph. (c) The graph of the frictional force versus the applied force; note that $f_s(\text{max}) > f_k$. This means that $\mu_s > \mu_k$.

Friction

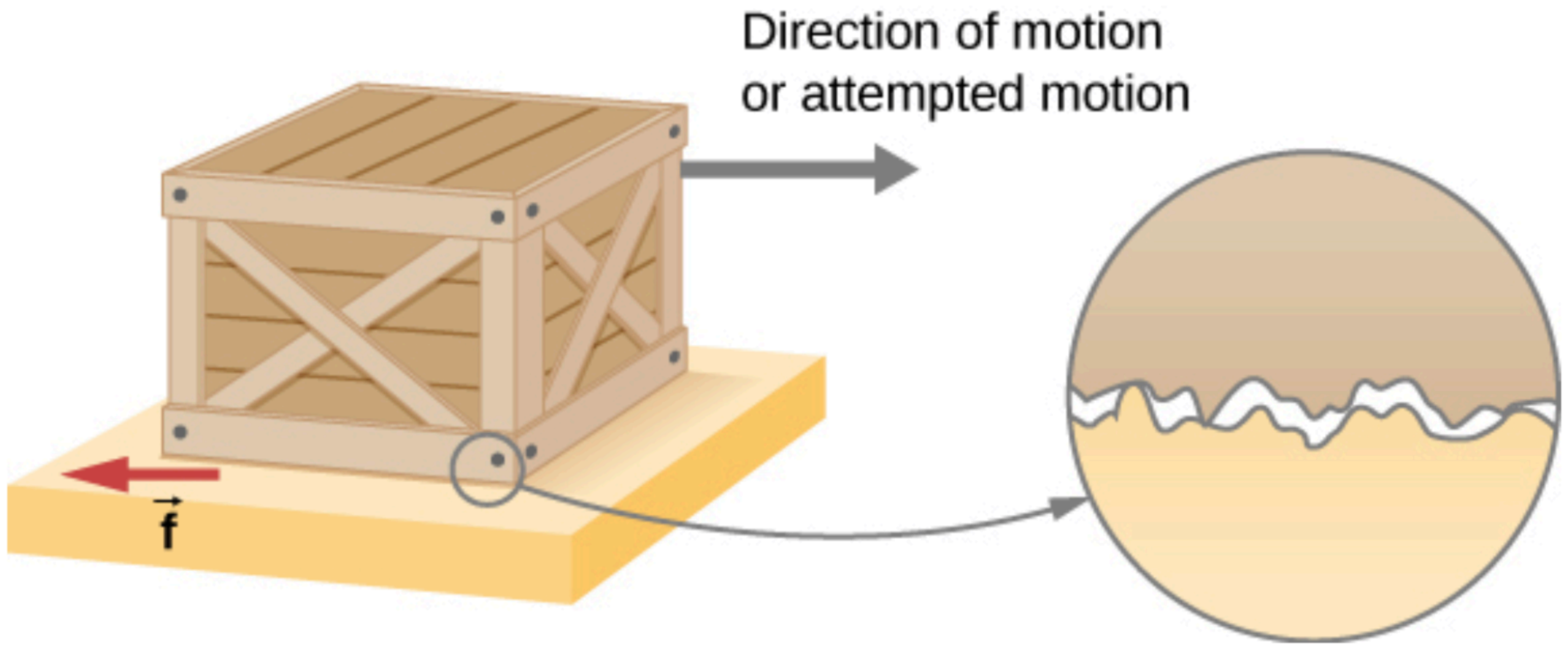


Figure 6.10 Frictional forces, such as $\vec{\mathbf{f}}$, always oppose motion or attempted motion between objects in contact. Friction arises in part because of the roughness of the surfaces in contact, as seen in the expanded view. For the object to move, it must rise to where the peaks of the top surface can skip along the bottom surface. Thus, a force is required just to set the object in motion. Some of the peaks will be broken off, also requiring a force to maintain motion. Much of the friction is actually due to attractive forces between molecules making up the two objects, so that even perfectly smooth surfaces are not friction-free. (In fact, perfectly smooth, clean surfaces of similar materials would adhere, forming a bond called a "cold weld.")

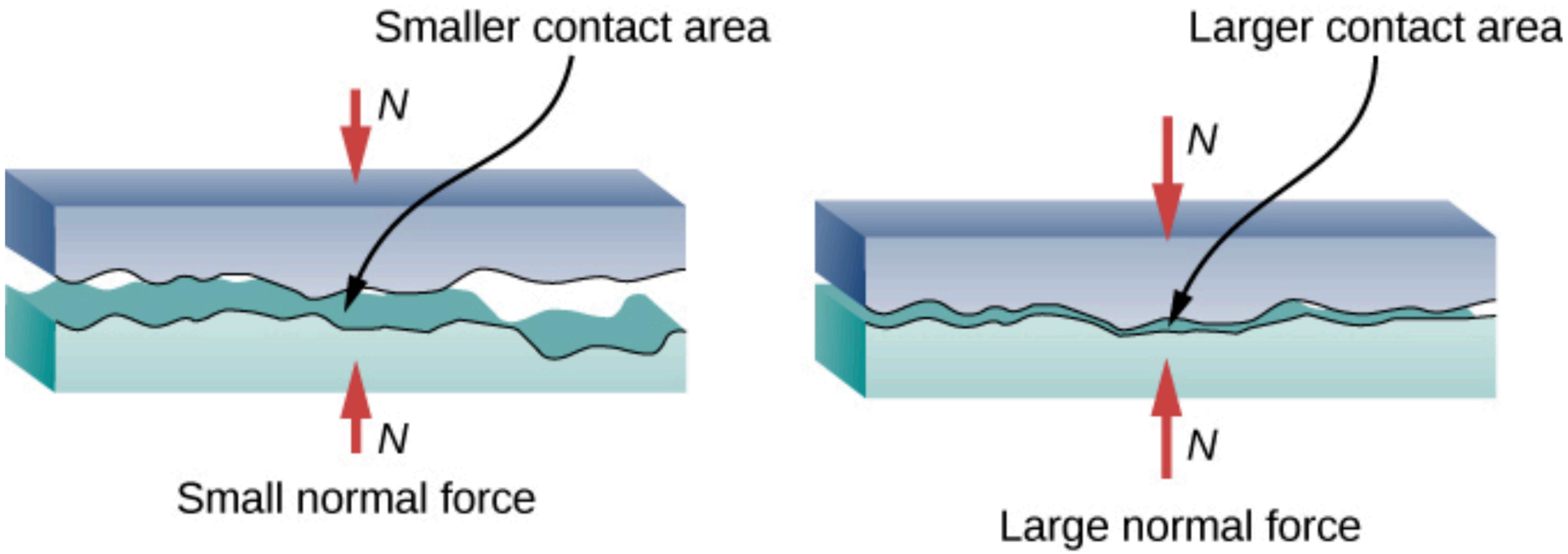


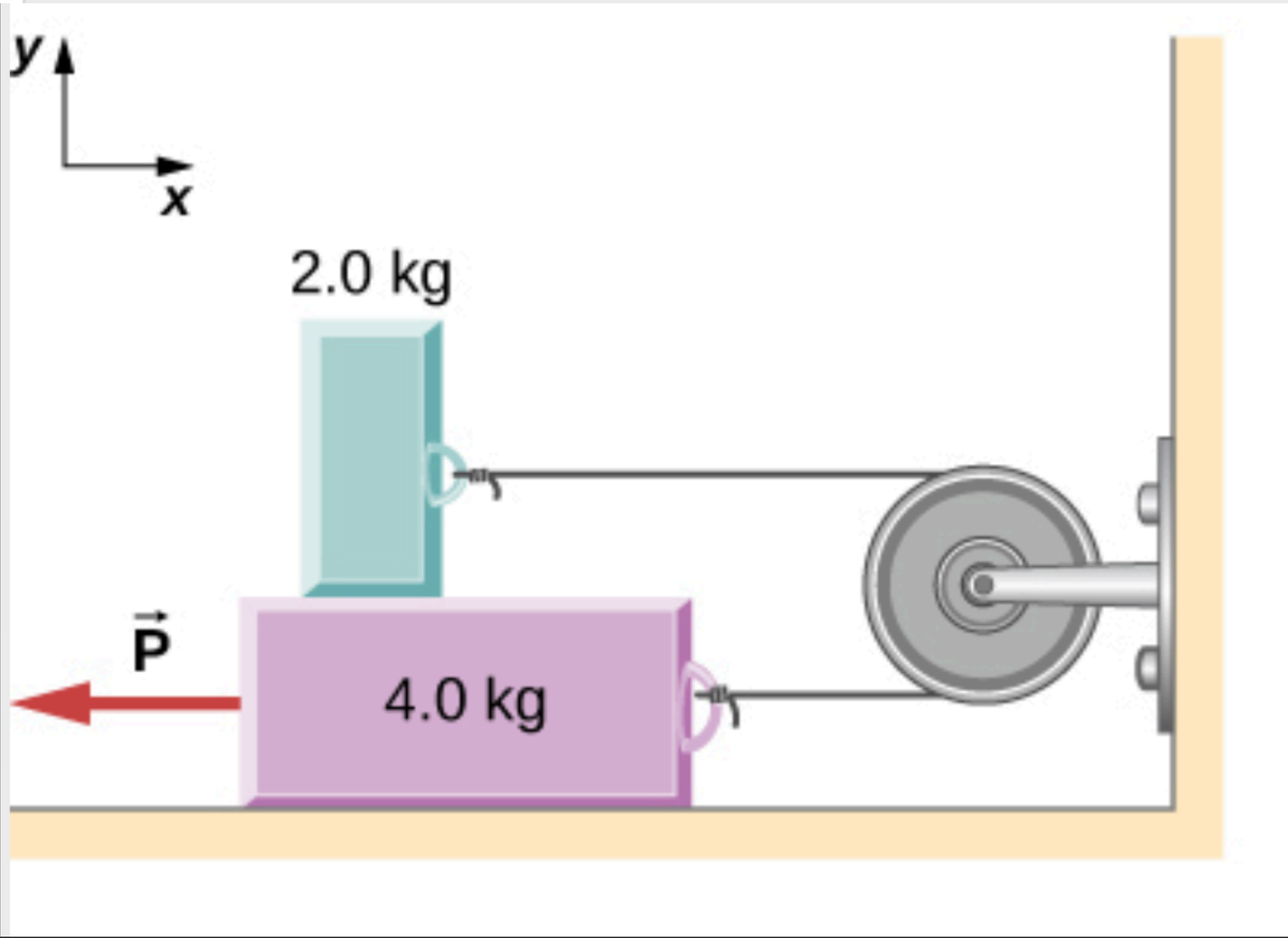
Figure 6.15 Two rough surfaces in contact have a much smaller area of actual contact than their total area. When the normal force is larger as a result of a larger applied force, the area of actual contact increases, as does friction.

Friction

EXAMPLE 6.12

Sliding Blocks

The two blocks of Figure 6.17 are attached to each other by a massless string that is wrapped around a frictionless pulley. When the bottom 4.00-kg block is pulled to the left by the constant force $\vec{\mathbf{P}}$, the top 2.00-kg block slides across it to the right. Find the magnitude of the force necessary to move the blocks at constant speed. Assume that the coefficient of kinetic friction between all surfaces is 0.400.



Friction

EXAMPLE 6.12

Sliding Blocks

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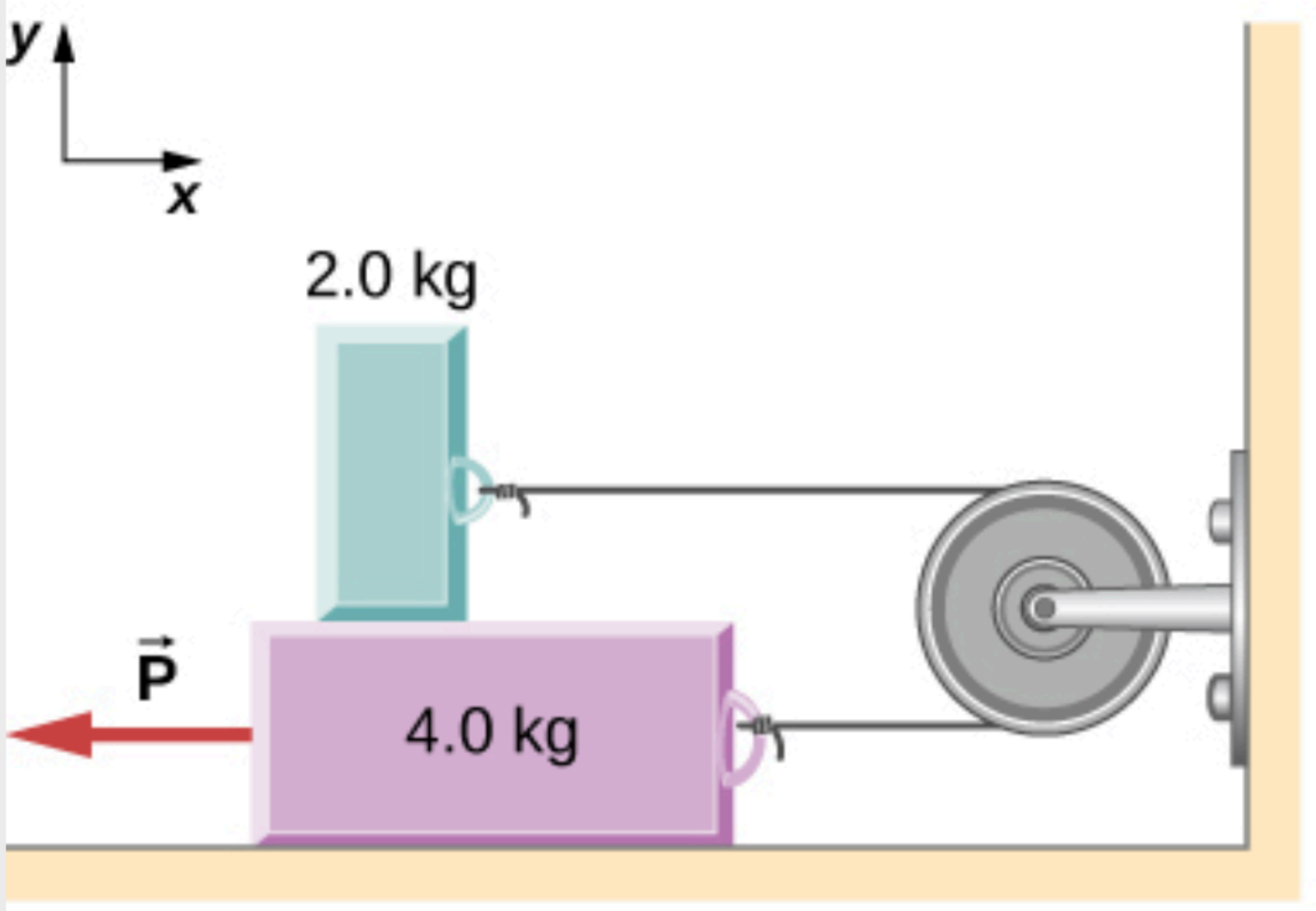

Strategy

We analyze the motions of the two blocks separately. The top block is subjected to a contact force exerted by the bottom block. The components of this force are the normal force N_1 and the frictional force $-0.400N_1$. Other forces on the top block are the tension $T\mathbf{i}$ in the string and the weight of the top block itself, 19.6 N. The bottom block is subjected to contact forces due to the top block and due to the floor. The first contact force has components $-N_1$ and $0.400N_1$, which are simply reaction forces to the contact forces that the bottom block exerts on the top block. The components of the contact force of the floor are N_2 and $0.400N_2$. Other forces on this block are $-P$, the tension $T\mathbf{i}$, and the weight –39.2 N.

Solution

Since the top block is moving horizontally to the right at constant velocity, its acceleration is zero in both the horizontal and the vertical directions. From Newton's second law,

$$\begin{aligned} \sum F_x &= m_1 a_x \qquad & \sum F_y &= m_1 a_y \\ T - 0.400N_1 &= 0 \qquad & N_1 - 19.6\,\text{N} &= 0. \end{aligned}$$

Solving for the two unknowns, we obtain $N_1 = 19.6\,\text{N}$ and $T = 0.40N_1 = 7.84\,\text{N}$. The bottom block is also not accelerating, so the application of Newton's second law to this block gives

$$\begin{aligned} \sum F_x &= m_2 a_x \qquad & \sum F_y &= m_2 a_y \\ T - P + 0.400\,N_1 + 0.400\,N_2 &= 0 \qquad & N_2 - 39.2\,\text{N} - N_1 &= 0. \end{aligned}$$

The values of N_1 and T were found with the first set of equations. When these values are substituted into the second set of equations, we can determine N_2 and P. They are

$$N_2 = 58.8\,\text{N} \quad \text{and} \quad P = 39.2\,\text{N}.$$

Centripetal Motion

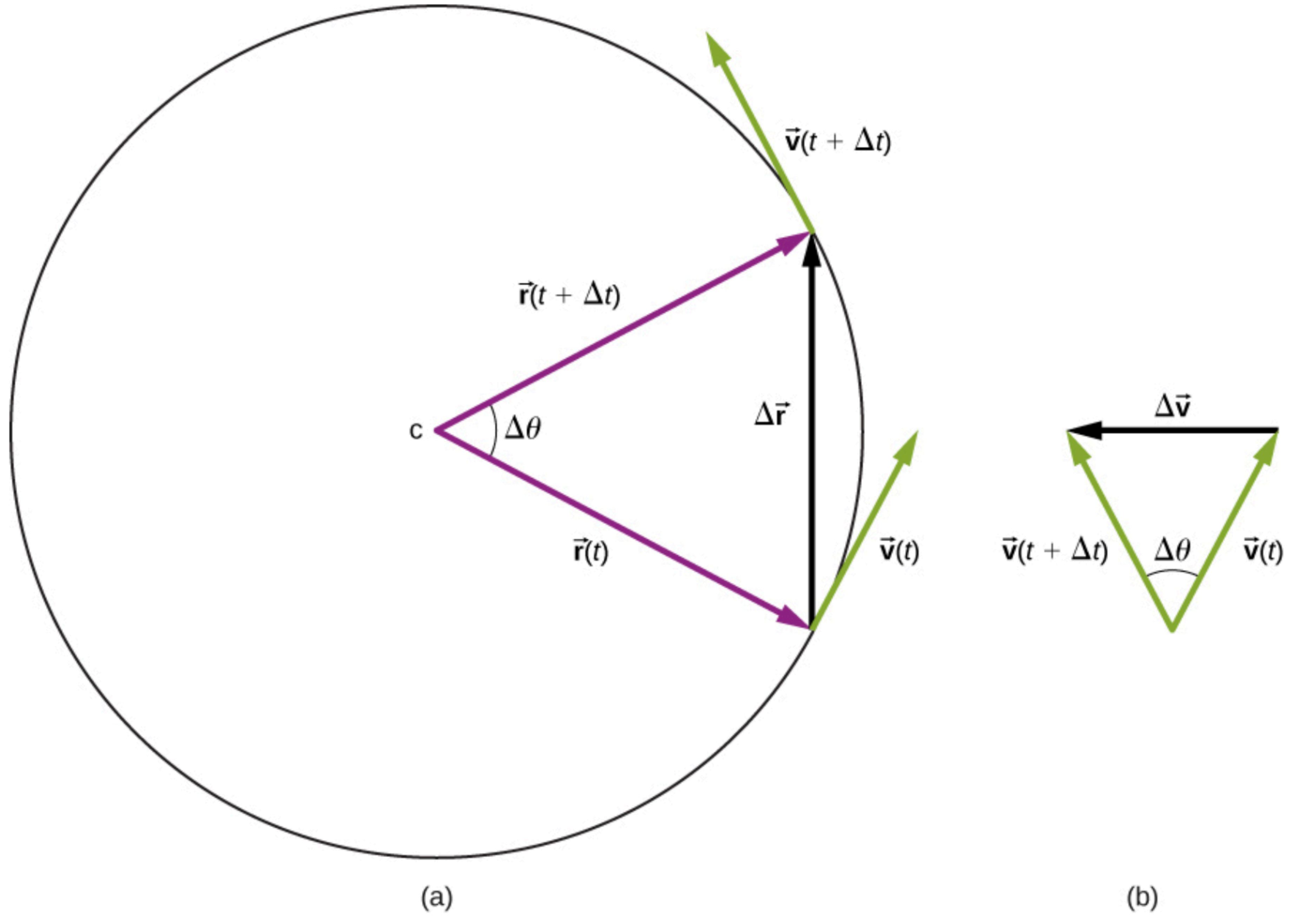

Figure 4.18 (a) A particle is moving in a circle at a constant speed, with position and velocity vectors at times t and $t + \Delta t$. (b) Velocity vectors forming a triangle. The two triangles in the figure are similar. The vector $\Delta\vec{v}$ points toward the center of the circle in the limit $\Delta t \to 0$.

We can find the magnitude of the acceleration from

$$a = \lim_{\Delta t \to 0}\left(\frac{\Delta v}{\Delta t}\right) = \frac{v}{r}\left(\lim_{\Delta t \to 0}\frac{\Delta r}{\Delta t}\right) = \frac{v^2}{r}.$$

The direction of the acceleration can also be found by noting that as Δt and therefore $\Delta\theta$ approach zero, the vector $\Delta\vec{v}$ approaches a direction perpendicular to $\vec{v}$. In the limit $\Delta t \to 0, \Delta\vec{v}$ is perpendicular to $\vec{v}$. Since $\vec{v}$ is tangent to the circle, the acceleration $d\vec{v}/dt$ points toward the center of the circle. Summarizing, a particle moving in a circle at a constant speed has an acceleration with magnitude

$$a_c = \frac{v^2}{r}. \quad (4.27)$$

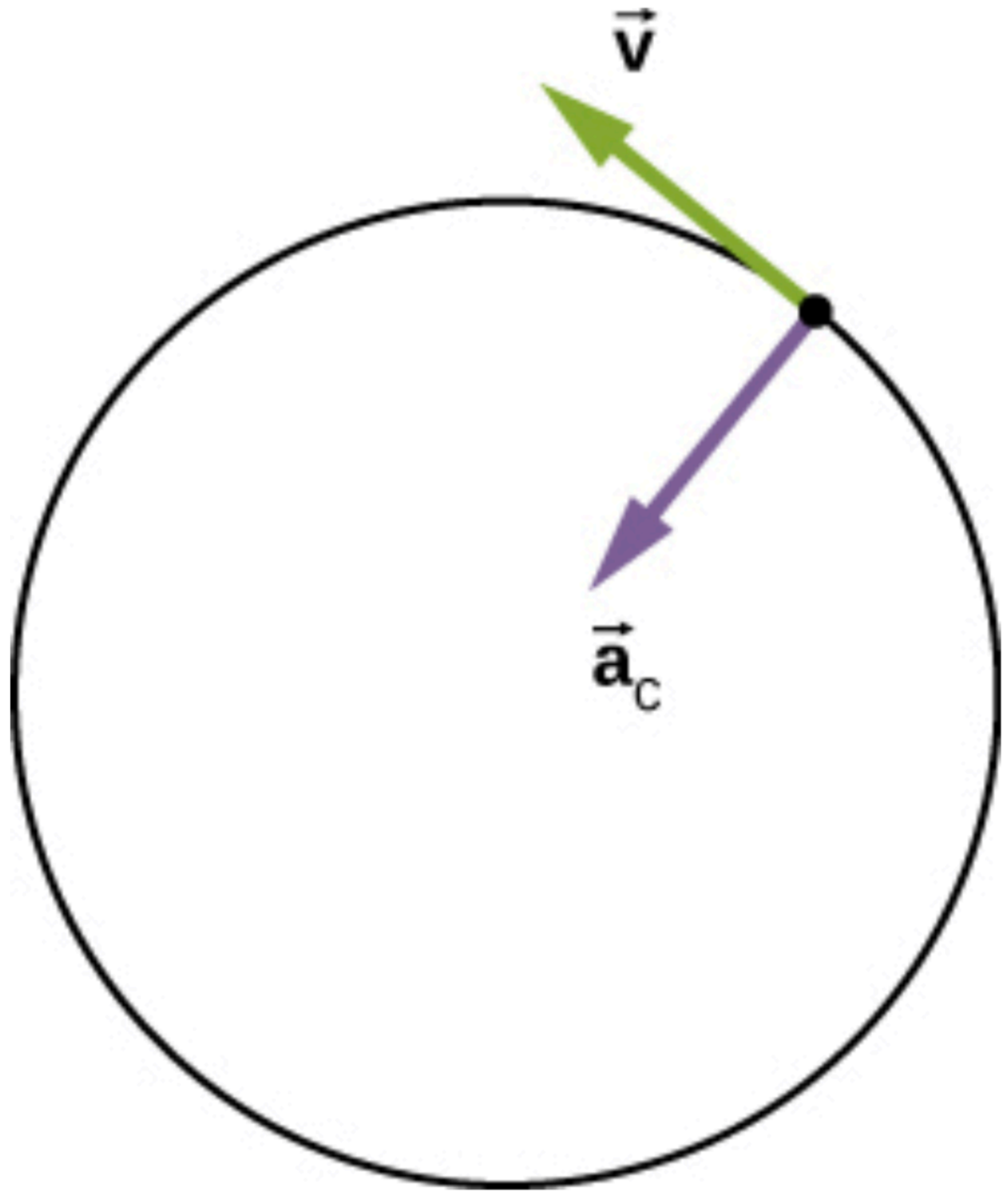

Figure 4.19 The centripetal acceleration vector points toward the center of the circular path of motion and is an acceleration in the radial direction. The velocity vector is also shown and is tangent to the circle.

Centripetal Motion

By substituting the expressions for centripetal acceleration a_c ($a_c = \frac{v^2}{r}$; $a_c = r\omega^2$), we get two expressions for the centripetal force F_c in terms of mass, velocity, angular velocity, and radius of curvature:

$$F_c = m\frac{v^2}{r}; \quad F_c = mr\omega^2. \tag{6.3}$$


arc of projectile motion

Key Equations

Magnitude of static friction	$f_s \leq \mu_s N$
Magnitude of kinetic friction	$f_k = \mu_k N$
Centripetal force	$F_c = m\frac{v^2}{r}$ or $F_c = mr\omega^2$
Ideal angle of a banked curve	$\tan\theta = \frac{v^2}{rg}$
Drag force	$F_D = \frac{1}{2}C\rho Av^2$
Stokes' law	$F_s = 6\pi r\eta v$

Clicker Questions

CQ.7.3

A skier with a mass of 67 kg is skiing down a snowy slope with an incline of 37° . Find the friction if the coefficient of kinetic friction (μ_k) is 0.07. (Take Earth's gravity as 9.8 m/s^2)

a) 27.7 N

b) 34.7 N

c) 36.7 N

d) 46.0 N

A B C D E

CQ.7.3

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a) 27.7 N

b) 34.7 N

✓ c) 36.7 N

d) 46.0 N

Detailed solution: $f_k = \mu_k mg \cos\theta = 36.7\,\text{N}$

A

B

C

D

E

CQ.7.4

A team of six dogs pulls a sled with waxed wood runners on wet snow (μ_k = 0.08). The loaded sled with its rider has a mass of 210 kg.

If each dog exerts an average force of 35 N applied force, what is the acceleration of the sled? (Take Earth's gravity as 9.8 m/s^2

a) 0.22 m/s^2

b) 0.46 m/s^2

c) 0.78 m/s^2

d) 1.00 m/s^2

A B C D E

CQ.7.4

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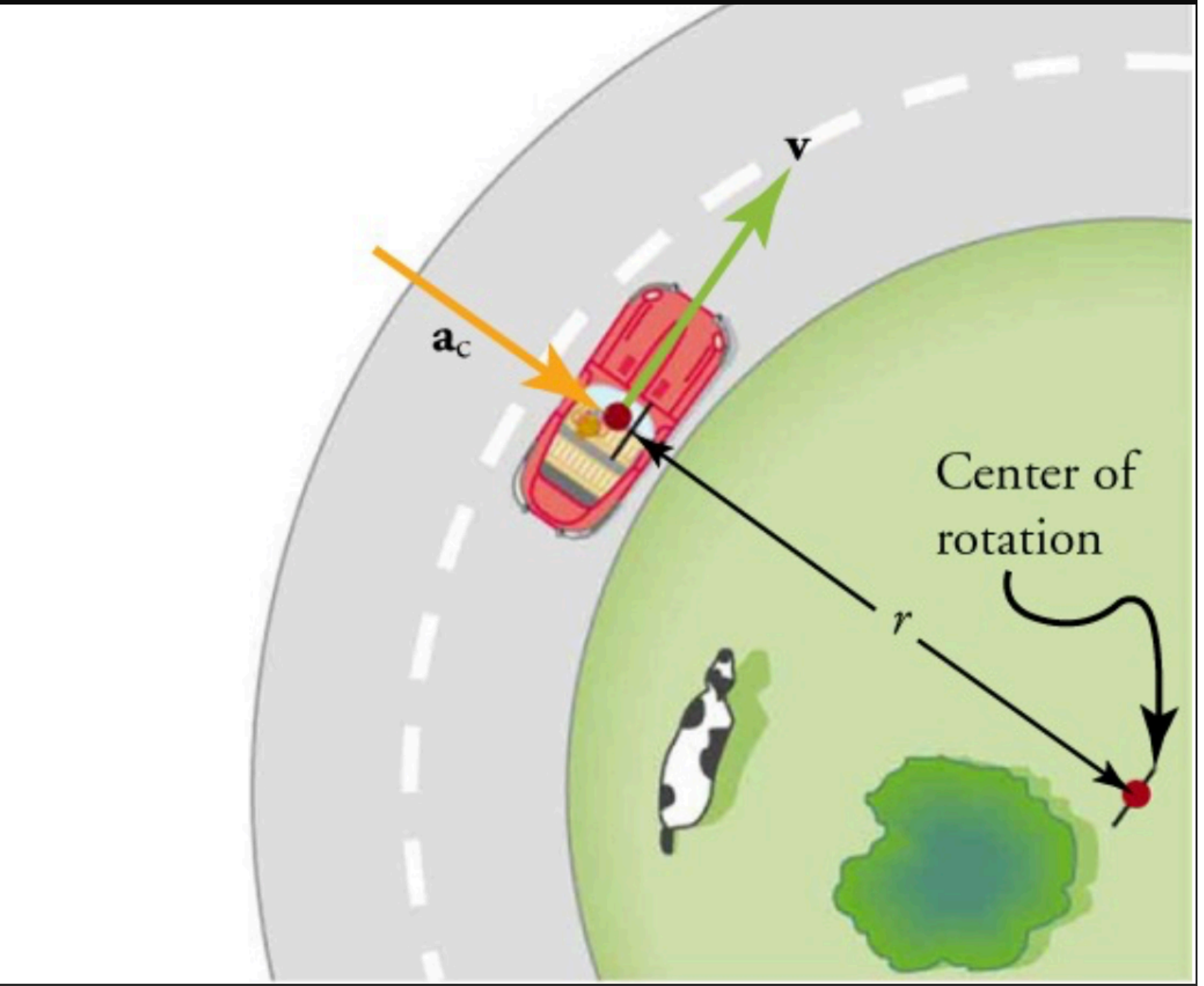
A B C D E

CQ.7.5



A car follows a curve of radius 500 m at a speed of 25.0 m/s (about 90 km/h). What is the magnitude of the car's centripetal acceleration? Compare the centripetal acceleration for this fairly gentle curve taken at highway speed with acceleration due to gravity g.

a) The centripetal acceleration is 0.1 m/s and is 0.1 times the acceleration due to gravity.

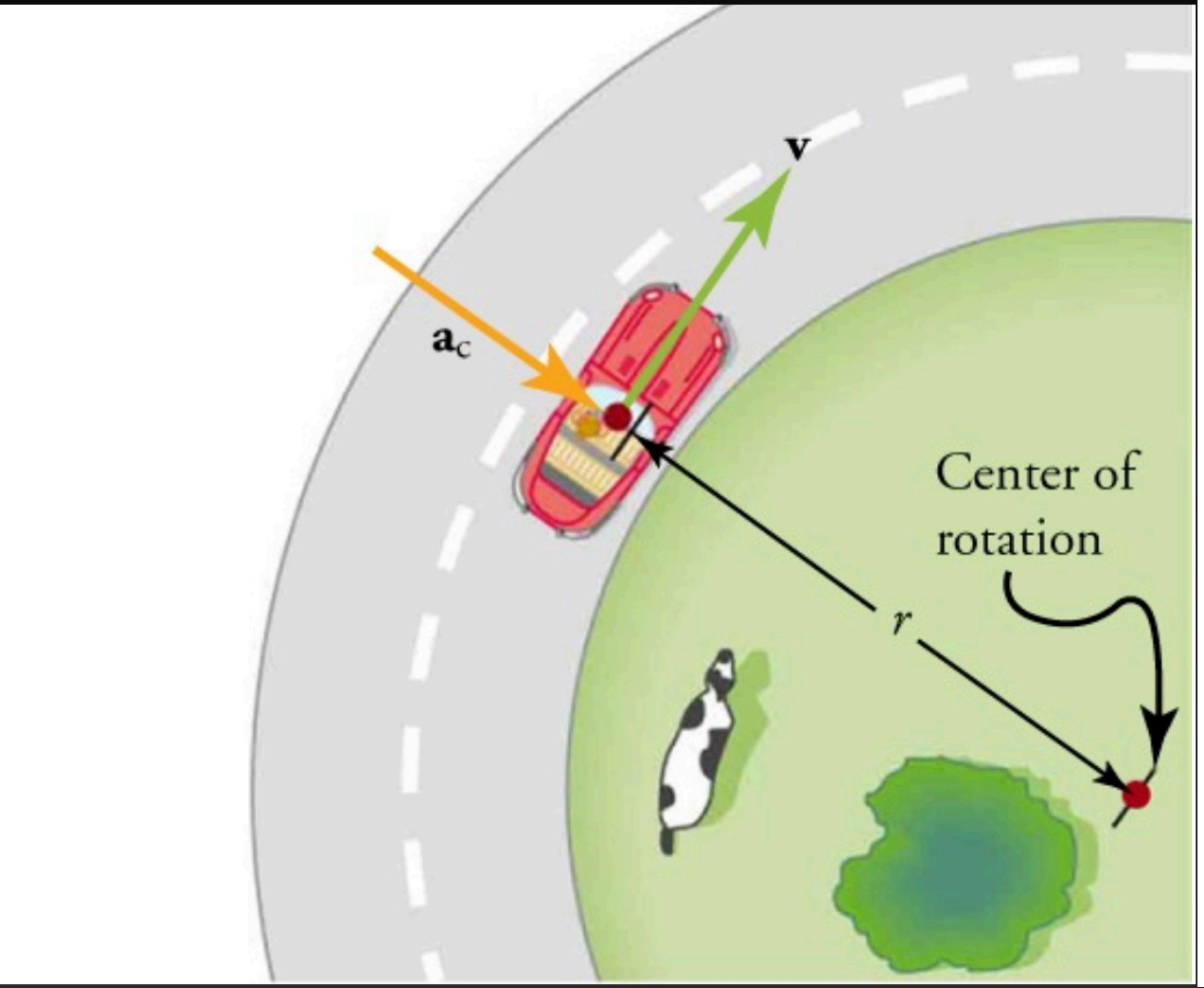
b) The centripetal acceleration is 1.25 m/s^2 and is 0.1 times the acceleration due to gravity.

c) The centripetal acceleration is 0.1 m/s and is 0.01 times the acceleration due to gravity.

d) The centripetal acceleration is 1.25 m/s^2 and is 0.01 times the acceleration due to gravity.

A B C D E

CQ.7.5



A car follows a curve of radius $500\ \mathrm{m}$ at a speed of $25.0\ \mathrm{m/s}$ (about $90\ \mathrm{km/h}$). What is the magnitude of the car's centripetal acceleration? Compare the centripetal acceleration for this fairly gentle curve taken at highway speed with acceleration due to gravity g.

a) The centripetal acceleration is $0.1\ \mathrm{m/s}$ and is 0.1 times the acceleration due to gravity.

The centripetal acceleration is $a_c = \frac{v^2}{r}$, where v is tangential velocity and r is the radius of curvature of th circular path. It is incorrect that the centripetal acceleration is $a_c = \frac{v}{r}$.

✔ b) The centripetal acceleration is $1.25\ \mathrm{m/s^2}$ and is 0.1 times the acceleration due to gravity.

The centripetal acceleration can be obtained by using the relation $a_c = \frac{v^2}{r}$, where v is tangential velocity and r is the radius of curvature of the circular path. Also, the comparison is done by taking the ratio of centripetal acceleration to the acceleration due to gravity.

c) The centripetal acceleration is $0.1\ \mathrm{m/s}$ and is 0.01 times the acceleration due to gravity.

It is incorrect that $a_c = \frac{v}{r}$. The centripetal acceleration is $a_c = \frac{v^2}{r}$, where v is tangential velocity and r is t radius of curvature of the circular path.

d) The centripetal acceleration is $1.25\ \mathrm{m/s^2}$ and is 0.01 times the acceleration due to gravity.

It is correct that the centripetal acceleration is $a_c = \frac{v^2}{r}$, but you have compared the centripetal acceleratio with the acceleration due to gravity incorrectly. The comparison is done by taking the ratio of centripetal acceleration to the acceleration due to gravity.

A B C D E

CQ.7.6

Is an object in uniform circular motion accelerating? Why or why not?

a) Yes, because the velocity is not constant.

b) No, because the velocity is not constant.

c) Yes, because the velocity is constant.

d) No, because the velocity is constant.

A

B

C

D

E

CQ.7.6

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b) No, because the velocity is not constant.

c) Yes, because the velocity is constant.

d) No, because the velocity is constant.

A B C D E

CQ.7.7

An object is in uniform circular motion. Suppose the centripetal force was removed. In which direction would the object now travel?

a) in the direction of the centripetal force

b) in the direction opposite to the direction of the centripetal force

c) in the direction of the tangential velocity

d) in the direction opposite to the direction of the tangential velocity

A B C D E

CQ.7.7

An object is in uniform circular motion. Suppose the centripetal force was removed. In which direction would the object now travel?

a) in the direction of the centripetal force

b) in the direction opposite to the direction of the centripetal force

✓ c) in the direction of the tangential velocity

d) in the direction opposite to the direction of the tangential velocity

A B C D E

CQ.7.8

A 50 kg bicyclist starts his ride down the road with an acceleration of $1 m/s^2$ in air with a density of $1.2 kg/m^3$. If his velocity at a given moment is 2m/s, how much force is he exerting? Assume the area of his body is $0.5 m^2$.

a) The bicyclist is exerting 1.1 N of force.

b) The bicyclist is exerting 49 N of force.

c) The bicyclist is exerting 50 N of force.

d) The bicyclist is exerting 51 N of force.

A	B	C	D	E

CQ.7.8

A 50 kg bicyclist starts his ride down the road with an acceleration of $1 m/s^2$ in air with a density of $1.2 kg/m^3$. If his velocity at a given moment is 2m/s, how much force is he exerting? Assume the area of his body is $0.5 m^2$.

a) The bicyclist is exerting 1.1 N of force.

b) The bicyclist is exerting 49 N of force.

c) The bicyclist is exerting 50 N of force.

✔ d) The bicyclist is exerting 51 N of force.

Detailed solution: The F_{NET} of the bicyclist is calculated as ma = 50 kg x 1 m/s^2 = 50 N. Since $F_{NET} = F_{CYC} - F_D$ we can solve the equation to find F_{CYC}. The drag force can be calculated using the equation $F_D = ½ C\rho Av^2$ where C = 0.9, ρ = $1.2 kg/m^3$, A = $0.5 m^2$, and v = 2m/s. F_D is calculated to be 1.08 N, so F_{CYC} must be 51.08 N. Then, adjust for significant figures.

A B C D E

CQ.7.9

A 2.20 kg toy plane takes off with an acceleration of 3.30 m/s^2. The engine supplies a force of 8.15 N. Determine the magnitude of drag force acting on the plane as it accelerates.

a) 7.26 N

b) 15.4 N

c) 0.89 N

d) 0.0 N

A B C D E

CQ.7.9

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a) 7.26 N

b) 15.4 N

✔ c) 0.89 N

d) 0.0 N

Detailed solution: Without any drag force the airplane would accelerate at **3.7 m/s^2**. The drag force opposes a little bit of the force supplied by the motor. If you chose **15.4 N** you may have added a number that should have been subtracted. **7.26 N** is the net force acting on the plane. You'll need this to calculate the drag force.

A B C D E

See you next class!

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