Essential University Physics

Richard Wolfson

2nd Edition

Using Newton's Laws 如何使用牛頓定律

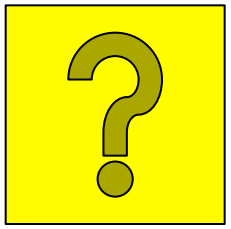
In this lecture you'll learn 本章簡介

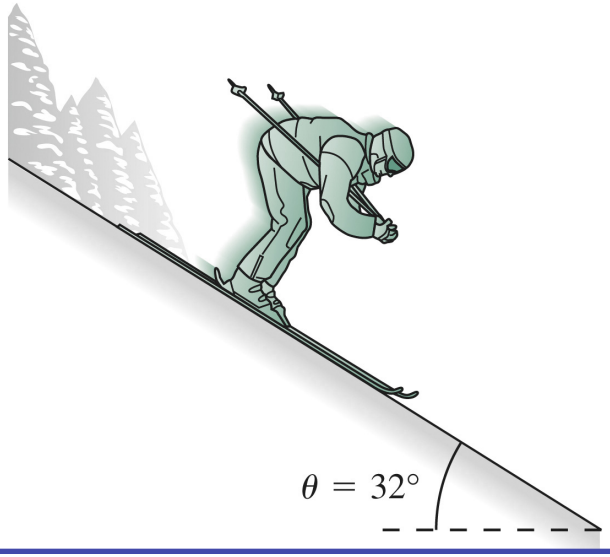
- To use Newton's second law to solve problems involving 要使用第二定律解決問題
  - Objects moving in two dimensions 二維的運動
  - Multiple objects多個物體
  - Circular motion水平圓周運動
  - Frictional forces摩擦力
    - And the nature of friction 摩擦力的性質

A Typical Problem: 一般性的問題

1. What's the skier's acceleration? 滑雪者的加速度 ？

2. What's the force the snow exerts on the skier? 雪地對滑雪者的施力？





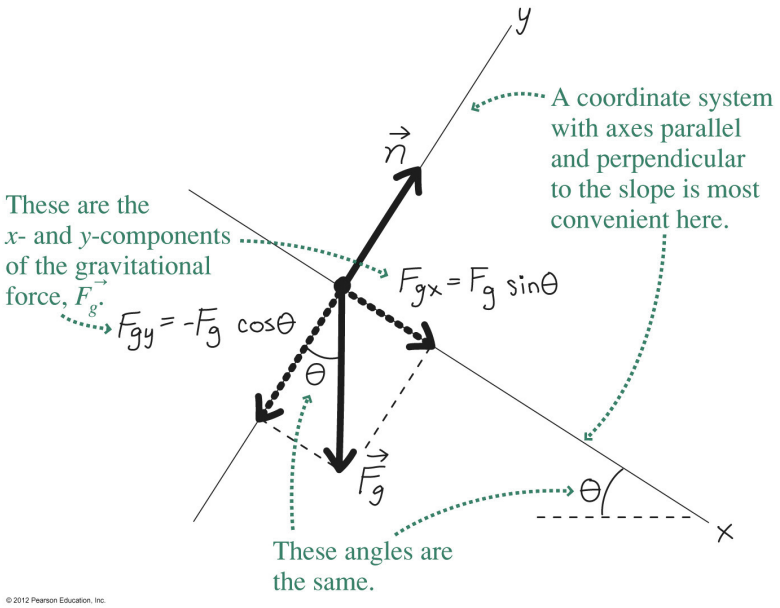
- Physical diagram: 示意圖

- Newton's law:

$$\vec{F}_{\text{net}} = m\vec{a},$$

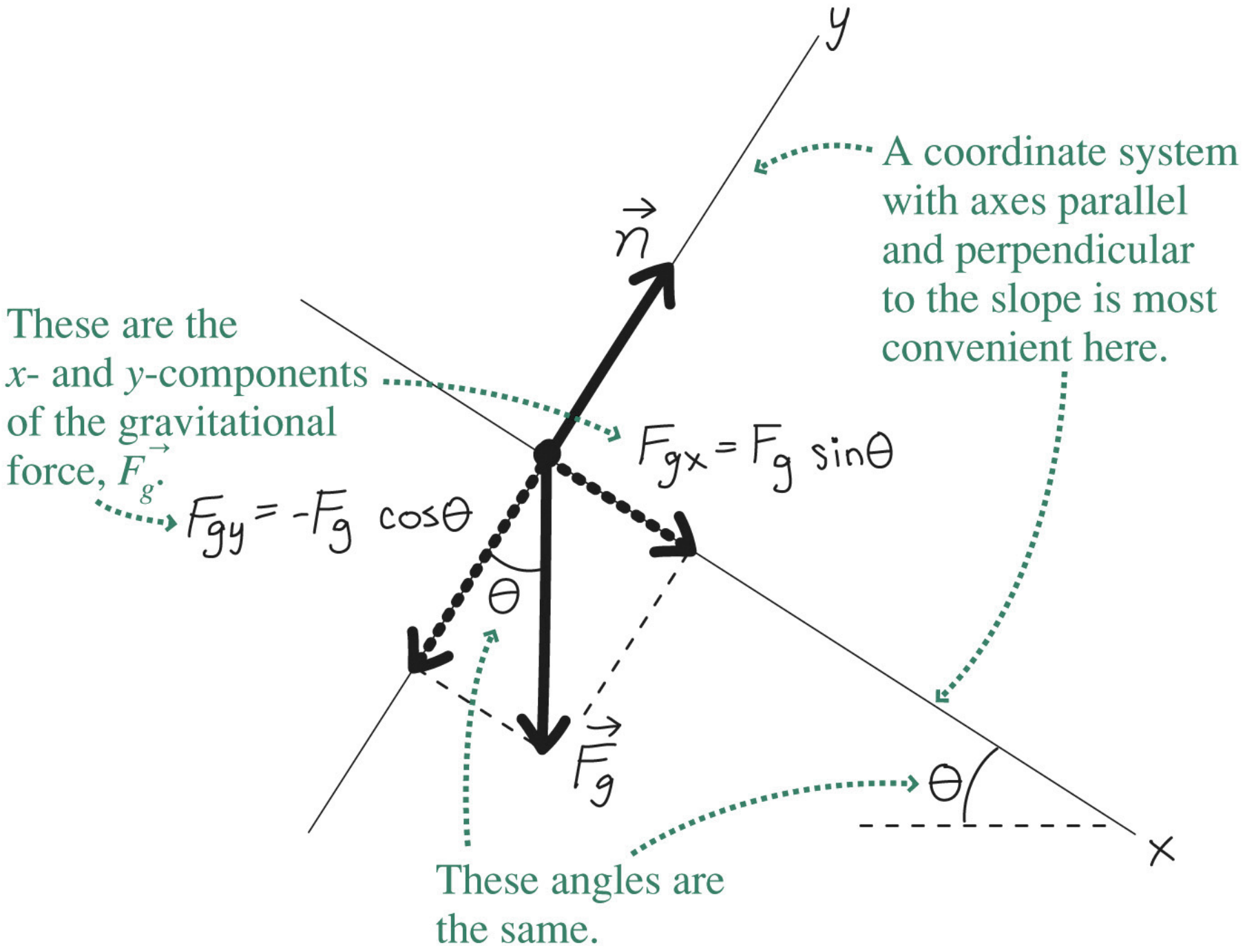
$$\vec{F}_{\text{net}} = \vec{n} + \vec{F}$$

- Free-body diagram:
  受力圖



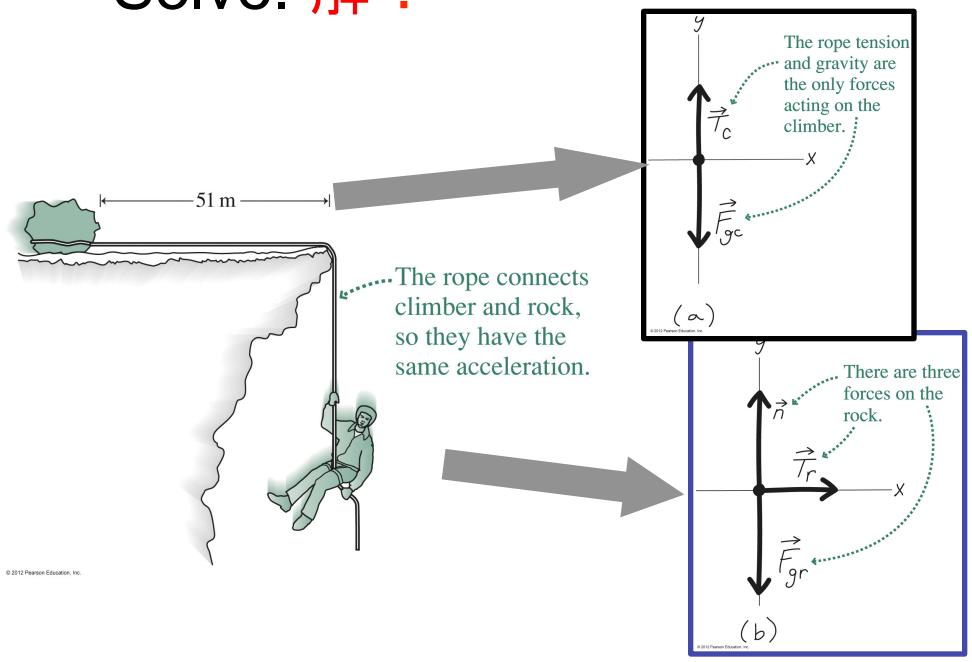
- In components:
  - *x*-component: $mg\sin\theta = ma$
  - *y*-component: $n - mg\cos\theta = 0$

- Solve (with m = 65 kg and θ = 32 °) to get the answers:
  - $a = g\sin\theta = (9.8\ \text{m/s}^2)\sin 32° = 5.2\ \text{m/s}^2$
  - $n = mg\cos\theta = (65\ \text{kg})(9.8\ \text{m/s}^2)\cos 32° = 540\ \text{N}$



Multiple Objects 好幾個物體的情形

- Solve problems involving multiple objects by first identifying each object and all the forces on it.一個一個地處理
- Draw a free-body diagram for each.每一個的受力圖
- Write Newton's law for each. 列下各別的2nd Law
- Identify connections between the objects, which give common terms in the Newton's law equations.哪些量互連
- Solve. 解！



- Newton's law:

$$\text{climber: } \vec{T}_c + \vec{F}_{gc} = m_c\vec{a}_c$$

$$\text{rock: } \vec{T}_r + \vec{F}_{gr} + \vec{n} = m_r\vec{a}_r$$

- In components:

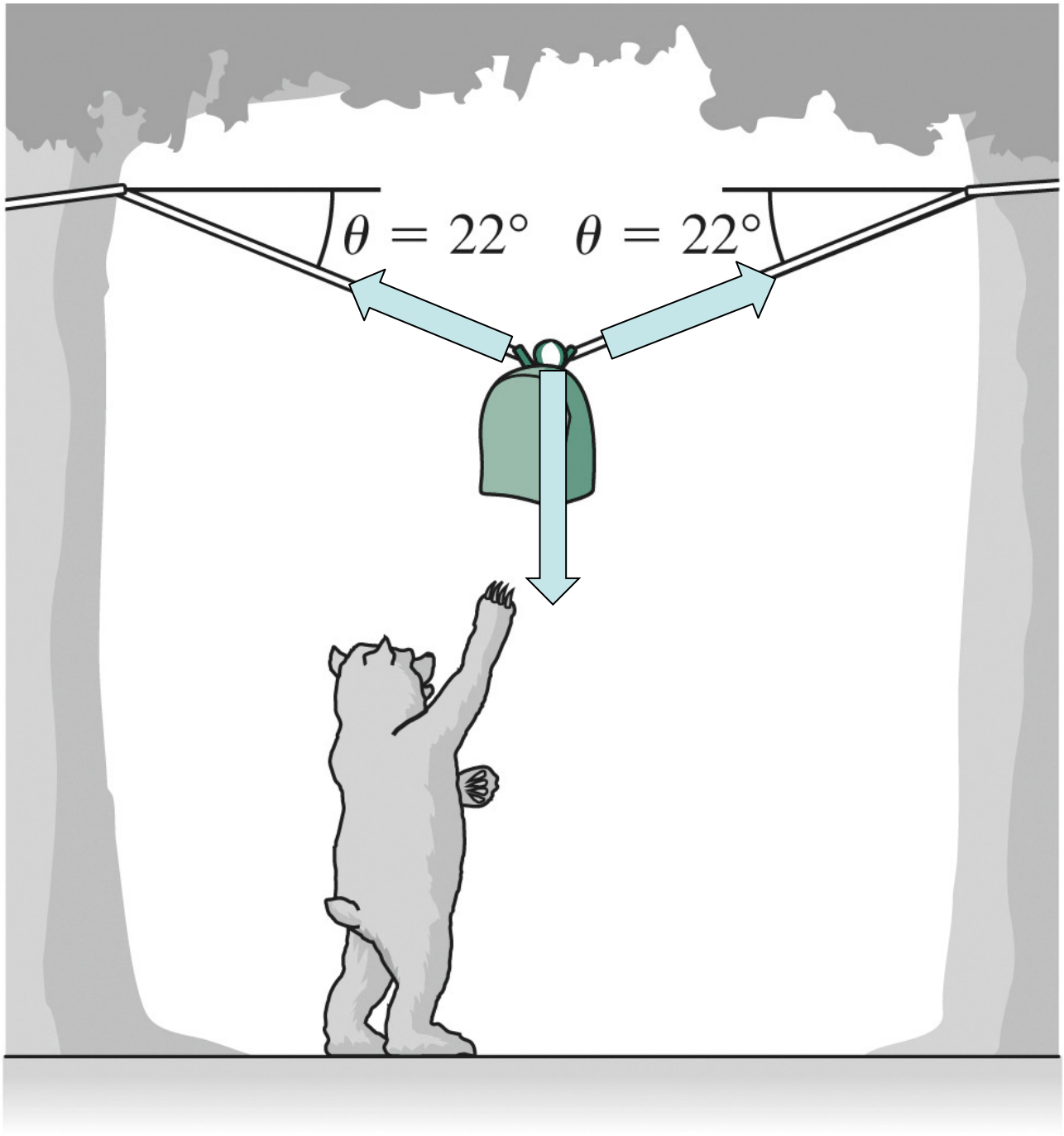
$$\text{climber, } y\text{: } T - m_c g = -m_c a$$

$$\text{rock, } x\text{: } T = m_r a$$

$$\text{rock, } y\text{: } n - m_r g = 0$$

- Solution:

$$a = \frac{m_c g}{m_c + m_r}$$



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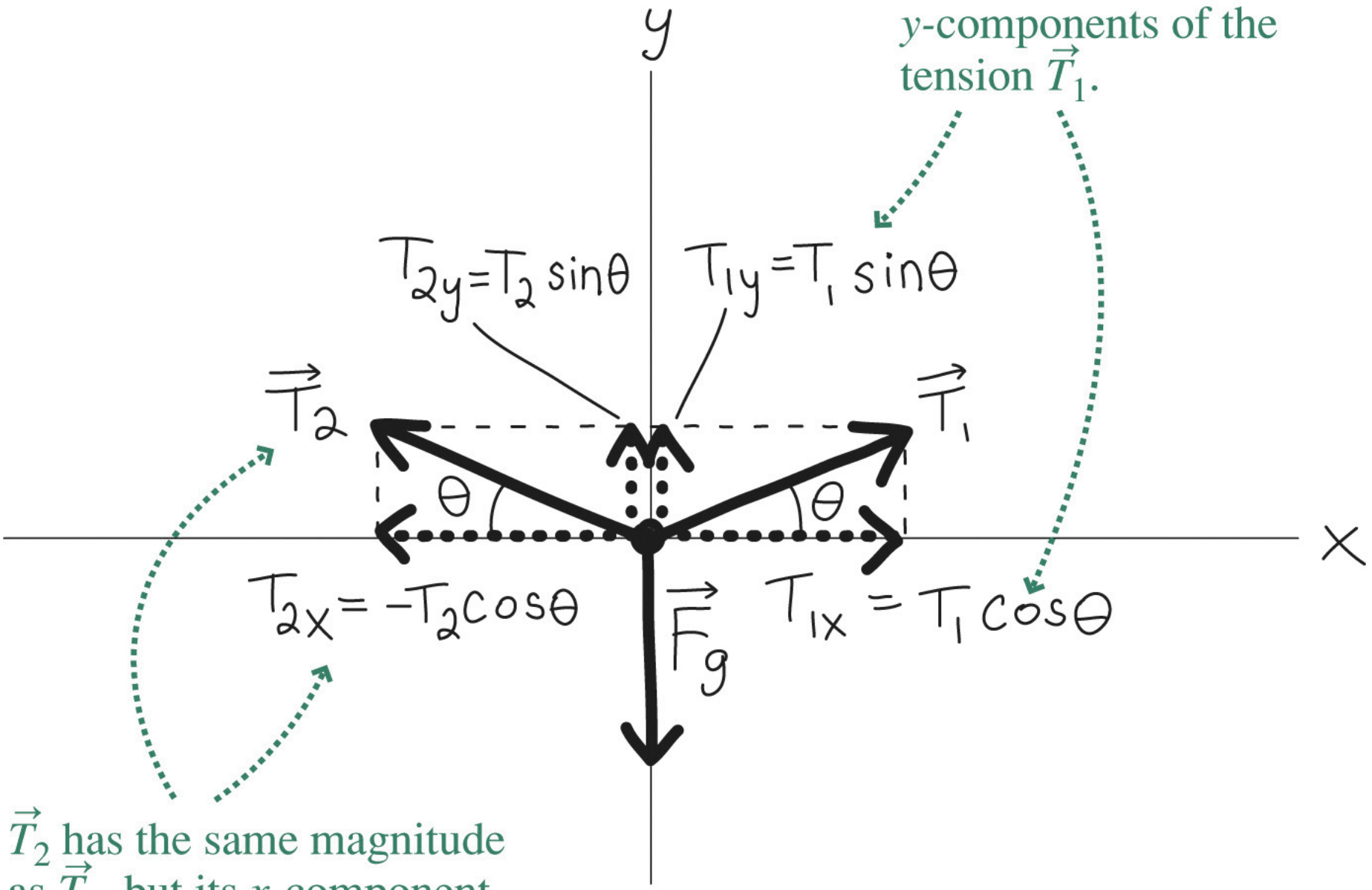
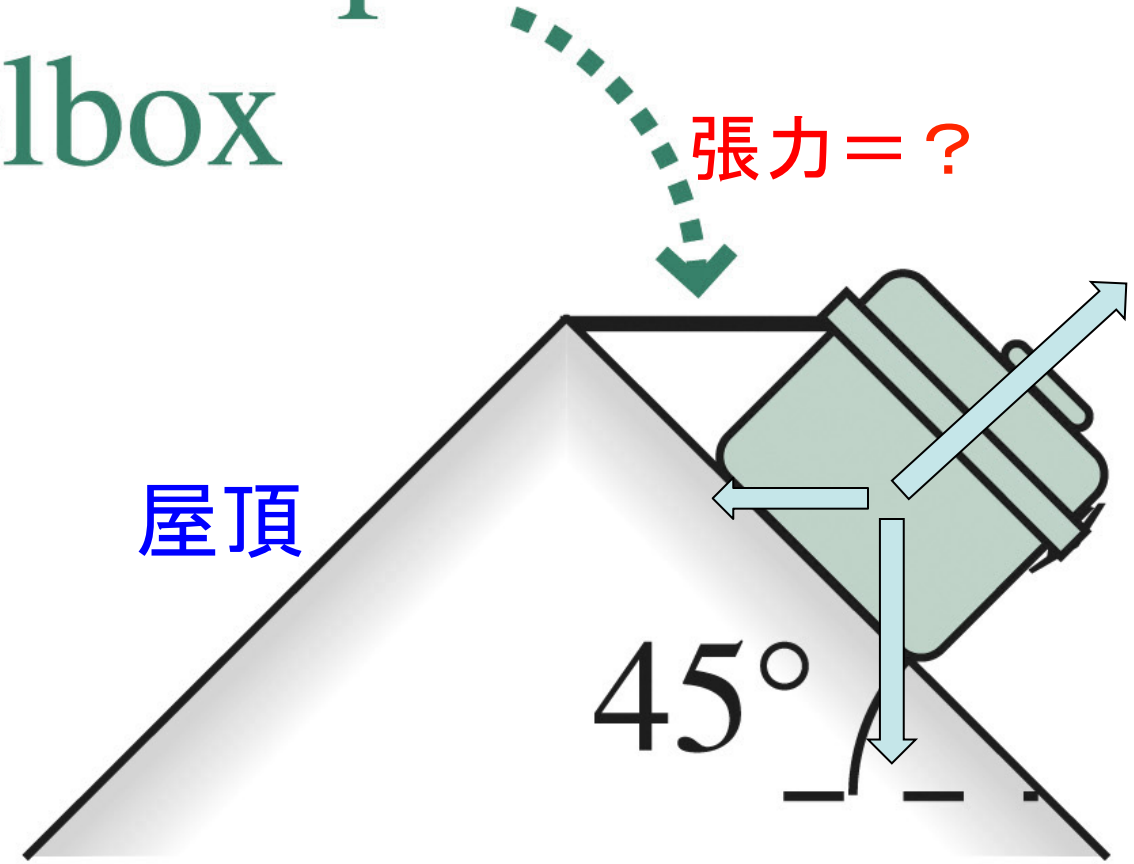
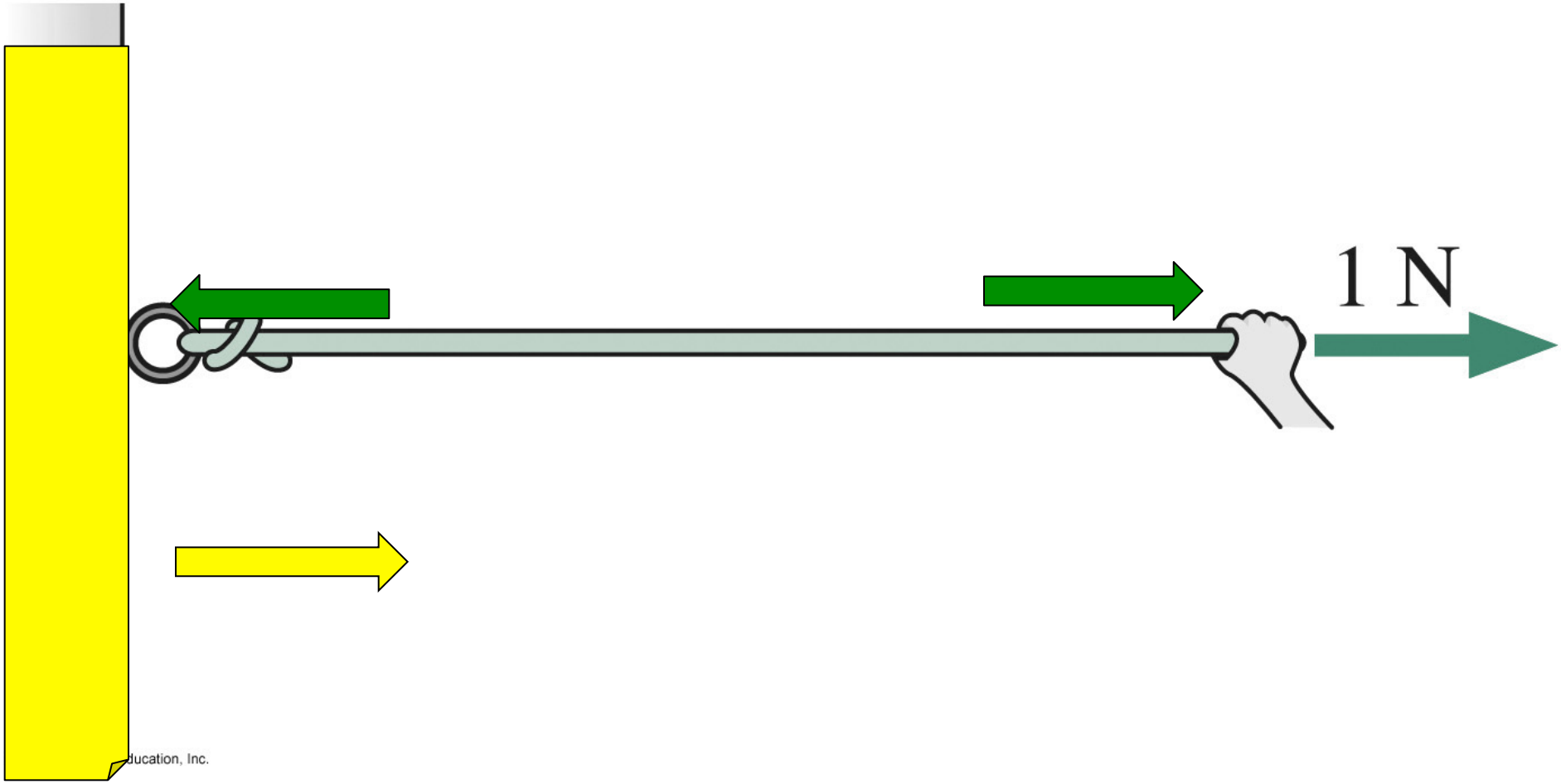
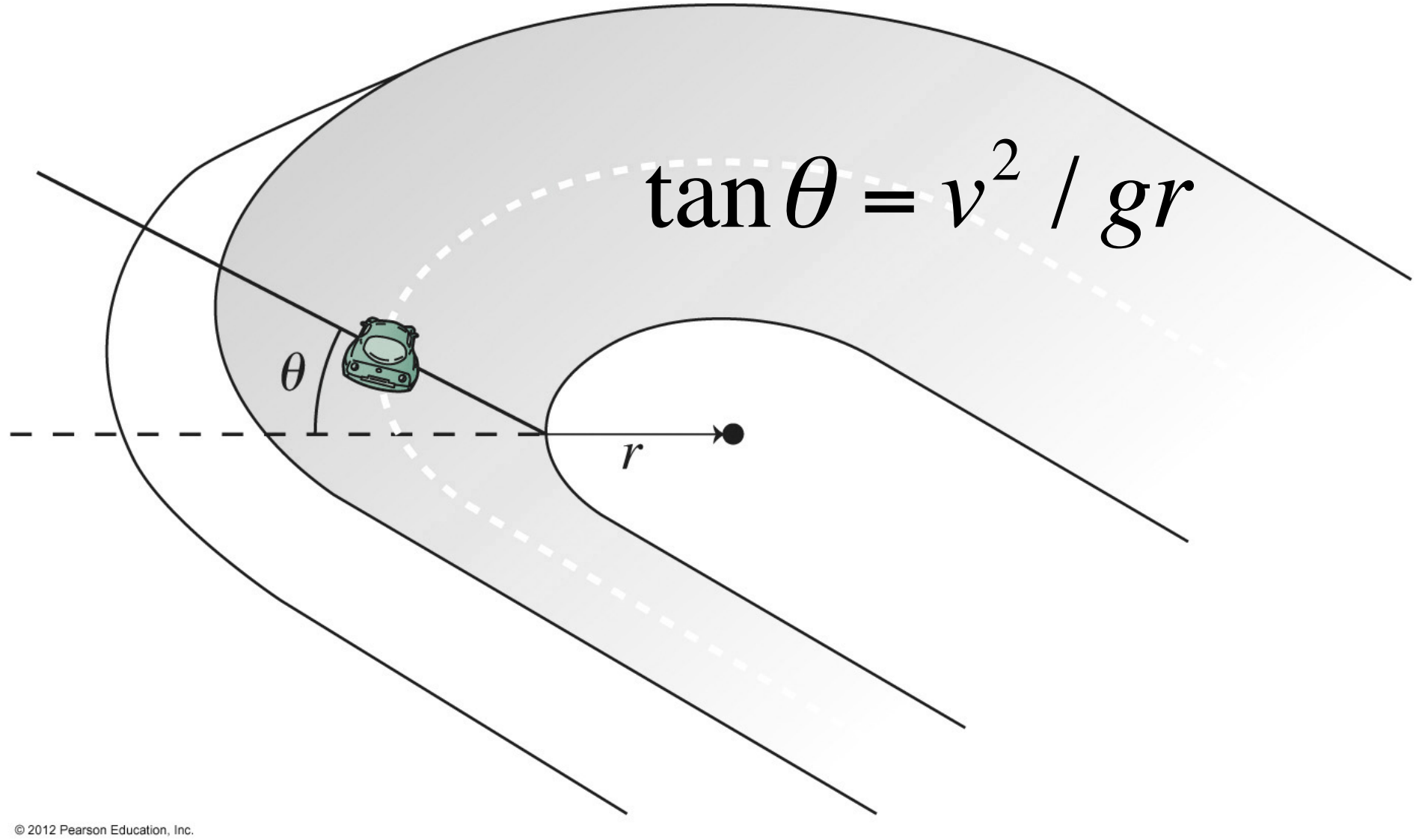
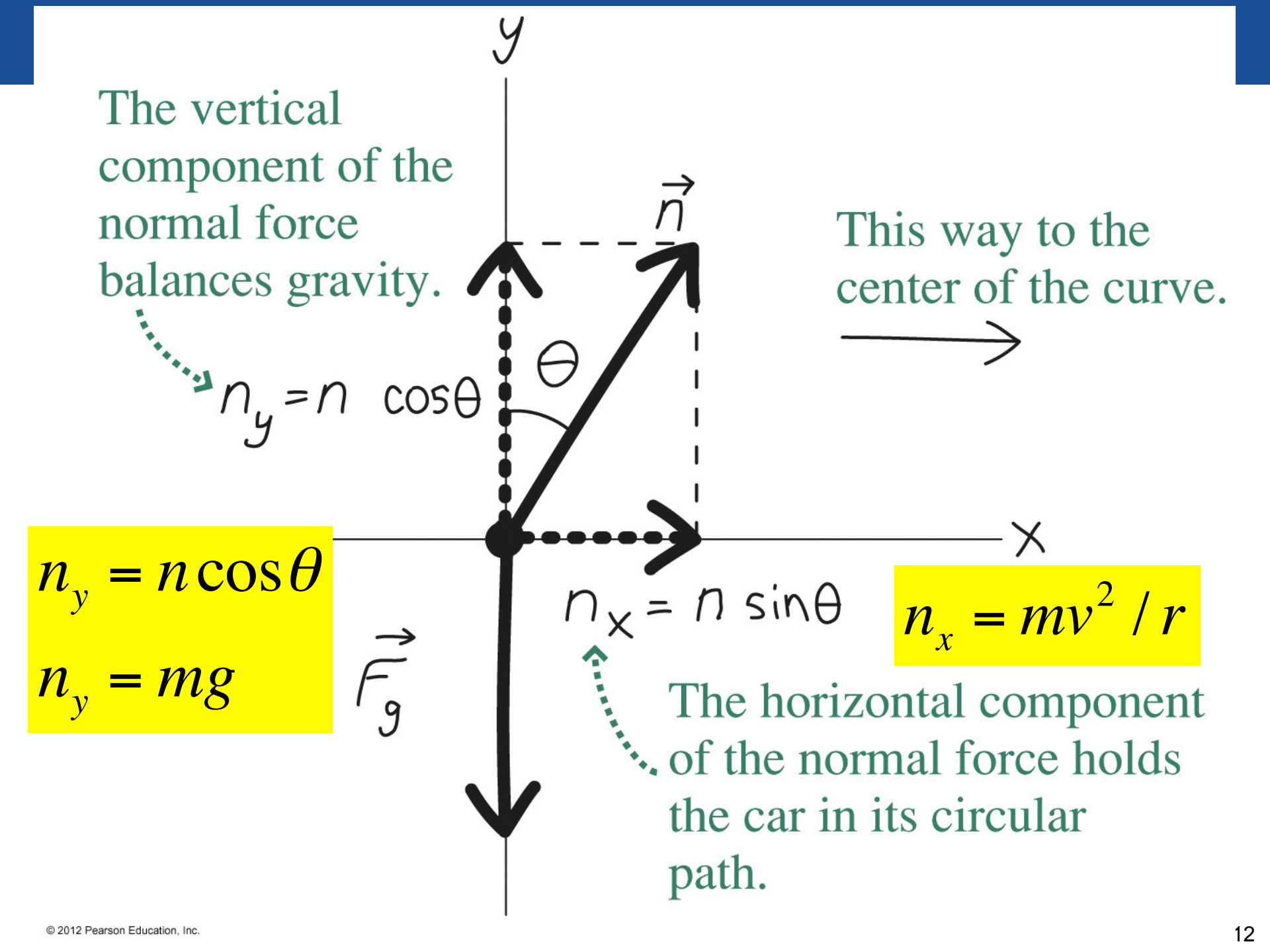


How does the rope tension compare with the toolbox weight?





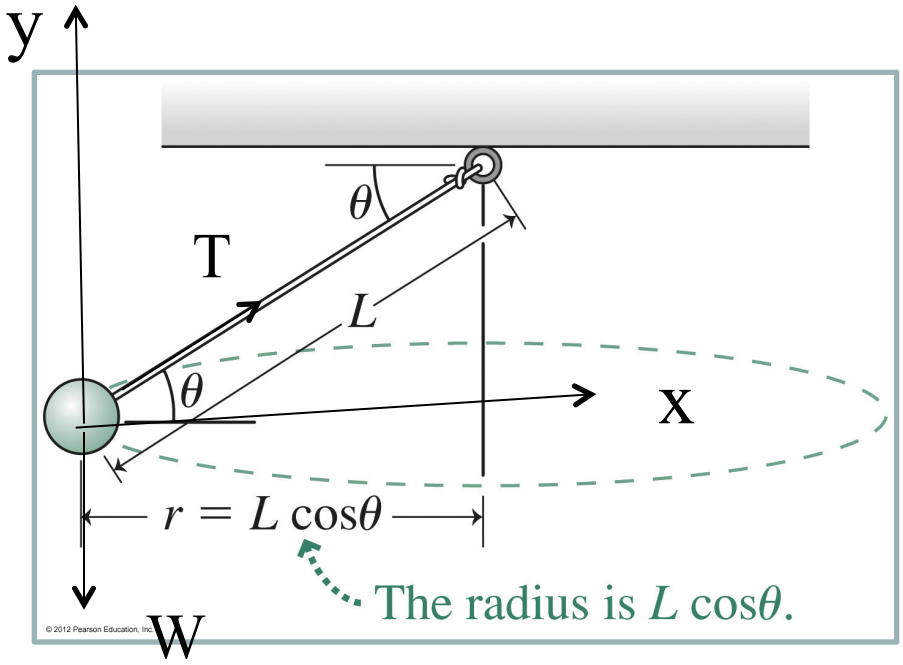




Circular Motion 水平圓周運動

A ball whirling on a string: 用一條繩子水平轉一個球

- Problems involving circular motion are no different from other Newton's law problems.本質上並沒有特殊之處
- Identify the forces, draw a free-body diagram, write Newton's law. 一樣的找出相關的力 畫受力圖 牛頓定律



Circular Motion 圓周(弧)運動

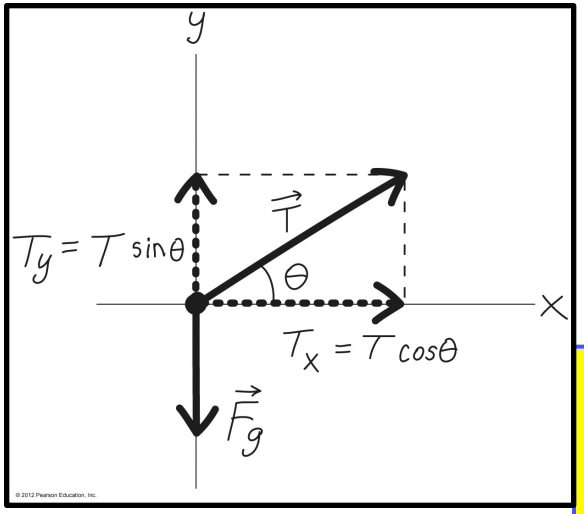
- The magnitude of the **centripetal force** on an object of mass *m* in circular motion with radius *r* is

向心力

$$F = ma = \frac{mv^2}{r}$$

  - the acceleration has magnitude v^2/r and points toward the center of the circle. 向心加速度

Free-body diagram:



- Newton's law: $\vec{T} + \vec{F}_g = m\vec{a}$

- In components:

$$x: \quad T\cos\theta = \frac{mv^2}{L\cos\theta}$$

$$y: \quad T\sin\theta - mg = 0$$

- Solve for the ball's speed:

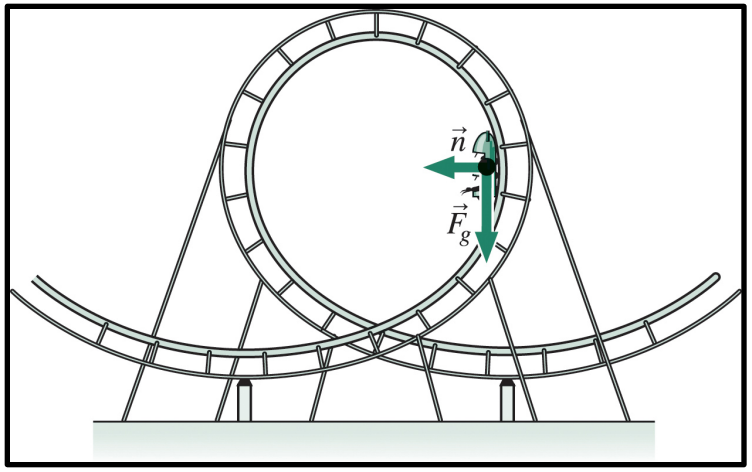
$$v = \sqrt{\frac{TL\cos^2\theta}{m}} = \sqrt{\frac{(mg/\sin\theta)L\cos^2\theta}{m}} = \sqrt{\frac{gL\cos^2\theta}{\sin\theta}}$$

Loop-the-Loop! 轉！轉！轉

- The two forces acting on the roller-coaster car are: 旋轉車受力
  - Gravity 重力 垂直向下
  - normal force 正向力 與軌道垂直
- Gravity is always downward, and the normal force is perpendicular to the track.
- At the position shown, the two forces are at right angles: 圖裡, 在車的位置 兩力正交
  - The net force $m\vec{a}$ is *not* toward the center

因為∴

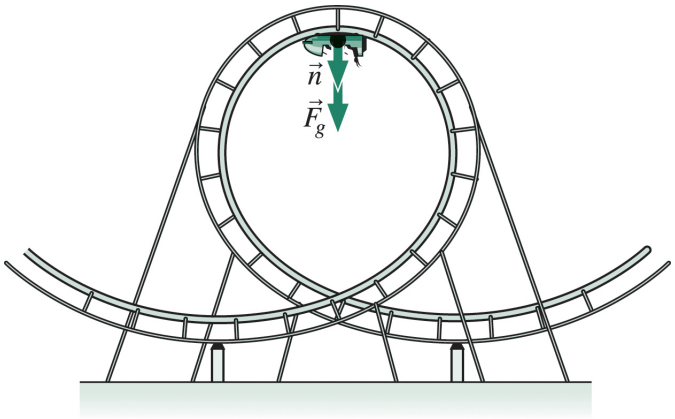
$$\text{Newton's law}: \quad m\vec{a} = \vec{n} + \vec{F}_g$$



- At the top of the loop, both forces are downward:在最高點 兩力向下

$$n_y = n,\ F_{gy} = mg \quad \Rightarrow \quad n + mg = \frac{mv^2}{r}$$

  - Solving for *v*, we obtain 解v得到 $v = \sqrt{nr/m + gr}$
  - For the car to stay in contact with the track, the normal force must be greater than zero. n必須不為零才不會脫軌
  - So the minimum speed is the speed that let the normal force get arbitrarily close to zero at the top of the loop. n=0時,v最小
  - Then gravity alone provides the force that keeps the car in circular motion. 由G負責

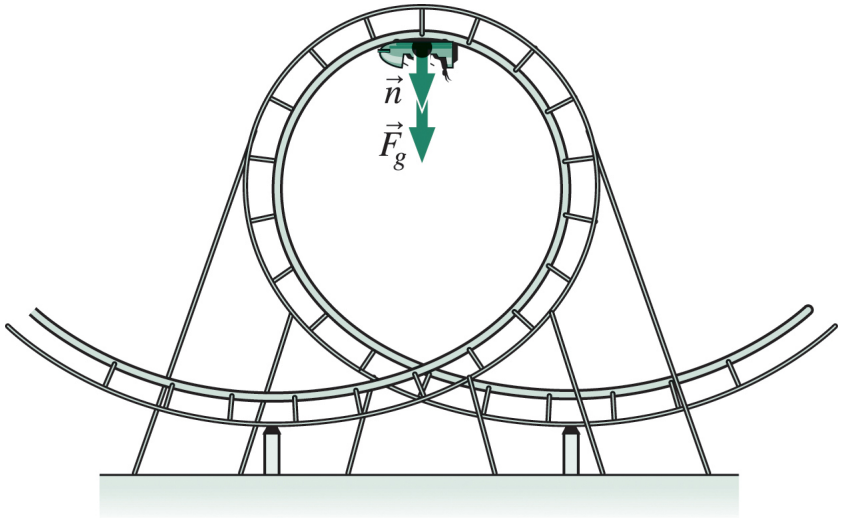


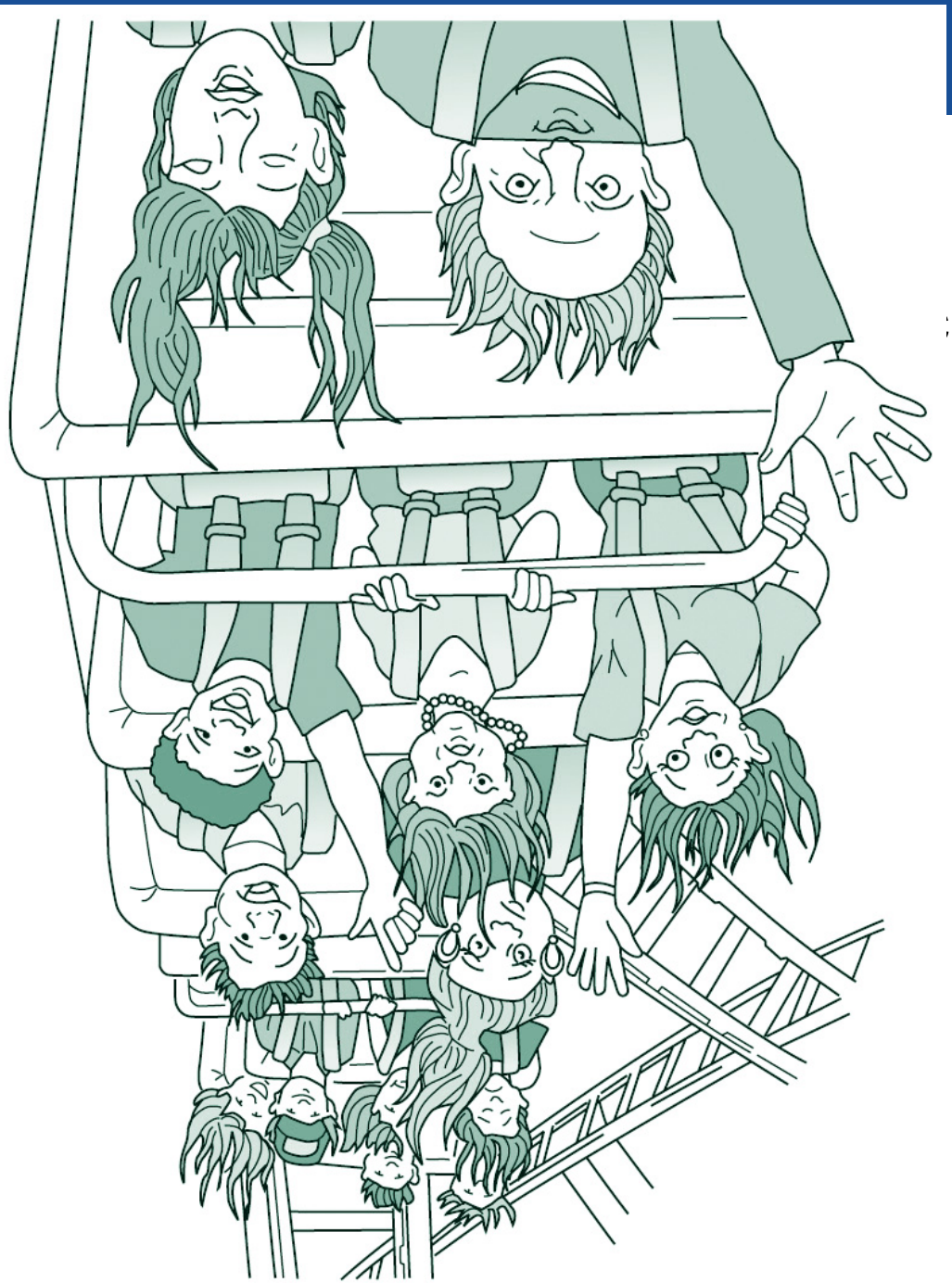
Loop-the-Loop!

- Therefore Newton's law has a single component, with the gravitational force *mg* providing the acceleration v^2/r that holds the car in its circular path:

$$\vec{F} = m\vec{a} \quad \rightarrow \quad mg = \frac{mv^2}{r}$$

  - Solving for the minimum speed at the loop top gives $v = \sqrt{gr}$.
  - Slower than this at the top, and the car will leave the track!
  - Since this result is independent of mass, car and passengers will all remain on the track as long as $v \geq \sqrt{gr}$.





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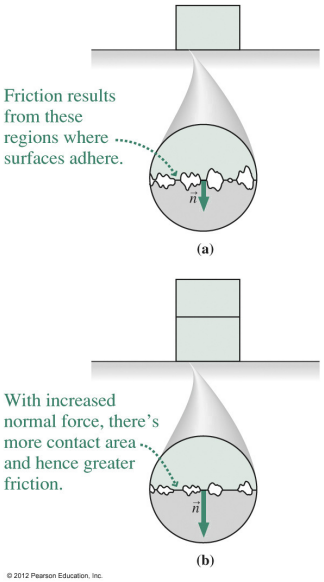
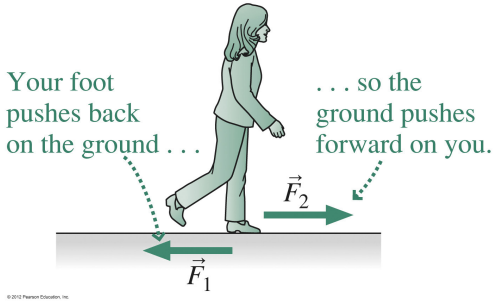
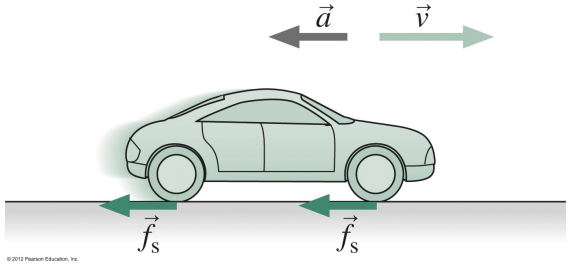
Friction

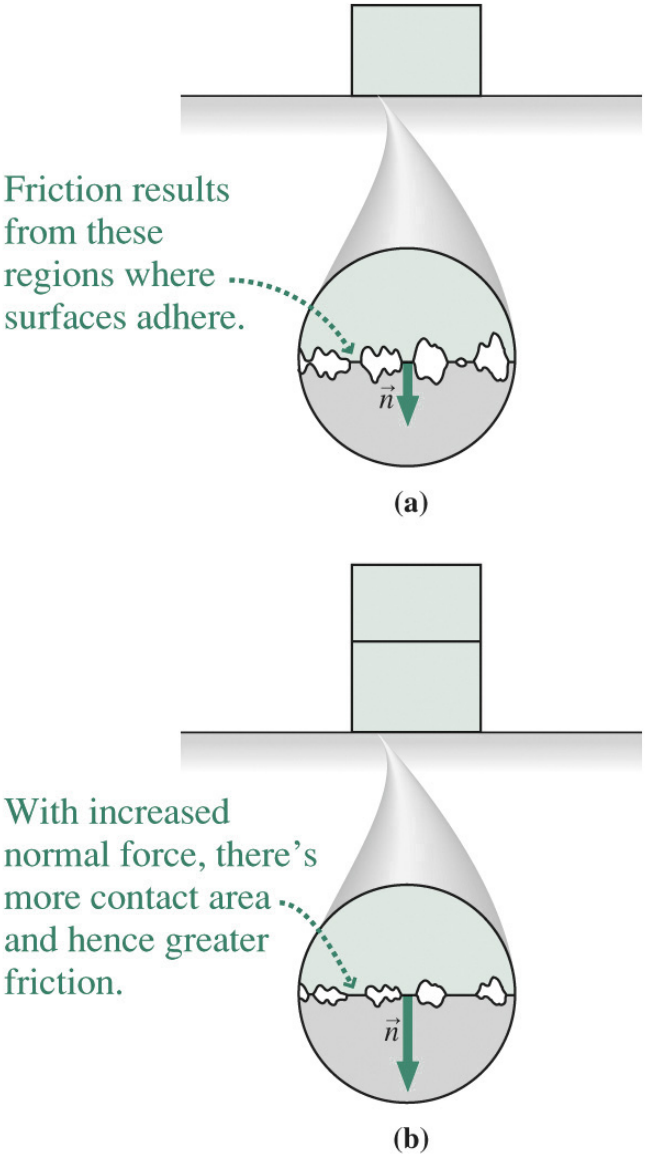
- **Friction** is a force that opposes the relative motion of two contacting surfaces.
- **Static friction** occurs when the surfaces aren't in motion; its magnitude is $f_s \geq \mu_s n$, where n is the normal force between the surfaces and μ_s is the **coefficient of static friction.**
- **Kinetic friction** occurs between surfaces in motion; its magnitude is $f_k = \mu_k n$.

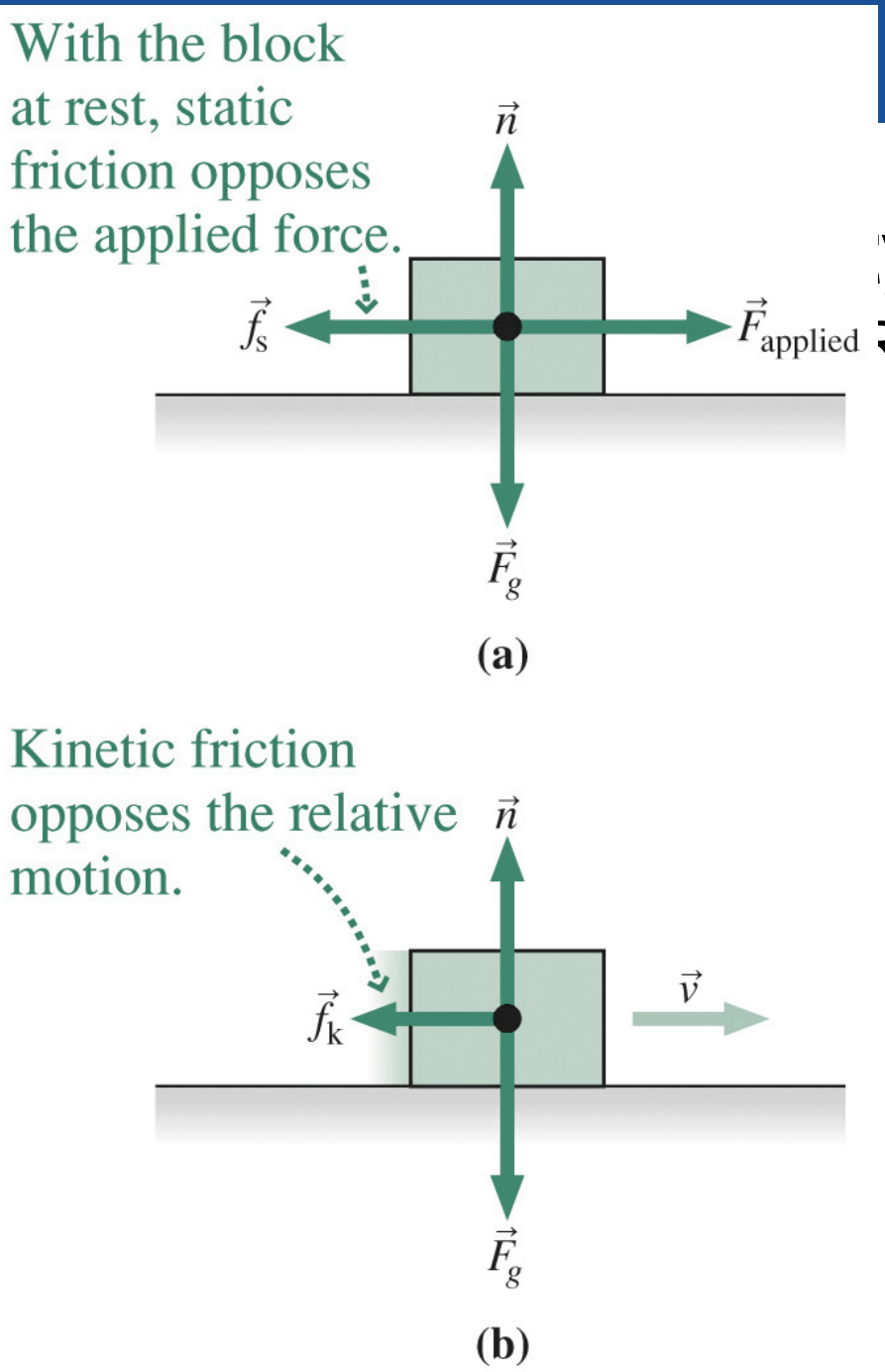


Friction is important in walking, driving and a host of other applications:









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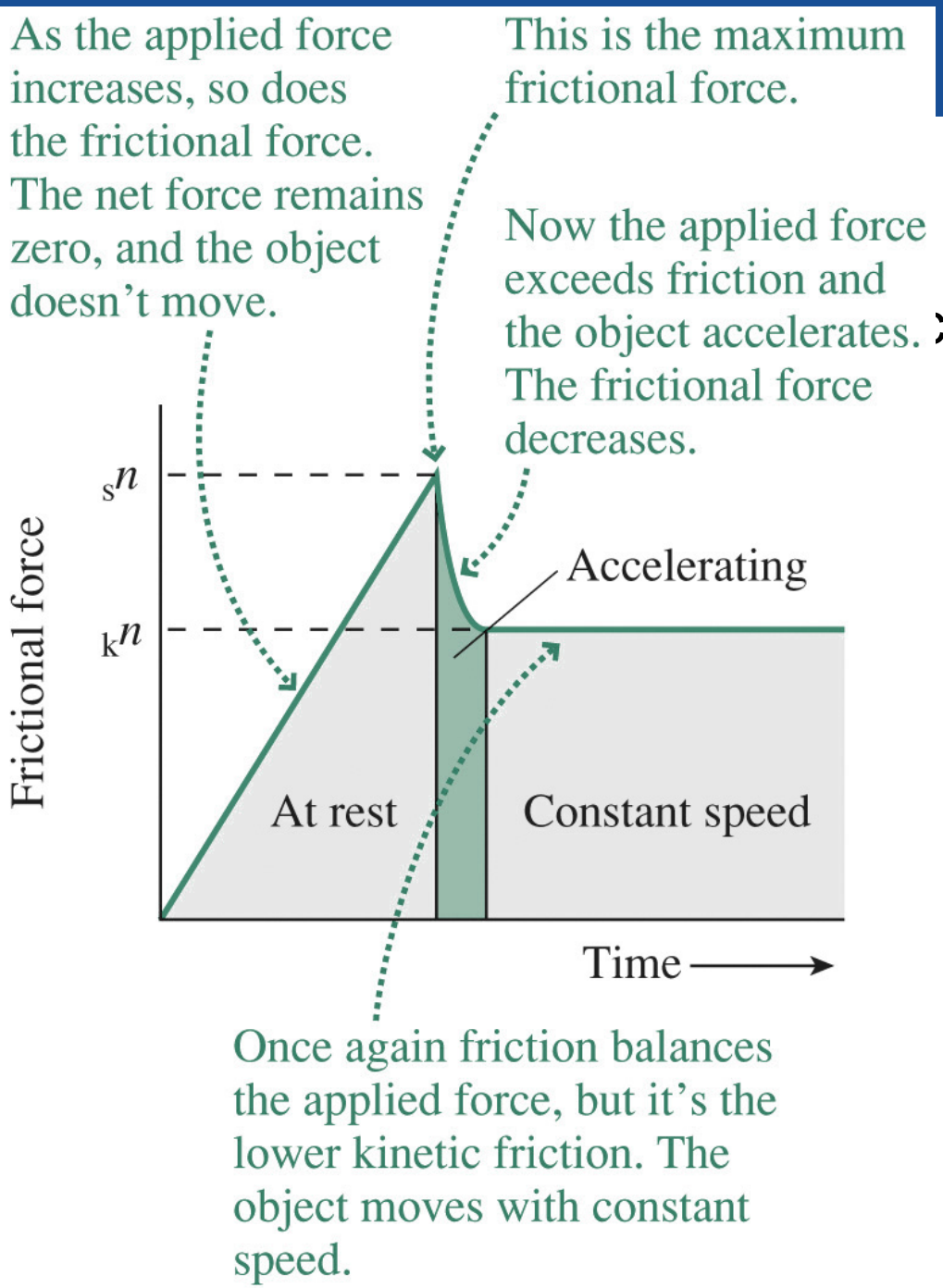

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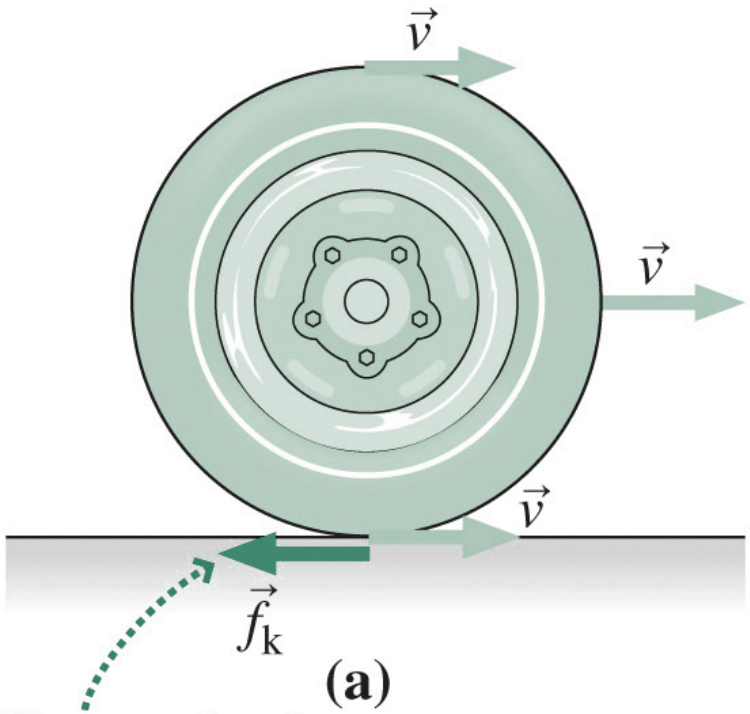
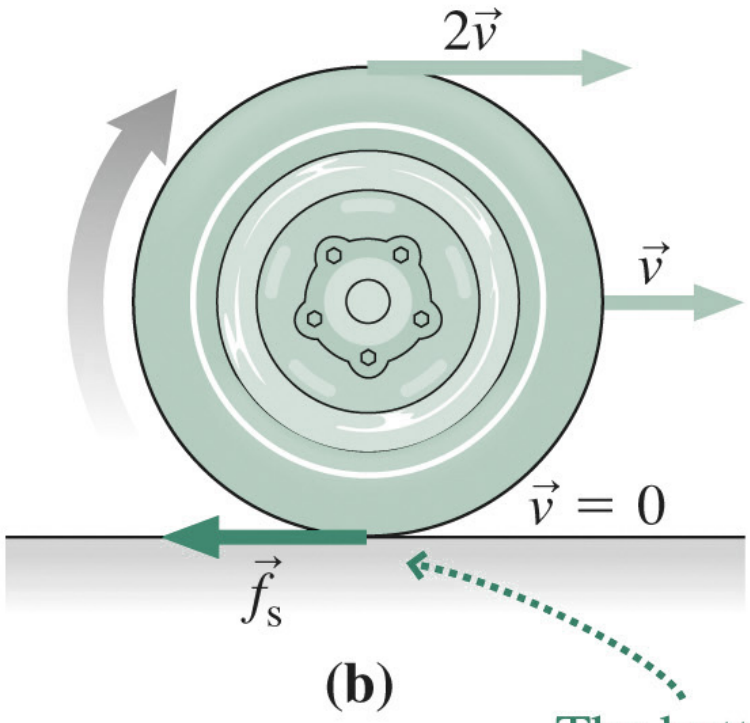


When a wheel skids, the force is kinetic friction.

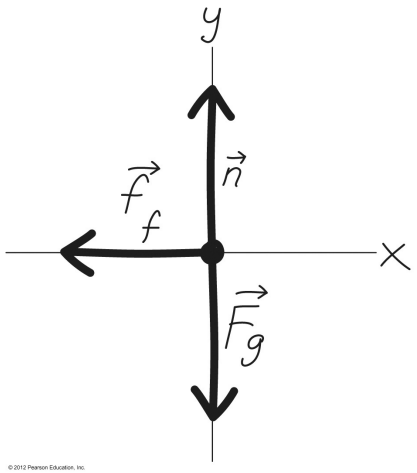


The bottom of the rolling wheel is momentarily at rest, so the force is static friction.

Solving Problems with Friction

- Problems with friction are like all other Newton's law problems.
- Identify the forces, draw a free-body diagram, write Newton's law.
- You'll need to relate the force components in two perpendicular directions, corresponding to the normal force and the frictional force.

- Example: A braking car: What's the acceleration?



- Newton's law: $\vec{F}_g + \vec{n} + \vec{f}_f = m\vec{a}$
- In components:

$$x: \quad -\mu n = ma_x$$
$$y: \quad -mg + n = 0$$

- Solve for *a*:

y equation gives $n = mg$,

so x equation gives $a_x = -\dfrac{\mu n}{m} = -\mu g$

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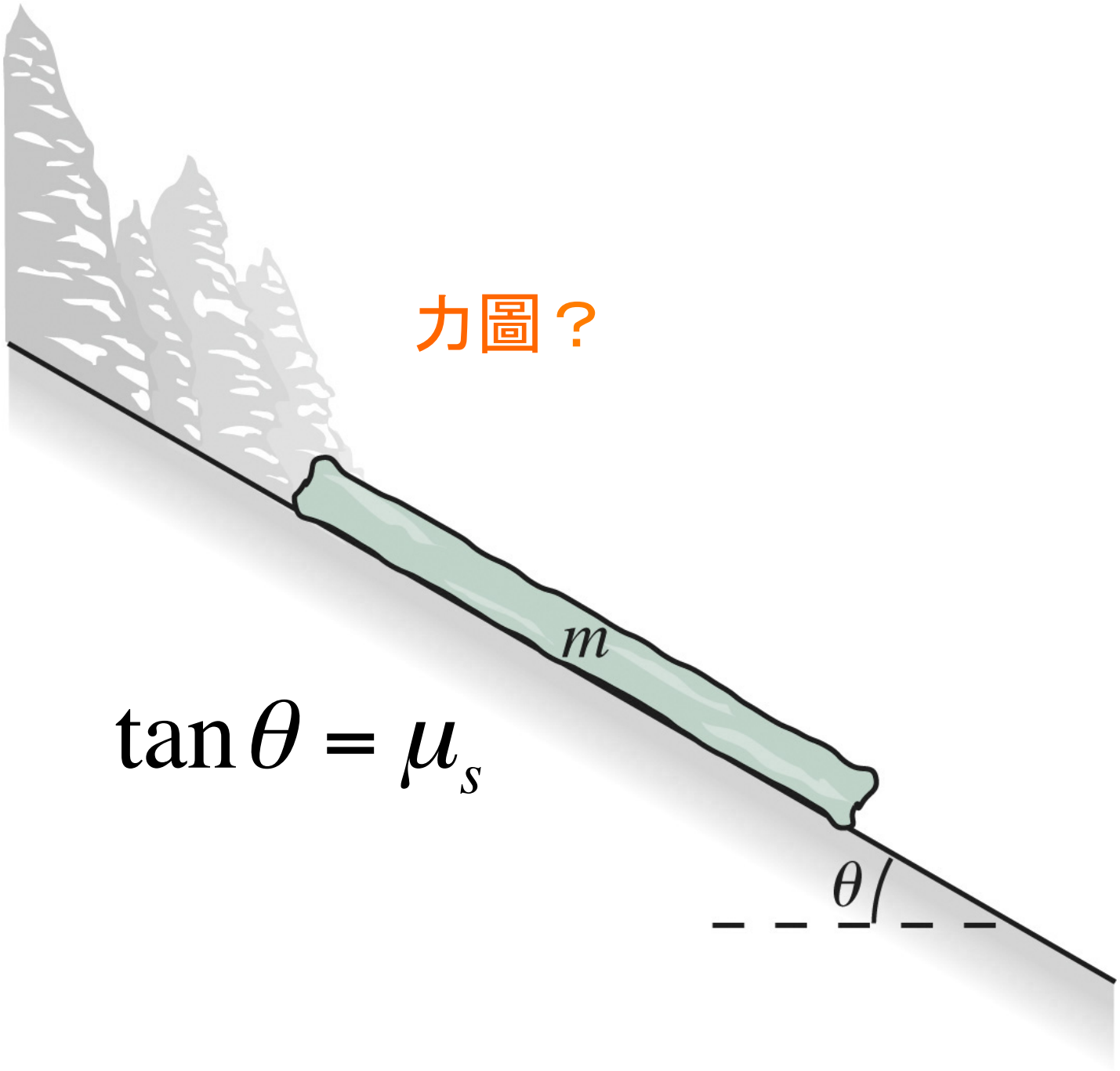
力圖？



$$\tan\theta = \mu_s$$

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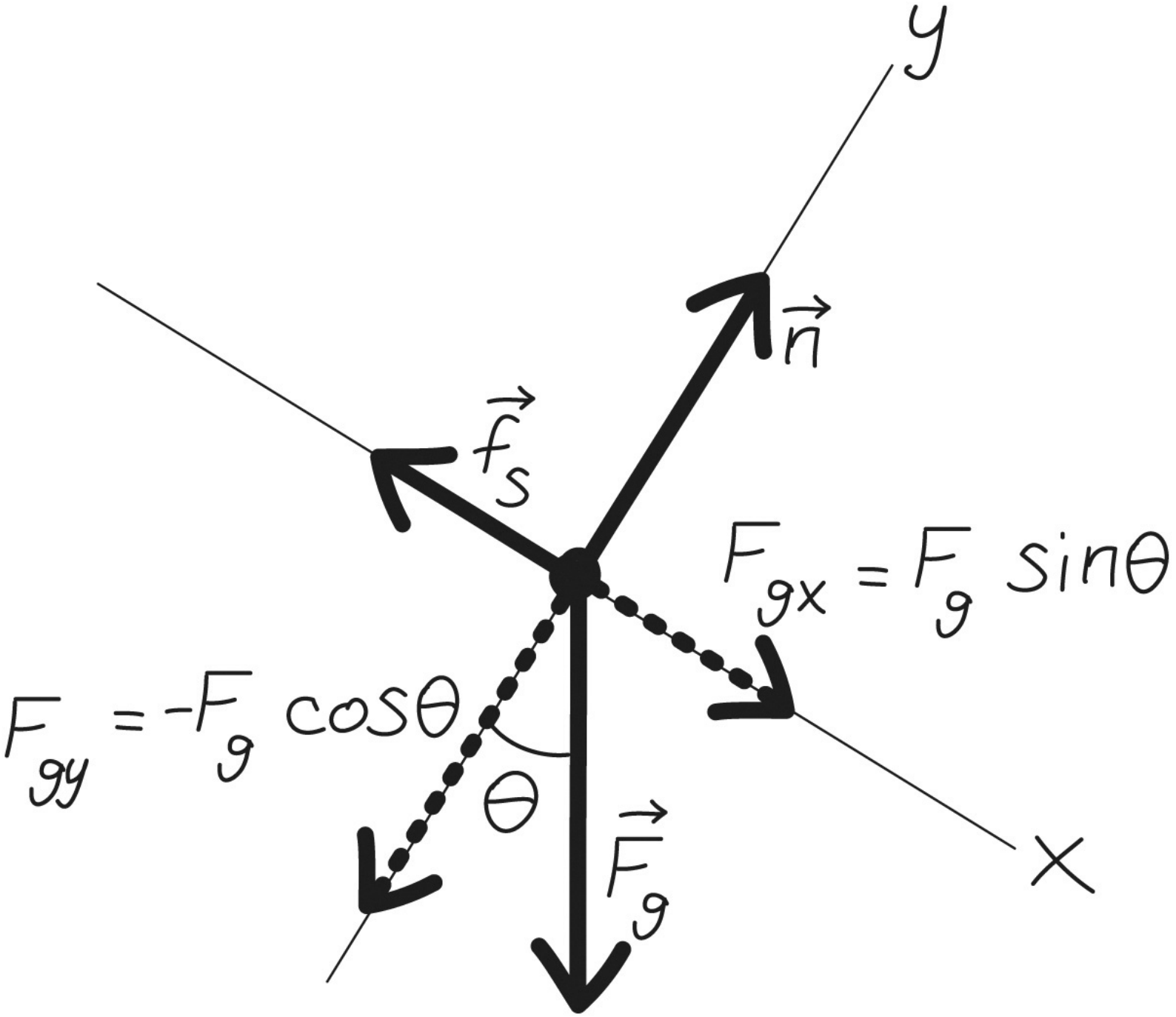

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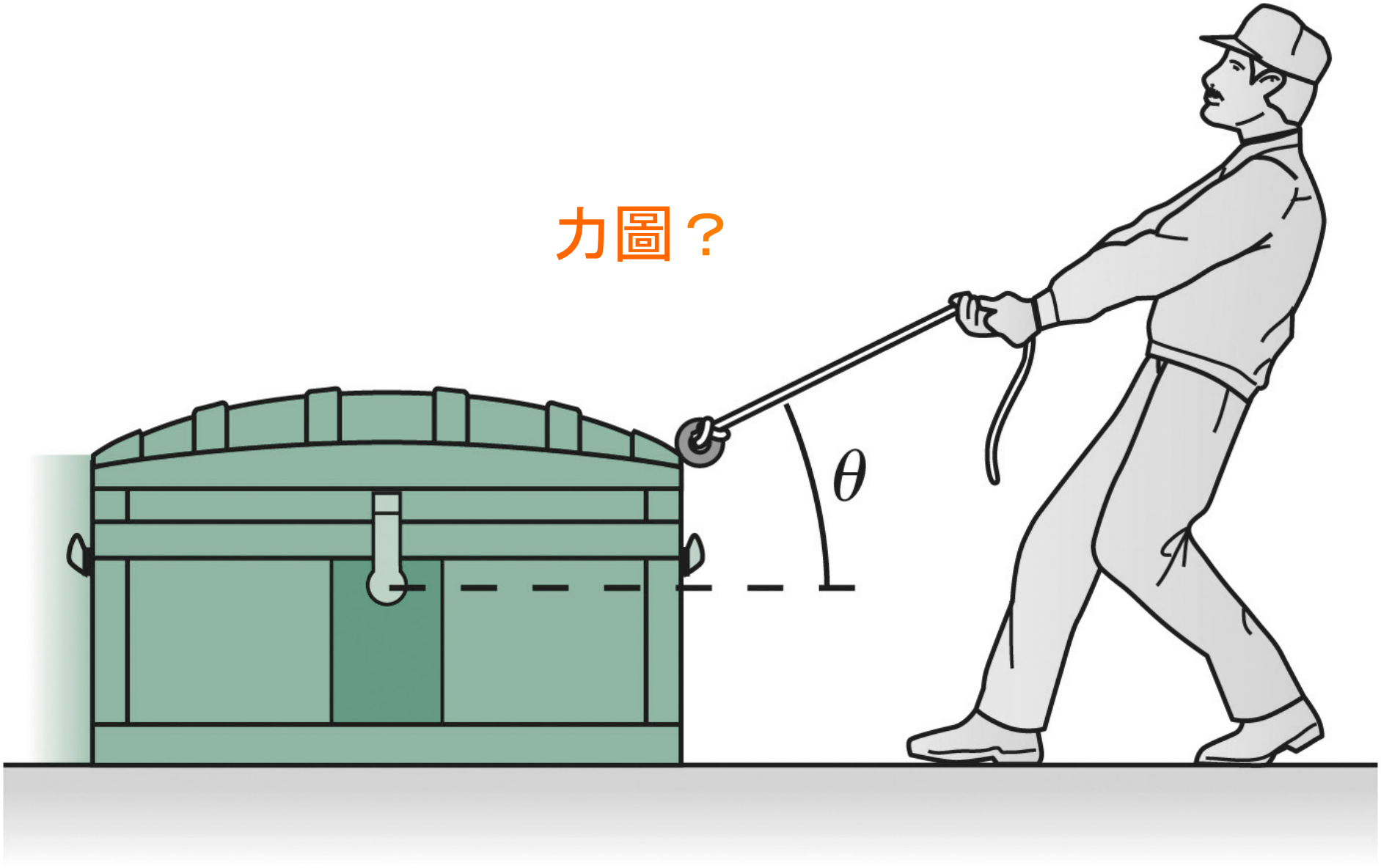

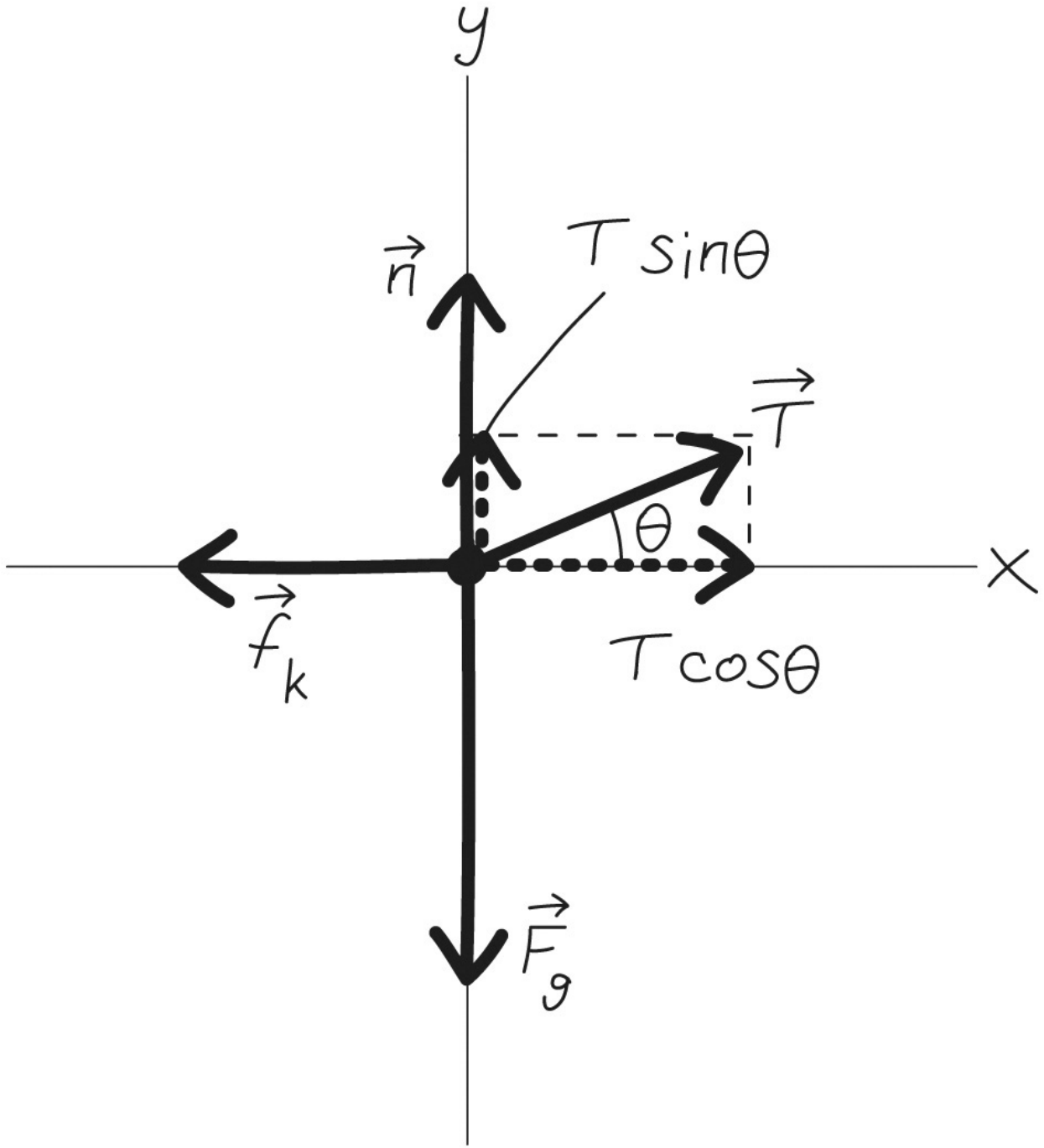

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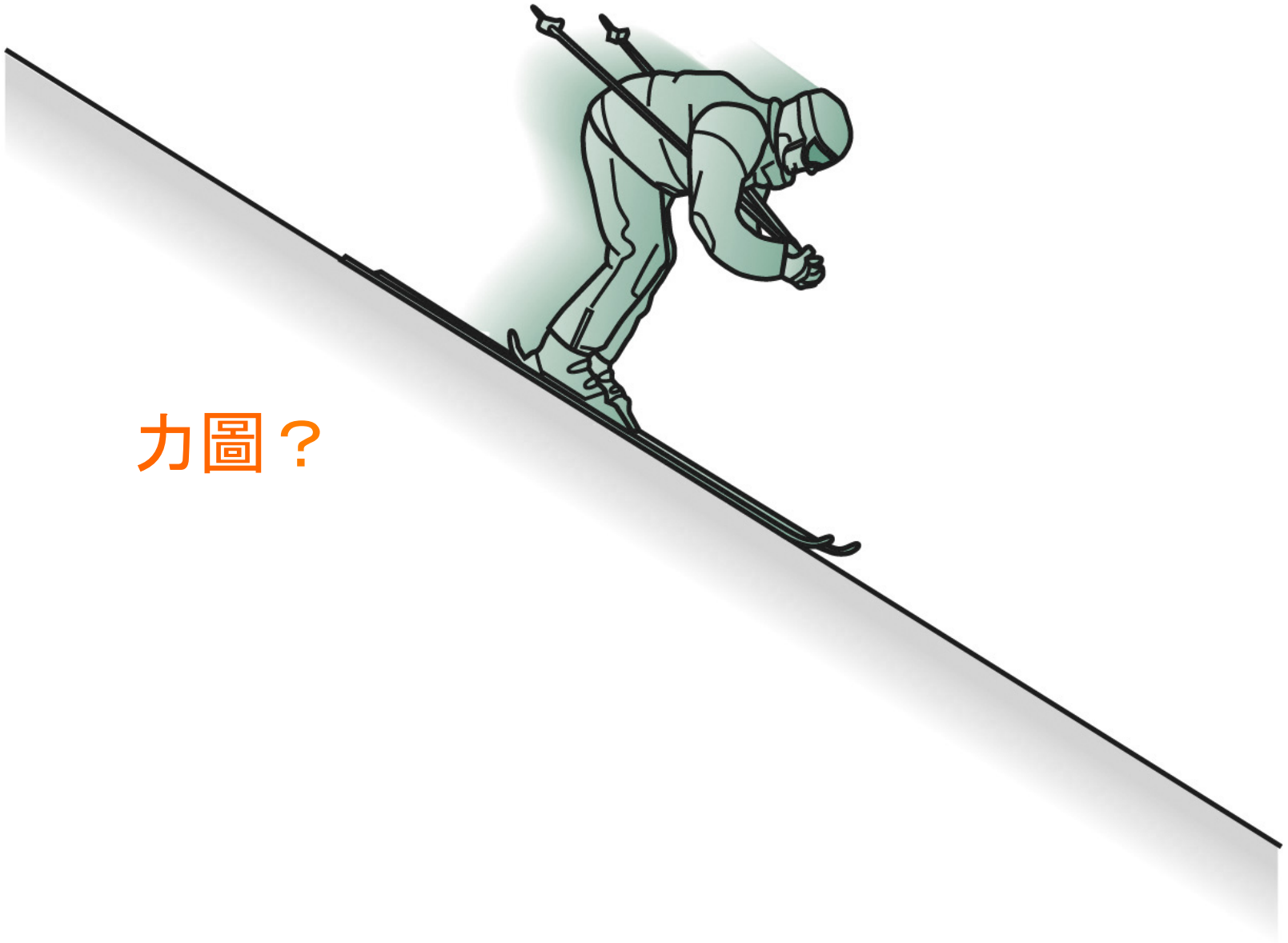
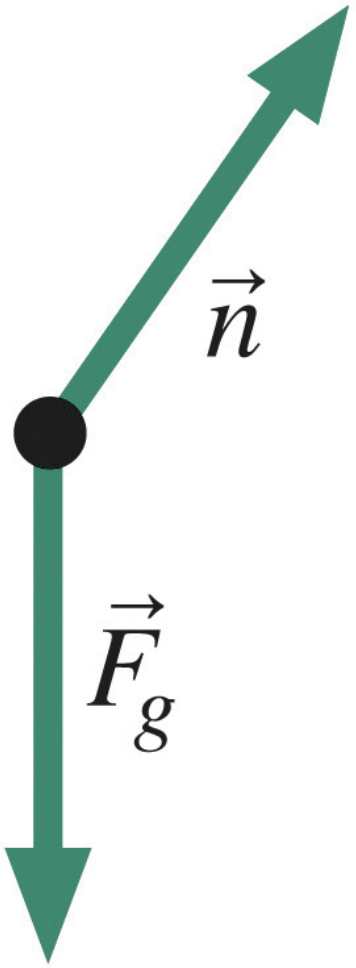
A skier on a frictionless slope



力圖？

Free-body diagram showing the two forces acting



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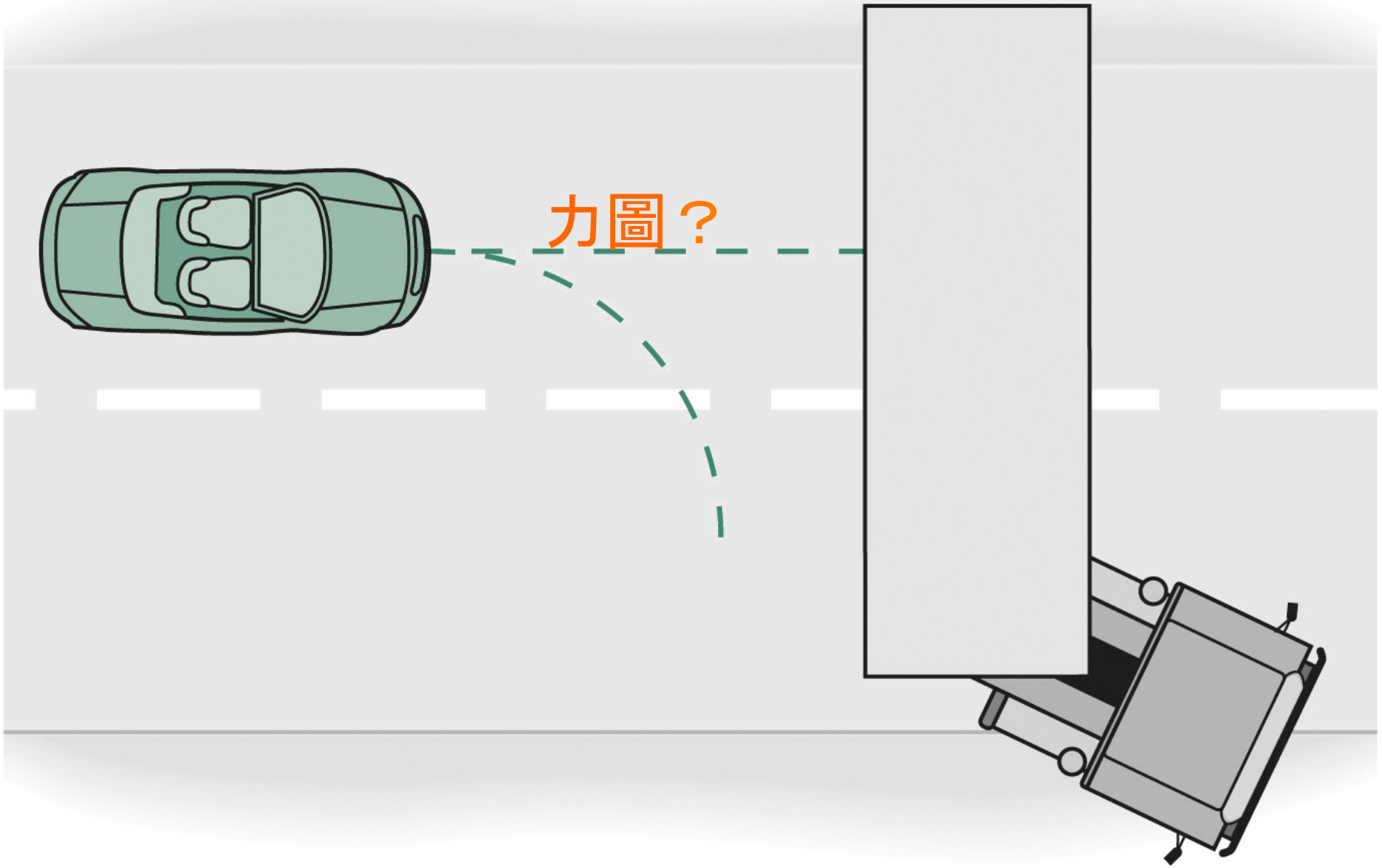

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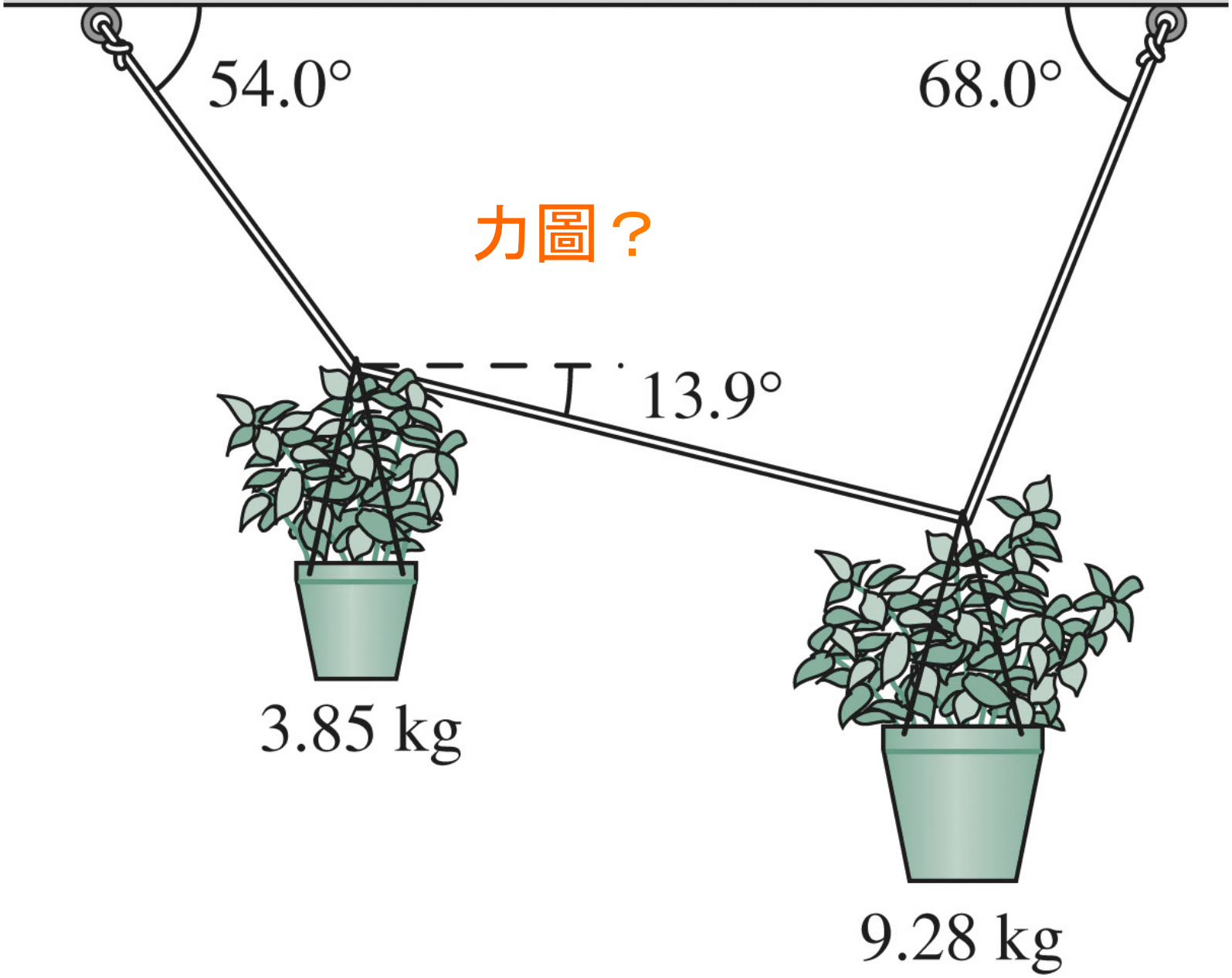

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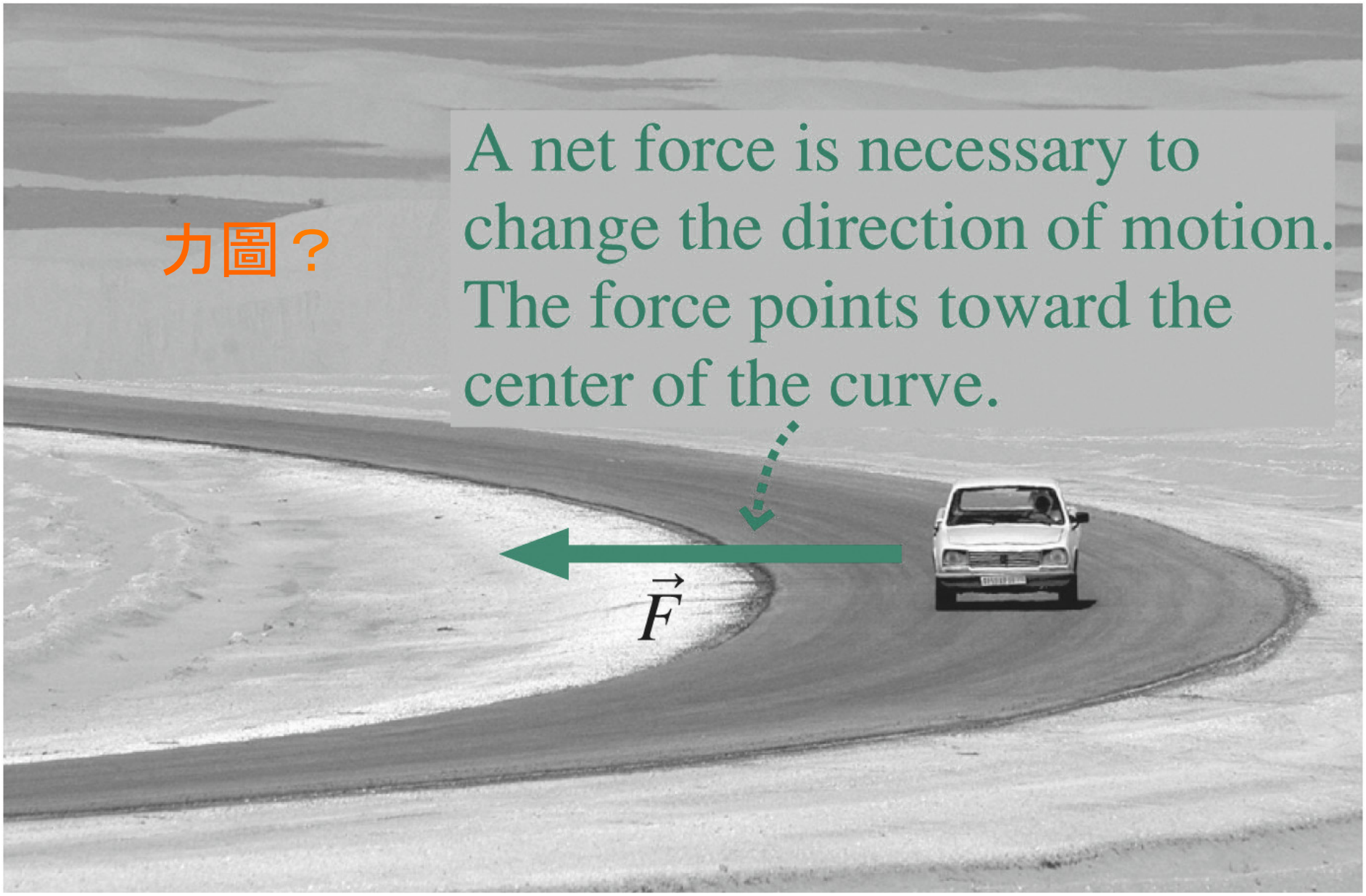
A net force is necessary to change the direction of motion. The force points toward the center of the curve.



Summary

- Newton's laws are a universal description of motion, in which force causes not motion itself but change in motion.
- All Newton's law problems are the same.
- They're handled by
  - Identifying all the forces acting on the object or objects of interest.
  - Drawing a free-body diagram.
  - Writing Newton's law in vector form:
    - Equating the net force to the mass times the acceleration.
  - Establishing a coordinate system.
  - Writing Newton's law in components.
  - Solving for the quantities of interest.

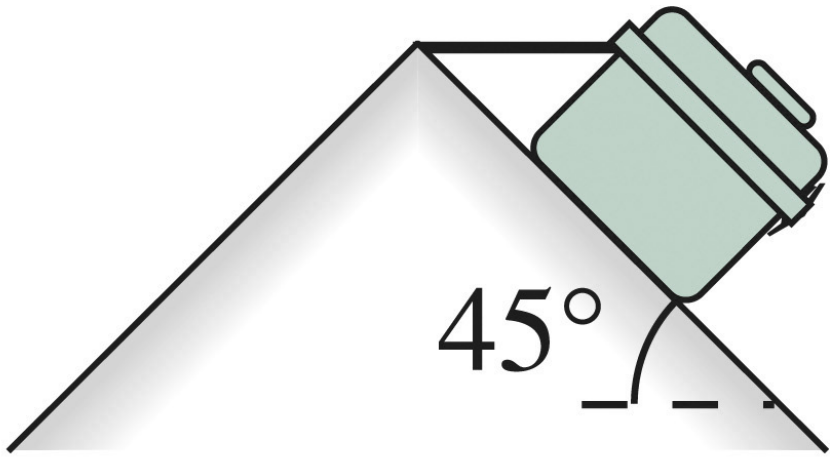
Clicker Question 1

- A roofer's toolbox rests on an essentially frictionless metal roof with a 45° slope, secured by a horizontal rope as shown. The rope tension is _____ the box's weight.

A. greater than

B. equal to

C. less than



Clicker Question 4

- A ball of mass *m* is suspended by a string from the ceiling inside an elevator. If the elevator is moving upward with a constant speed, the tension in the string

A. is greater than *mg*.
B. is equal to *mg*.
C. is less than *mg*.
D. depends on the speed of the elevator.

Clicker Question 6

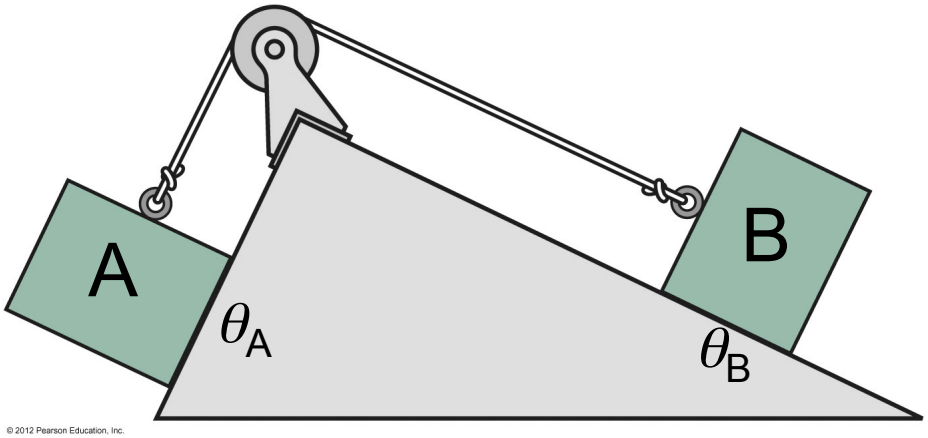
- You try to push a 10-kg box across the floor. If the coefficient of static friction between the box and the floor is 0.20, what is the approximate minimum force that must be applied to start the box moving from rest?

A. 50 N
B. 40 N
C. 20 N
D. 10 N
E. 2.0 N

Clicker Question 5

- Two identical blocks are placed on slopes of unequal angles ($\theta_A > \theta_B$), connected by a rope passing over a pulley. After being released,

A. mass A slides down and mass B slides up.
B. mass B slides down and mass A slides up.
C. both masses remain at rest.



Homework

- 13, 20, 36, 37, 45, 54, 63