Fundamentals Physics

Eleventh Edition

Halliday

Chapter 6

Force and Motion–II

1

6-1 Friction (1 of 33)

Learning Objectives

6.01 Distinguish between friction in a static situation and a kinetic situation.

6.02 Determine direction and magnitude of a frictional force.

6.03 For objects on horizontal, vertical, or inclined planes in situations involving friction, draw free-body diagrams and apply Newton's second law.

 2

2

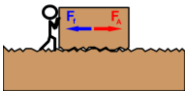
6-1 Friction (2 of 33)

- Friction forces are essential:
  - Picking things up
  - Walking, biking, driving anywhere
  - Writing with a pencil
  - Building with nails, weaving cloth
- But overcoming friction forces is also important:
  - Efficiency in engines
  - (20% of the gasoline used in an automobile goes to counteract friction in the drive train)
  - Roller skates, fans
  - Anything that we want to remain in motion

6-1 Friction (3 of 33)

- Three experiments:
  - Slide a book across a counter. The book slows and stops, so there must be an acceleration parallel to the surface and opposite the direction of motion.
  - Push a crate or other heavy object that does not move. To keep the crate stationary, an equal and opposite force must oppose you. If you push harder, the opposing force must also increase to keep the crate stationary. Keep pushing harder. Eventually the opposing force will reach a maximum, and the crate will slide.
  - Push a book at a constant speed across the counter. There must be an equal and opposite force opposing you, otherwise the book would accelerate. Again, the force is parallel to the surface and opposite the direction of motion.


Courtesy of Sparisoma Viridi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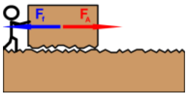
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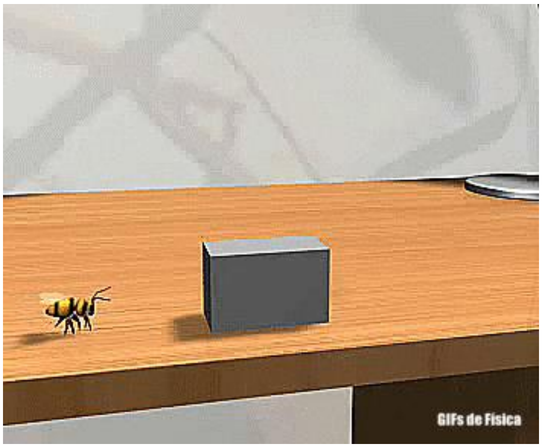
6-1 Friction (4 of 33)

- Two types of friction
- The **static frictional force**:
  - The opposing force that prevents an object from moving
  - Can have any magnitude from 0 N up to a maximum
  - Once the maximum is reached, forces are no longer in equilibrium and the object slides
- The **kinetic frictional force**:
  - The opposing force that acts on an object in motion
  - Has only one value
  - Generally smaller than the maximum static frictional force

6-1 Friction (5 of 33)



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6-1 Friction (6 of 33)

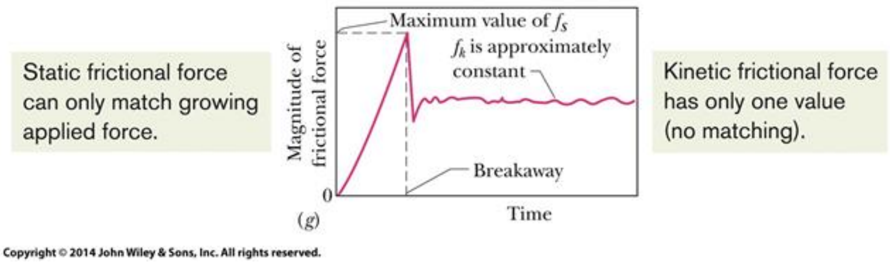

Figure 6-1

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6-1 Friction (7 of 33)

- Microscopic picture: surfaces are bumpy
- Friction occurs as contact points slide over each other
- Two specially prepared metal surfaces can cold-weld together and become impossible to slide, because there is so much contact between the surfaces

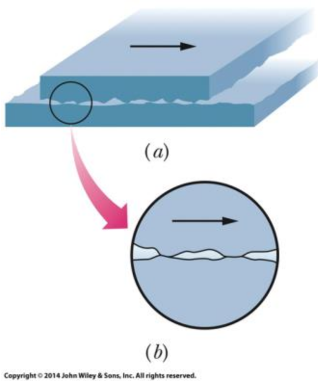

Figure 6-2

- Greater force normal to the contact plane increases the friction because the surfaces are pressed together and make more contact
- Sliding that is jerky, due to the ridges on the surface, produces squeaking/squealing/sound

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8

6-1 Friction (8 of 33)

- The properties of friction
  1. If the body does not move, then the applied force and frictional force balance along the direction parallel to the surface: equal in magnitude, opposite in direction and its magnitude will be

$$f_s < \mu_s F_N$$

  2. The magnitude of f_s has a maximum $f_{s,\ \max}$ given by:

$$f_{s,max} = \mu_s F_N, \qquad \textbf{Equation (6-1)}$$

where μ_S is the **coefficient of static friction**. If the applied force increases past $f_{s,\ \max}$, sliding begins.

6-1 Friction (9 of 33)

- The properties of friction
  3. Once sliding begins, the frictional force decreases to f_k given by:

$$f_k = \mu_k F_N, \qquad \textbf{Equation (6-1)}$$

where μ_k is the **coefficient of kinetic friction**.

- Magnitude F_N of the normal force measures how strongly the surfaces are pushed together
- The values of the friction coefficients are unitless and must be determined experimentally

6-1 Friction (10 of 33)

- Assume that μ_k does not depend on velocity
- Note that these equations are not vector equations

6-1 Friction (11 of 33)

Checkpoint 1

A block lies on a floor, (a) What is the magnitude of the frictional force on it from the floor? (b) If a horizontal force of 5 N is now applied to the block, but the block does not move, what is the magnitude of the frictional force on it? (c) If the maximum value $f_{s,\,max}$ of the static frictional force on the block is 10 N, will the block move if the magnitude of the horizontally applied force is 8 N? (d) If it is 12 N? (e) What is the magnitude of the frictional force in part (c)?

Answer:

(a) 0

(b) 5 N

(c) no

(d) yes

(e) 8 N

6-1 Friction (12 of 33)

Problem 6.9

A 3.5 kg block is pushed along a horizontal floor by a force $\vec{F}$ of magnitude 15 N at an angle θ = 40° with the horizontal (Fig. 6-19). The coefficient of kinetic friction between the block and the floor is 0.25.

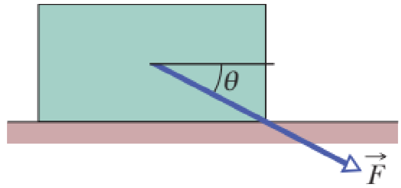


Figure 6-19

Calculate the magnitudes of (a) the frictional force on the block from the floor and (b) the block's acceleration.

6-1 Friction (13 of 33)

Problem 6.9

For a force applied at an angle:

- We choose $+x$ horizontally rightwards and $+y$ upwards
- Decompose the force into x and y components
- Observe that the 15 N force has components $F_x = F\cos\theta$ and $F_y = -F\sin\theta$

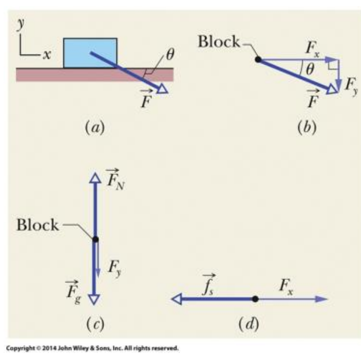


Figure 6-3

6-1 Friction (14 of 33)

Problem 6.9

Balance the vertical components (F_N, F_g, F_y)

$$F_N - F_y - F_g = 0$$

or,

$$F_N - F\sin\theta - mg = 0$$

or

$$F_N = (15\text{ N})\sin 40^\circ + (3.5\text{ kg})\left(9.8\frac{\text{m}}{\text{s}^2}\right) = 44\text{ N}$$

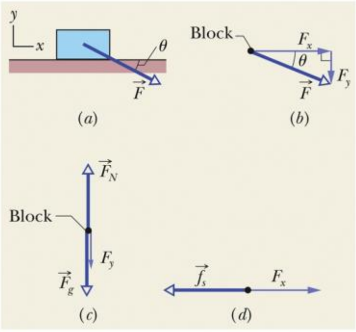


Figure 6-3

6-1 Friction (15 of 33)

Problem 6.9

- Calculate the friction force
  $f_k = \mu_k F_N = (0.25)(44\text{ N}) = 11\text{ N}$
- Balance the horizontal components (f, F_x)
  $$F_x - f_k = ma$$

or,

$$F\cos 40^\circ - (11\text{ N}) = (3.5\text{ kg})a$$

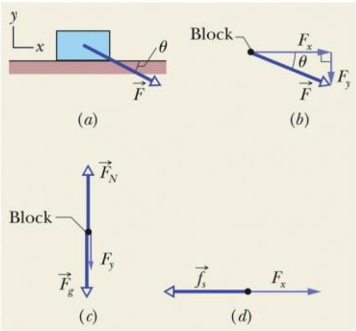


Figure 6-3

6-1 Friction (16 of 33)

Problem 6.9

$F \cos 40^{\circ} - (11 \text{ N}) = (3.5 \text{ kg})a$

to yield

$$a = \frac{(15 \text{ N}) \cos 40^{\circ} - (11 \text{ N})}{3.5 \text{ kg}}$$

$$= 0.14 \frac{\text{m}}{\text{s}^2}$$

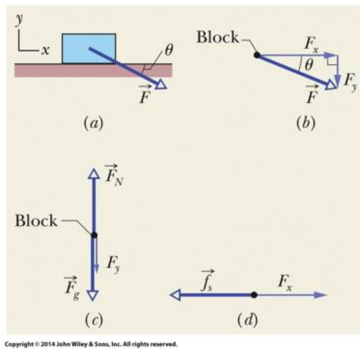


Figure 6-3

6-1 Friction (17 of 33)

Problem 6.19

A 12 N horizontal force $\vec{F}$ pushes a block weighing 5.0 N against a vertical wall (Fig. 6-26). The coefficient of static friction between the wall and the block is 0.60, and the coefficient of kinetic friction is 0.40.

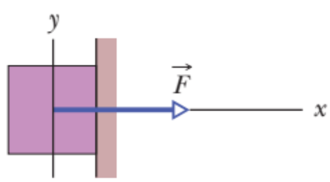


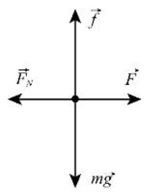
Figure 6-26

Assume that the block is not moving initially. (a) Will the block move? (b) In unit-vector notation, what is the force on the block from the wall?

6-1 Friction (18 of 33)

Problem 6.19

The free-body diagram is shown.

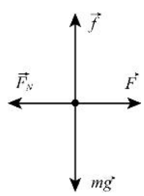


To determine if the block falls, we find the magnitude f of the force of friction required to hold it without accelerating and also find the normal force of the wall on the block.

We compare f and $\mu_s F_N$. If $f < \mu_s F_N$, the block does not slide on the wall but if $f > \mu_s F_N$, the block does slide.

6-1 Friction (19 of 33)

Problem 6.19



For the horizontal component apply Newton's second law to give

$$F - F_N = 0$$

so,

$$F_N = F = 12\ N$$

and

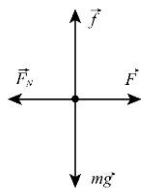
$$\mu_s F_N = (0.60)(12\text{ N}) = 7.2\text{ N}$$

Since the block is not moving, then the vertical component is

$$f - mg = 0$$

6-1 Friction (20 of 33)

Problem 6.19



So

$$f = mg = 5.0\text{ N}$$

Since $f < \mu_s F_N$ the block does not slide.

With $f = 5.0$ N and $F_N = 12$ N then the force of the wall on the block is

$$\vec{F} = -F_x\hat{\imath} + f\hat{\jmath} = -(12\text{ N})\hat{\imath} + (5.0\text{ N})\hat{\jmath}$$

6-1 Friction (21 of 33)

Problem 6.29

In Fig. 6-34, blocks A and B have weights of 44 N and 22 N, respectively. (a) Determine the minimum weight of block C to keep A from sliding if μ_s between A and the table is 0.20. (b) Block C suddenly is lifted off A. What is the acceleration of block A if μ_k between A and the table is 0.15?

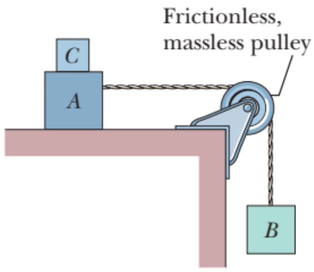
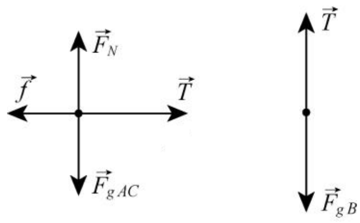


Figure 6-34

6-1 Friction (22 of 33)

Problem 6.29



Free-body diagrams for the blocks A and C, considered as a single object, and for the block B are shown. Assume the blocks are not moving. For the blocks on the table, we take the x axis to be to the right and the y axis to be upward. From Newton's second law, we have for the x component

$$T - f = 0$$

and the y component

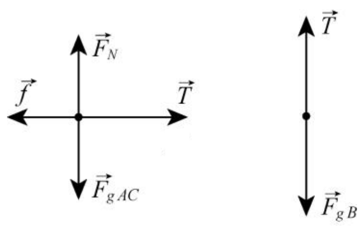
$$F_N - F_{gAC} = 0$$

 23

23

6-1 Friction (23 of 33)

Problem 6.29



For block B take the downward direction to be positive. Then Newton's second law for that block is

$$F_{gB} - T = 0$$

From this third equation and the first equation we obtain

$$f = T = F_{gB} = 22\ \text{N}$$

While the second equation yields,

$$F_N = F_{gAC}$$

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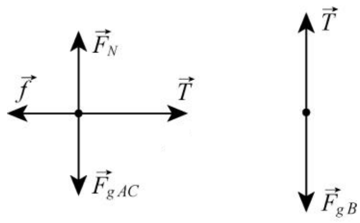
6-1 Friction (24 of 33)

Problem 6.29

If sliding is not to occur, f must be less than $\mu_s F_N$, or $F_{gB} < \mu_s F_{gAC}$.



The smallest that F_{gAC} can be with the blocks still at rest is

$$F_{gAC} = \frac{F_{gB}}{\mu_s} = (22\text{ N})/(0.20) = 110\text{ N}$$

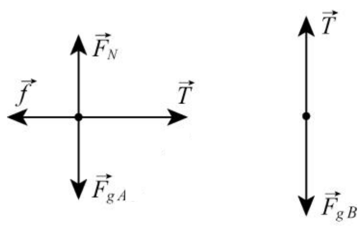
Since the weight of block A is 44 N, the least weight for C is

$$(110 - 44)\text{ N} = 66\text{ N}$$

6-1 Friction (25 of 33)

Problem 6.29

When block C is suddenly lifted, then the vertical and horizontal motion of block A are respectively governed by the following Newton's law



$$F_N - F_{gA} = 0$$

and

$$T - f = T - \mu_k F_N = T - \mu_k F_{gA} = \frac{F_{gA}}{g} a$$

And the equation of motion for block B is given by

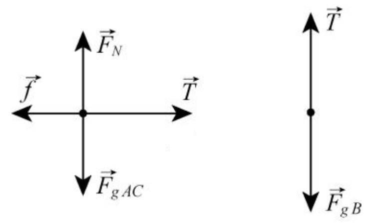
$$F_{gB} - T = \frac{F_{gB}}{g} a$$

6-1 Friction (26 of 33)

Problem 6.29

Eliminating T from the last two equations, yield

$$a = \frac{g\left(F_{gB} - \mu_k F_{gA}\right)}{F_{gA} + F_{gB}}$$

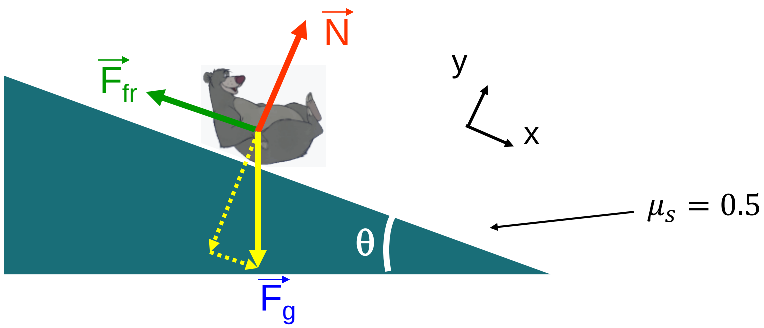


or,

$$a = \frac{\left(9.8\frac{m}{s^2}\right)\left(22\text{ N} - (0.15)(44\text{ N})\right)}{44\text{ N} + 22\text{ N}} = 2.3\frac{m}{s^2}$$

6-1 Friction (27 of 33)

Baloo on a Frictional Plane



What angle should we tilt the plane so that the Baloo slides?

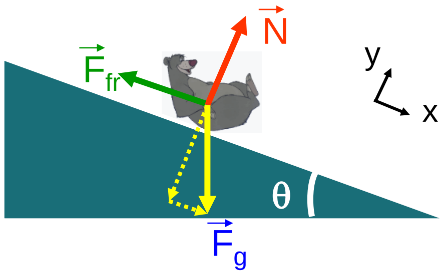
6-1 Friction (28 of 33)

Baloo on a Frictional Plane

Breaking F_g into components:

$$F_{g,x} = mg\sin\theta$$

$$F_{g,y} = mg\cos\theta$$



Summing forces in the

y direction:

$$F_{net,y} = ma_y = 0$$
$$N - F_{g,y} = 0$$
$$N = F_{g,y} = mg\cos\theta$$

x direction:

$$F_{net,x} = ma_x > 0$$
$$F_{g,x} - f_{s,\max} > 0$$
$$F_{g,x} = mg\sin\theta > fs_{s,\max}$$

6-1 Friction (29 of 33)

Baloo on a Frictional Plane

We have:

$$N = mg\cos\theta$$

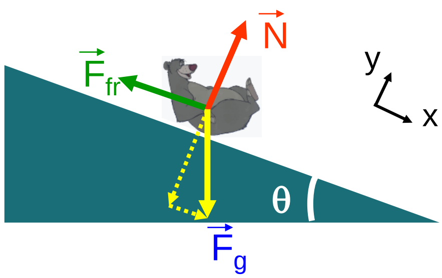
Thus,

$$mg\sin\theta > \mu_s N$$

$$mg\sin\theta > \mu_s(mg\cos\theta)$$

$$\sin\theta > \mu_s(\cos\theta)$$

$$\tan\theta > \mu_s$$

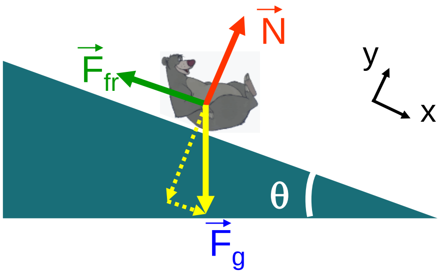


So, for Baloo to slip:

$$\theta > \tan^{-1}(0.5) = 26.6°$$

6-1 Friction (30 of 33)

Baloo on a Frictional Plane



If we tilt the ramp just pass $\theta = 26.6°$ and $a = 2\ m/s^2$. What is μ_k?

Summing forces in the

y direction:

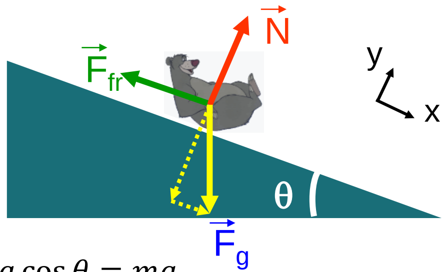
$$F_{net,y} = ma_y = 0$$
$$N - F_{g,y} = 0$$
$$N = F_{g,y} = mg\cos\theta$$

x direction:

$$F_{net,x} = ma_x$$
$$F_{g,x} - f_k = ma_x$$
$$mg\sin\theta - \mu_k N = ma_x$$
$$mg\sin\theta - \mu_k mg\cos\theta = ma_x$$

6-1 Friction (31 of 33)

Baloo on a Frictional Plane



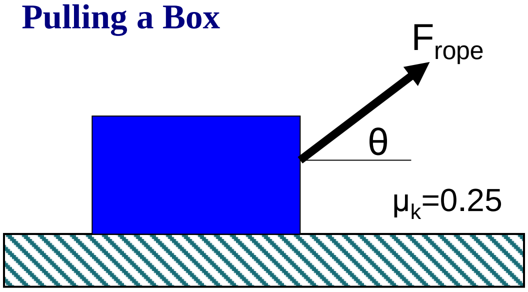
$$mg\sin\theta - \mu_k mg\cos\theta = ma_x$$

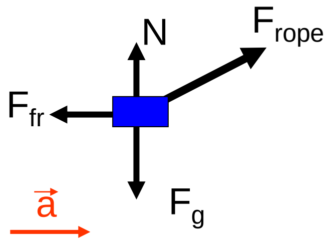
$$\mu_k = \frac{g\sin\theta - a_x}{g\cos\theta}$$

$$\mu_k = \frac{(2m/s^2) + (9.8m/s^2)\sin(26.6°)}{(9.8m/s^2)\cos(26.6°)} = 0.27$$

6-1 Friction (32 of 33)

Pulling a Box





Summing forces:

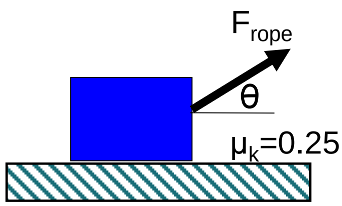
$$y: F_{rope}\sin\theta + N - F_g = 0 \rightarrow N = mg - F_{rope}\sin\theta$$

$$x: F_{rope}\cos\theta - F_{fr} = ma \rightarrow F_{rope}\cos\theta - \mu_k N = ma$$

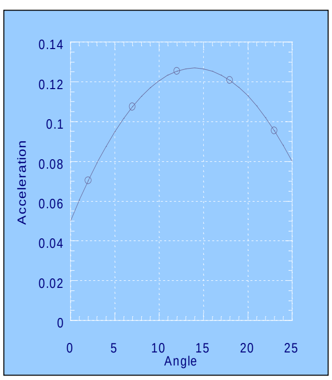
$$F_{rope}\cos\theta - \mu_k\left(mg - F_{rope}\sin\theta\right) = ma$$

6-1 Friction (33 of 33)

Pulling a Box



$$a = \frac{F_{rope}(\cos\theta + \mu_k\sin\theta) - \mu_k mg}{m}$$



To find the maximum:

$$\frac{da}{d\theta} = \frac{d}{d\theta}\left(\frac{F_{rope}(\cos\theta + \mu_k\sin\theta) - \mu_k mg}{m}\right)$$

$$= \frac{F_{rope}}{m}(-\sin\theta + \mu_k\cos\theta) = 0$$

$$\mu_k\cos\theta = \sin\theta$$

$$\boxed{\theta = \tan^{-1}(\mu_k) = 14.0^\circ \text{ for } \mu_k = 0.25}$$

MythBusters
Friction on Interleaved Book Pages

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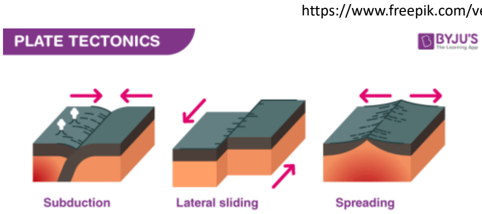
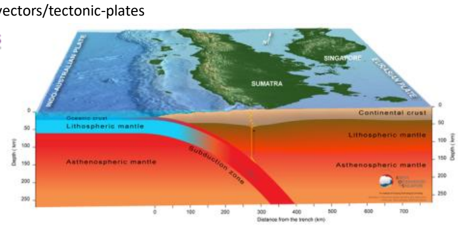
Tectonic Plate

https://www.freepik.com/vectors/tectonic-plates





https://byjus.com/physics/plate-tectonics/

https://tectonicplatesindonesia.weebly.com/causes.html

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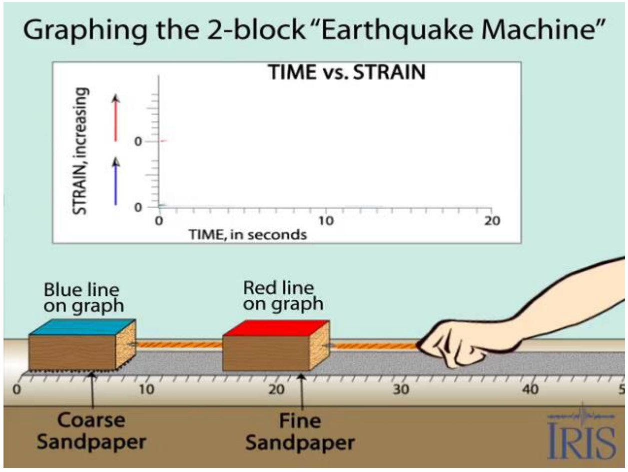
Slip Model of Tectonic Quake



https://www.iris.edu/hq/inclass/animation/earthquake_machine_graphing_time_vs_strain

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6 Summary (1 of 1)

Friction

- Opposes the direction of motion or attempted motion
- Static if the object does not slide
- Static friction can increase to a maximum

$$f_{s,\ \max} = \mu_s F_N,$$ **Equation (6-1)**

- Kinetic if it does slide

$$f_k = \mu_k F_N,$$ **Equation (6-2)**

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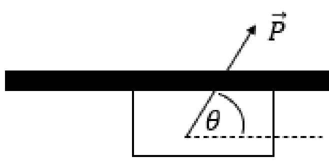
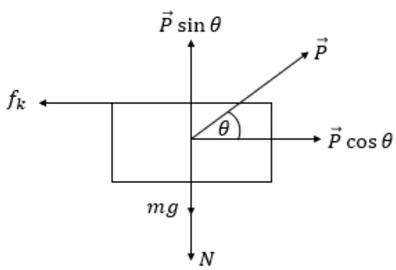
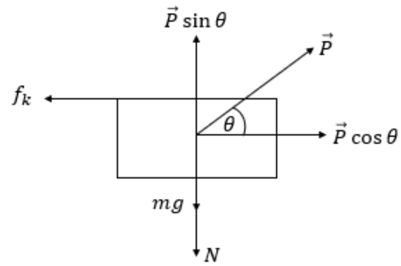
6-1 Friction (20 of 26)

Seorang siswa menggunakan gaya $\vec{P}$ sebesar 80 N dan sudut $\theta = 60°$ untuk mendorong balok 5 kg di langit-langit kamarnya. Jika koefiisien gesek kinetik antara balok dan langit-langit adalah 0.40. Tentukan besar percepatan balok.





6-1 Friction (20 of 26)



Karena tidak ada percepatan pada arah vertikal, maka diperoleh Hukum II Newton pada arah sumbu vertikal :

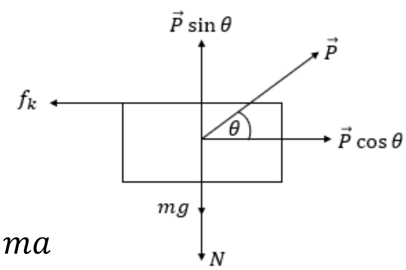
$$\sum F_y = 0$$

$$P\sin\theta - N - mg = 0$$

$N = P\sin\theta - mg$ Sehingga diperoleh gaya geseknya

$$f_k = \mu_k N = \mu_k(P\sin\theta - mg)$$

6-1 Friction (20 of 26)



Untuk Hukum II Newton arah horizontal

$$\sum F_x = ma$$

$$P\cos\theta - f_k = ma$$

$$P\cos\theta - \mu_k(P\sin\theta - mg) = ma$$

$$a = \frac{P\cos\theta - \mu_k(P\sin\theta - mg)}{m}$$

$$a = \frac{40 - 0.4\left(40\sqrt{3} - 50\right)}{5} = 6.45 = 6.5\ m/s^2 \therefore$$

