Today 5.3

L16

Today 5.3

L16

Friction

Today 5.3

Friday 5.4, 5.5

L16

Today 5.3

Friday 5.4, 5.5

L16

Circular motion dynamics

Today 5.3

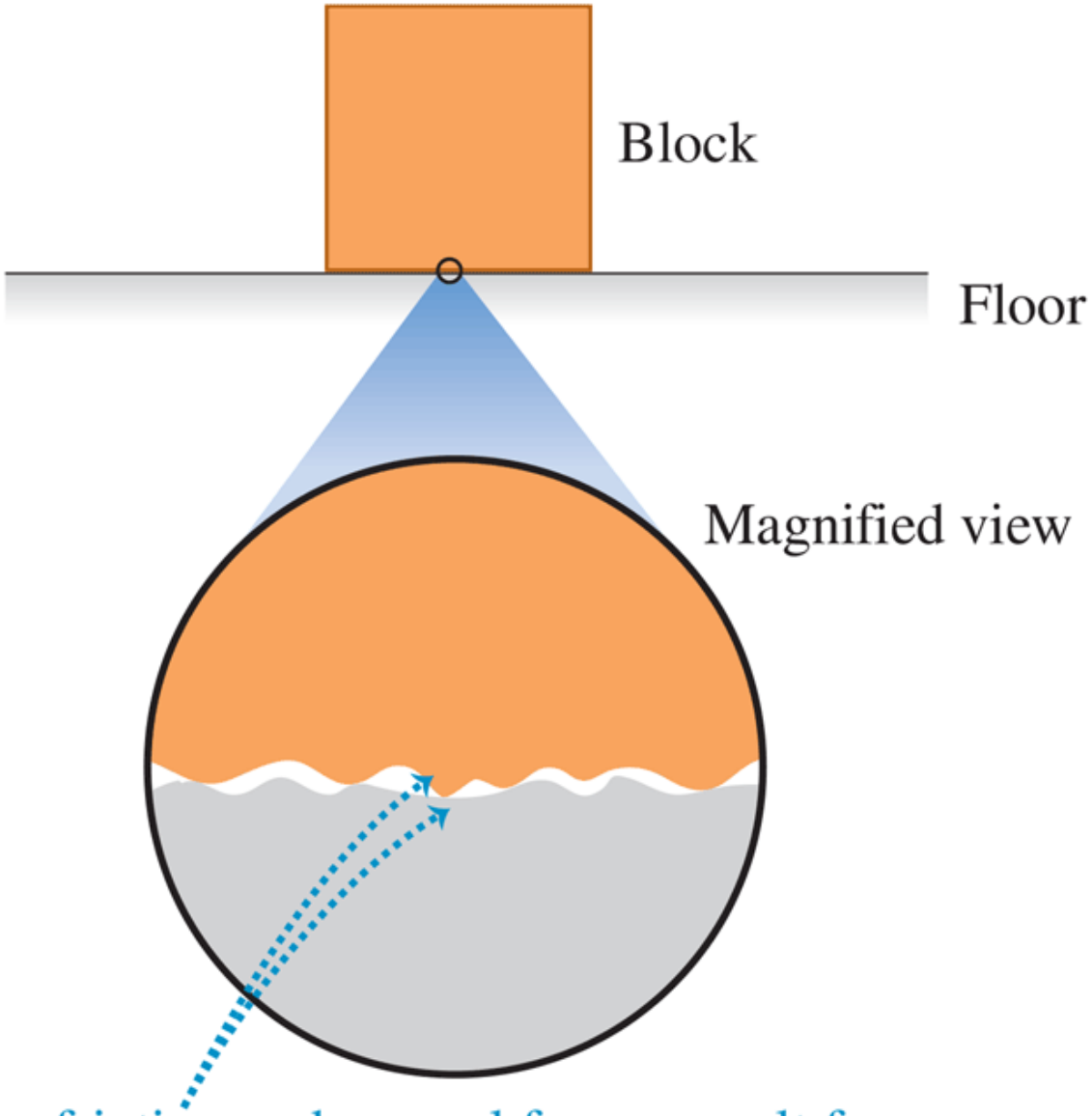
Friday 5.4, 5.5

L16

The Fundamental Forces of nature

Friction

Friction



The friction and normal forces result from interactions between molecules in the block and in the floor where the two rough surfaces touch.

Friction

coefficient of static friction $\equiv \mu_s$

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coefficient of kinetic friction $\equiv \mu_K$

Friction

coefficient of static friction $\equiv \mu_s$

coefficient of kinetic friction $\equiv \mu_K$

Materials	Coefficient of Static Friction, μ_s	Coefficient of Kinetic Friction, μ_k
Steel on steel	0.74	0.57
Aluminum on steel	0.61	0.47
Copper on steel	0.53	0.36
Brass on steel	0.51	0.44
Zinc on cast iron	0.85	0.21
Copper on cast iron	1.05	0.29
Glass on glass	0.94	0.40
Copper on glass	0.68	0.53
Teflon on Teflon	0.04	0.04
Teflon on steel	0.04	0.04
Rubber on concrete (dry)	1.0	0.8
Rubber on concrete (wet)	0.30	0.25

Friction

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coefficient of kinetic friction $\equiv \mu_K$

Let $F_F \equiv$ Force due to friction

Friction

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Let $F_F \equiv$ Force due to friction. 2 cases:

$F_F \leq N\mu_s$, static

$F_F = N\mu_k$, kinetic

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For static case, F_F only provides enough force to keep item static

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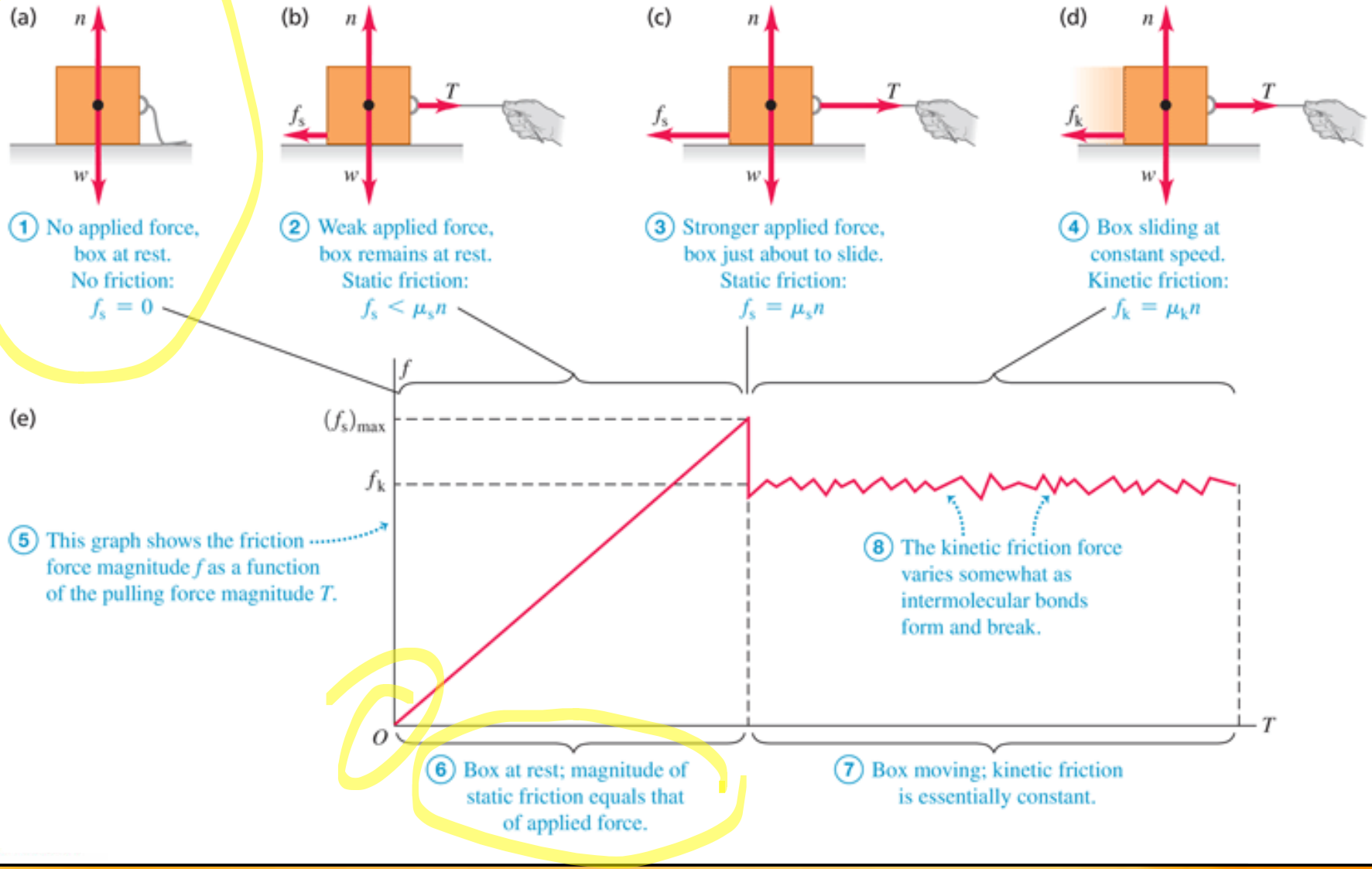
For both cases, N is the normal force between the two items that are in frictional contact.

Friction


(a)
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(b)
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(4) Box sliding at constant speed. Kinetic friction: $f_k = \mu_k n$
(e)
f
$(f_s)_{max}$
f_k
(5) This graph shows the friction force magnitude f as a function of the pulling force magnitude T.
(8) The kinetic friction force varies somewhat as intermolecular bonds form and break.
O
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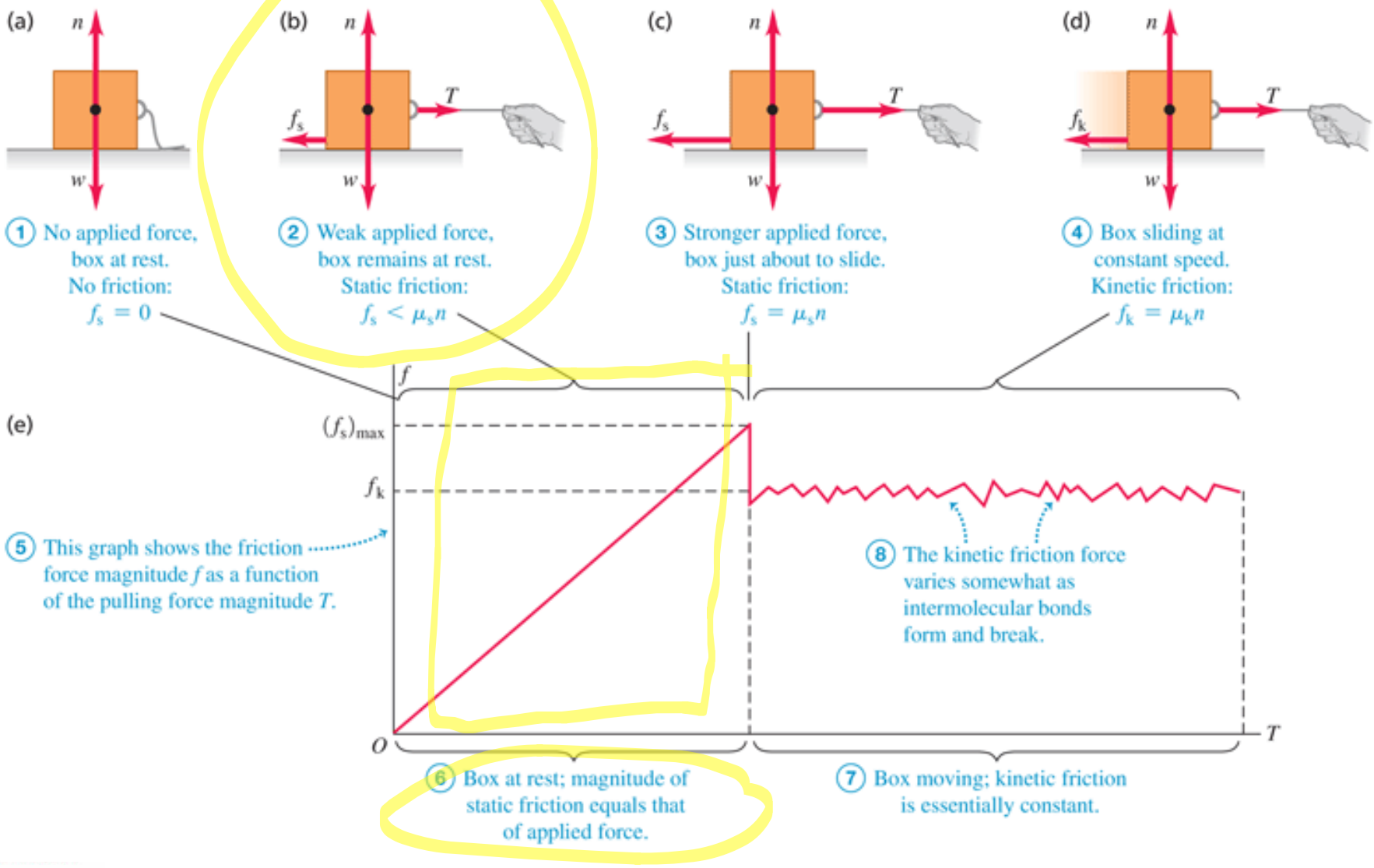
(6) Box at rest; magnitude of static friction equals that of applied force.
(7) Box moving; kinetic friction is essentially constant.

Friction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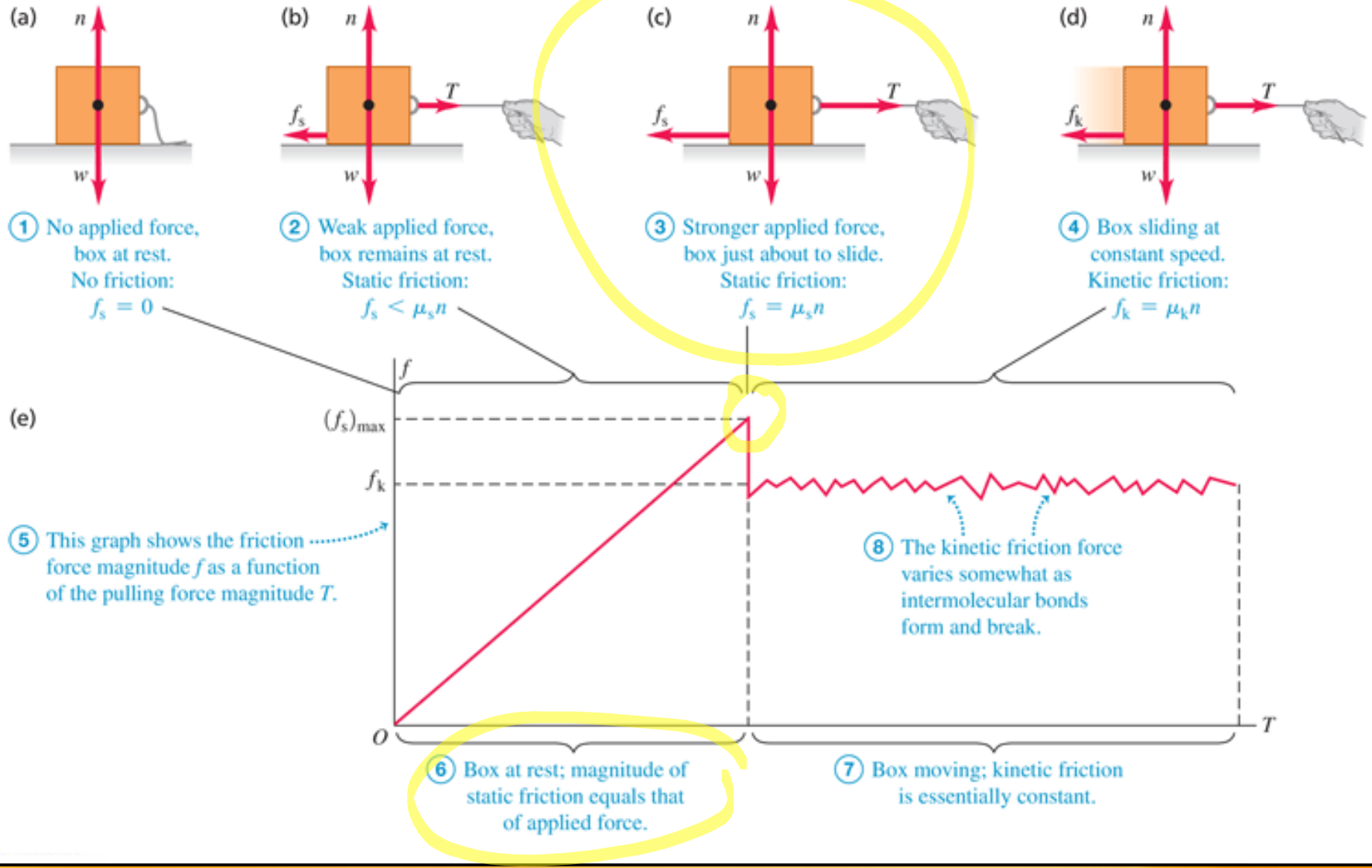
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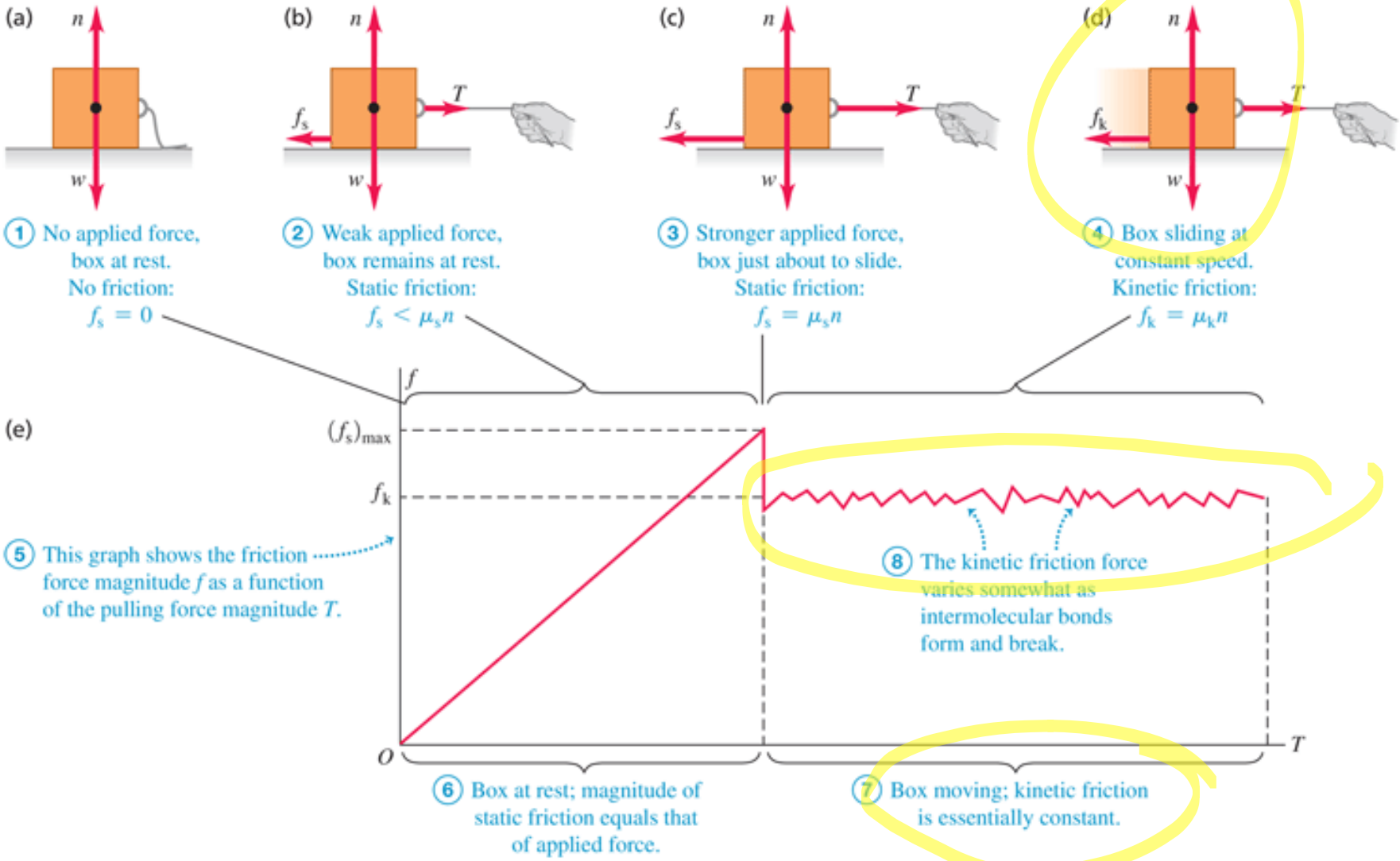
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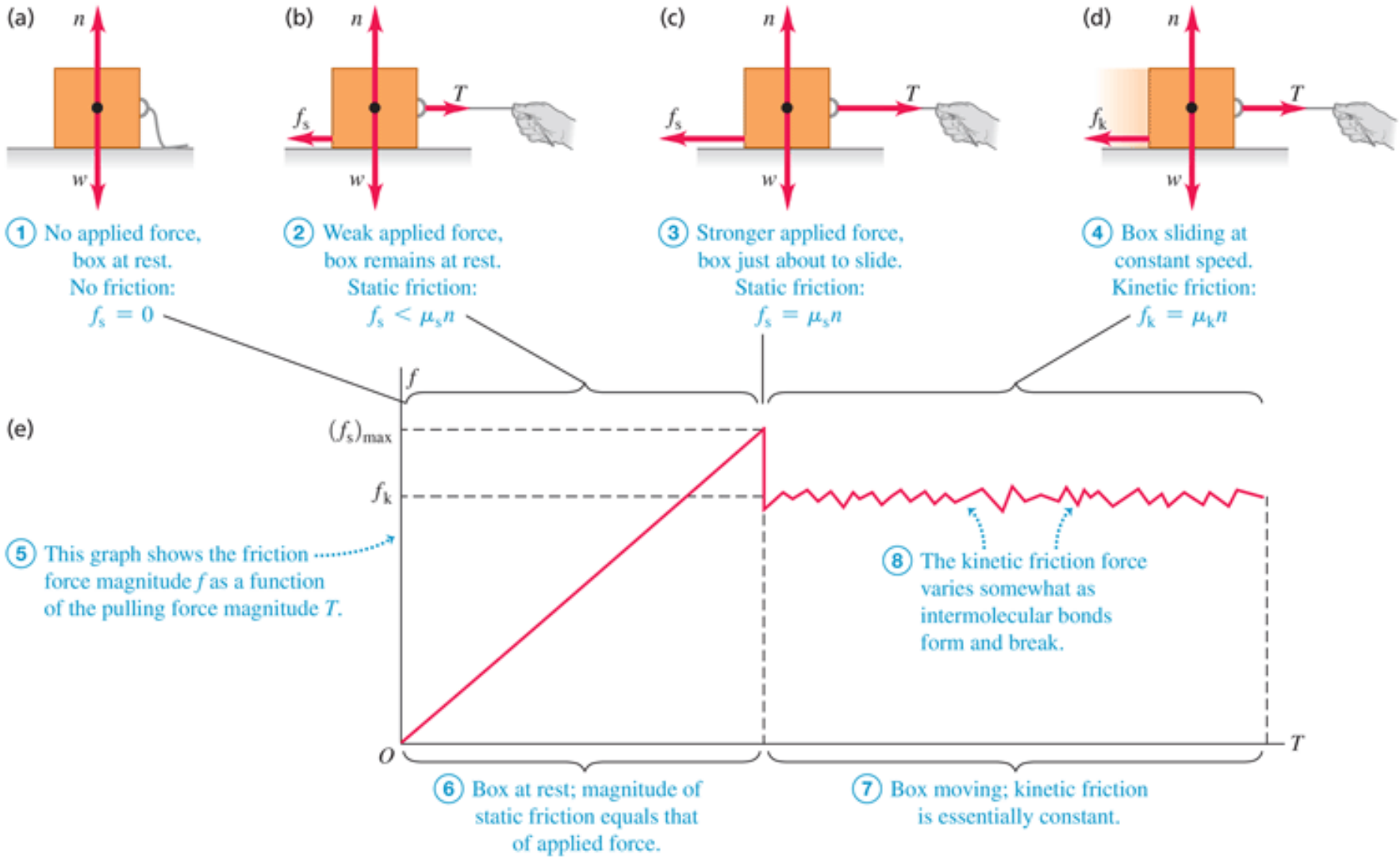
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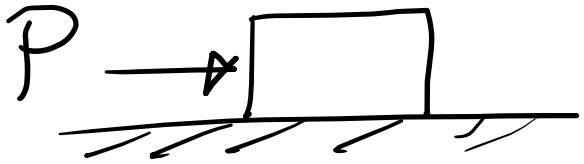
Example: Box of mass m on surface being pushed with a force P (shown below). For this problem there is friction between the box & surface



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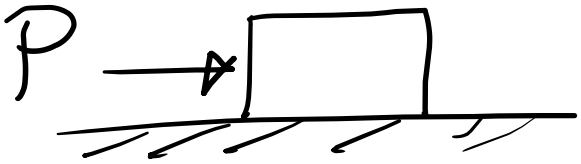
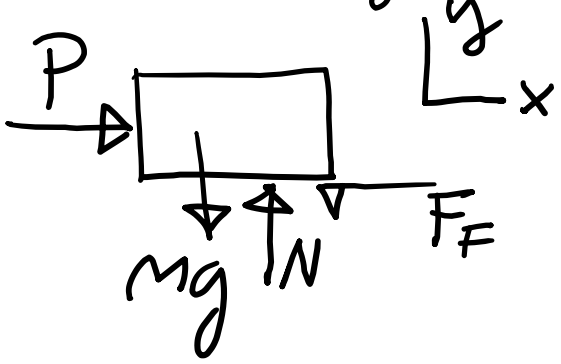


Free body Diagram :



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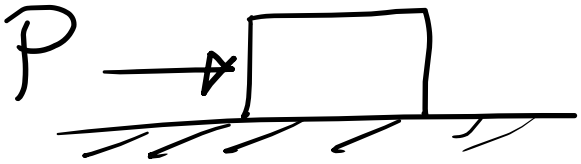

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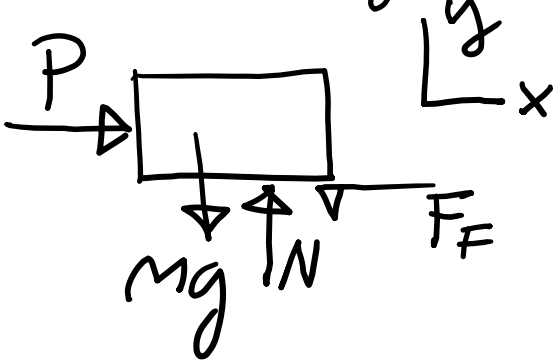

$$\Rightarrow \sum F_x = ma_x \quad \& \quad \sum F_y = ma_y$$

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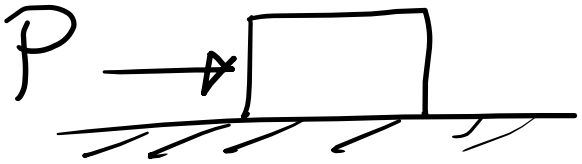

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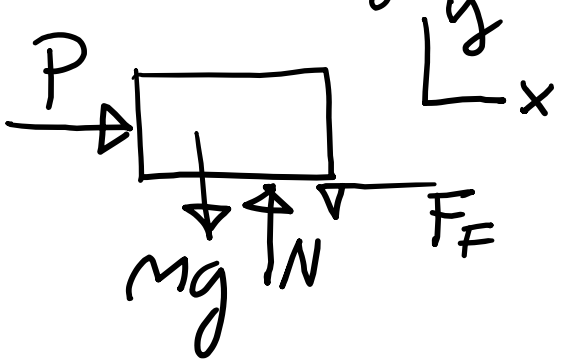

$\Rightarrow \sum F_x = ma_x$ & $\sum F_y = ma_y$

$\Rightarrow P - F_F = ma_x$

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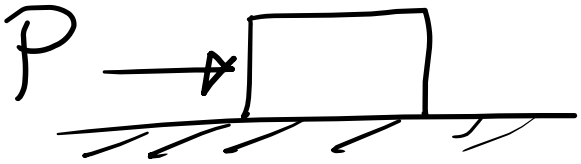

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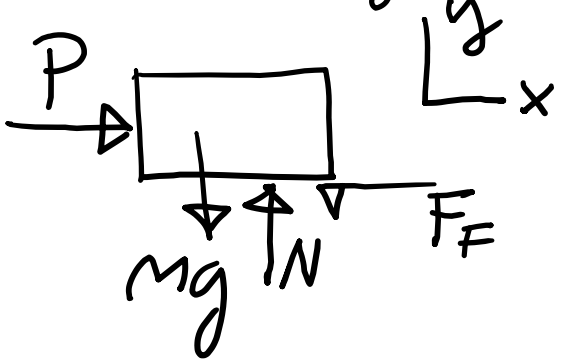

$\Rightarrow \sum F_x = ma_x$ & $\sum F_y = ma_y$

$\Rightarrow P - F_F = ma_x$ & $N - mg = ma_y$ (0)

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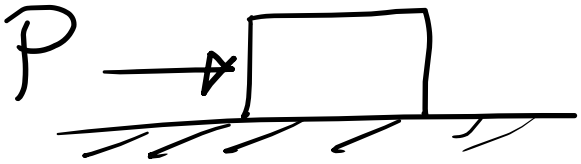

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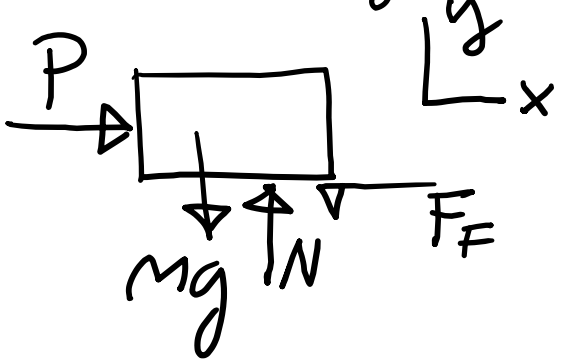

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$\Rightarrow P - F_F = ma_x$ & $N - mg = m\cancel{a_y}^{0} \Rightarrow N = mg$

So far we have $P - F_F = ma_x$ & $N = mg$

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So far we have $P - F_F = ma_x$ & $N = mg$

For static case: $a_x = 0 \Rightarrow P = F_F$ But

$F_F \leq N\mu_s$ & $N = mg \Rightarrow P \leq mg\mu_k$ IF

$P > mg\mu_k$, we must go to Kinetic case.

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Note: μ_k is always less than μ_s. As an example, if box & surface are both steel, we could have $\mu_s = 0.6$ & $\mu_k = 0.1$

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$P = 2N$ & $m = 1kg$ & $\mu_k = 0.1$

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$P = 2N$ & $m = 1kg$ & $\mu_k = 0.1$, then

$a_x = (2 - 0.981)\,m/s^2 = 1.019\,m/s^2$

You want to move a 500 N crate across a level floor. To start the crate moving, you have to pull with a 230 N horizontal force. Once the crate starts to move, you can keep it moving at constant velocity with only 200 N. What are the coefficients of static and kinetic friction?

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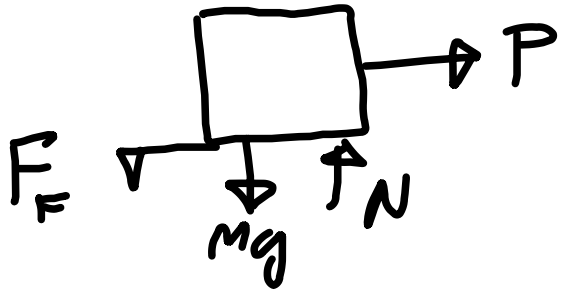

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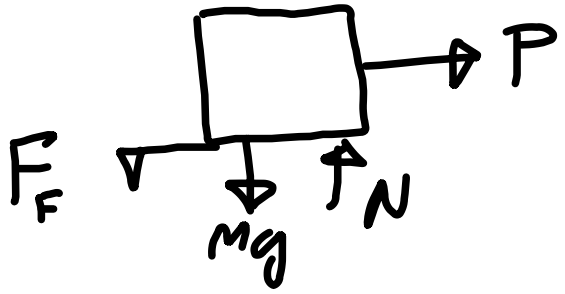
MAX STATIC: $P_1 = 230N$ & $F_F = \mu_s N$



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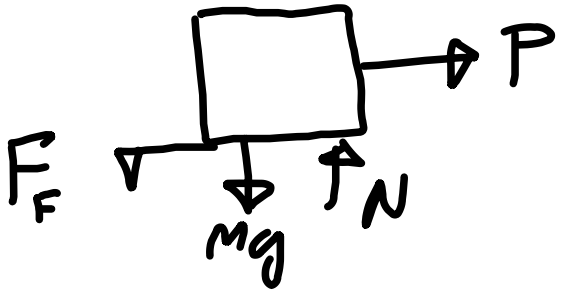
KINETIC



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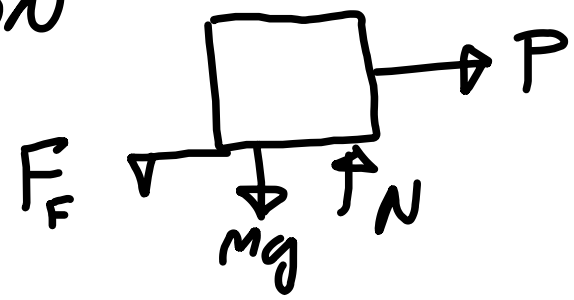

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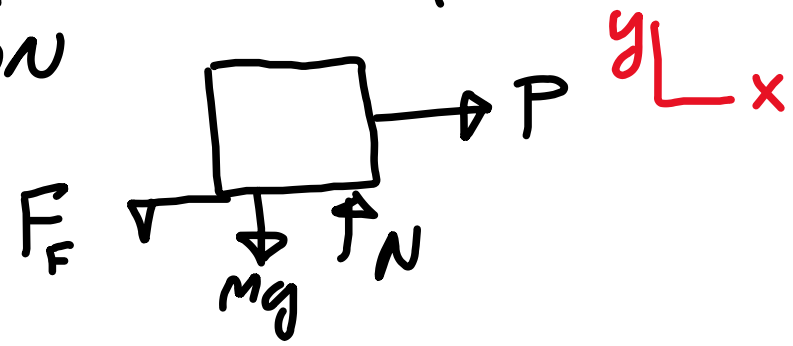

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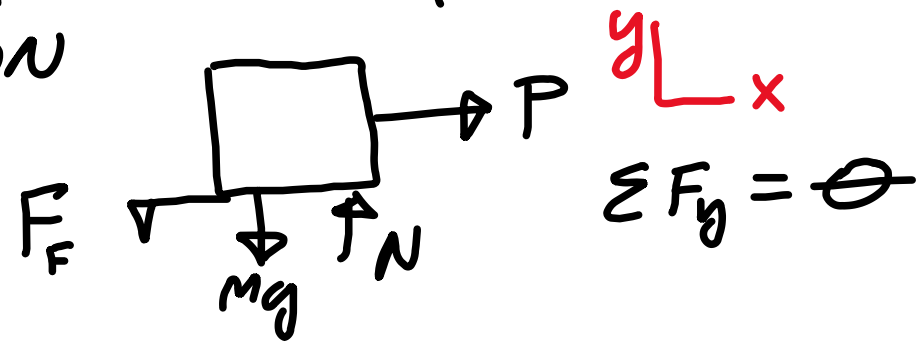

$\Sigma F_y = 0$

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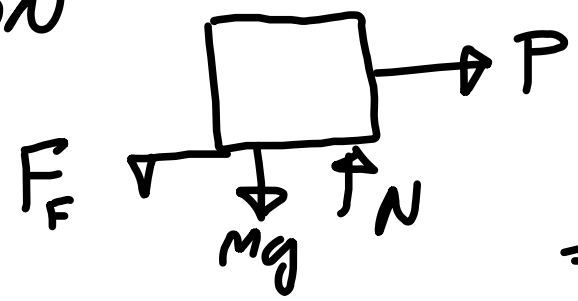

y
x

$\Sigma F_y = 0$

$\Rightarrow N = mg$

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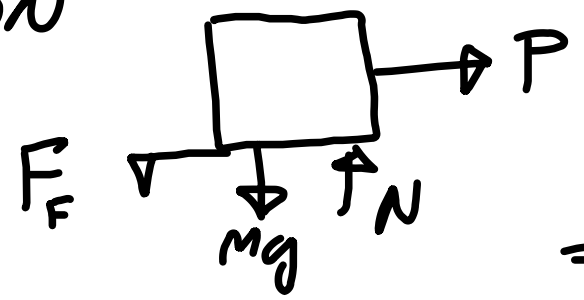

$\Sigma F_y = 0$

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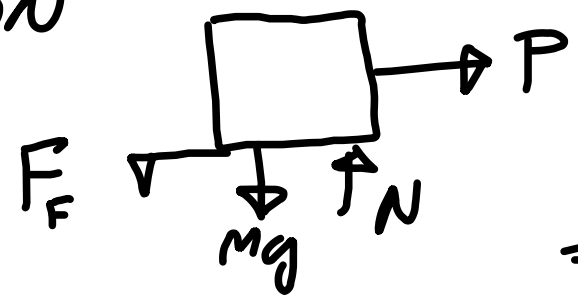

y
x

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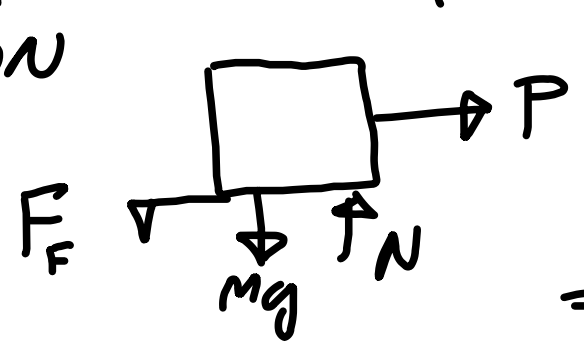

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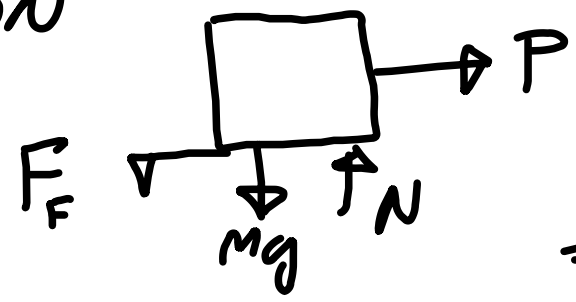

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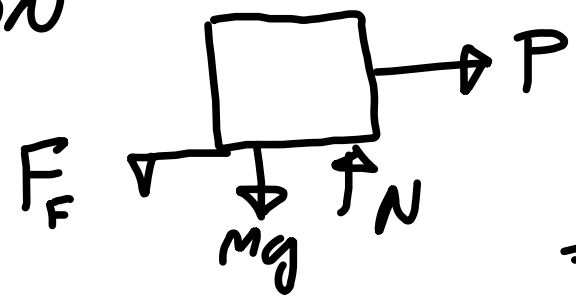

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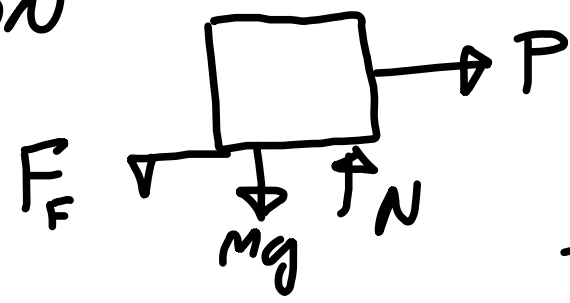

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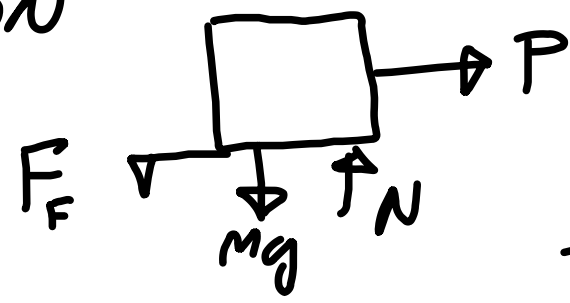

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KINETIC with v = const.

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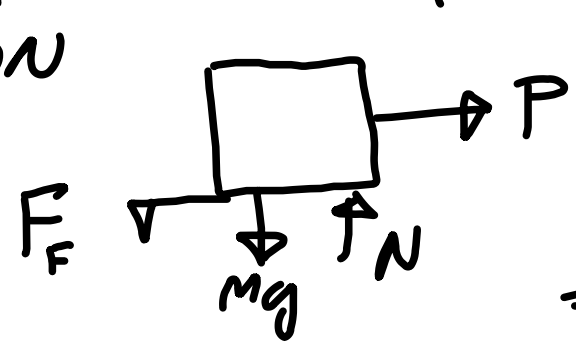

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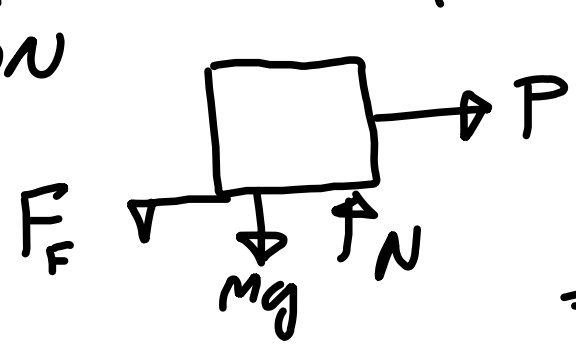

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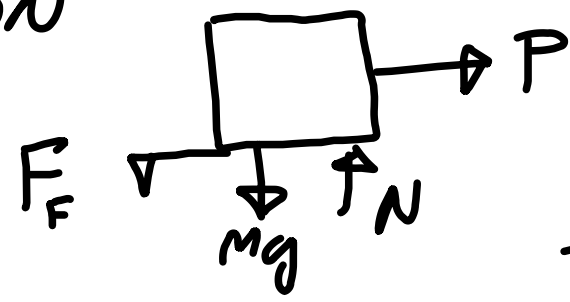

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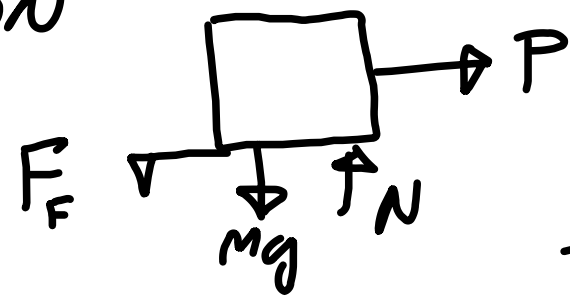

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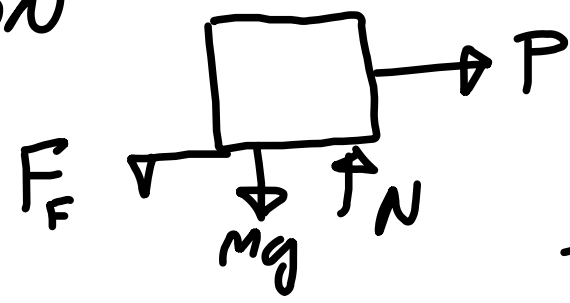

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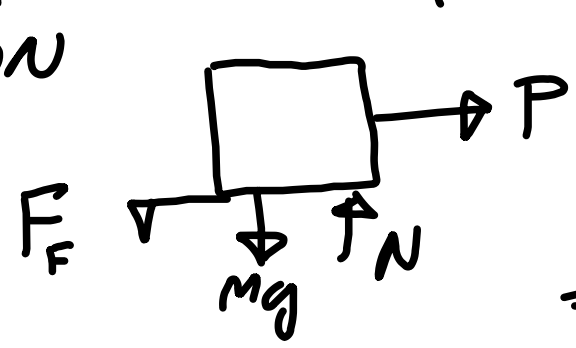

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In Example 5.13, what is the friction force if the crate is at rest on the surface and a horizontal force of 50 N is applied to it?

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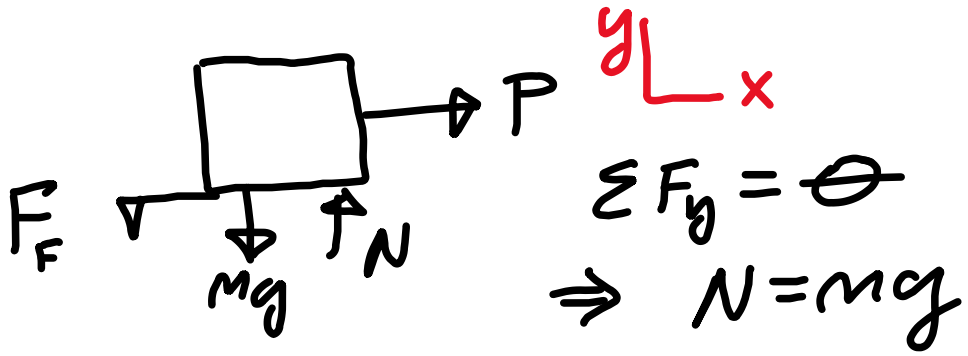

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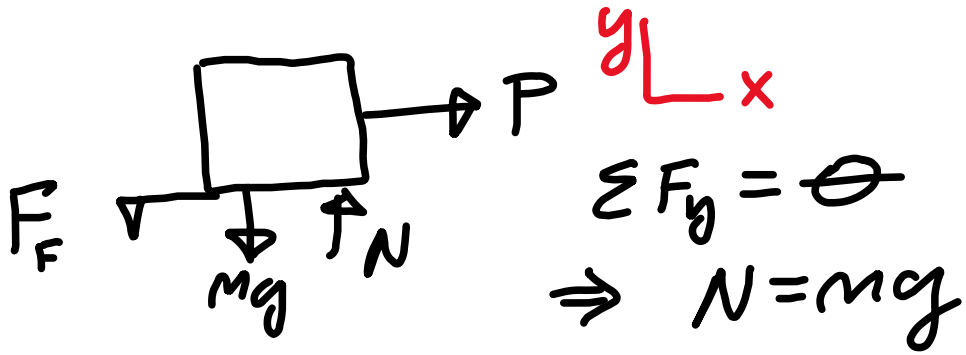

$\Sigma F_y = 0 \Rightarrow N = mg$

$\Sigma F_x = 0 \Rightarrow -F_F + P = 0$

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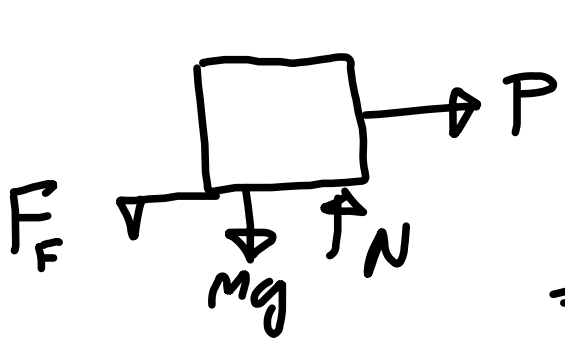

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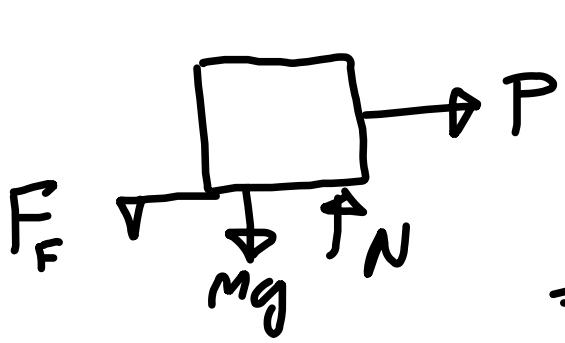

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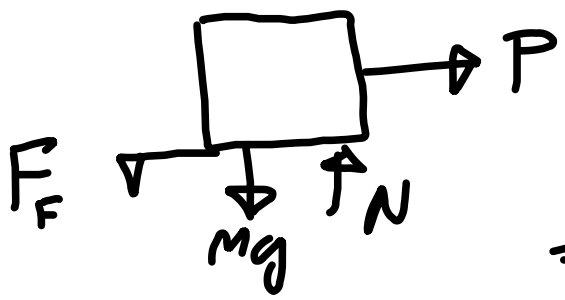

y
x

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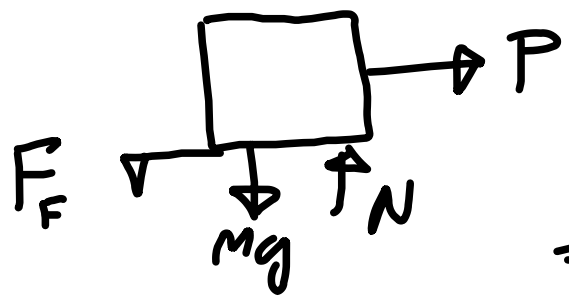

y | — x

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where $N\mu_s = (500\,N)(0.46)$

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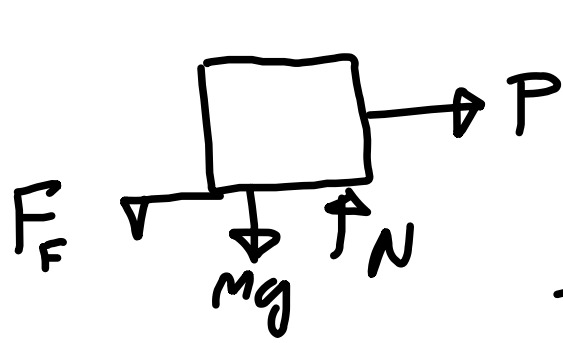

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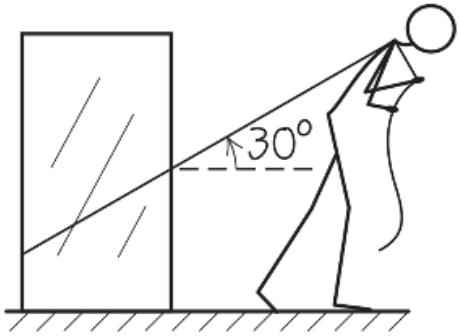
where $N\mu_s = (500N)(0.46) = 230N$

In Example 5.13, suppose you move the crate by pulling upward on the rope at an angle of 30° above the horizontal. How hard must you pull to keep it moving with constant velocity? Assume that $\mu_k = 0.40$.



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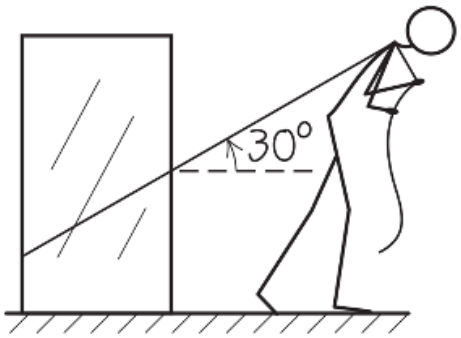

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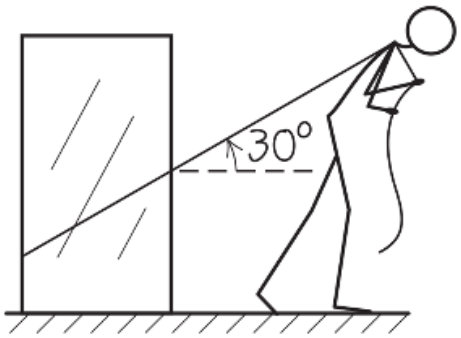
$W = 500\,N$, $\mu_K = 0.4$



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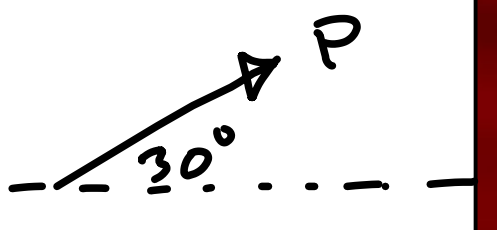

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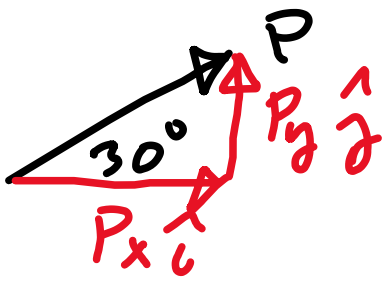
$\vec{P} = P_x\hat{i} + P_y\hat{j}$



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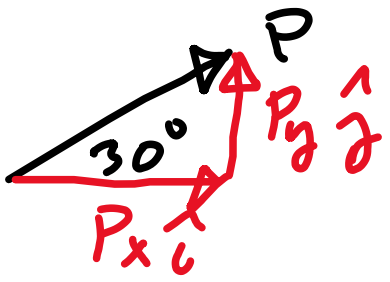
$\vec{P} = P_x\hat{i} + P_y\hat{j}$

$= P[\hat{i}\cos 30^\circ + \hat{j}\sin 30^\circ]$



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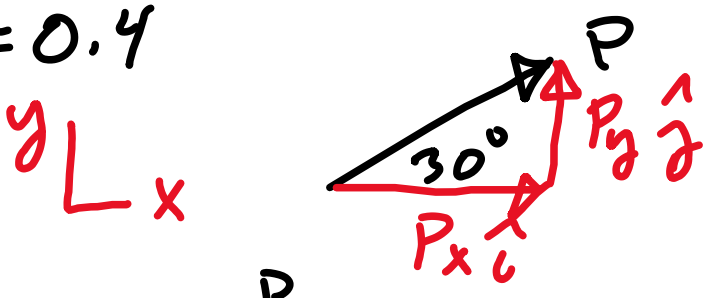

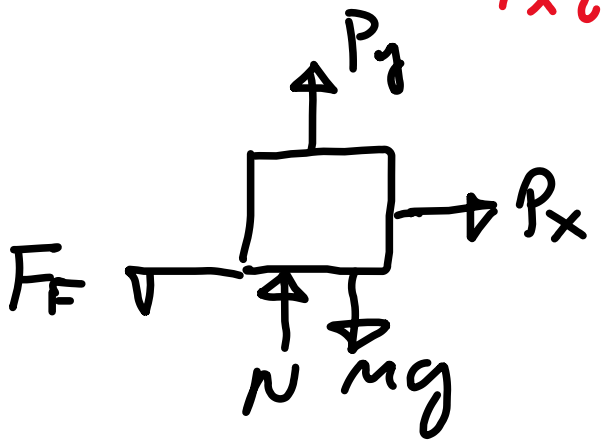

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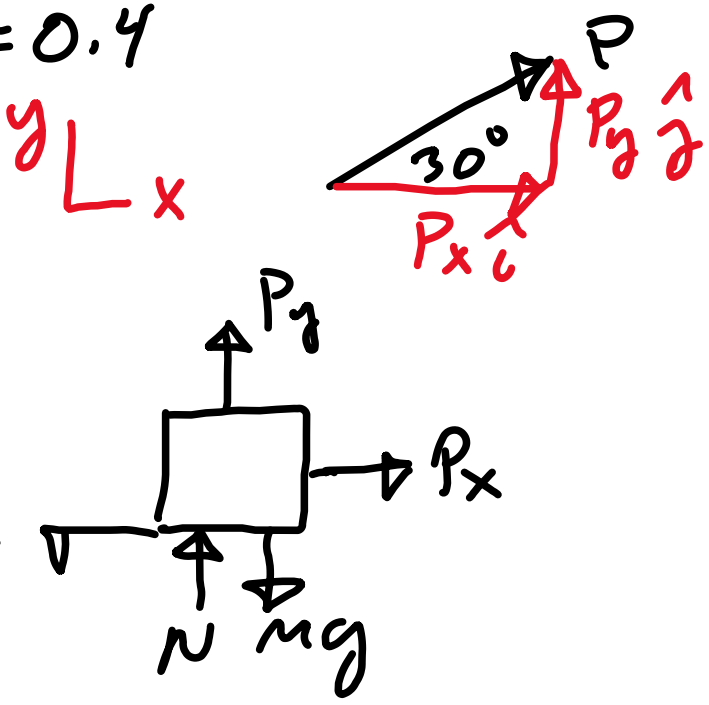
$$\Sigma F_y = 0$$



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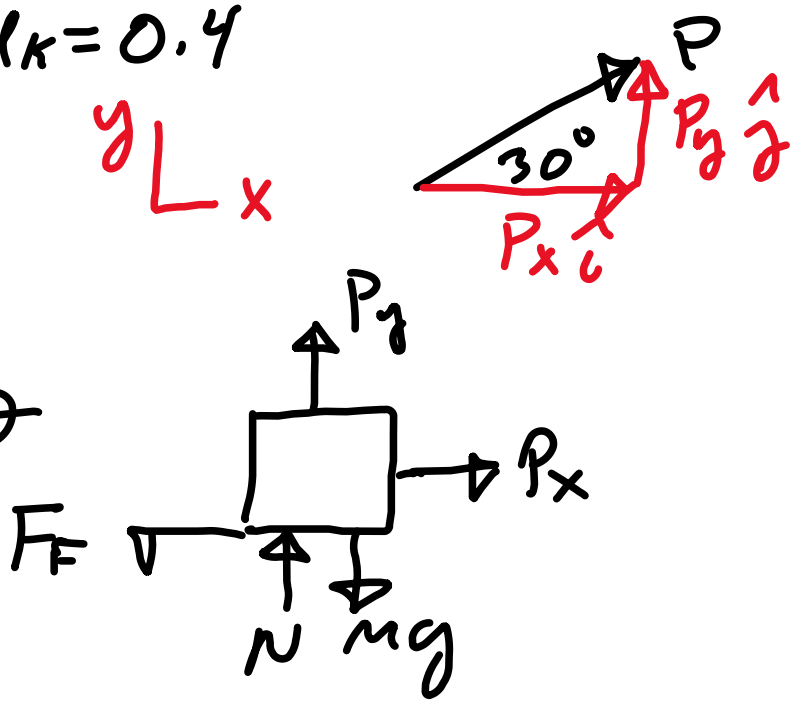
$$= P[\hat{i}\cos 30^\circ + \hat{j}\sin 30^\circ]$$

$$\Sigma F_y = 0 \Rightarrow P_y + N - mg = 0$$



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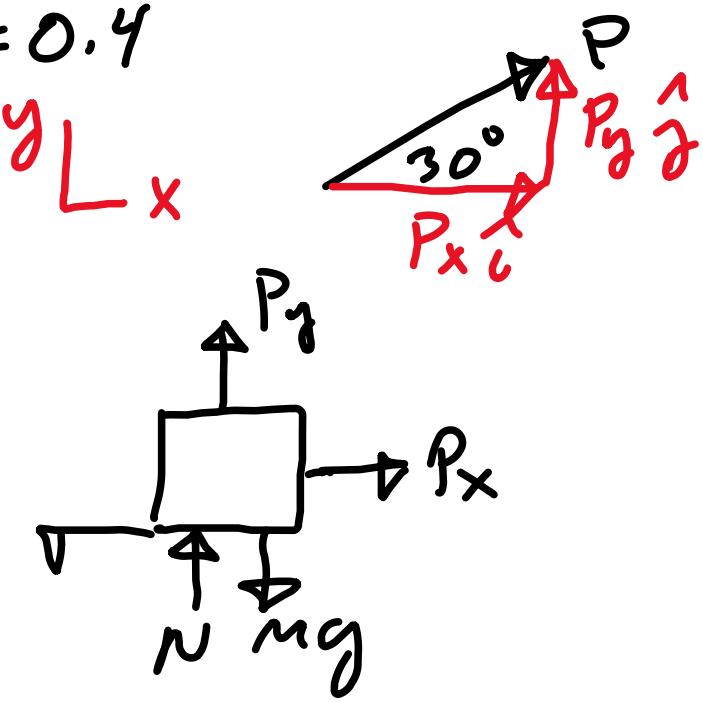
$\Sigma F_y = 0 \Rightarrow P_y + N - mg = 0$

$N = mg - P_y$



In Example 5.13, suppose you move the crate by pulling upward on the rope at an angle of 30° above the horizontal. How hard must you pull to keep it moving with constant velocity? Assume that $\mu_k = 0.40$.

$W = 500\,N$, $\mu_K = 0.4$

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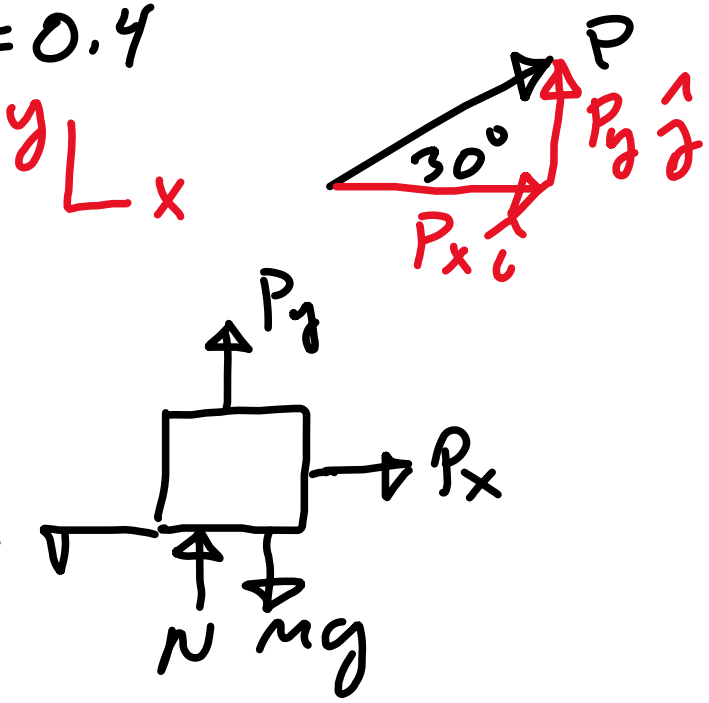

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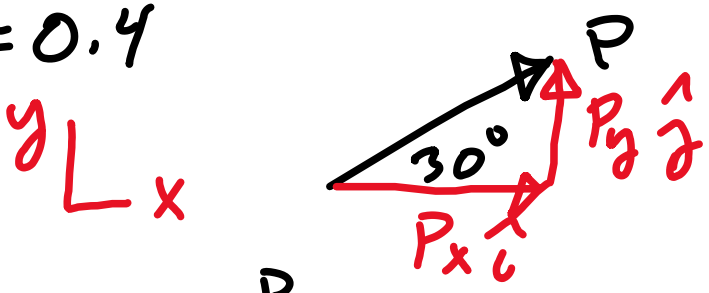

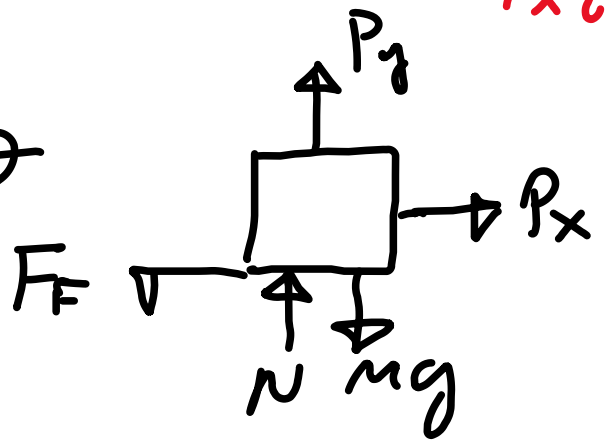

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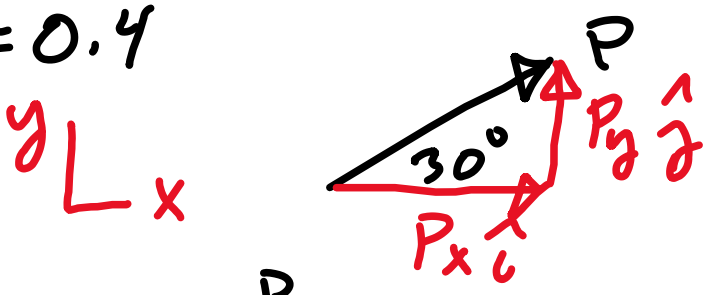

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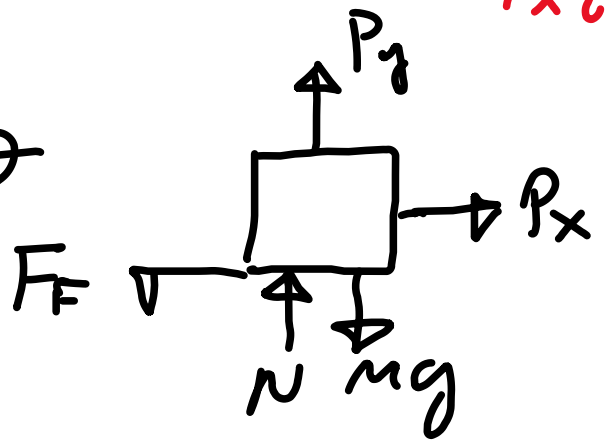

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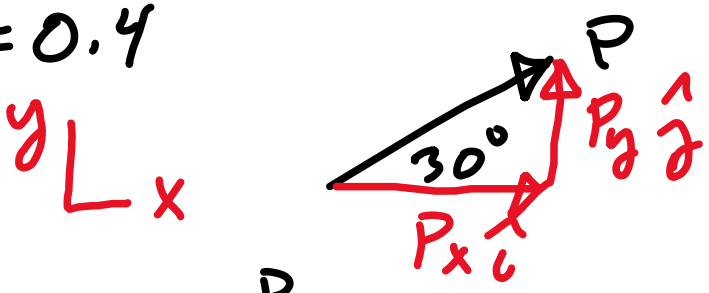

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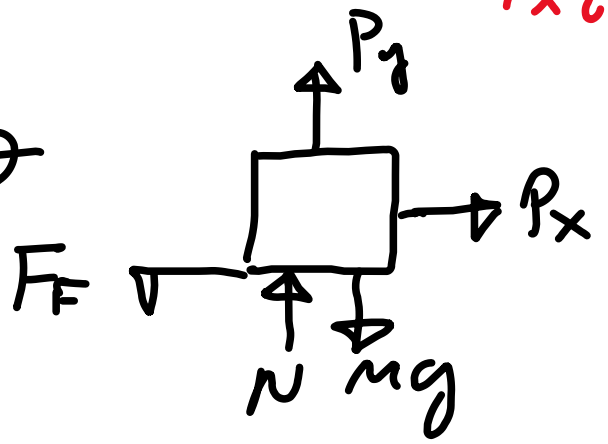

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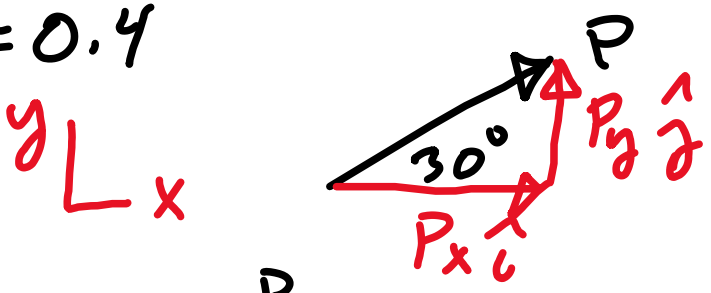

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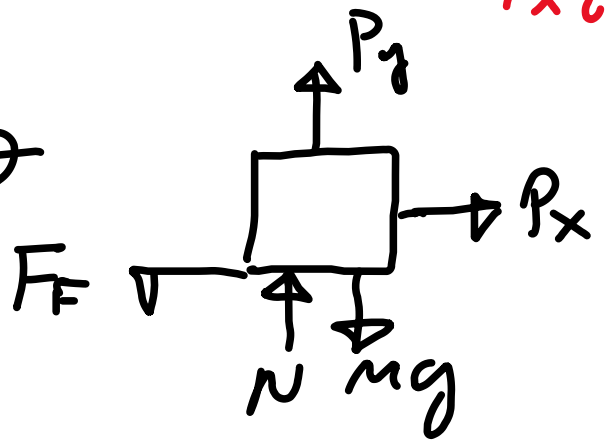

$$\Rightarrow \quad P_x = F_F \Rightarrow P_x = N\mu_K \Rightarrow P\cos 30^\circ = [mg - P\sin 30^\circ]\mu_K$$

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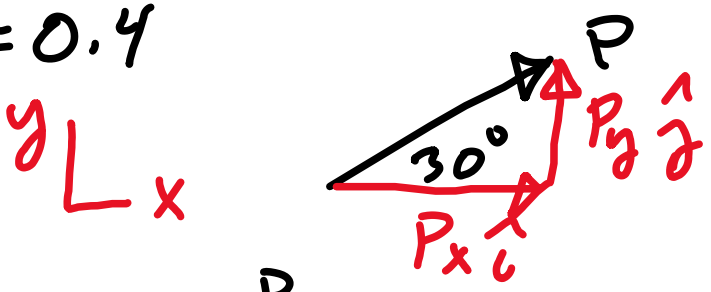

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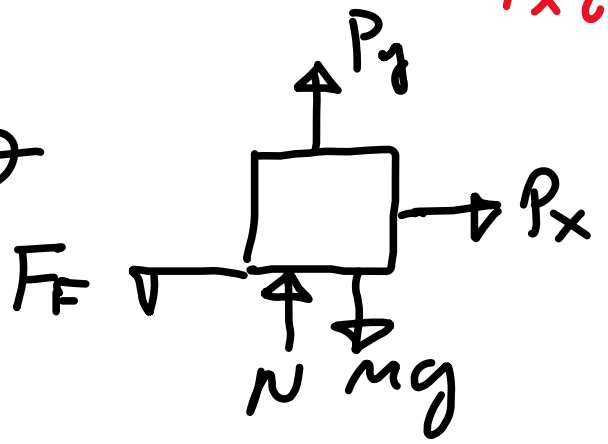

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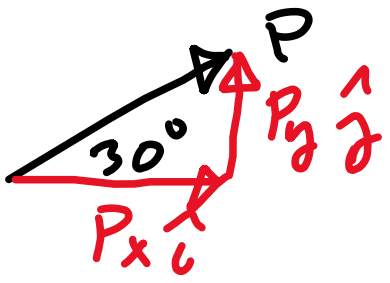

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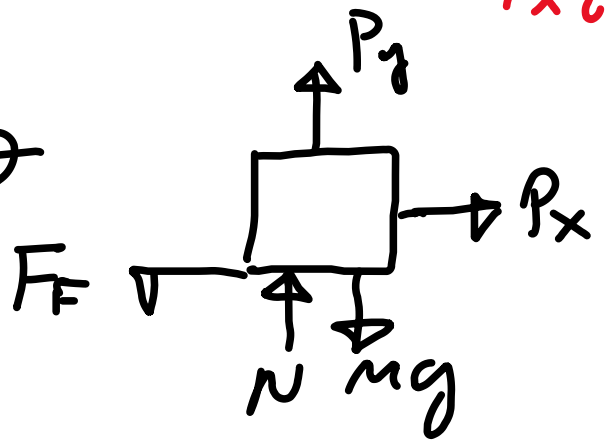

$$\Sigma F_x = 0 \Rightarrow P_x - F_F = 0$$

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$$\Rightarrow \quad P = \frac{mg\mu_K}{\cos 30^\circ + \mu_K \sin 30^\circ}$$

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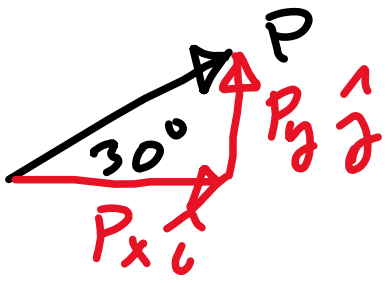

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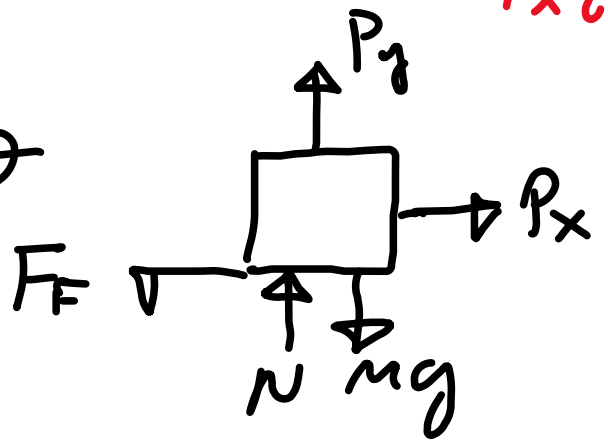

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$$\Rightarrow \quad P[\cos 30^\circ + \mu_K \sin 30^\circ] = mg\,\mu_K$$

$$\Rightarrow \quad P = \frac{(500N)(0.4)}{\cos 30^\circ + (0.4)\sin 30^\circ} = 188N$$

Let's go back to the toboggan we studied in Example 5.10. The wax has worn off, so there is now a nonzero coefficient of kinetic friction μ_k. The slope has just the right angle to make the toboggan slide with constant velocity. Find this angle in terms of w and μ_k.

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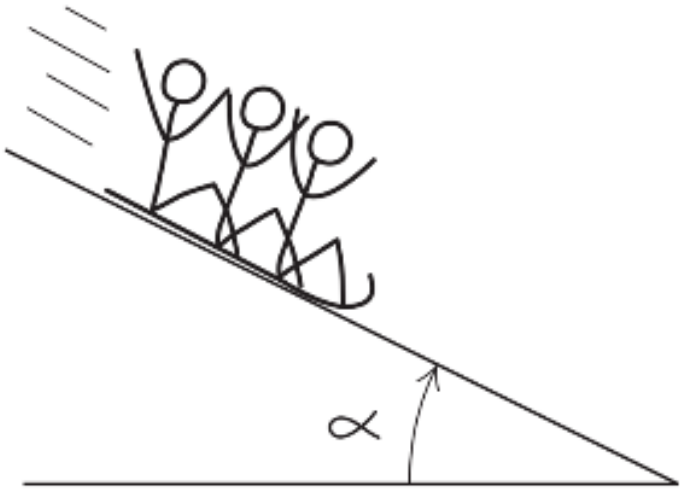

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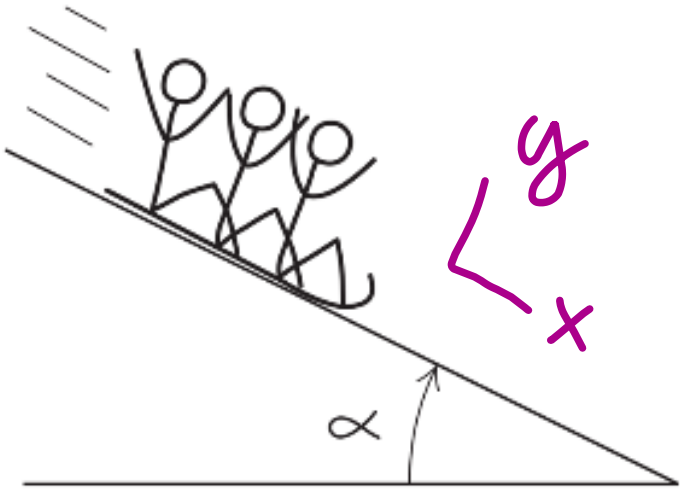

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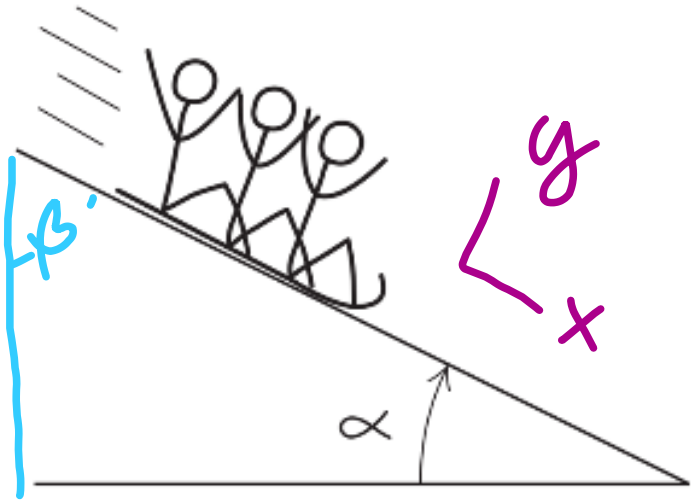

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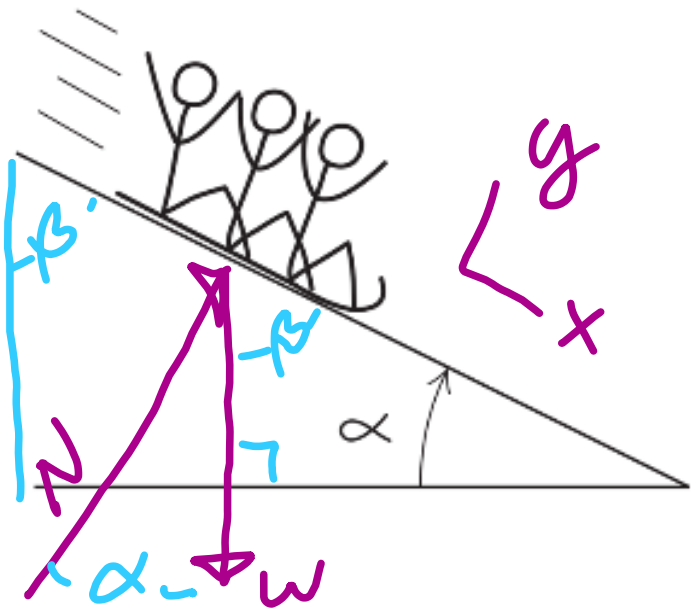

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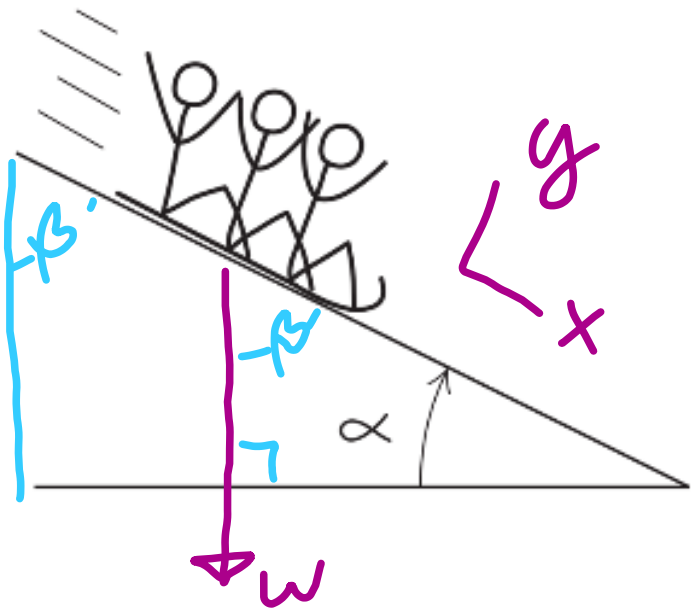

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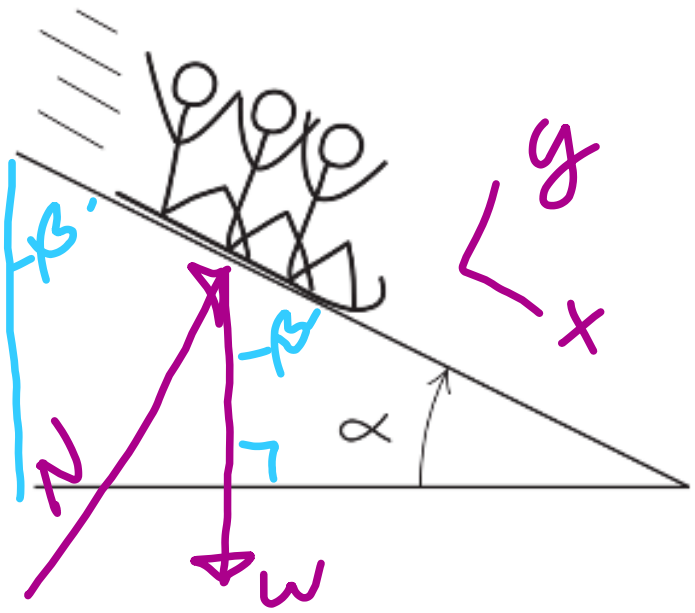

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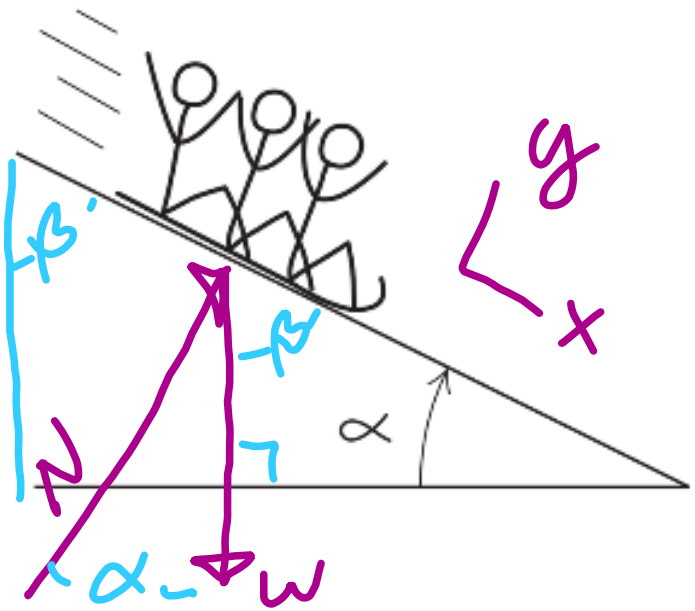

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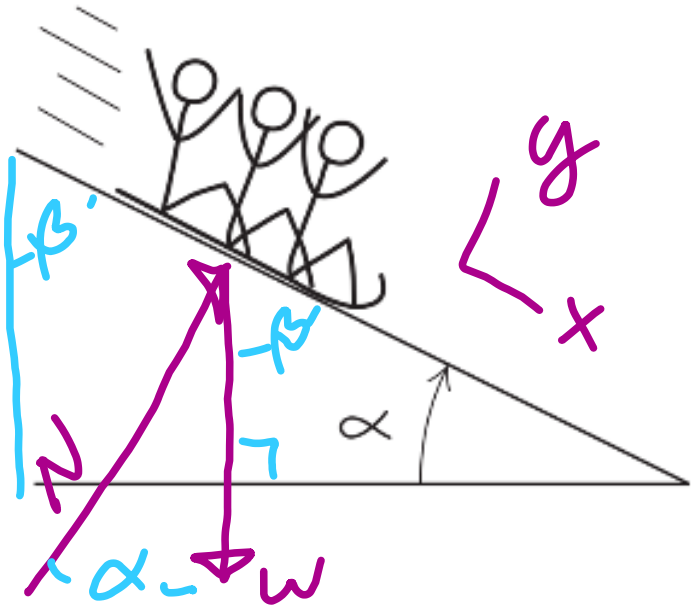

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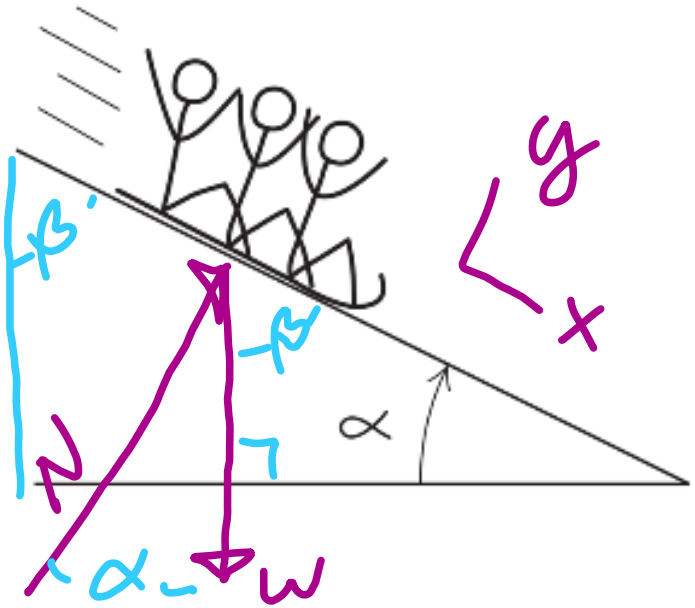

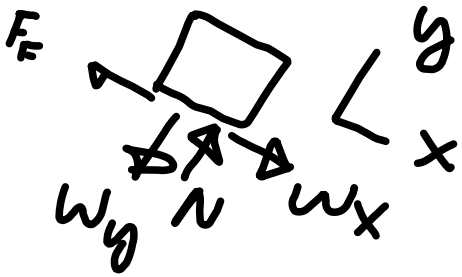

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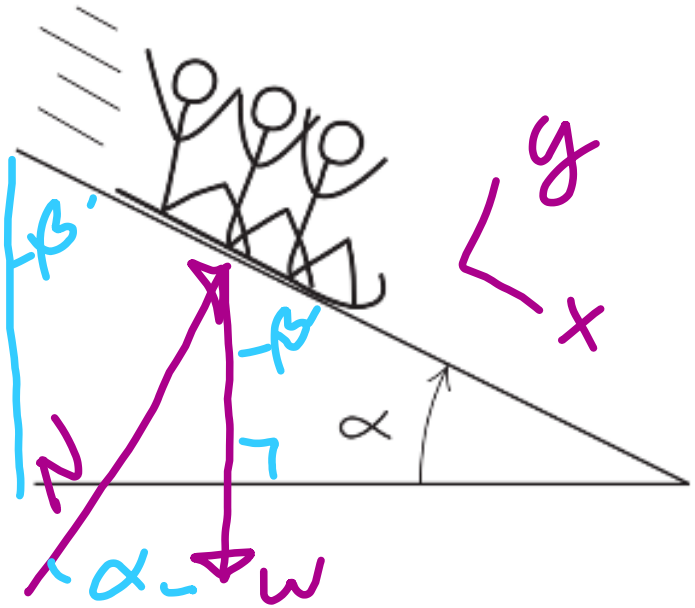

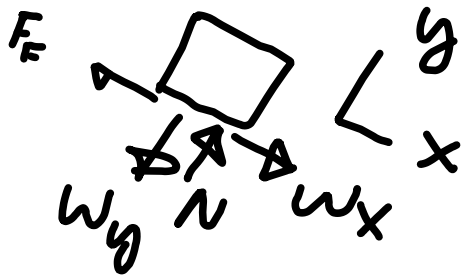

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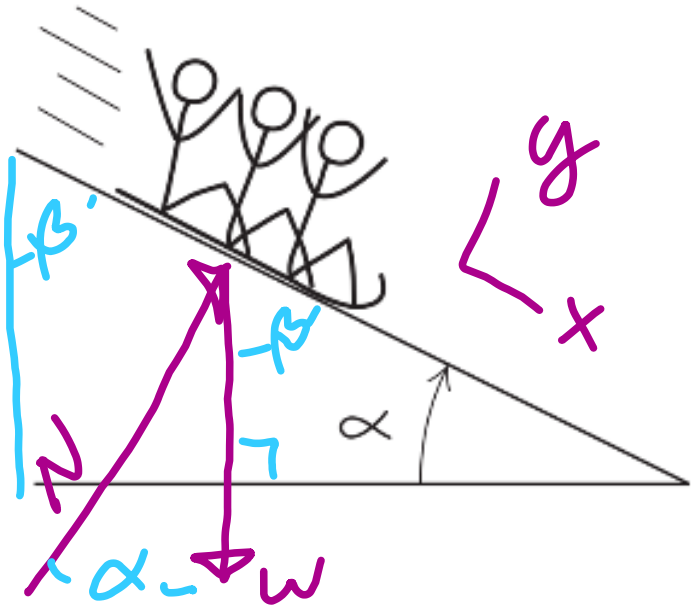

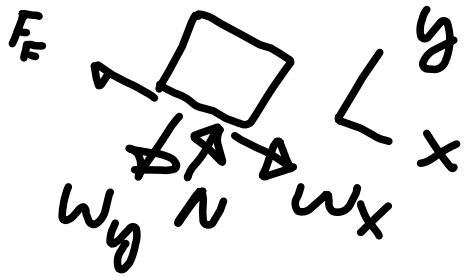

$$\Sigma F_y = 0 \Rightarrow N - mg\cos\alpha = 0$$

(w_y)

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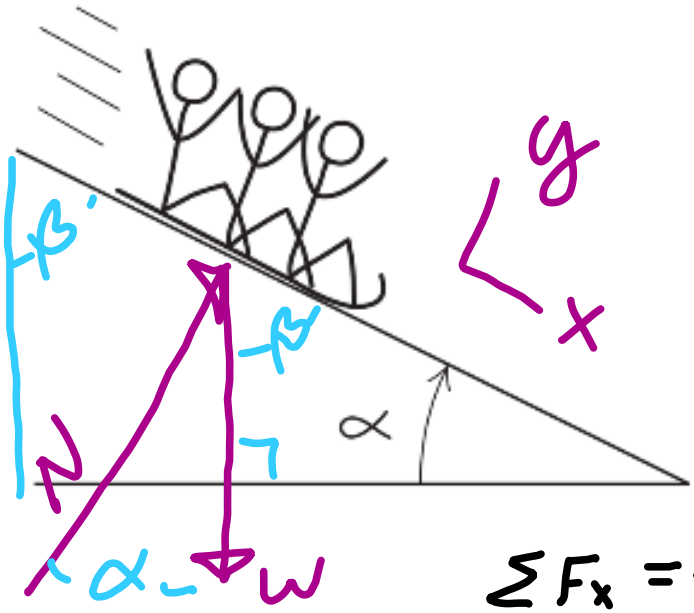

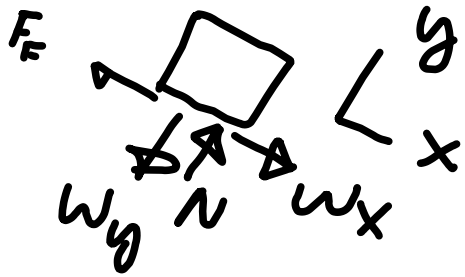

$$\Sigma F_y = 0 \Rightarrow N = mg\cos\alpha$$

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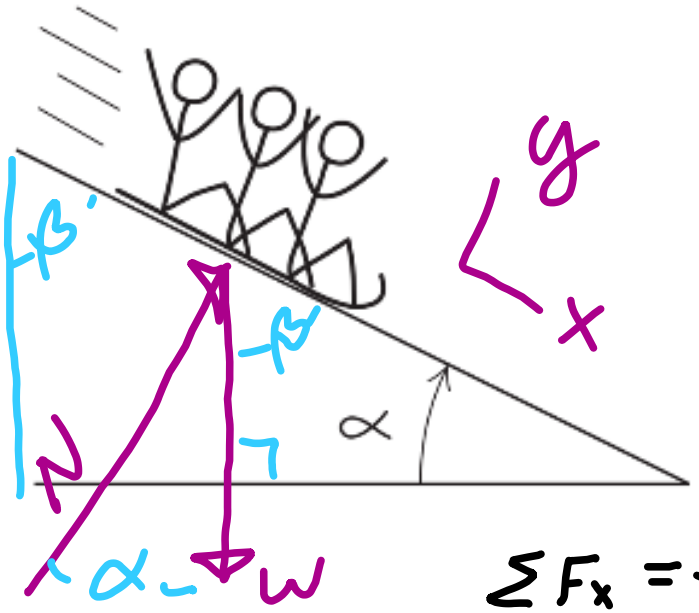

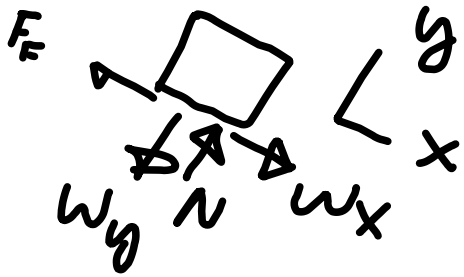

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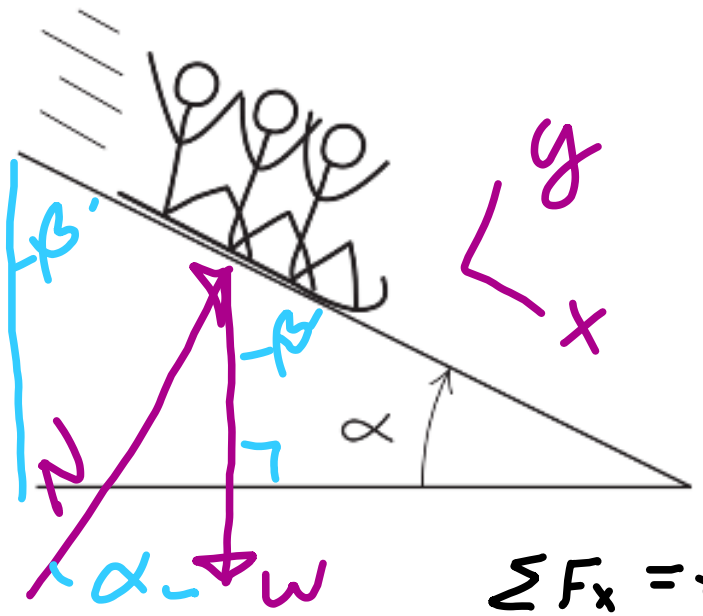

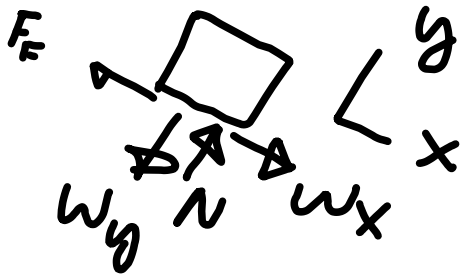

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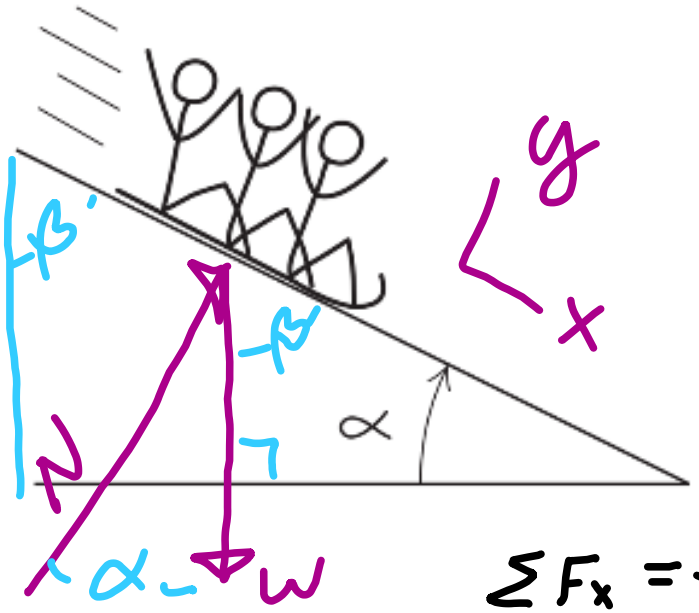

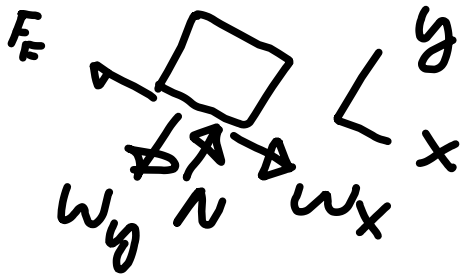

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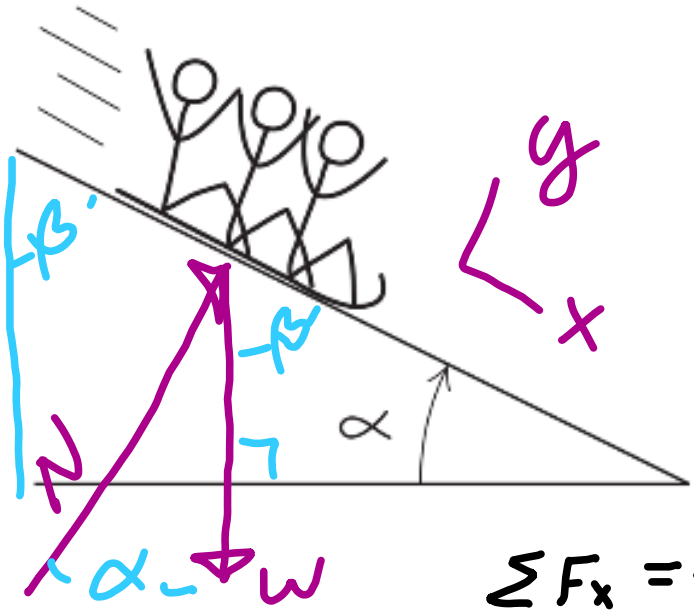

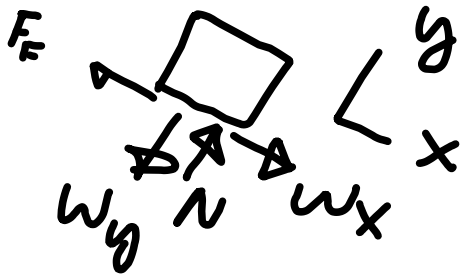

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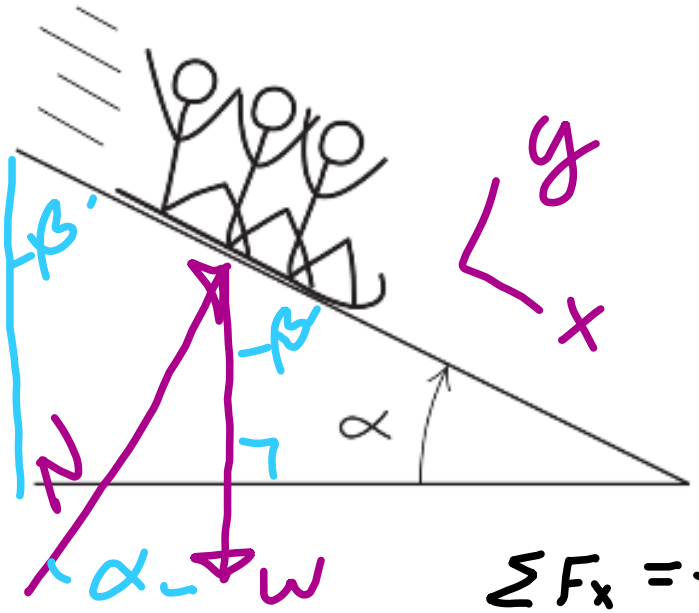

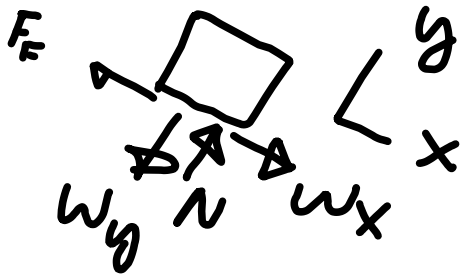

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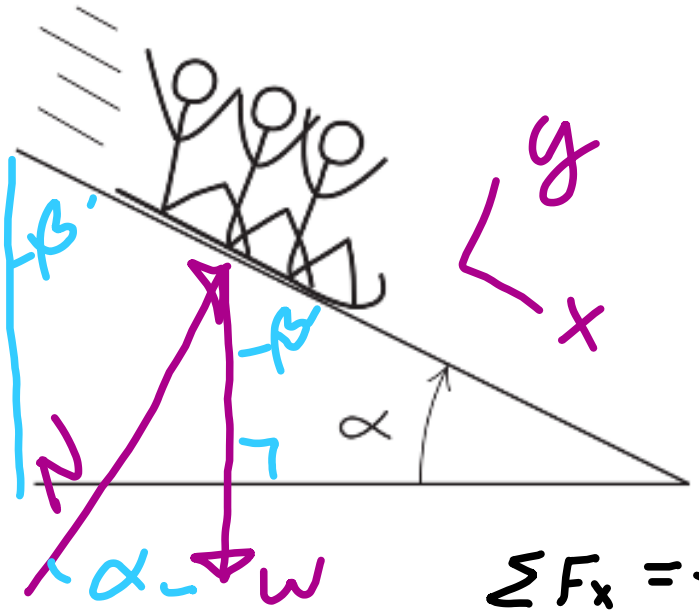

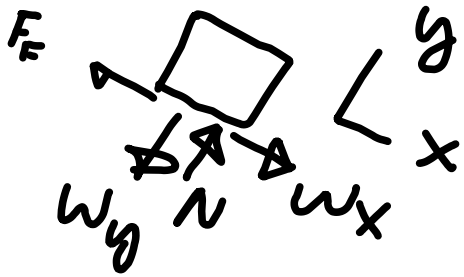

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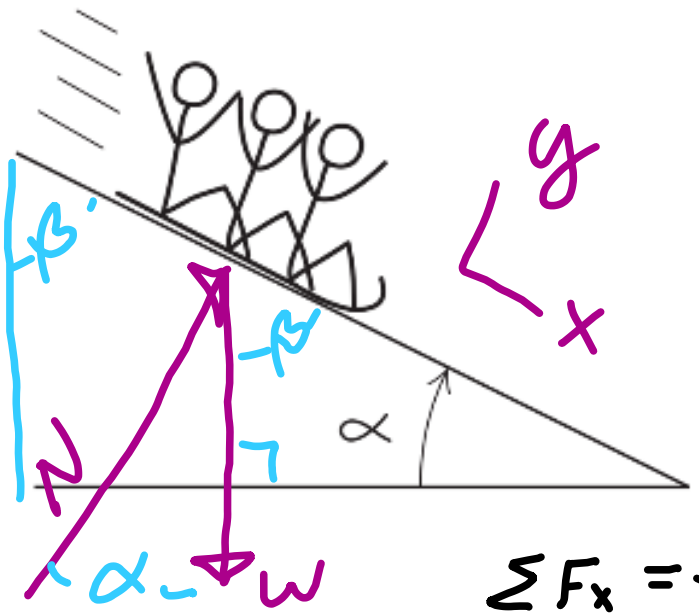

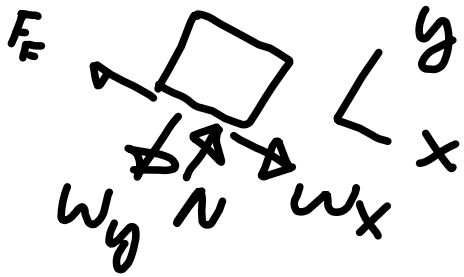

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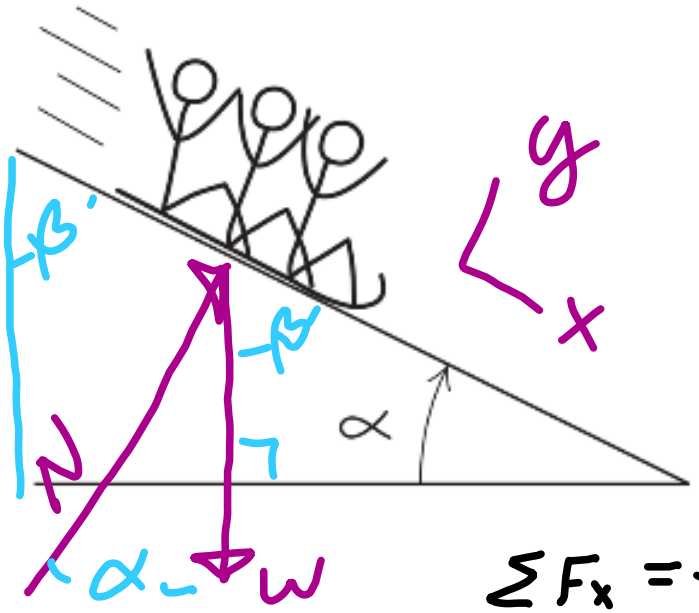

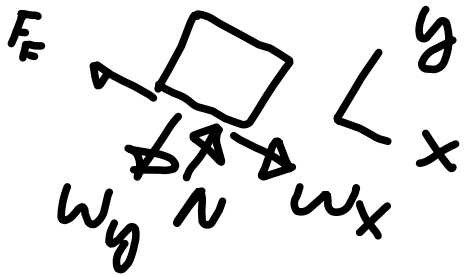

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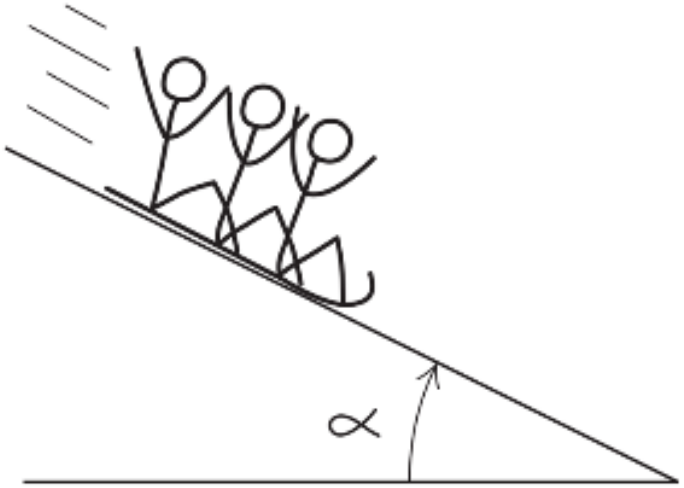
The same toboggan with the same coefficient of friction as in Example 5.16 *accelerates* down a steeper hill. Derive an expression for the acceleration in terms of g, α, μ_k, and w.



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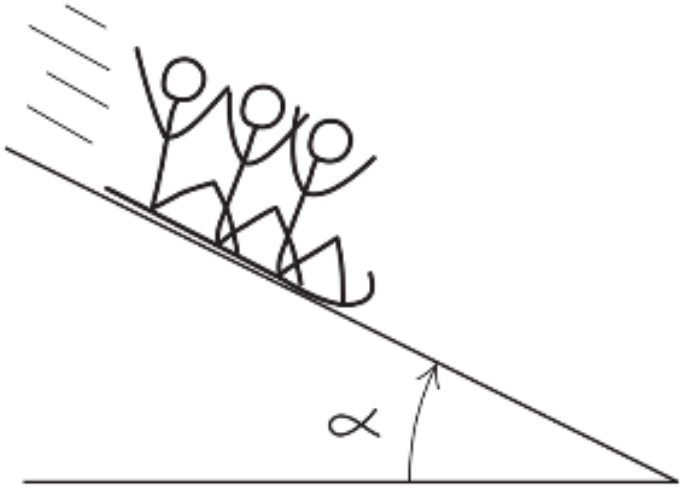

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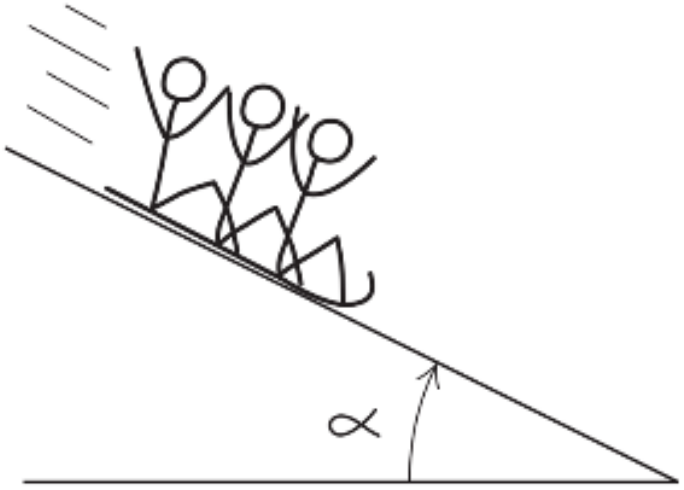

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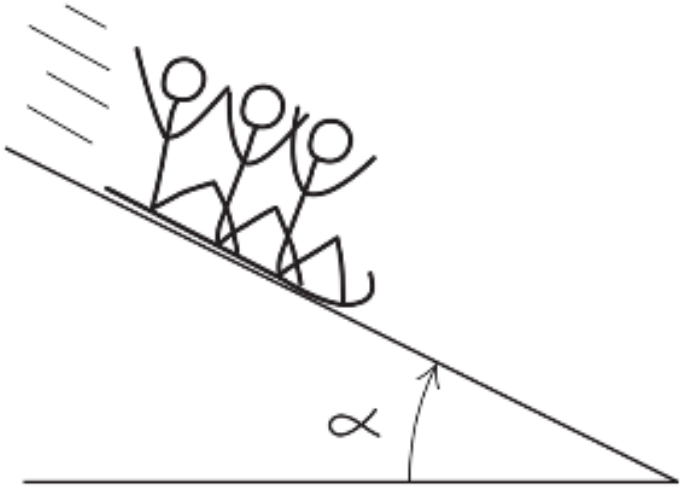

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$$\Sigma F_x = ma_x$$ → NOW

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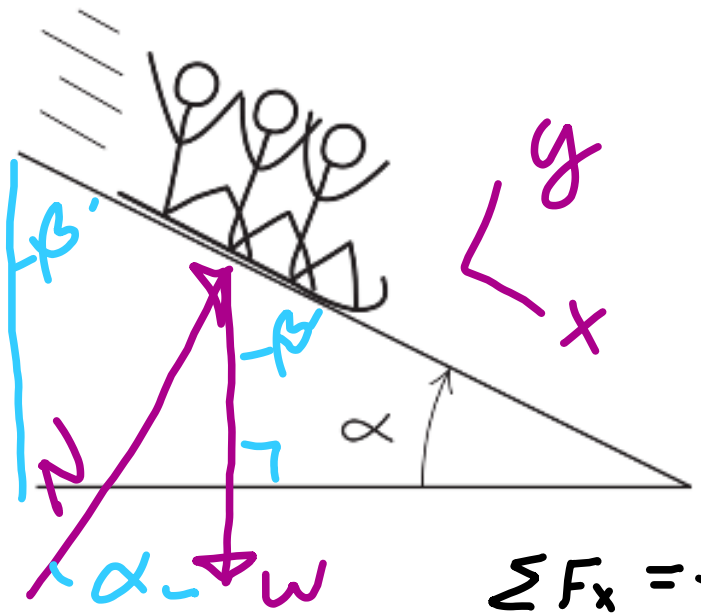

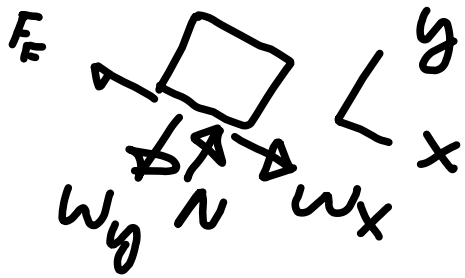

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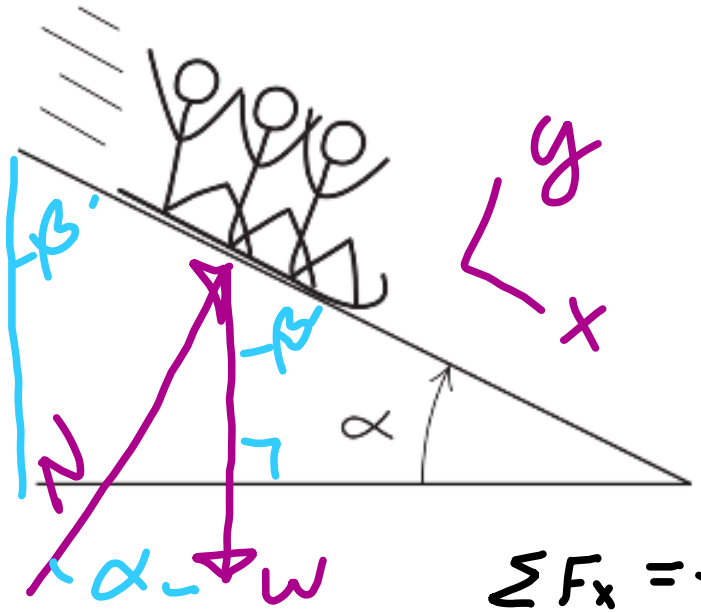

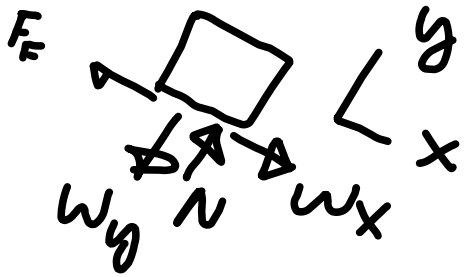

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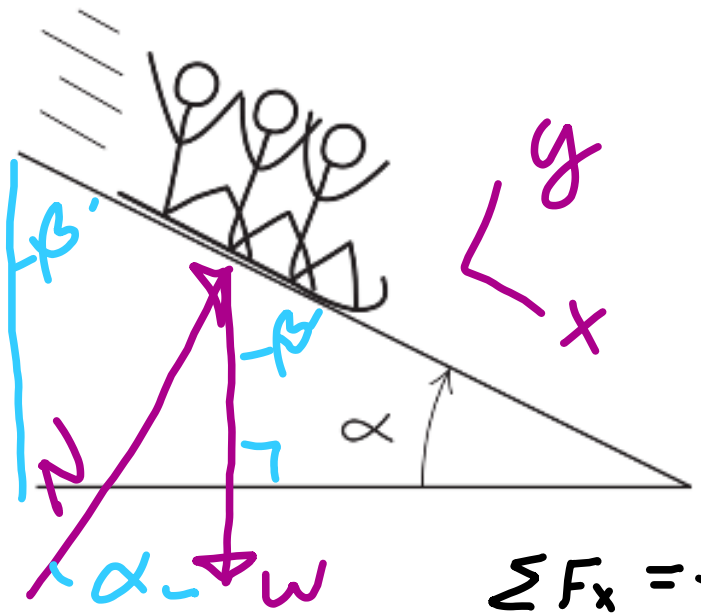

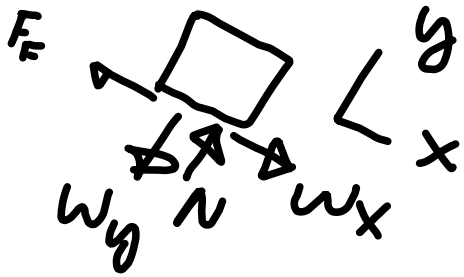

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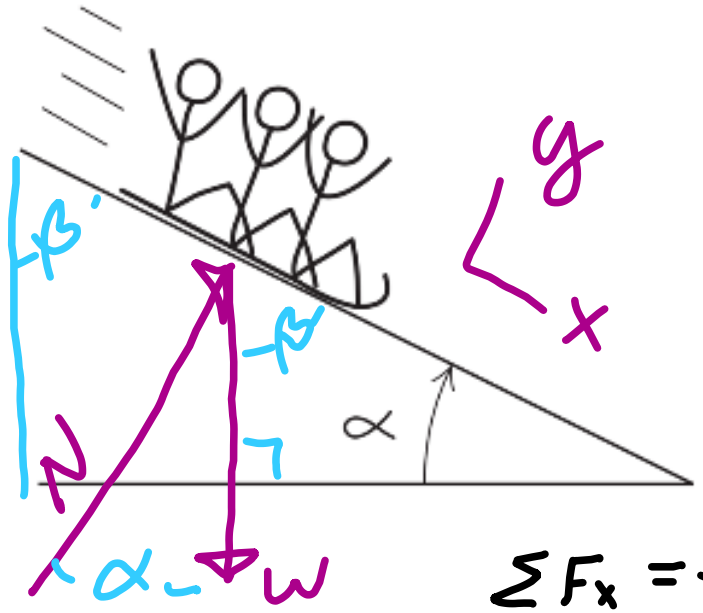

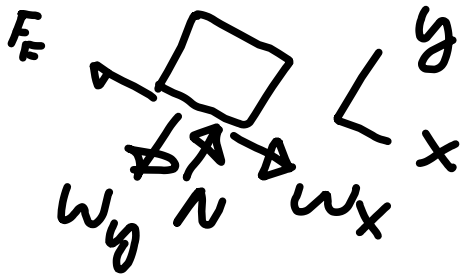

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