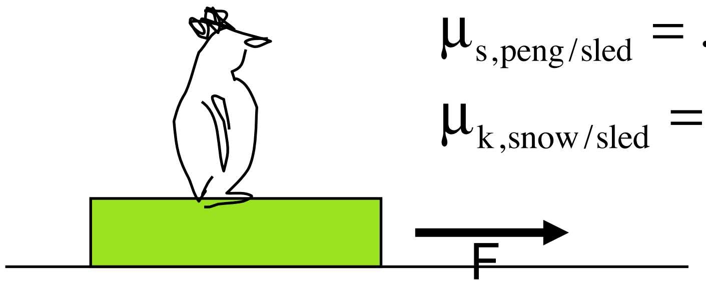
Problem 4.78

$m_p g = 70$ nts $\quad m_s g = 60$ nts

$\mu_{k,peng/sled} = .2$

$\mu_{s,peng/sled} = .7$

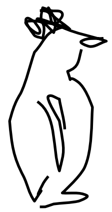
$\mu_{k,snow/sled} = .1$



A 60 N sled is pulled by a force F across snow. The coefficient of kinetic friction between the snow and the sled is .1. A 70 N penguin riding on the sled has a coefficient of static friction of .7 and kinetic friction of .2 between it and the sled. How large does F have to be to get before the penguin breaks loose and slide over the sled? (This is the same as asking what the maximum force F can be and NOT have the penguin break loose.)

EXTRA: Once he's broken loose, what will his acceleration be?

penguin



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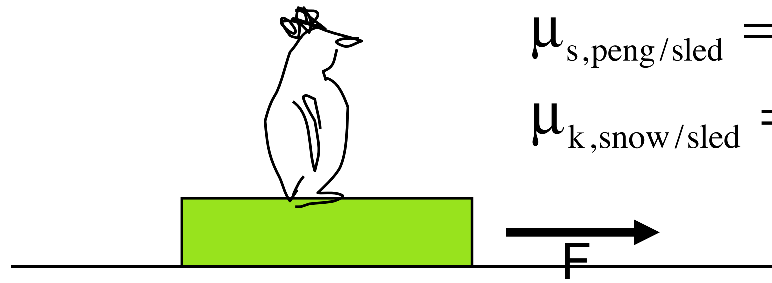
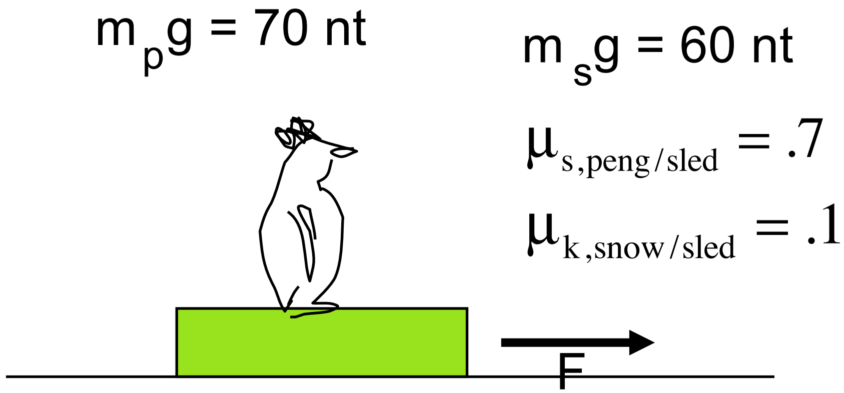
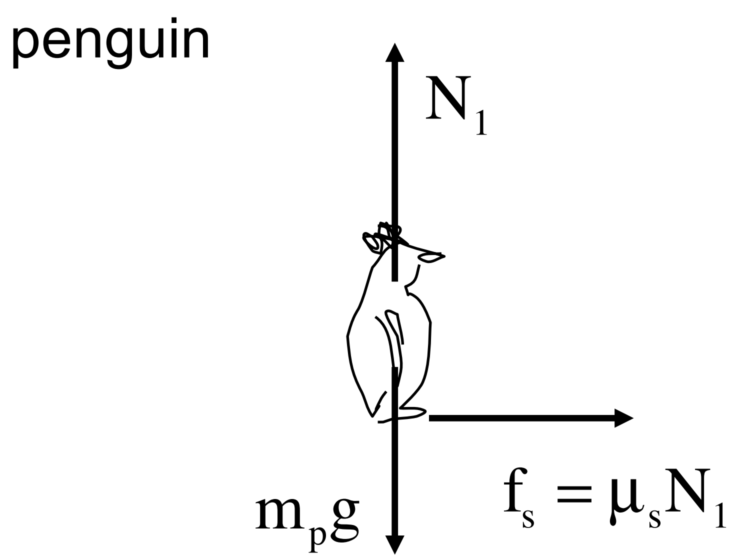


sled

If the penguin breaks loose, what direction will he travel RELATIVE TO THE SLED? In fact, he will lag back to the left. That means the static frictional force on him must be to the right. Put a little differently, if the sled moves out from under the penguin, in what direction will he accelerate relative to the ground? It will be to the right. Where does that force come from? Static friction! Add the normal from the block and gravity and you get:





Summing the forces on the penguin in both directions:

$$\sum F_y :$$

$$N_1 - m_p g = m_p \cancelto{0}{a_y}$$

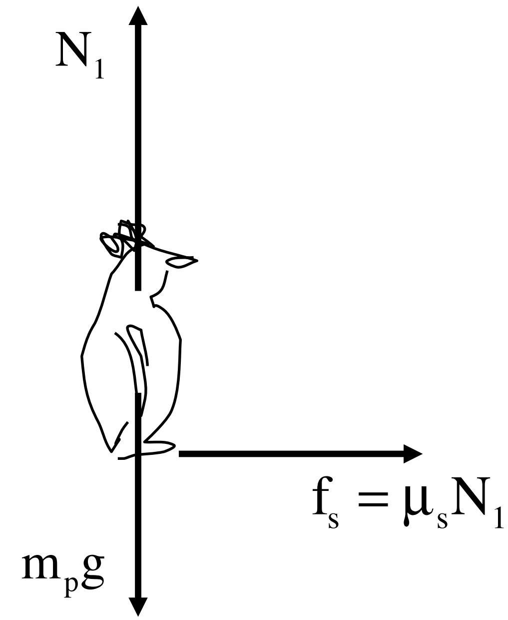
$$\Rightarrow \quad N_1 = m_p g$$

$$\sum F_x :$$

$$\mu_s N_1 = m_p a$$

$$\Rightarrow \quad \mu_s \left(m_p g\right) = m_p a_{penguin}$$

$$\Rightarrow \quad a_{penguin} = \mu_s g$$



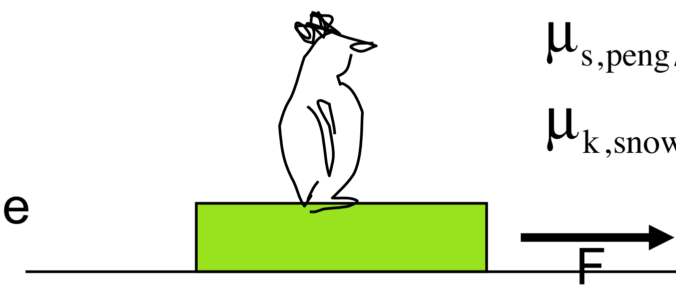
AS FOR THE SLED with the sled and penguin accelerating at the same rate: The most obvious forces are gravity, F and the normal force from the floor. Additionally, there is the normal force from the penguin, friction from the floor AND friction from the penguin.

$m_p g = 70$ nt

$m_s g = 60$ nt

$\mu_{s,peng/sled} = .7$

$\mu_{k,snow/sled} = .1$

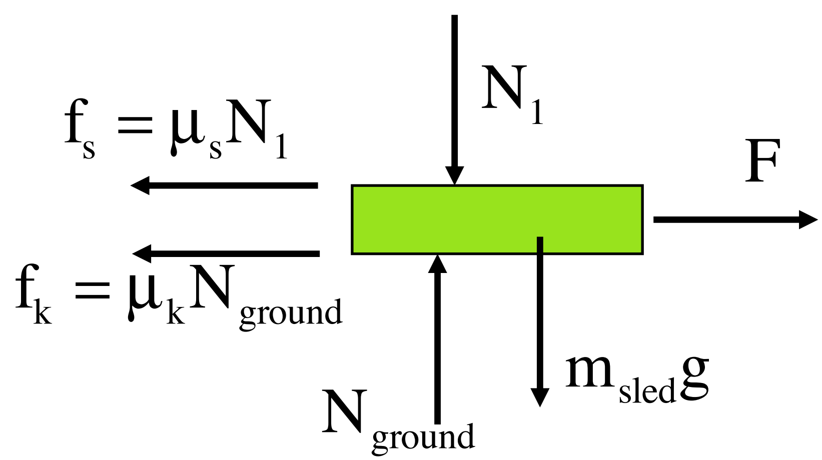


The frictional force due to the ground will be opposite the direction of motion, or to the left.

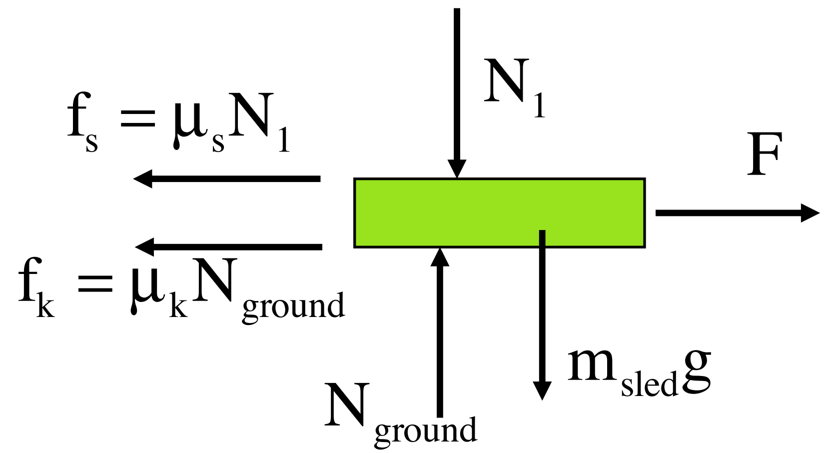
The frictional force due to the penguin will be opposite the direction of friction ON the penguin, or to the left.

And the normal force from the penguin will be opposite the direction of normal force ON the penguin.

sled



Summing the forces on the sled in both directions, then coupling with the equation from the penguin:



$$\sum F_{vert}:$$

$$N_{gr} - N_1 - m_{sled} g = m_{sled} \cancelto{0}{a}_{vert}$$

$$\Rightarrow \quad N_{gr} - (m_p g) - m_{sled} g = 0$$

$$\Rightarrow \quad N_{gr} = (m_p + m_{sled}) g$$

$$\sum F_{horizontal}:$$

$$F - \mu_s (N_1) - \mu_s (N_{gr}) = m_{sled} a_{\text{sled and penguin}}$$

$$\Rightarrow \quad F - \mu_s (m_p g) - \mu_k (m_p + m_{sled}) g = m_{sled} (\mu_s g)$$

$$\Rightarrow \quad F = \mu_s (m_p g) + \mu_k (m_p + m_{sled}) g + m_{sled} (\mu_s g)$$

$$\Rightarrow \quad F = \mu_s m_p g + (\mu_k m_p g + \mu_k m_{sled} g) + \mu_s m_{sled} g$$

$$\Rightarrow \quad F = (m_p g + m_{sled} g)(+\mu_k + \mu_s)$$

$$\Rightarrow \quad F = (70 \text{ nts} + 60 \text{ nts})(+.1 + .7)$$

$$\Rightarrow \quad F = 104 \text{ nts}$$