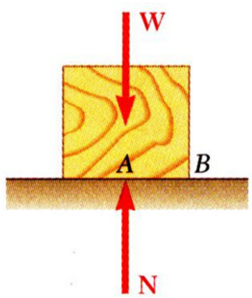
Chapter 8: Friction

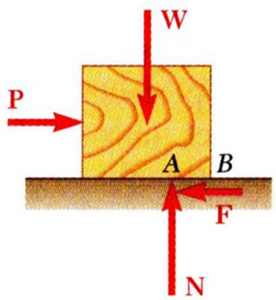
8.1 - 8.2 Coulomb Friction Model

Thus far we have been considering problems in equilibrium without friction. In reality, **friction** is always present between any **two surfaces in contact** which may be **moving** with respect to each other or **impending to move**.

There are two types of friction: **Coulomb friction** (dry) and *fluid friction*. Fluid friction applies to lubricated mechanisms. The present discussion is limited to dry friction between nonlubricated surfaces.

Consider the block resting on a flat surface:





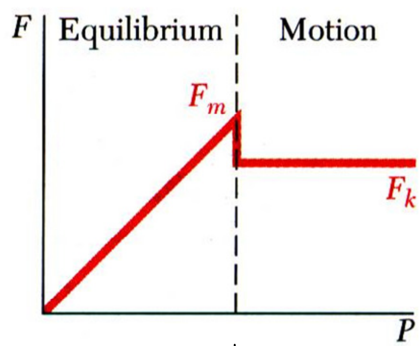


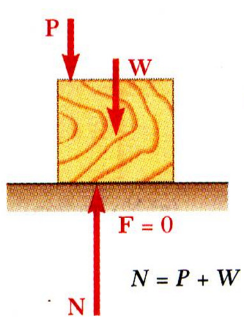
Table 8.1. Approximate Values of Coefficient of Static Friction for Dry Surfaces

Metal on metal	0.15–0.60
Metal on wood	0.20–0.60
Metal on stone	0.30–0.70
Metal on leather	0.30–0.60
Wood on wood	0.25–0.50
Wood on leather	0.25–0.50
Stone on stone	0.40–0.70
Earth on earth	0.20–1.00
Rubber on concrete	0.60–0.90

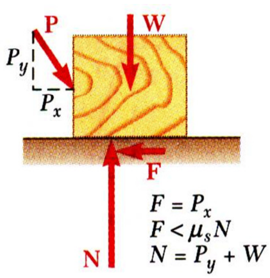
Static Friction	**Kinetic Friction**
$F_{static} \le F_{\max} = \mu_s N$	$F_{kinetic} = \mu_k N$

Note: Friction forces are

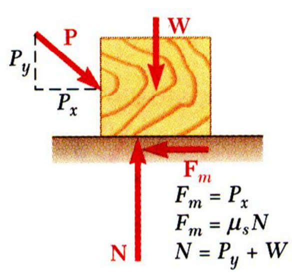
- Always opposes relative motion between two surfaces.
- Limited in magnitude and will not prevent motion if sufficiently large forces are applied.
- Dependent on type and condition of contact surfaces
- Proportional to the normal force
- Independent of contact area



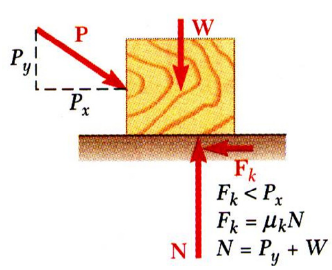
- No friction, ($P_x = 0$)



- No motion, ($P_x < F_m$)



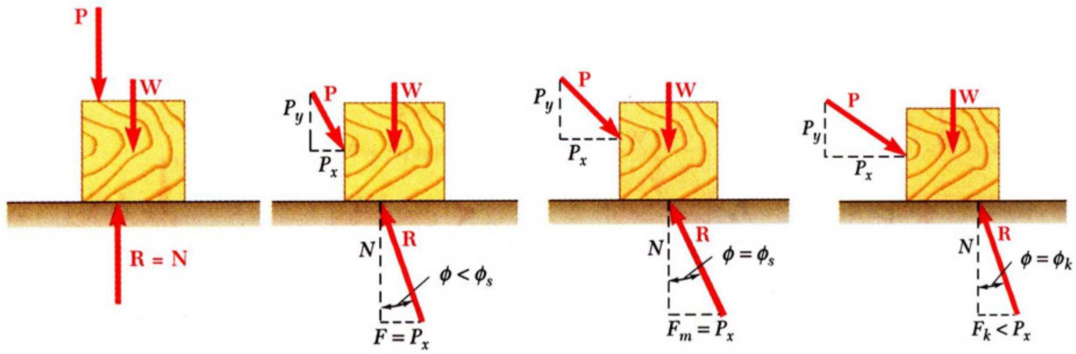
- Motion impending, ($P_x = F_m$)



- Motion, ($P_x > F_m$)

8.3 - 8.4 Angles of Friction; Dry Friction

The frictional force between two surfaces can also be expressed as an angle.
- the angle that the resultant makes with direction of the normal force.

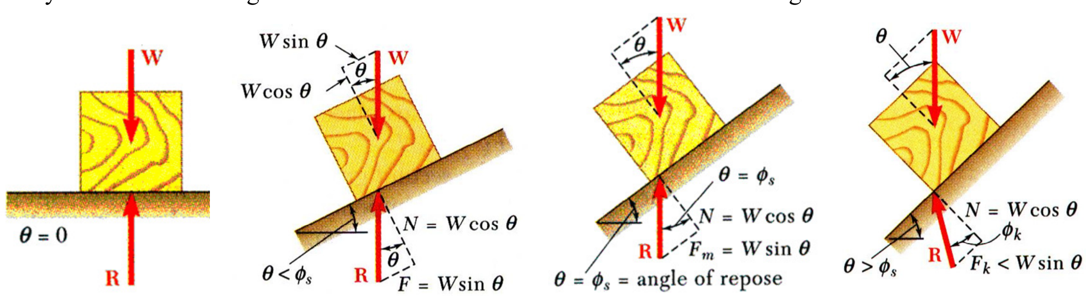


- No friction
- No motion
- Motion impending
- Motion

$$\tan\phi_s = \frac{F_m}{N} = \frac{\mu_s N}{N}$$
$$\tan\phi_s = \mu_s$$

$$\tan\phi_k = \frac{F_k}{N} = \frac{\mu_k N}{N}$$
$$\tan\phi_k = \mu_k$$

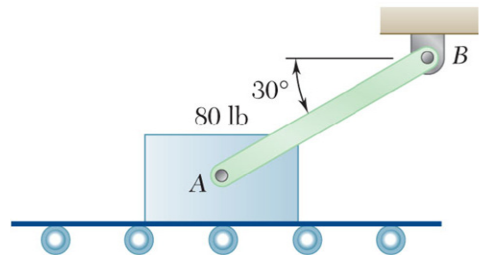
Another way to visualize the angles of static and kinetic friction is with a block resting on an incline.



- No friction
- No motion
- Motion impending
- Motion

For problems involving Friction:
- Assume equilibrium and draw FBD including the required friction forces for equilibrium.
- Check if the required friction forces are less than F_{max} (Static).
  - If less => analysis correct; DONE.
  - If more => equilibrium does NOT hold; REDO with kinetic friction and DYNAMICS.

Read Examples 8.1, 8.2 and 8.3.



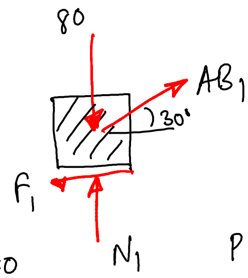
Exercise 8.10

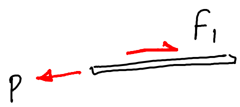
$\mu_S = 0.25$ and $\mu_K = 0.20$

Find the force required to pull the belt

- to the left
- to the right.

① Moving to the left:





$F_1 = \mu_k N_1$

$\sum F_x = 0$

$\Rightarrow -\mu_k N_1 + AB_1 \cos 30° = 0$

$\sum F_y = 0$

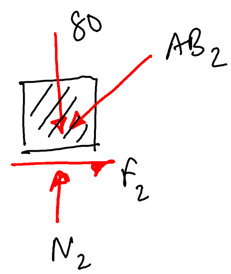
$\Rightarrow N_1 - 80 + AB_1 \sin 30° = 0$

$\Rightarrow$ $N_1 = 71.72$ lb

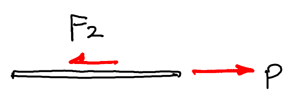
and $AB_1 = 16.56$ lb

$\Rightarrow$ $\boxed{P = F_1 = 14.34 \text{ lb}}$

② Moving to the right



$F_2 = \mu_k N_2$



$\sum F_x = 0$

$\Rightarrow \mu_k N_2 - AB_2 \cos 30° = 0$

$\sum F_y = 0$

$\Rightarrow N_2 - 80 - AB_2 \sin 30° = 0$

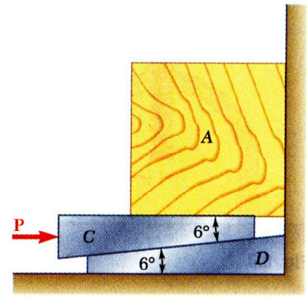
$\Rightarrow$ $N_2 = 90.44$ lb

and $AB_2 = 20.89$ lb

$\Rightarrow$ $\boxed{P = F_2 = 18.09 \text{ lb}}$

Monday, November 30, 2009
9:07 AM

8.5 - 8.6 Wedges and Threaded Screws



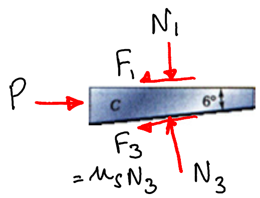
Wedges are used to make small adjustments in height for heavy objects.

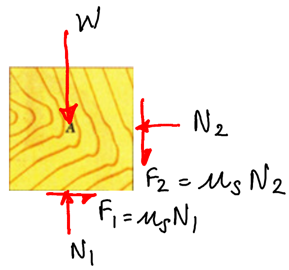
The force required to lift the object is usually much smaller than its weight.
The force required to lower the object is even smaller.

Wedges are usually *self-locking* i.e. upon the removal of the force **P**, the wedge stays in place.

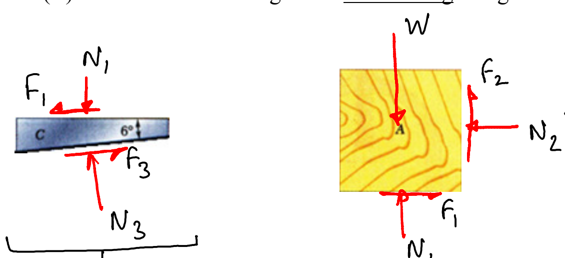
Consider the FBD of the block and the wedge for different cases:

Case (I) Raising the block:





Case (II) Block under self weight and <u>self-locking</u> wedge:



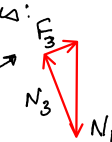
<u>Note</u>:

Usually $N_2 = 0 \Rightarrow F_2 = 0$

$\Rightarrow N_1 = W$ and $F_1 = 0$

i.e. No friction is required to keep the block A on C.

Thus:

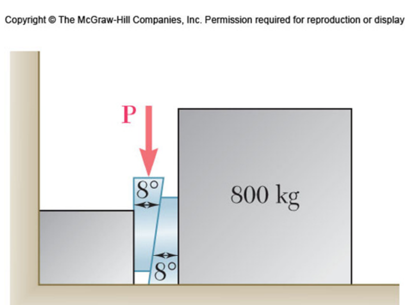


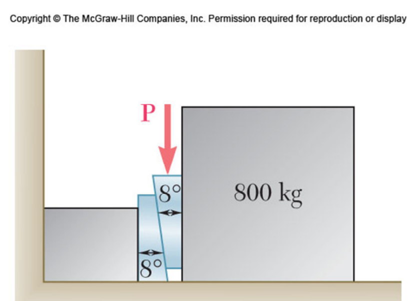
$F_3 < \mu_s N_3$

Read Example 8.4

<u>Exercise 8.48 & 8.49</u>

Determine **P.**
$\mu s = 0.3$





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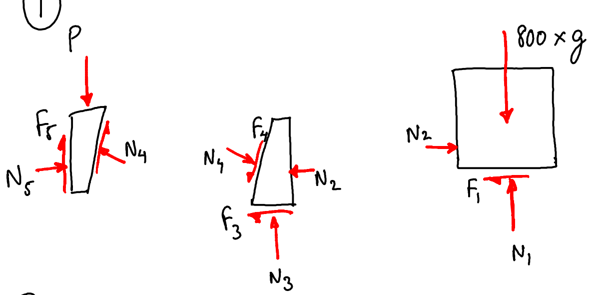
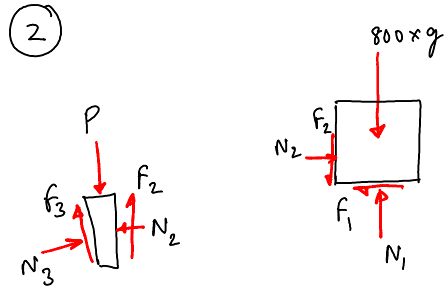


⑥ Unknowns: $N_1 \quad N_2 \quad N_3 \quad N_4 \quad N_5 \quad P$
($F_1 \; F_2 \; F_3 \; F_4 \; F_5$ are in terms of Ns)

② + ② + ② = ⑥ equations

2



④ Unknowns: $N_1 \quad N_2 \quad N_3 \quad P$

② + ② = ④ equations

Wednesday, December 02, 2009
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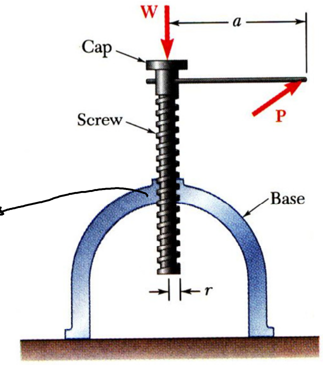
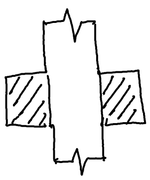
Square Threaded Screws



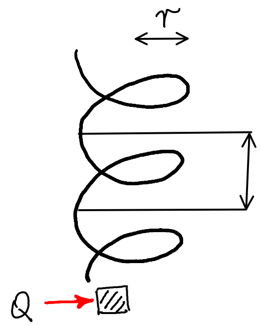
Square-threaded screws frequently used in jacks, presses, etc.
Analysis similar to block on inclined plane.
Recall friction force does not depend on area of contact.

Imagine the socket in the" base" of the figure as a spiral ramp.
Think of one revolution of the thread block in the spiral:

Thread Block in screw.



Base socket



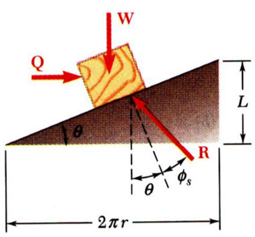
Moment of force P is equal to moment of force Q about the shaft of the screw:

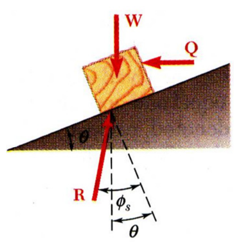
$$\sum M_{shaft} = 0$$

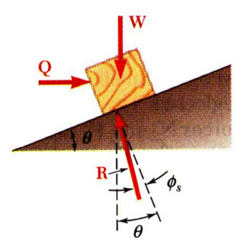
$$\Rightarrow Qr = Pa$$

$$\Rightarrow Q = Pa/r$$

Pushing the block up the ramp.
"Unwrap" the spiral ramp:







- Impending motion upwards. Solve for Q.
- $\phi_s > \theta$, Self-locking, solve for Q to lower load.
- $\phi_s > \theta$, Non-locking, solve for Q to hold load.

Moment of force Q is equal to moment of force P.

$$Qr = Pa$$

Thus solve for Q and calculate the sequined P by:

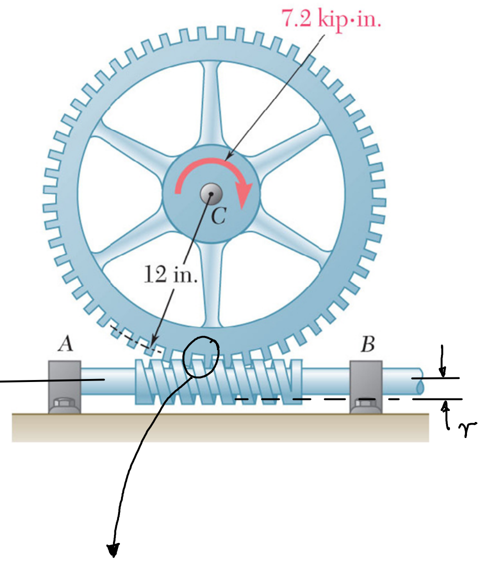
$$\Rightarrow P = \frac{Qr}{a}$$

Saturday, December 05, 2009
3:56 PM

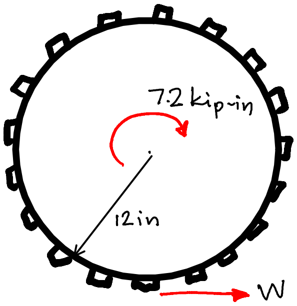
Read example 8.5.

<u>Exercise 8.67</u>

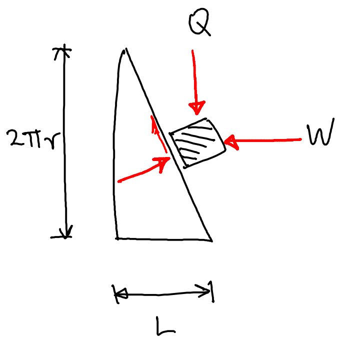
Worm gear AB has mean radius 1.5 in. and a lead of 0.375in.
$\mu s = 0.12$
Determine the couple-moment that must be applied to the shaft AB to rotate the big gear counter clockwise.



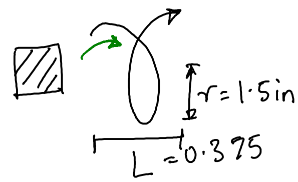
$M = Q r = ?$



$W = \frac{7.2}{12} = \underline{0.6 \text{ kips}}$

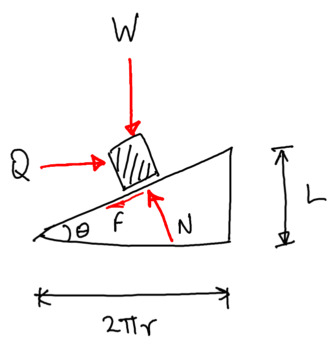


Unwrap



$\tan\theta = \left(\frac{0.375}{1.5}\right)$

rotate by 90°



$$\left.\begin{aligned} \sum f_x &= Q - F\cos\theta - N\sin\theta = 0 \\ \sum f_y &= -W - F\sin\theta + N\cos\theta = 0 \end{aligned}\right\}$$

Unknowns: $\underline{N, Q}$

$\Rightarrow$ Couple moment required $= M = Q r$