FINISH CH 4:

**Friction** $f$ ($F = ma$)

**Statics Problems** (Hanging Bird Feeders!)

**Newton's 3rd Law**
Friction

Give a block on table a push

Starts with $u \rightarrow$ then slows down and stops

i.e. it has an acc $(\cdot)$

$\therefore F = ma$

FBD:

Gravity is perp to $u \left[a\right]$ so something is missing!
Friction!

\[ \alpha \text{ is } \leftarrow \]

so Friction is \leftarrow

**FBD:**

\[
\begin{align*}
\vec{f} & \quad \leftarrow \\
\vec{n} & \quad \rightarrow \\
mg & \quad \downarrow
\end{align*}
\]

Frictional force \( f \) (N)

Lower case \( \alpha \)

Units
so object with $\text{U} \rightarrow \text{Right}$ friction is $\leftarrow \text{f} \leftarrow \text{Left}$

so if I slide object to left, will $f$ cause acceleration ??

of course not!!

object slows down and stops!

so: $\text{U} \leftarrow \square \rightarrow \text{f} \leftarrow [\text{a} \rightarrow \text{J}]$
Friction opposes motion

$f \leftarrow \frac{F}{\mu} \rightarrow v$

$\frac{v}{\mu} \rightarrow f$

Not like forces we've seen before.

Due to forces (atomic) between block and table (roughness)

(OK! - a bit oversimplified)
Experimentally:

Two types of friction:

- Static $f_s$
- Kinetic $f_k$

Stationary objects! Moving objects!

Both $f_s$, $f_k < n$

The force between surfaces perp to surface:
MAGNITUDE OF $f$
GIVEN BY
COEFFICIENT OF FRICION:

$\mu_s$ \quad STATIC
$\mu_k$ \quad KINETIC

EXPERIMENTALLY:

$\begin{align*}
  f_s & \leq \mu_s n \\
  f_k & = \mu_k n
\end{align*}$

WHILE STATIONARY ONCE IT'S MOVING

WHY DOES $f_s$ HAVE A LESS-OR-EQUAL SIGN?
Because nature is really clever:
It "adjusts" $f_s$

1) Object with **No Horizontal Force**

$$f_s = 0$$
$$F_{NET} = 0$$

2) Object with **Small** Horizontal Force $F < \mu_s n$

$$f_s = F$$
$$F_{NET} = 0 \ (\alpha = 0)$$

3) Object with **Large** Horizontal Force $F > \mu_s n$

$F > f_s$

$F_{NET} = F - f_s$
$$\alpha \neq 0$$

Starts to move!
When an object starts to move, $f_k$ takes over.

$$f_k = \mu_k n$$

[Experimental approximation]

So students can solve problems!

**Note:** Coeff. of friction we can have $\mu_k = \mu_s$

and $\mu_k < \mu_s$

but not $\mu_k > \mu_s$!

Because if $f_k > f_s$, it couldn't start moving for $F = \mu_s n$.

[Think about it]
SO THE SIMPLEST EXAMPLE:

START SOMETHING MOVING WITH

\[ F = \mu S \cdot n \]

THEN USE \[ F' = \mu K \cdot n \]

\[ f_k = \mu A \cdot n \Rightarrow F' \Rightarrow 0 \]

SO \[ F_{net} = F' - f_k = 0 \]

SO \[ u = \text{CONST}! \]
So in general:

\[ \mathbf{F}_{\text{Net}} = \mathbf{F}_{\text{Applied}} - \mathbf{f}_K, s \]

So if \( \mathbf{F}_{\text{App}} > \mathbf{f}_K \)

DO FBD, FORCES

**VERTICAL:** \( n = mg \).

**HOR:** \( \mathbf{F}_{\text{Net}} = \mathbf{F}_{\text{App}} - \mathbf{f}_K \)

But \( \mathbf{f}_K = \mu_K n = \mu_K mg \)

WE KEEP DOING THIS SORT OF THING!

So \( \mathbf{F}_{\text{Net}} = \mathbf{F}_{\text{App}} - \mathbf{f}_K = \mathbf{F}_{\text{App}} - \mu_K mg = ma \)
Let's revisit object sliding down slope without and with friction.

**Without Friction:**

\[ F_{\text{down slope}} = mg \cos \theta \]

\[ F = ma \]

\[ mg \sin \theta = ma \]

\[ a = g \sin \theta \]
Object sliding down slope with friction:

FBD:

F down slope: \( F = mg \sin \theta - f_k \)

\( f_k = \mu_k n \) where: \( n = mg \cos \theta \)

\( f_k = \mu_k mg \cos \theta \)

so: \( F = mg \sin \theta - \mu_k mg \cos \theta = ma \)

so: \( a = g (\sin \theta - \mu_k \cos \theta) \) (Check it out)
Slope:

What if there is too much friction?

→ Object doesn't move

FBD:

\[ f_s \quad n \]

\[ mg \cos \theta \quad mg \sin \theta \]

\[ a = 0 \quad a = 0 \]

So:

\[ mg \sin \theta - f_s = 0 \]

\[ f_s \leq \mu_s n \quad \text{i.e.} \quad f_s \leq \mu_s mg \cos \theta \]

Increase \( \theta \) from \( 0^\circ \)
AT SOME ANGLE THE BLOCK BEGINS TO SLIDE.

IE MAX FRICTION \( f_s = \mu_s n \)

IS NOT ENOUGH. \( = \mu_s mg \cos \theta \)

CRITICAL \( \Theta \): WHEN

\[ \mu_s mg \cos \theta = mg \sin \theta \]

OR:

\[ \mu_s \cos \theta = \sin \theta \]

IE: \( \tan \Theta = \mu_s \)

WE CAN FIND \( \mu_s \) BY EXPERIMENT!
COEFFICIENTS OF FRICTION

STEEL ON STEEL \( \mu_s = 0.74 \), \( \mu_k = 0.57 \)

TEFLON ON TEFLOM \( \mu_s = 0.04 \), \( \mu_k = 0.04 \)

The same!

SEE BOOK FOR MORE

NOTE

When \( \theta \) begins to slide at some \( \Theta \),

\[ \mu_s = \tan \Theta \]

\( \tan 45^\circ = 1 \)

So if \( \theta > 45^\circ \), \( \mu_s > 1 \)

\( \theta < 45^\circ \), \( \mu_s < 1 \)