Rules of thumb for static friction:

1) It takes on any value between zero and the maximum possible force of static friction, \( f_{s,max} = \mu_s N \)
2) It is independent of the area of contact between the surfaces
3) It is parallel to the surface of contact, and in the direction that opposes relative motion
4) Only applies when the surfaces in contact are at rest relative to each other.

Which graph corresponds to the static friction as a function of the force applied, \( F_x \)? (\( F_{min} = \) the min. force necessary for movement)

Rules of Thumb for Kinetic Friction:

1) Proportional to the magnitude of the normal force, \( N \), between the surfaces, \( f_k = \mu_k N \)
2) Independent of the relative speed of the surfaces
3) Independent of the area of contact between the surfaces
4) Always opposes the direction of motion.
5) Only applies if the surfaces in contact are moving relative to each other.

Which graph on the right represents the force of kinetic friction as a function of the force applied, \( F_x \)?

Example: A flat bed truck slowly tilts its bed upward to dispose of a 95.0kg crate. For small angles of tilt the crate stays put, but when the tilt angle exceeds 23.2°, the crate begins to slide. What is the coefficient of static friction between the bed of the truck and the crate?

Answer: \( \mu_s = \tan(23.2°) \approx 0.43 \)
1) A 60 kg crate is pulled across a level floor via a horizontal rope. The coefficient of kinetic friction between the crate and the floor is 0.4, and the coefficient for static friction is 0.5. Find the acceleration of the crate if the rope has tension
   a) 250 N
   b) 500 N

   \[
   N = mg = 588 \text{ N} \rightarrow \text{max static friction} = (0.5)(588 \text{ N}) = 294 \text{ N}
   \]
   This is more than the pull of the rope, so static friction is strong enough to hold the crate in place.
   So the answer for part a) is zero acceleration

   In part b) the pull is more than static friction can hold, so the crate will move forward and the kinetic friction force is equal to
   \[
   F_{\text{friction}} = (0.4)(588 \text{ N}) = 235 \text{ N}
   \]
   Using \( F = ma \) we get 
   \[
   a = \frac{(500 \text{ N} - 235 \text{ N})}{60 \text{ kg}} = 4.4 \text{ m/s}^2
   \]

2) Answer problem 1) again, now with the rope inclined at an angle of 20°. Don’t forget to draw a free-body diagram for the forces on the crate.

   this time we need to break the rope force into components before we can do anything else: \( F_{\text{rope},x} = F_{\text{rope}} \cos(20°) \) ; \( F_{\text{rope},y} = F_{\text{rope}} \sin(20°) \)
   in part a) we have \( F_{\text{rope}} = 250 \text{ N} \), so \( F_{\text{rope},x} = 235 \text{ N} \) and \( F_{\text{rope},y} = 85.5 \text{ N} \)

   Our normal force is now less than the previous problem (because the rope is lifting up a bit on the crate). We find it from \( F = ma \):
   \[
   N = mg - F_{\text{rope},y} = 588 \text{ N} - 85.5 \text{ N} = 502 \text{ N} \rightarrow \text{max static friction} = (0.5)(502 \text{ N}) = 251 \text{ N} \rightarrow \text{still too much for the rope pull to overcome} \rightarrow \text{so } a = 0 \text{ again}
   \]

   Part b) we have \( F_{\text{rope}} = 500 \text{ N} \), so \( F_{\text{rope},x} = 470 \text{ N} \) and \( F_{\text{rope},y} = 171 \text{ N} \)
   Now \( N = 417 \text{ N} \) and kinetic friction is \( (0.4)(417 \text{ N}) = 167 \text{ N} \)

   Using \( F = ma \) we find 
   \[
   a = \frac{(470 \text{ N} - 167 \text{ N})}{60 \text{ kg}} = 5 \text{ m/s}^2
   \]

3) A flat bed truck slowly tilts its bed upward to dispose of a 95.0kg crate. The bed is raised to an angle of 25° and the crate begins to slide. If the coefficient of kinetic friction between the bed of the truck and the crate is 0.3, what is the acceleration of the crate?

   Answer: \( a = 1.48 \text{ m/s}^2 \)