Chapter 6

Applications of Newton's Laws

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Learning Goals for Chapter 5

- Learn how to apply Newton's First Law & Second Law.
- Understand the cause of apparent weight and "weightlessness"
- Learn how to characterize friction and fluid resistance when applying net F = ma.
- ** Note: The value of the acceleration depends on the frame of reference. Newton's Laws are only valid when frame is an inertial reference frame. Technically a set of axes fixed to the Earth is not an inertial reference frame due to the rotation of the Earth, but the Earth's rotation is very slow that we treat it as an inertial reference frame for **most** laboratory situations.

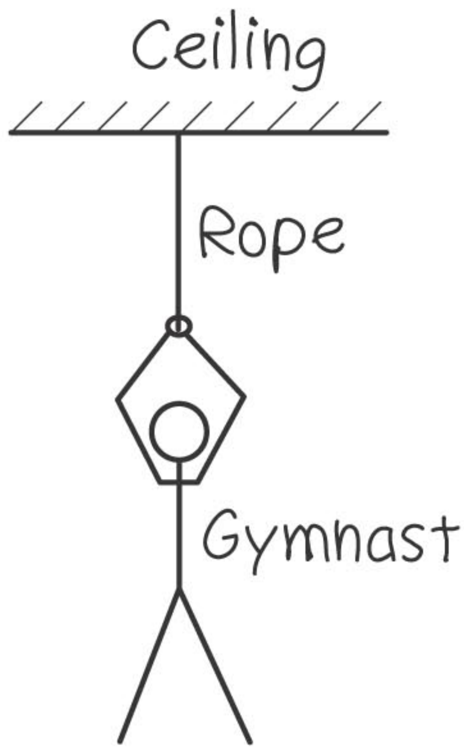
Newton's First Law

- Newton's First Law: $net\ \vec{F} = 0 \Leftrightarrow \vec{a} = 0$
- Acceleration =0 => velocity = constant (could be zero).
  - A commonly situation is velocity = 0 (or called static equilibrium)

1-D static equilibrium—Figure 5.1

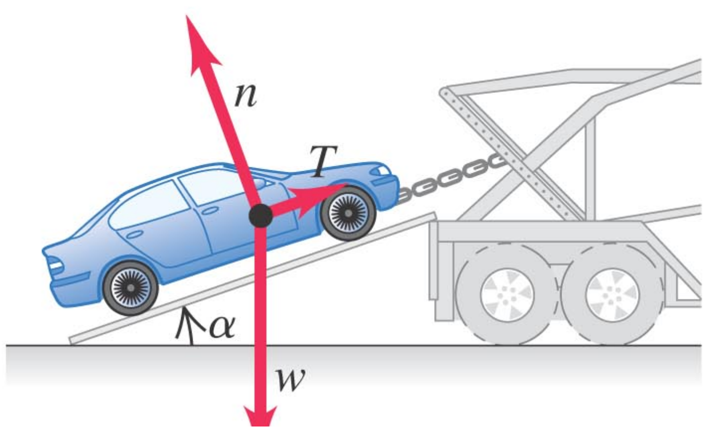
- Consider an athlete (m_G=50 kg) hanging on a massless rope.
- Find the tension of the rope (Let g =10 m/s^2)

(a) The situation



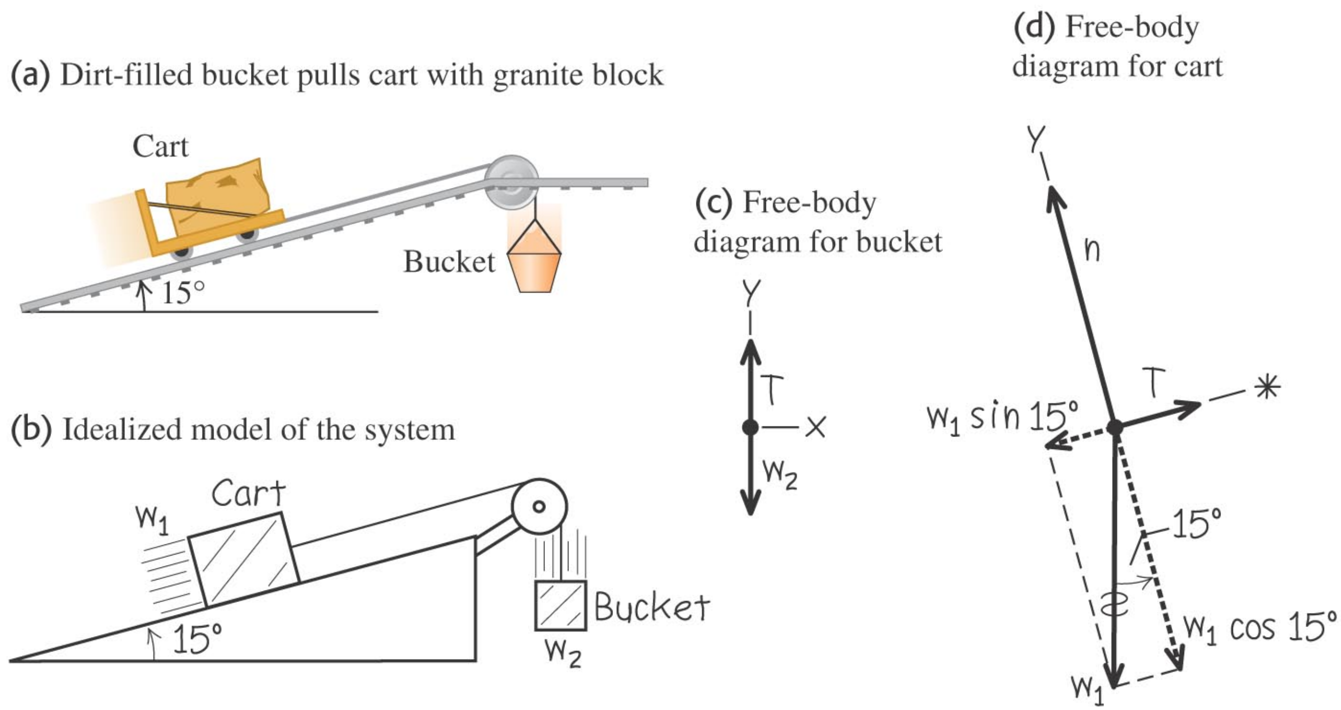
2-D Static Equilibrium - Figure 5.4

- An object on an inclined plane will have components of force in *x* and *y* directions. You can orientate the axes any way you like but aligning one of axes along the incline is convenient.
- Assume the incline surface is frictionless, find the tension in terms of the weight and the angle such that the car is not moving.



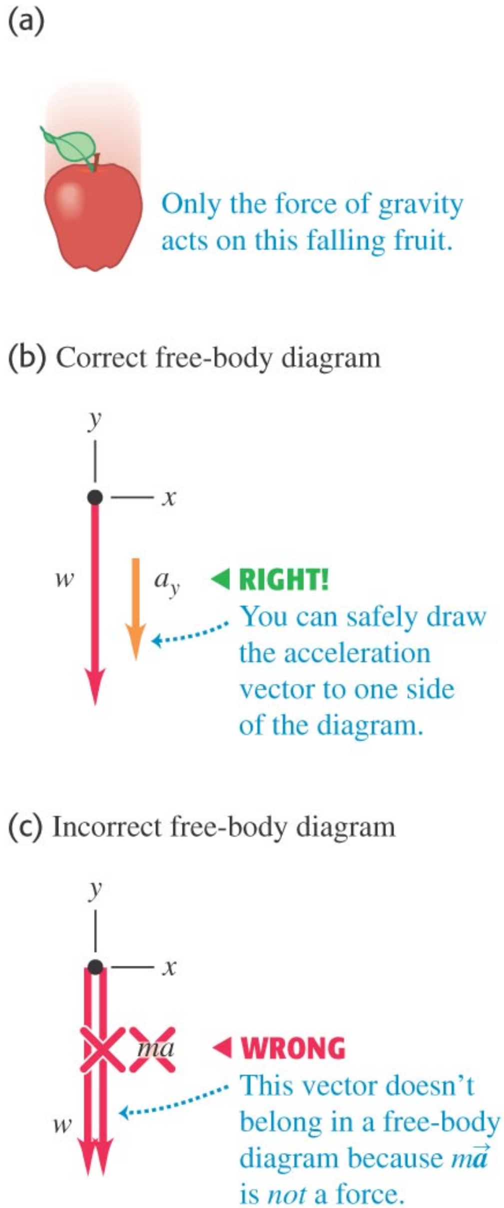
Static equilibrium - Effect of a "frictionless" pulley

- In **static** situation, the effect of a frictionless pulley is to **re-direct** the tension along the rope. (However, in dynamics, the tension of the rope on either sides of the pulley will be different unless the pulley is also massless. Rotational dynamics will discussed in Ch. 9 & 10).
- Example below: Let the cart be 1000 pounds, what is the weight of the bucket needed to balance the cart?



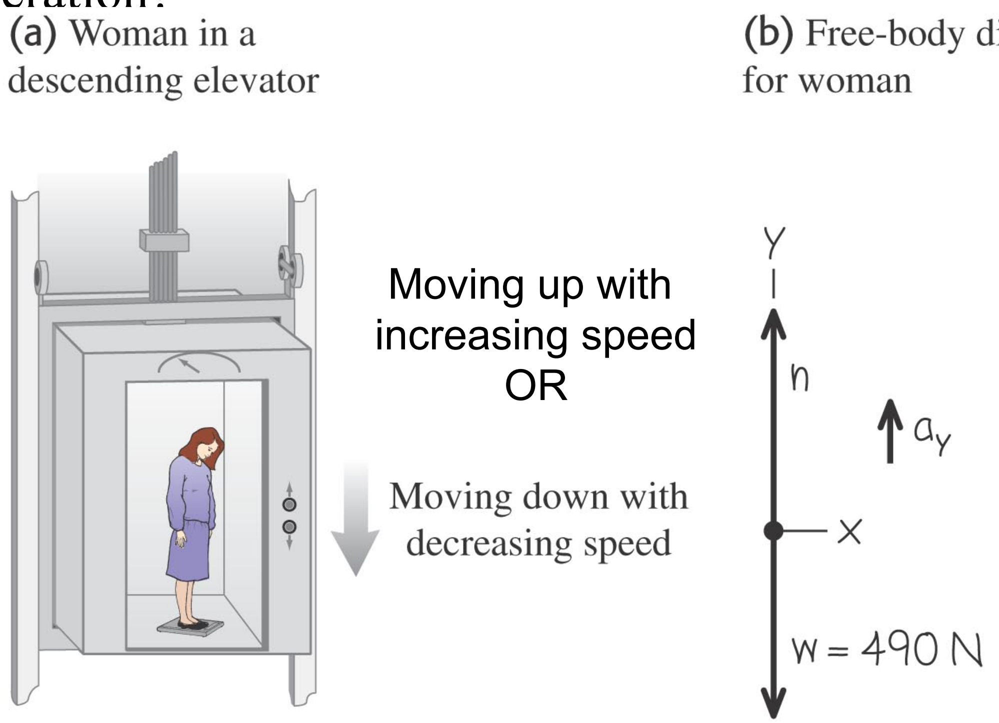
Beware of incorrect free-body diagram

- "ma" is not a force due to interaction. "ma" is a consequence of a force acting on the object.
- For example, when the apple is under free-free, only gravity acts on the apple.



Newton's Second Law and "Apparent Weight"

- Suppose the elevator has a upward acceleration (this can happens when the elevator is moving upward with increasing speed OR moving downward with decreasing speed)
- Suppose the person is stepping on a scale, the "normal force" exerted by the scale on the person > weight of the person; the magnitude of the normal force is the "apparent weight". What happens if the elevator has a DOWNWARD acceleration?



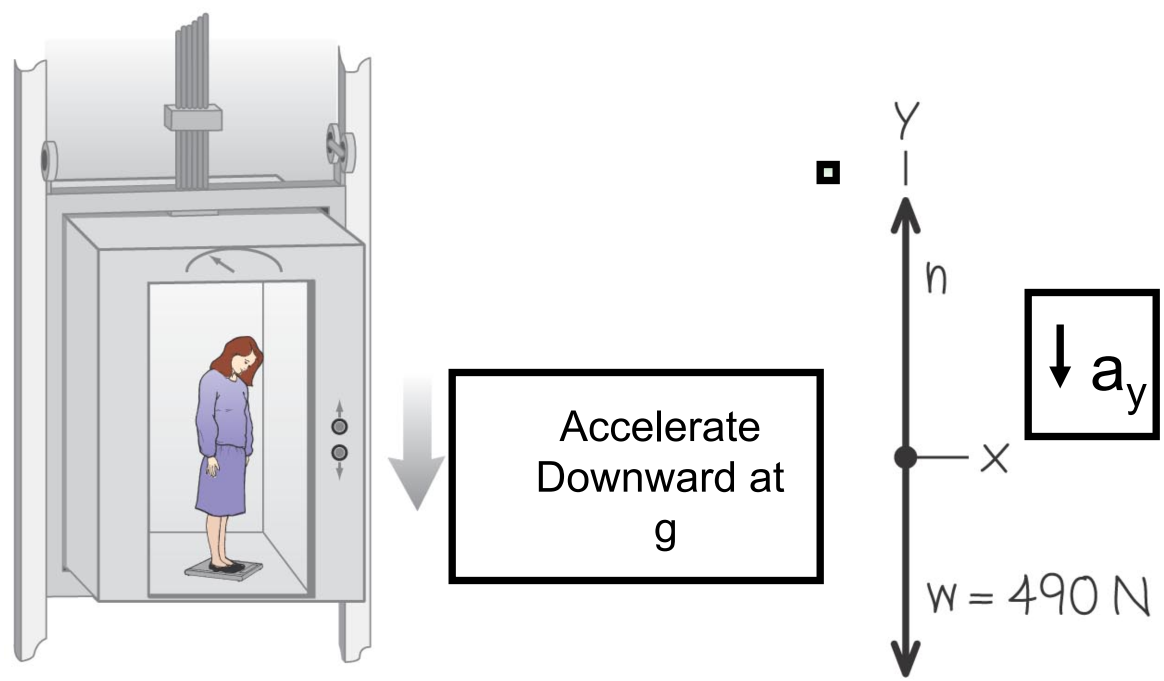
$$n - w = ma_y$$

Apparent "weightlessness"

- Suppose the elevator's cable broke and the elevator and everything in it are undergoing free-fall, i.e. $a_y=-g=-9.8 m/s^2$?

(a) Woman in a descending elevator

(b) Free-body diagram for woman



$$n - w = ma_y = -mg$$

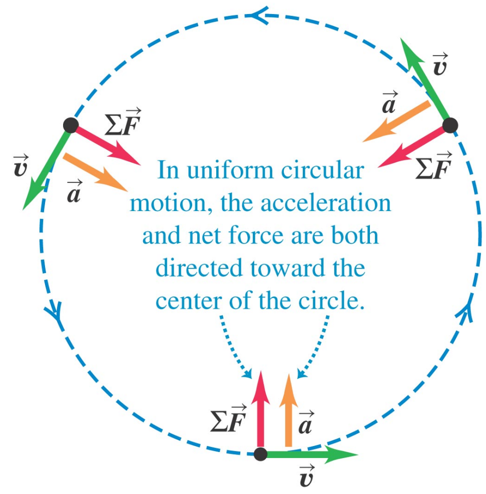
$$\Rightarrow n = w - mg = 0$$

Newton's second Law and uniform circular motion

- In uniform circular motion, both the acceleration and net force point to the center.

$$|a_c| = \frac{|v|^2}{r}$$

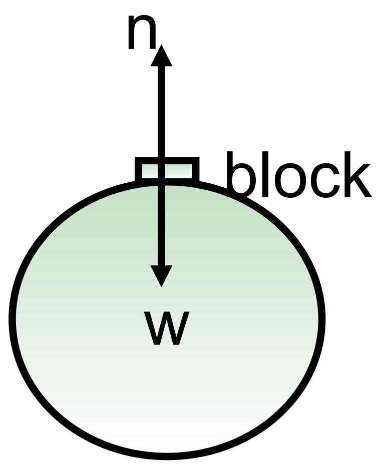
$$net\ \vec{F} = m\vec{a}_c$$

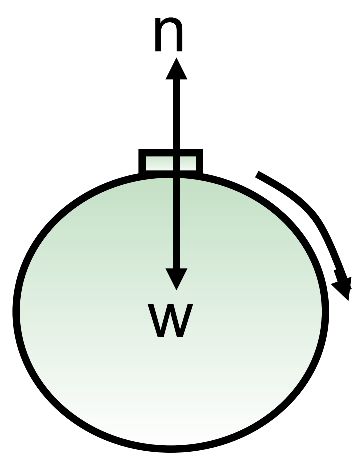


Identify the circular path, the radius, the speed and the net force.

Example: A swinging pendulum consisting of a string (length =0.5m) and a mass (m=1kg) has a speed of 10 m/s when the mass reaches the bottom. Find the tension of the string.

Rotation of the Earth and apparent weight





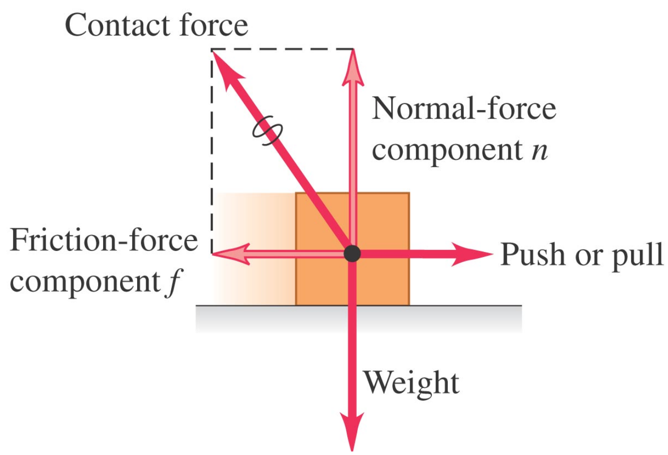
With respect to the Earth,
the block is not accelerating.
If the Earth were not rotating,
then it would have been an inertial
reference frame and we can
apply Newton's 1st Law:
$\mathrm{Net}\vec{F}=0 \Rightarrow n=w$

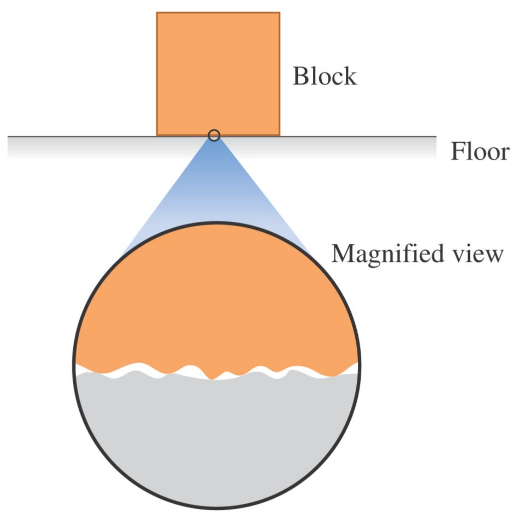
The Earth is rotating, we cannot use it
as an inertial reference frame. However,
a space ship in outer space with its engine off
is an inertial reference frame.
The astronaut sees that the block is rotating,
hence there is a a centripetal accelerating pointing
"downward" to the center.
Applying Newton's 2nd Law to find n
in terms of w, the radius of the Earth,
and the rotatoion speed of the Earth.

Frictional forces, static and kinetic —Figures 5.17 and 5.18

- Frictional force arise from microscopic imperfections of the two surfaces.
- The amount of frictional force is difference depending on whether the object is moving or not.
- Object not moving (static friction)
- Object is moving (kinetic friction)

The friction and normal forces are really components of a single contact force.

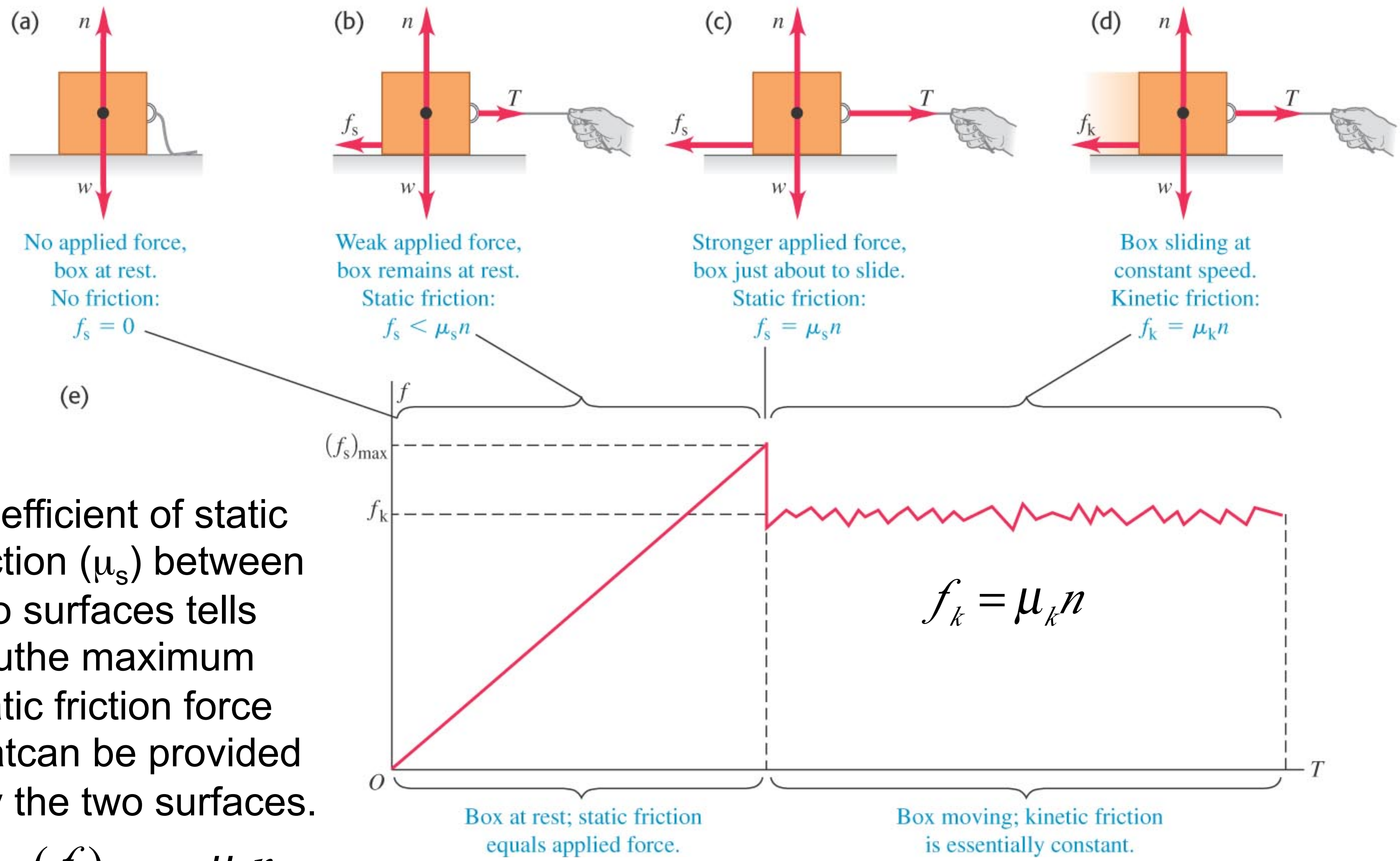




On a microscopic level, even smooth surfaces are rough; they tend to catch and cling.

Empirical facts about friction

- Notice the transition between static and kinetic friction.



Coefficient of static friction (μ_s) between two surfaces tells youthe maximum static friction force thatcan be provided by the two surfaces.

$$(f_s)_{max} = \mu_s n$$

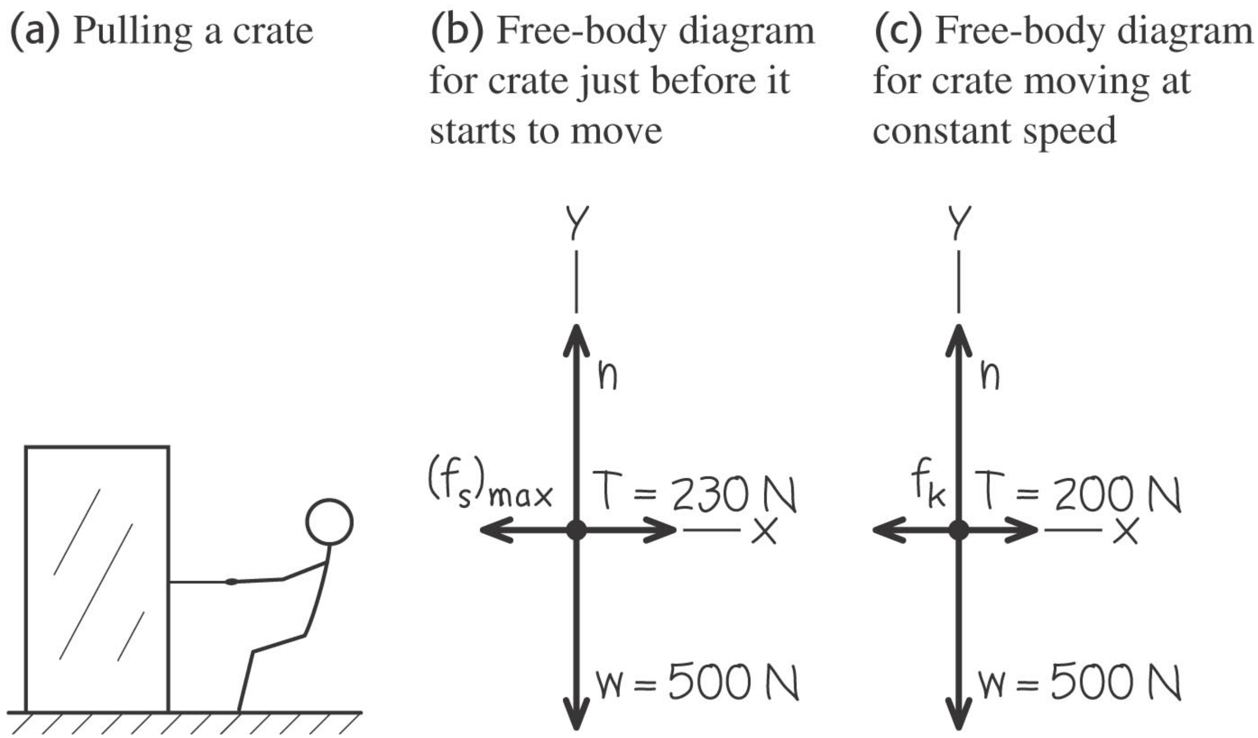
Coefficients of friction

Table 5.1 Approximate Coefficients of Friction

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

Example problem with friction

- To get the crate (W=500N) to start to move requires T=230N. To keep it moving at constant velocity requires T=200N. Find the static and kinetic coefficients of friction.

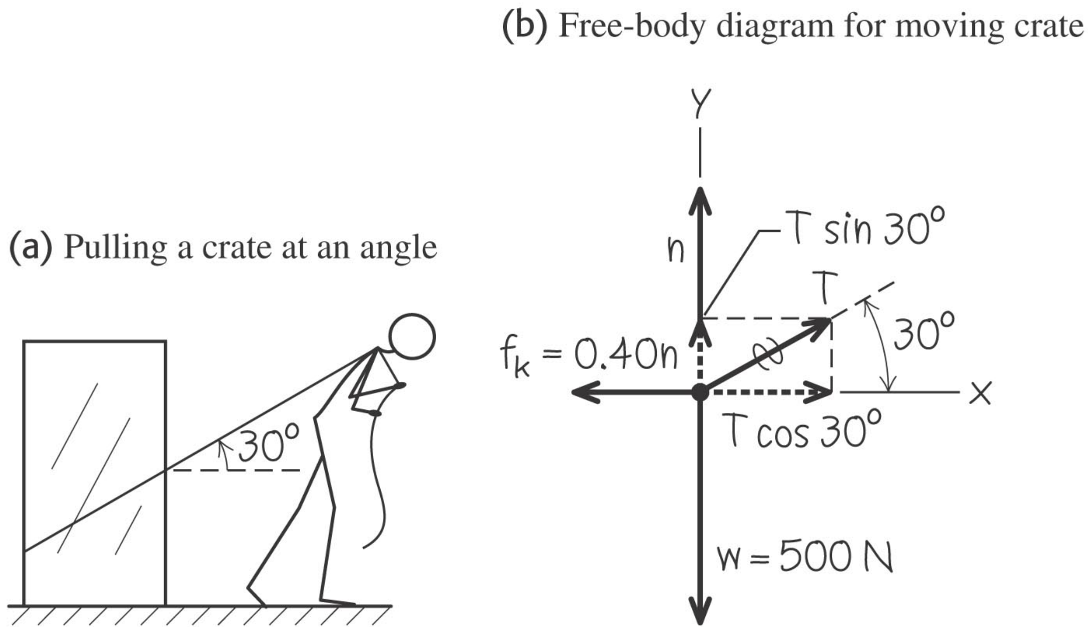


The angle at which tension is applied matters

- As one varies the angle at which tension is applied, the force spent to overcome friction changes because the normal force changes, see example below.

Gvien : w of crate $= 500\text{N}$, $\mu_k = 0.4$, tension applied at 30°

Find the tension required to keep the crate moving a constant acceleration of 2 m/s^2?



Static friction keeps a car from skidding when going around a curve.

A car is going around a circular curve with radius equals 100 meters.

The car is going at a constant speed of 20 m/s (~45 mph).

Find the minimum coefficient of static to keep the car from skidding.

(assume g=10 m/s^2)

Answer:

$$a_c = \frac{v^2}{r} = \frac{(20)^2}{100} = 4m/s^2$$

This centripetal acceleration is provided by the static friction between the tires and the road.

$$\Rightarrow ma_c = f_s$$

The maximum static friction can be provided is $\mu_s n = \mu_s mg$

$$\Rightarrow ma_c = \mu_s mg$$

$$\Rightarrow a_c = \mu_s g \Rightarrow \mu_s = \frac{a_c}{g} = \frac{4}{10} = 0.4$$

Q. On a rainy day, the coefficient of static between the tires and the road is only 0.3. What is the maximum speed without skidding?

Air-resistance causes terminal speed

- The force exerting on an object due to air resistance can be modeled by

  $F_{air} = Dv^2$

  The coefficient D depends on the shape of the object and the air density.

  Newton's second Law;

  $$mg - Dv^2 = ma = m\frac{dv}{dt}$$

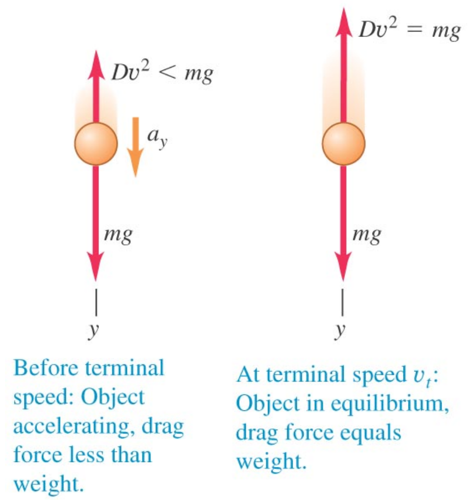
  This equation is not easy to solve to find v(t) because the net force is not constant.

  However, when the air resistance increases to the point to cancel mg, then v does not change anymore. This v is called the terminal velocity.

  It can obtained by setting $mg - Dv^2 = 0$

  $$\Rightarrow v_{\text{terminal}} = \sqrt{\frac{mg}{D}}$$

(a) Free-body diagrams for falling with air drag



(b) A skydiver falling at terminal speed