Lecture 5.1 – Introduction to Forces

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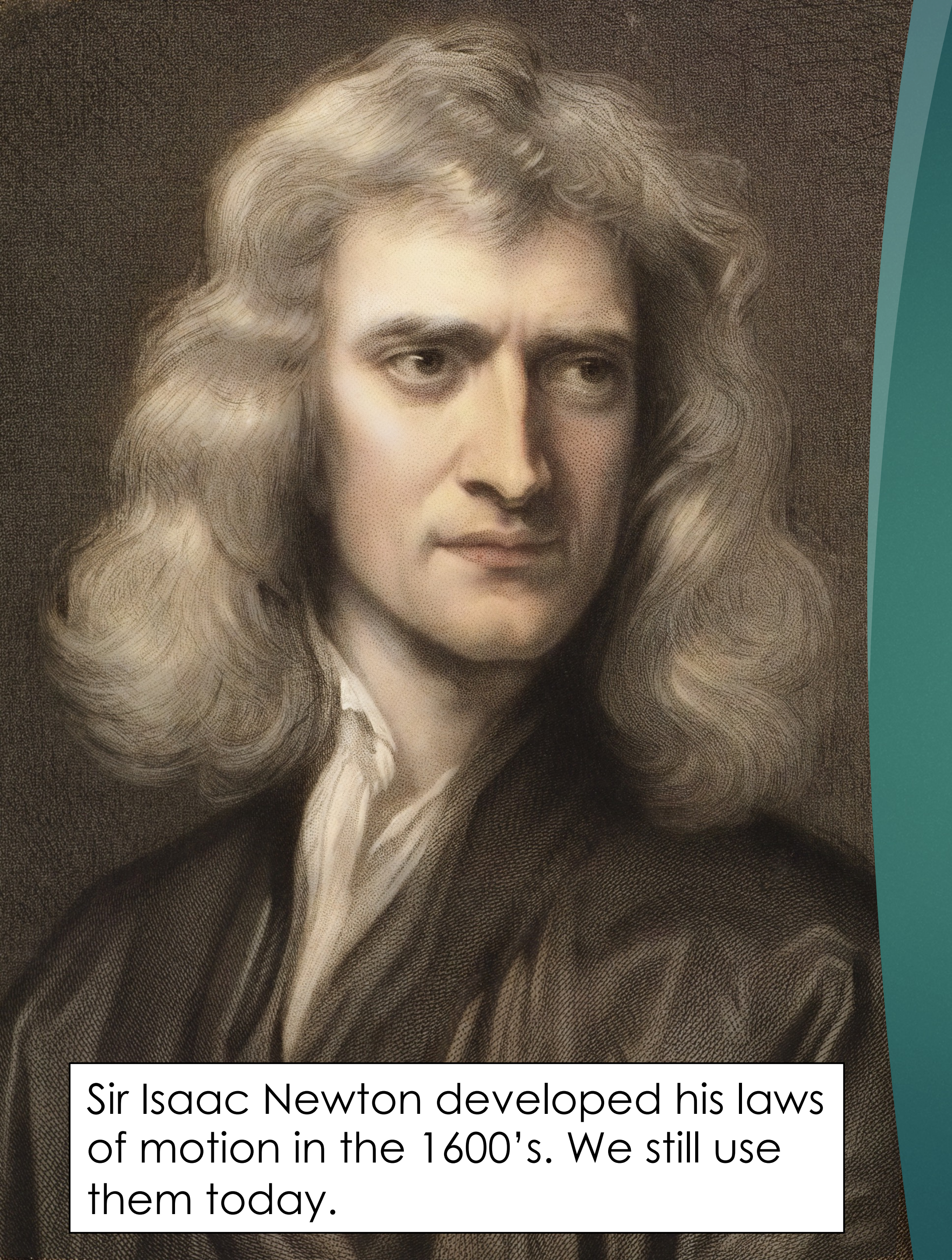
Forces and Motion

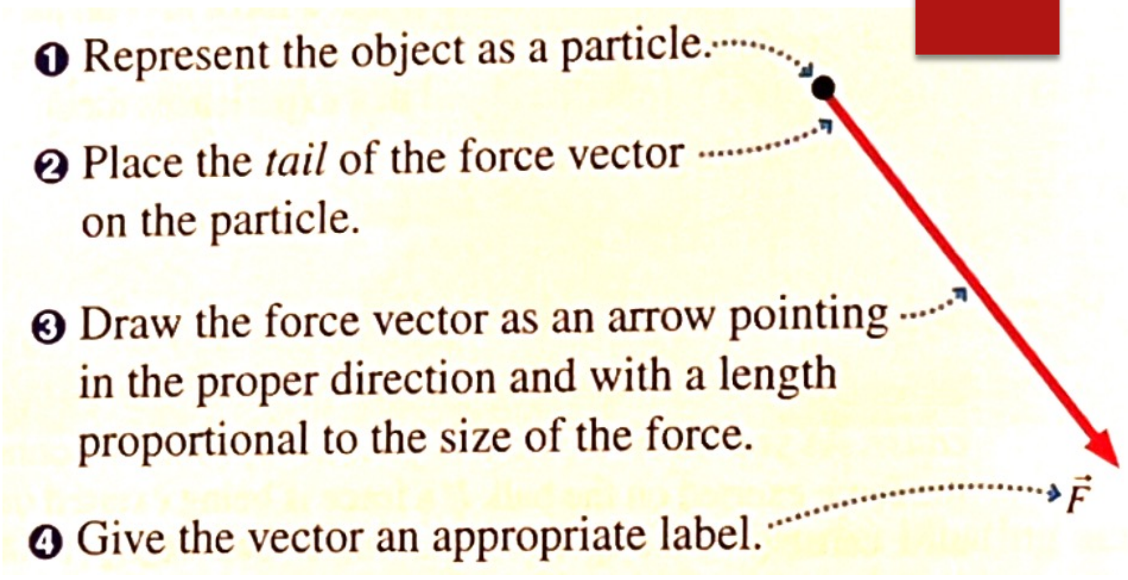
- Kinematics
  - *How* things move
- Dynamics
  - *Why* things move
- Kinematics + Dynamics = *Mechanics*
  - The science of motion

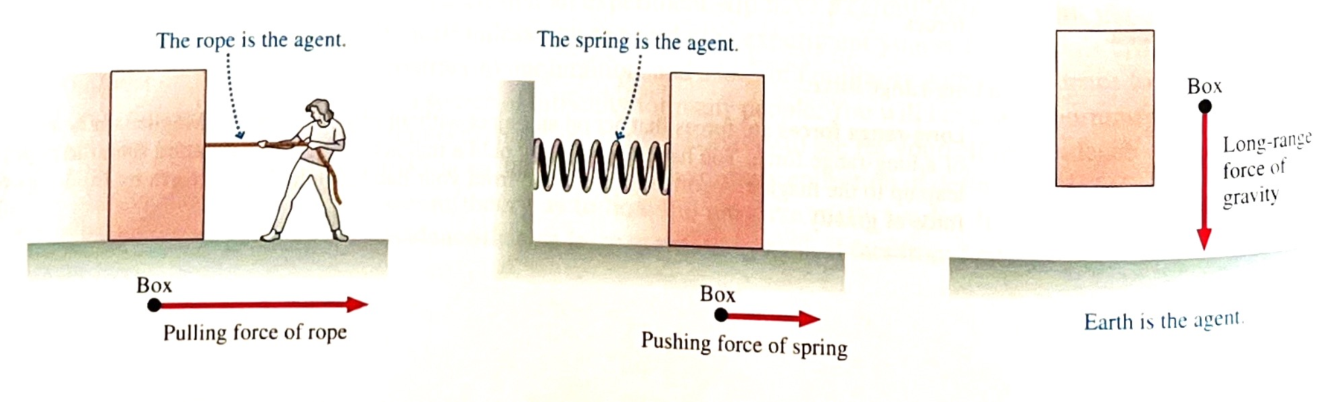


Sir Isaac Newton developed his laws of motion in the 1600's. We still use them today.

Description of a Force

- An *agent* acts on an *object*.
- A force is a vector
- A force can be a *contact* or *long-range* force.
- In general, forces are interactions between two objects (Newton's Third Law)





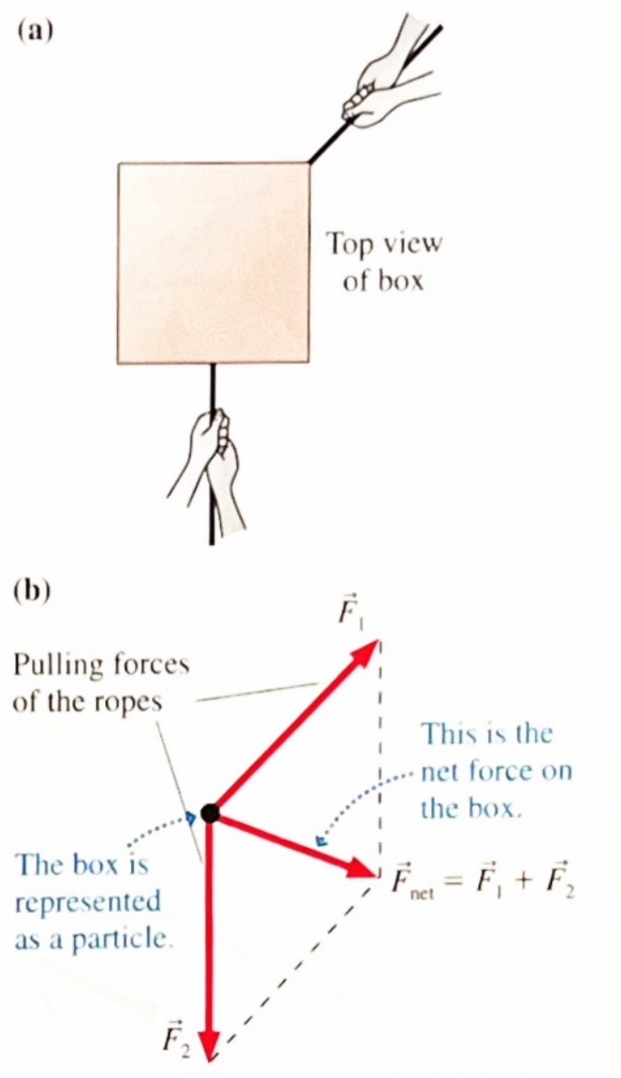
Summation of Forces

- When several forces are exerted on an object, they combine to form a *net force*.

$$\vec{F}_{net} = \sum_{i=1}^{N} \vec{F}_i = \vec{F}_1 + \vec{F}_2 + \cdots + \vec{F}_N$$

- The *net force* is also called the *resultant force*.
- This is a *superposition* of forces.

FIGURE 5.2 Two forces applied to a box.

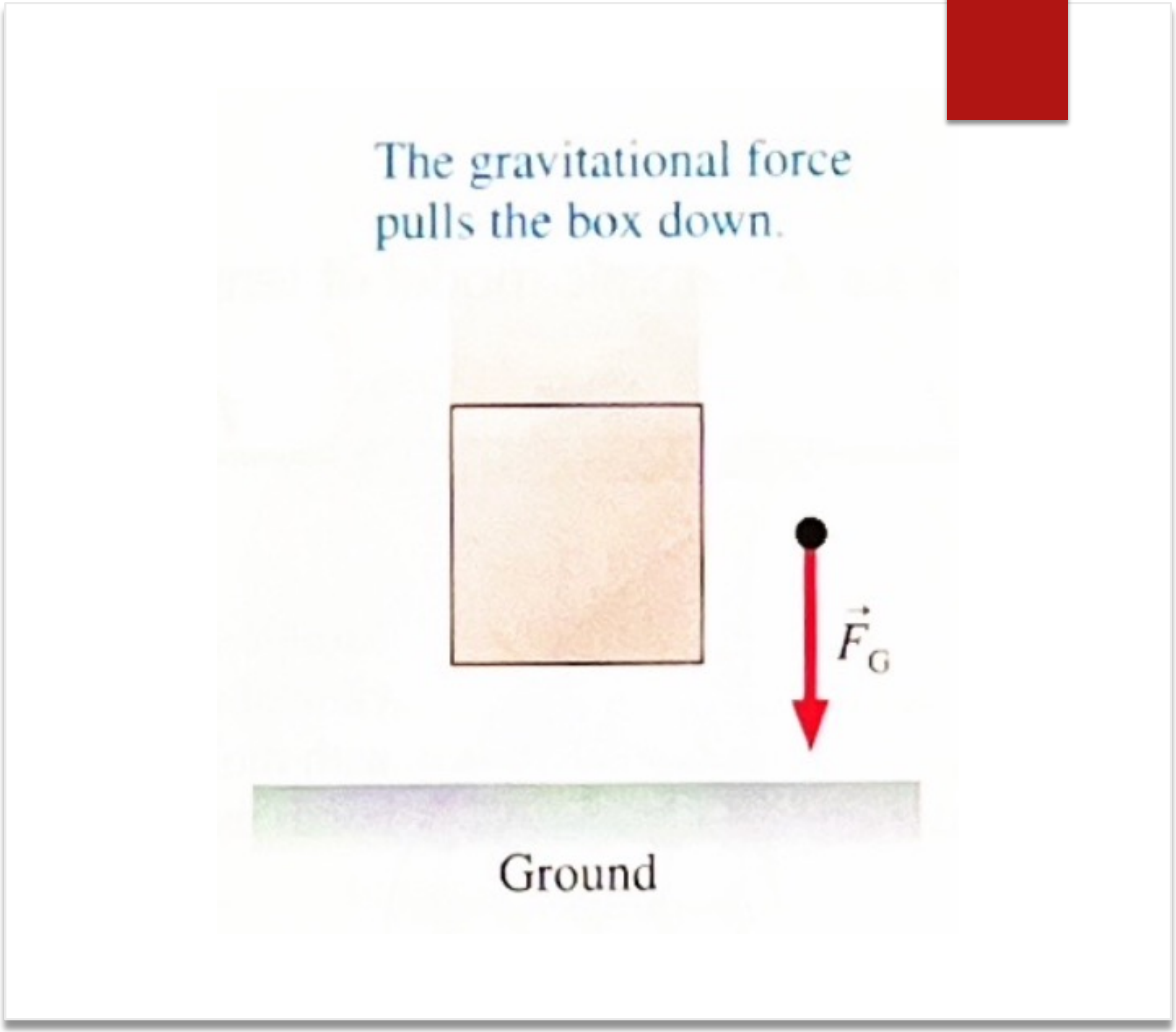


A List of Forces

- Gravity
- Spring Force
- Tension Force
- Normal Force
- Friction
- Drag
- Thrust
- Electric and Magnetic Forces

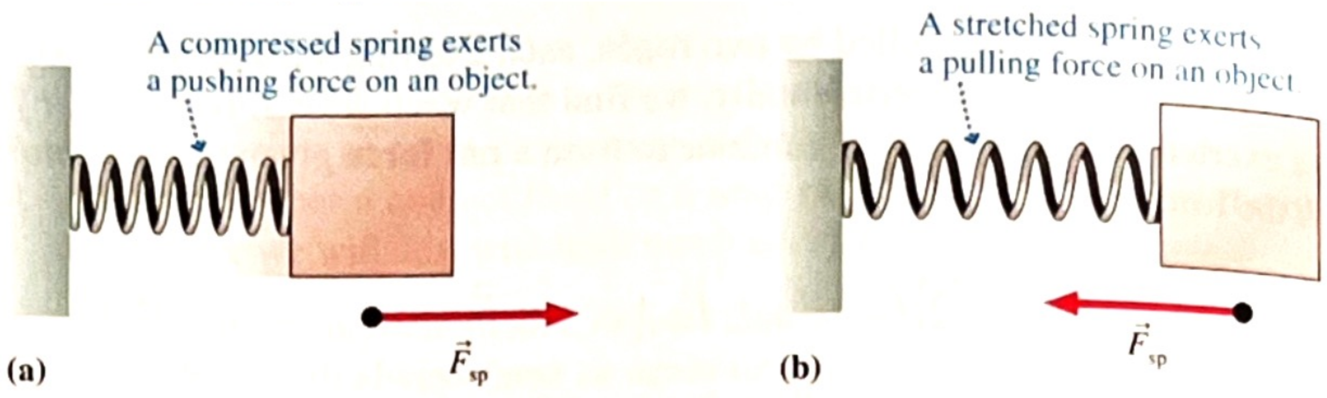
Gravity

- The gravitational pull of a planet on an object on or near the surface is called the <u>gravitational force</u>.
- The agent for the gravitational force is the entire planet pulling on the object.
- Gravity acts on *all* objects, whether moving or at rest.
- The symbol for the gravitational force is $\vec{F}_G$.
- Gravitational force vector always points vertically downward.



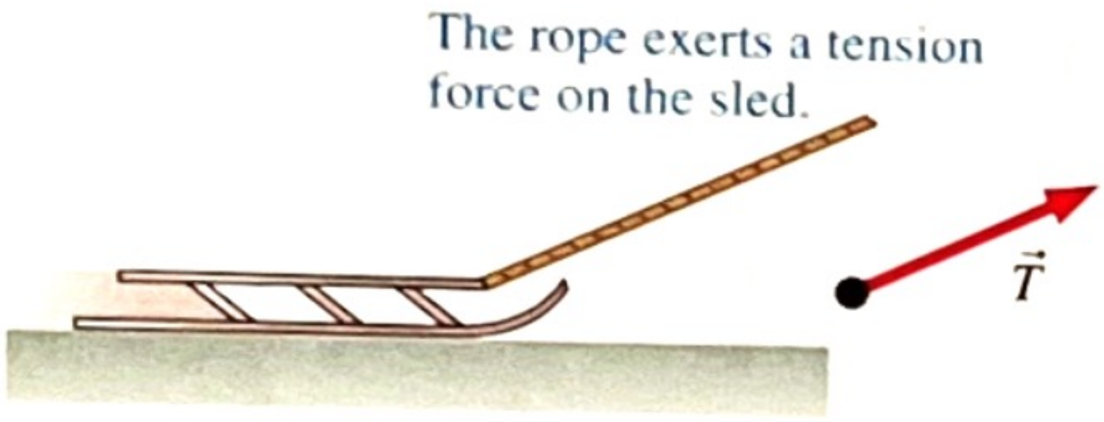
Spring Force

- A spring can either push or pull.
- The symbol used for the spring force is $\vec{F}_{\text{sp}}$.
- Whether pushing or pulling, the tail of the force vector is placed on the particle in the force diagram.



Tension

- A string/rope/wire pulling on an object creates a <u>tension force</u>.
- This force is represented by $\vec{T}$. (This is not the period, T)
- The direction of the tension force is always in the direction of the string or rope.
- On a molecular scale, the tension in a rope is supplied by all the molecules making up the rope. The bonds between these molecules act like springs!



The Normal Force

- An object sitting on a table is under the influence of gravity. However, the object is clearly not accelerating downward. Why not?
- The table MUST be applying an upwards force to “cancel out” gravity.
- This is the normal force (“normal” means perpendicular).
- The normal force is always perpendicular to the surface touched by an object.
- The normal force is supplied by the molecular “springs” (bonds) of the surface.
- The symbol for normal force is $\vec{n}$.

FIGURE 5.7 An atomic model of the force exerted by a table.

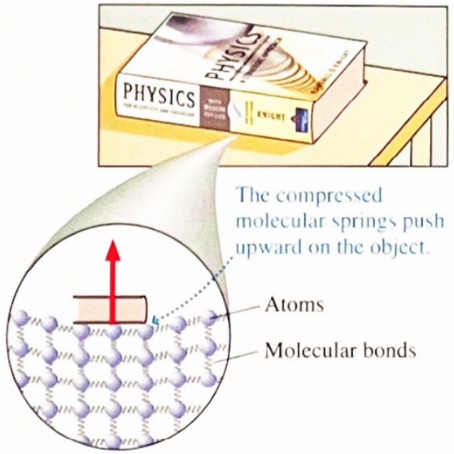


FIGURE 5.8 The wall pushes outward.

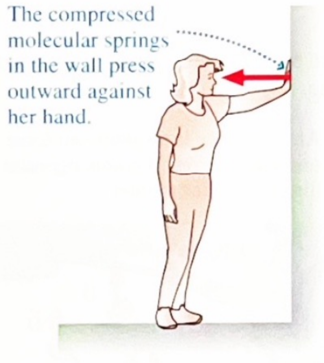
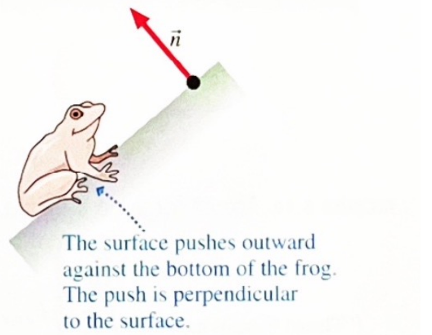


FIGURE 5.9 The normal force.



Friction

Friction is also exerted by a surface. However, it acts *tangent* to the surface.

Friction arises from atomic interactions between an object and the surface that it is traversing.

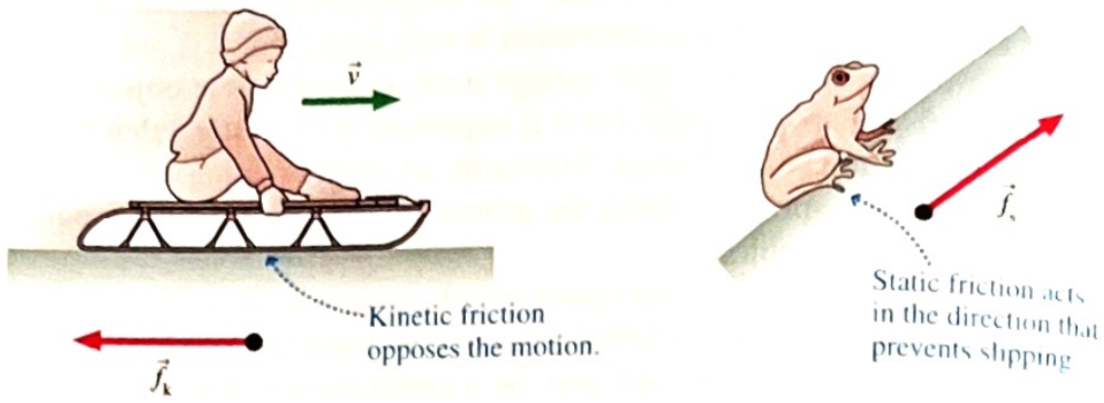
The rougher the surface, the more these atoms are forced into close proximity. Thus, the larger the frictional force.

There are two types of frictional forces:

> Kinetic friction ($\vec{f}_k$) acts when an object slides across a surface.
>
> Static friction ($\vec{f}_s$) keeps an object "stuck" on a surface and prevents motion.

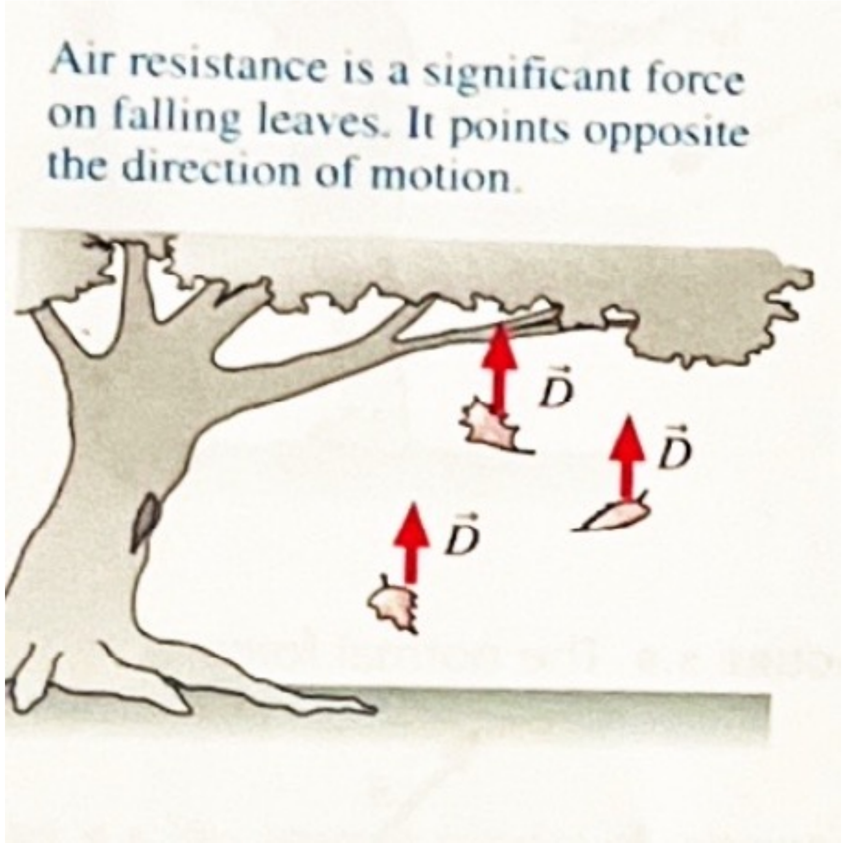
$\vec{f}_k$ points in the opposite direction of the motion while $\vec{f}_s$ points in the direction opposite of *potential* motion. ($\vec{f}_s$ is the force that "stops" the motion.)

FIGURE 5.10 Kinetic and static friction.



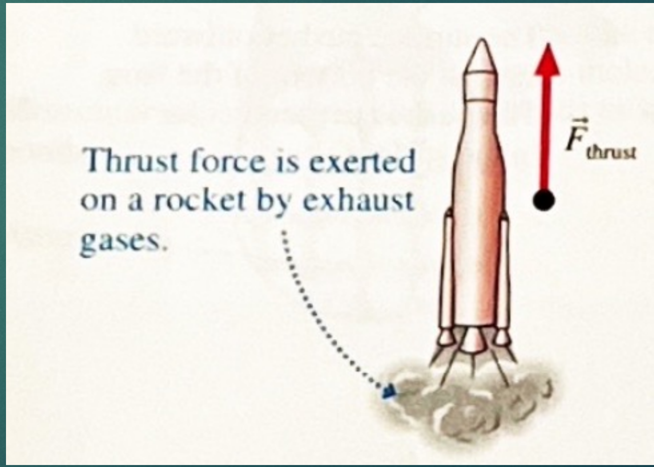
Drag

- The resistive force of a fluid is called drag.
- This could apply to an object in water OR the atmosphere.
- The drag force is denoted by $\vec{D}$.
- Like friction, drag points in the direction opposite of motion.
- For objects that are heavy, compact, and move relatively slowly, the drag force of air resistance is relatively small.



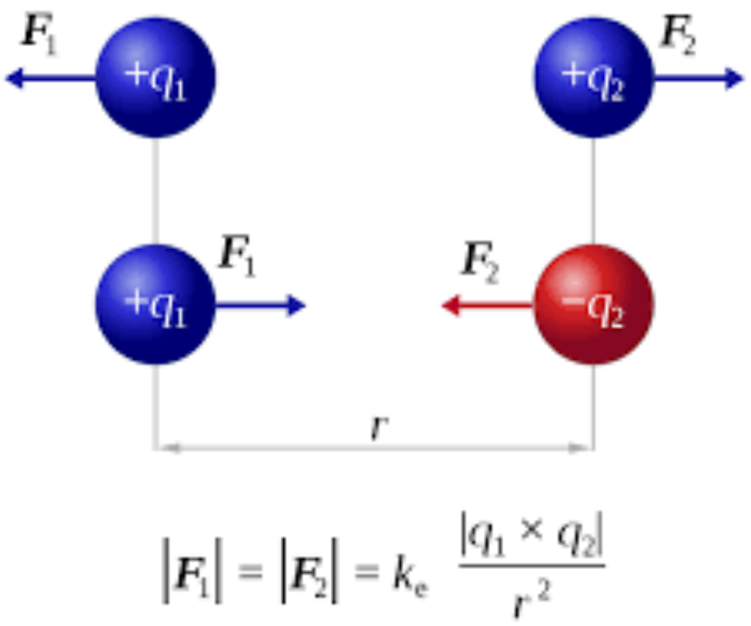
Thrust

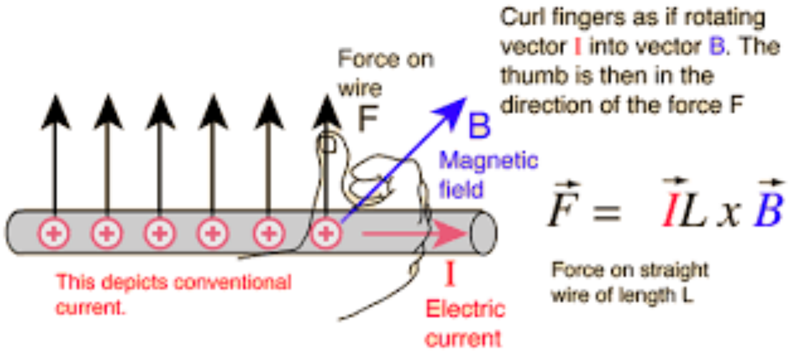
- Thrust is a contact force with the *agent* being the exhaust gas that pushes on the engine.
- This is an application of Newton's Third Law of motion (equal and opposite reactions).
- The symbol for thrust is $\vec{F}_{\text{thrust}}$.



Electric and Magnetic Forces

- Beyond the scope of Physics I (will be the focus of Physics II).
- These forces are long-range forces.
- These forces act on *charged* particles.





Identifying Forces

1. Identify the object of interest
2. Draw a picture of the situation
3. Draw a closed curve around the object
4. Locate every point on the boundary of the curve where other objects touch the object of interest
5. Name and label each contact force acting on the object
6. Name and label each long-range force acting on the object

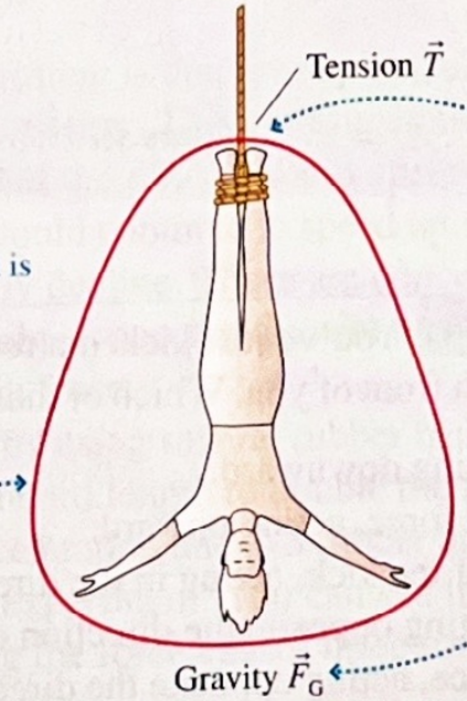
Example #1

EXAMPLE 5.1 Forces on a bungee jumper

A bungee jumper has leapt off a bridge and is nearing the bottom of her fall. What forces are being exerted on the bungee jumper?

VISUALIZE

FIGURE 5.13 Forces on a bungee jumper.



❶ Identify the object of interest. Here the object is the bungee jumper.

❷ Draw a picture of the situation.

❸ Draw a closed curve around the object.

❹ Locate the points where other objects touch the object of interest. Here the only point of contact is where the cord attaches to her ankles.

❺ Name and label each contact force. The force exerted by the cord is a tension force.

❻ Name and label long-range forces. Gravity is the only one.

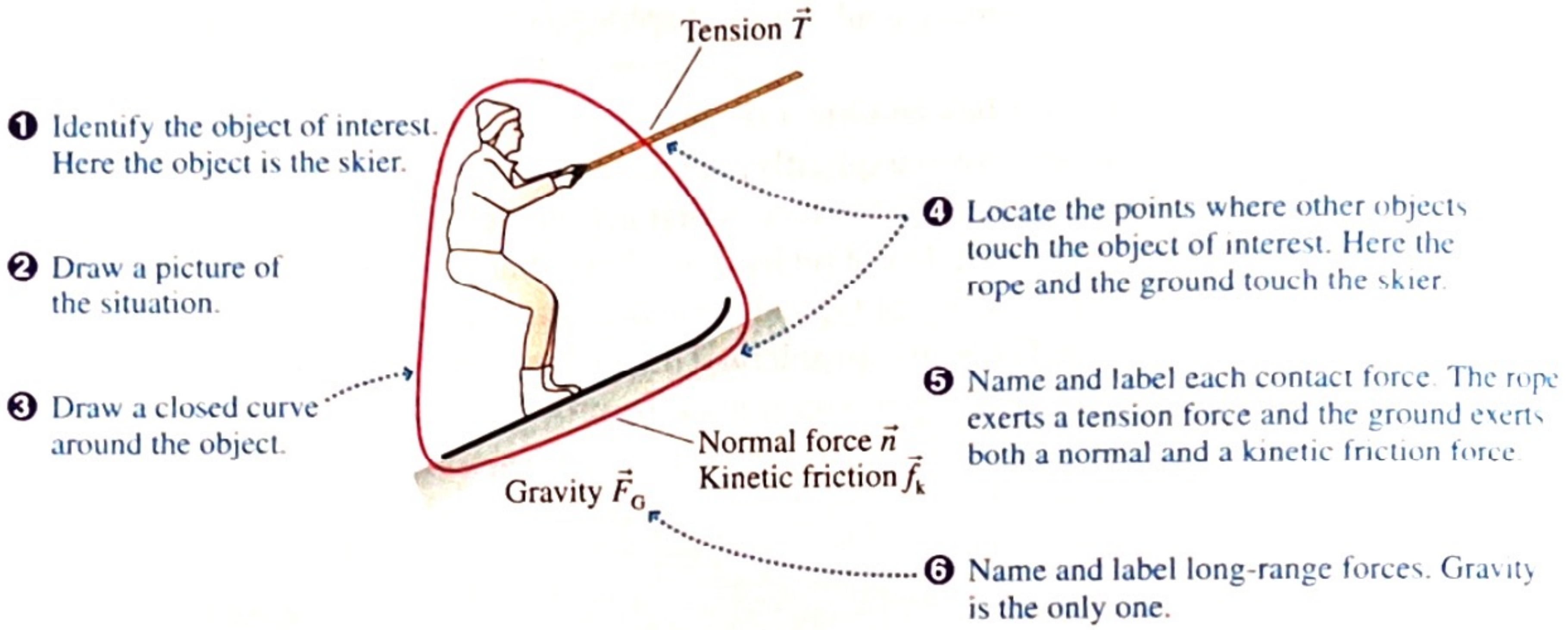
Example #2

EXAMPLE 5.2 Forces on a skier

A skier is being towed up a snow-covered hill by a tow rope. What forces are being exerted on the skier?

VISUALIZE

FIGURE 5.14 Forces on a skier.



A Thought Experiment

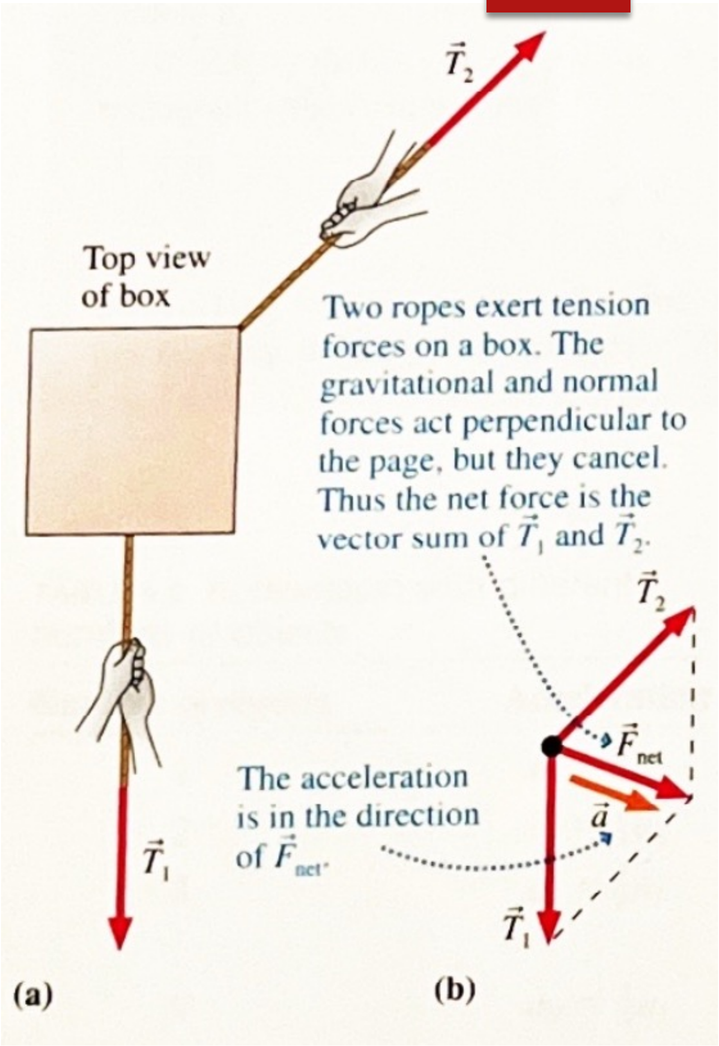
- The engine of a car provides a force, $\vec{F}$, which propels the vehicle forward from a stop.
- You notice that, with only you driving the car, the acceleration is $\vec{a}$.
- However, when you take a friend with you, the acceleration is $\frac{1}{2}\vec{a}$ when the same amount of force ($\vec{F}$) is applied. This makes sense because there is more "mass" in the car, making the magnitude of acceleration smaller.
- While driving four of your friends to dinner, you notice that having five people in the car reduces your acceleration considerably when the engine applies $\vec{F}$. Specifically, you notice the acceleration to be $\frac{1}{5}\vec{a}$.
- Clearly, there is a relationship between an applied force and the *amount of mass* the force is expected to move.

Newton's Second Law $(\vec{F}_{\text{net}} = m\vec{a})$

- An object of mass, *m*, subjected to forces will undergo an acceleration $\vec{a}$ given by:

$$\vec{a} = \frac{\vec{F}_{\text{net}}}{m}$$

- The force is distributed "across" mass.
- An object accelerates in the direction of the net force vector.
- An object only accelerates while the force is applied!



$$\vec{a} = \frac{\vec{F}_{net}}{m} = \frac{\vec{T}_1 + \vec{T}_2}{m} = \frac{1}{m}(\vec{T}_1 + \vec{T}_2)$$

What are the units of a force anyway?

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

$$\vec{F} = \text{mass} \times \text{acceleration}$$

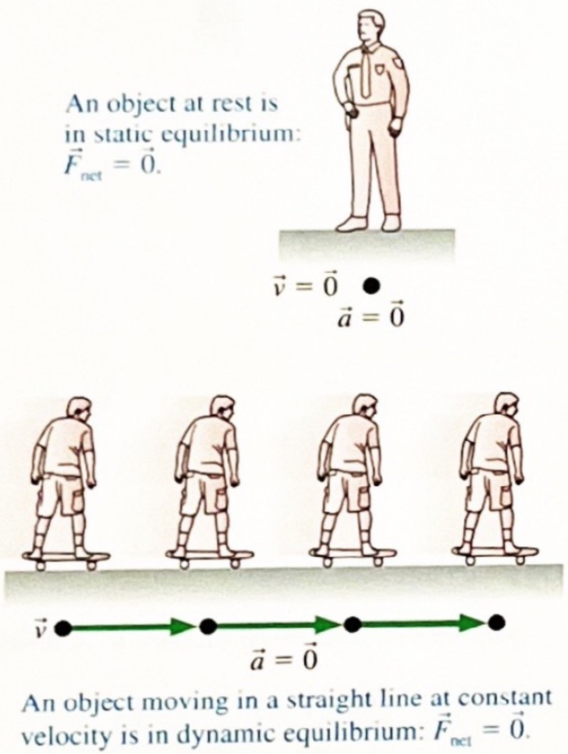
$$[kg]\times\left[\frac{m}{s^2}\right] = \left[kg\,\frac{m}{s^2}\right] = [N]$$

“Kilogram meter per second squared” is a secondary (derived) unit called a <u>Newton</u>.

Newton's First Law

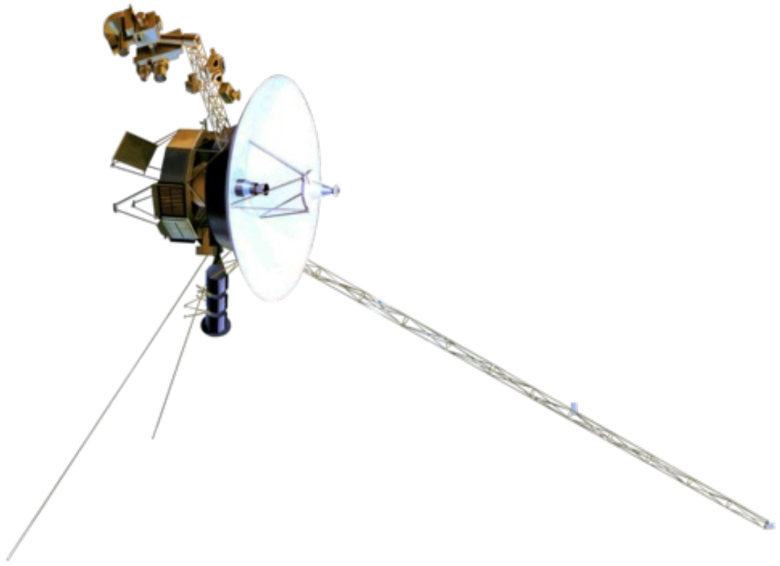
- First, Aristotle concluded that the natural state of an earthly object is to be at rest.
- Galileo found that an external influence (force) is needed to make an object accelerate. Otherwise, the natural state of an object is *uniform motion*.
- Newton's First Law: an object at rest will remain at rest (<u>static equilibrium</u>) and an object in motion will remain in motion (<u>dynamic equilibrium</u>) in a straight line if the net force acting on the object is zero.

FIGURE 5.21 Two examples of mechanical equilibrium.



Voyager 1

- Most distant human-made object from Earth
- 161 AU from Earth
- $\vec{F}_{\text{net}} \approx 0\text{N}$ since it is outside of the solar system. It is continuing at a near-constant velocity!



Newton's First Law (The Law of Inertia)

- Mass can be thought of as the amount of inertia an object has. *Inertia* is the tendency of an object to resist accelerating in response to a force.

- A force is what causes an object to change its velocity (accelerate)

- Newton's First Law *defines* a force (something that disturbs equilibrium).
- Newton's Second Law *describes* the response of an object to a force.
- Newton's Third Law *describes* the interaction between the object and agent in terms of forces.

Inertial Reference Frames

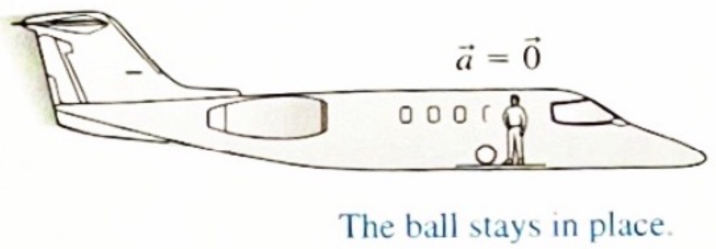
- Newton's Laws are only valid in inertial reference frames.

- What is an inertial reference frame?
  - A reference frame where Newton's First Law holds.

- In Figure (a), a ball placed on the ground when $\vec{a} = 0\,\frac{m}{s^2}$ will continue to sit. This agrees with Newton's First Law.
- In Figure (b), there is no apparent object/agent interaction that causes the ball to roll backwards. Thus, a reference frame "riding along" with the aircraft IS NOT an inertial reference frame.
- In both scenarios, a coordinate system outside on the ground would, in fact, be an inertial reference frame.

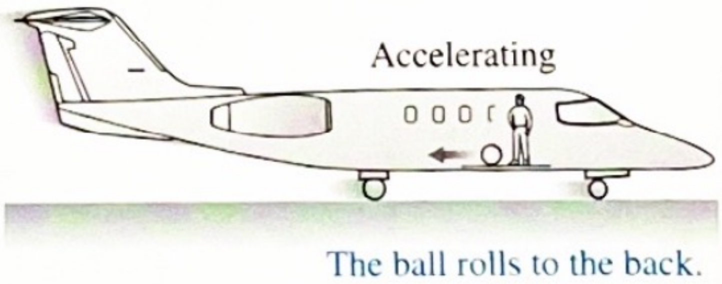
FIGURE 5.22 Reference frames.

(a)



A ball with no horizontal forces stays at rest in an airplane cruising at constant velocity. The airplane is an inertial reference frame.

(b)



The ball rolls to the back of the plane during takeoff. An accelerating plane is not an inertial reference frame.

Putting it all together: Free-Body Diagrams

A free-body diagram is a pictorial representation of a problem and represents the object as a particle.

This diagram shows ALL forces acting on the object as vectors.

To construct a free-body diagram:

1. Identify all forces acting on the object
2. Draw a coordinate system
3. Represent the object as a dot at the origin of the coordinate system
4. Draw vectors representing each of the identified forces
5. Draw and label the *net force* vector.

Example #3

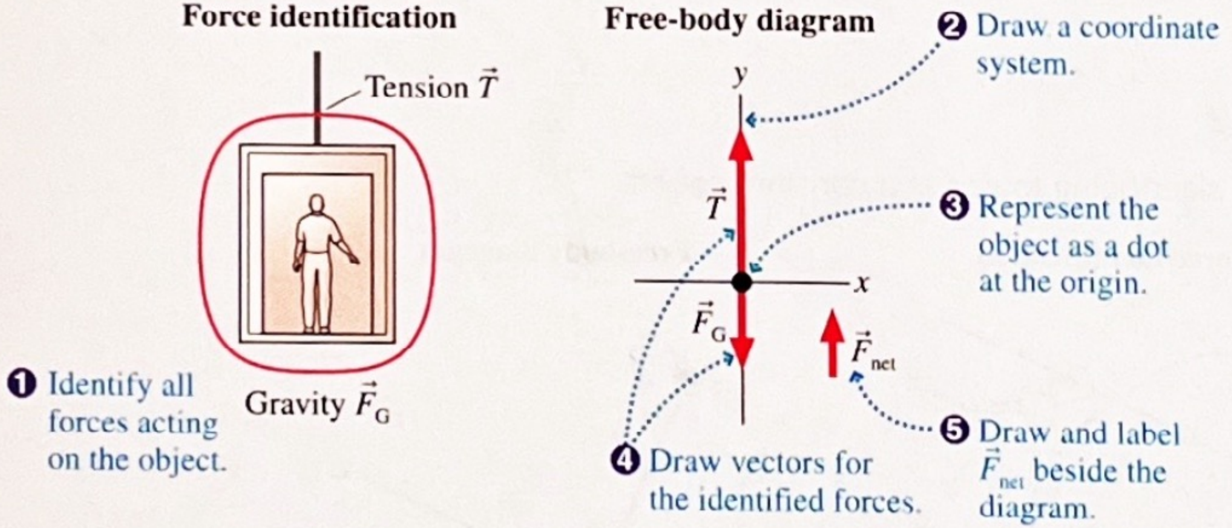
EXAMPLE 5.4 An elevator accelerates upward

An elevator, suspended by a cable, speeds up as it moves upward from the ground floor. Identify the forces and draw a free-body diagram of the elevator.

MODEL Treat the elevator as a particle.

VISUALIZE

FIGURE 5.23 Free-body diagram of an elevator accelerating upward.



ASSESS The coordinate axes, with a vertical y-axis, are the ones we would use in a pictorial representation of the motion. The elevator is accelerating upward, so $\vec{F}_{net}$ must point upward. For this to be true, the magnitude of $\vec{T}$ must be larger than the magnitude of $\vec{F}_G$. The diagram has been drawn accordingly.

Example #4

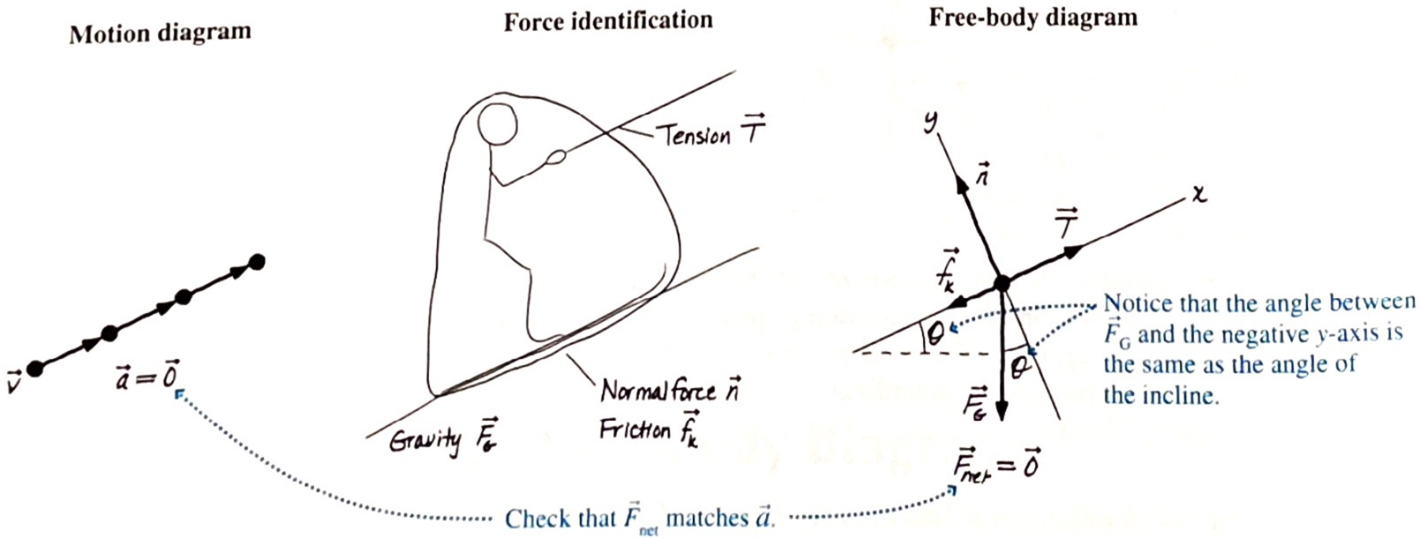
EXAMPLE 5.6 A skier is pulled up a hill

A tow rope pulls a skier up a snow-covered hill at a constant speed. Draw a pictorial representation of the skier.

MODEL This is Example 5.2 again with the additional information that the skier is moving at constant speed. The skier will be treated as a particle in *dynamic equilibrium*. If we were doing a kinematics problem, the pictorial representation would use a tilted coordinate system with the x-axis parallel to the slope, so we use these same tilted coordinate axes for the free-body diagram.

VISUALIZE

FIGURE 5.25 Pictorial representation for a skier being towed at a constant speed.



ASSESS We have shown $\vec{T}$ pulling parallel to the slope and $\vec{f}_k$, which opposes the direction of motion, pointing down the slope. $\vec{n}$ is perpendicular to the surface and thus along the y-axis. Finally, and this is important, the gravitational force $\vec{F}_G$ is vertically downward, not along the negative y-axis. In fact, you should convince yourself from the geometry that the angle θ between the $\vec{F}_G$ vector and the negative y-axis is the same as the angle θ of the incline above the horizontal. The skier moves in a straight line with constant speed, so $\vec{a} = \vec{0}$ and, from Newton's first law, $\vec{F}_{net} = \vec{0}$. Thus we have drawn the vectors such that the y-component of $\vec{F}_G$ is equal in magnitude to $\vec{n}$. Similarly, $\vec{T}$ must be large enough to match the negative x-components of both $\vec{f}_k$ and $\vec{F}_G$.

Summary

- Different Forces
- Identifying Forces
- Newton’s Three Laws of Motion
- Inertial Reference Frames
- Free-Body Diagrams