PHY131H1F
University of Toronto

Class 9 Preclass Video
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Based on Knight 3rd edition
Ch. 5, pgs. 116-133

Section 5.1

What is a force?

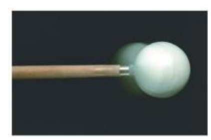
- A force is a *push* or a *pull*

- A force acts on an object
- Pushes and pulls are applied *to* something
- From the object's perspective, it has a force *exerted* on it

What is a force?

- A force requires an **agent**, something that acts or exerts power
- If you throw a ball, your hand is the agent or cause of the force exerted on the ball

- A force is a vector
- To quantify a push or pull, we need to specify both magnitude and a direction

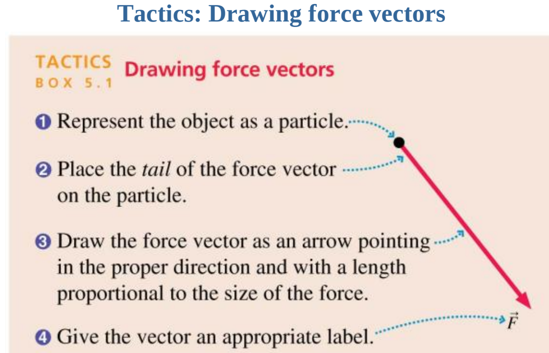


What is a force?

- **Contact forces** are forces that act on an object by touching it at a point of contact
- The bat must touch the ball to hit it

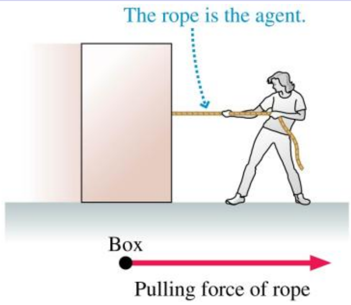
- **Long-range forces** are forces that act on an object without physical contact
- A coffee cup released from your hand is pulled to the earth by the long-range force of gravity

Tactics: Drawing force vectors



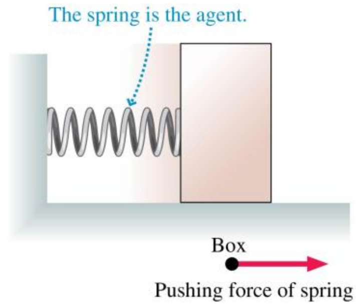
Example: Drawing a force vector

A box is pulled to the right by a rope.



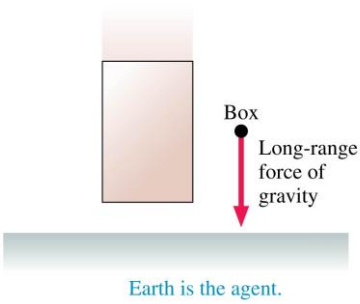
Example: Drawing a force vector

A box is pushed to the right by a spring.



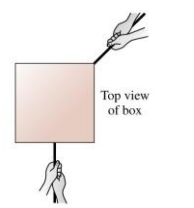
Example: Drawing a force vector

A box is pulled down by gravity.

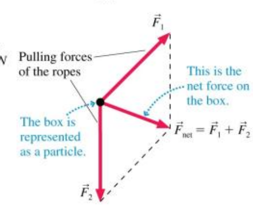


Combining Forces

- A box is pulled by two ropes, as shown
- When several forces are exerted on an object, they combine to form a **net force** given by the *vector* sum of *all* the forces



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

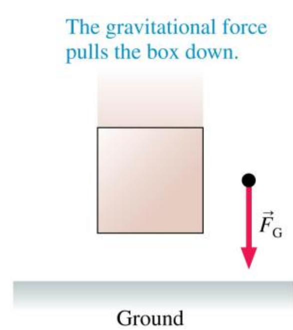


- This is called a **superposition of forces**

Section 5.2
A Short Catalog of Forces

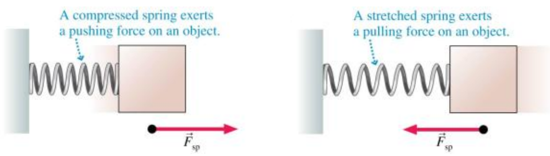
Gravity

- The pull of a planet on an object near the surface is called the **gravitational force**
- The agent for the gravitational force is the *entire planet*
- Gravity acts on *all* objects, whether moving or at rest
- The gravitational force vector always points vertically downward



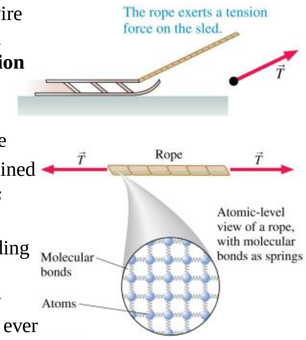
Spring Force

- A spring can either push (when compressed) or pull (when stretched)
- Not all springs are metal coils
- Whenever an elastic object is flexed or deformed in some way, and then "springs" back to its original shape when you let it go, this is a **spring force**



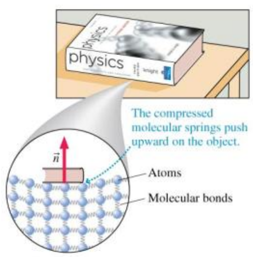
Tension Force

- When a string or rope or wire pulls on an object, it exerts a contact force called the **tension force**
- The tension force is in the direction of the string or rope
- A rope is made of *atoms* joined together by *molecular bonds*
- Molecular bonds can be modeled as tiny *springs* holding the atoms together
- Tension is a result of many molecular springs stretching ever so slightly



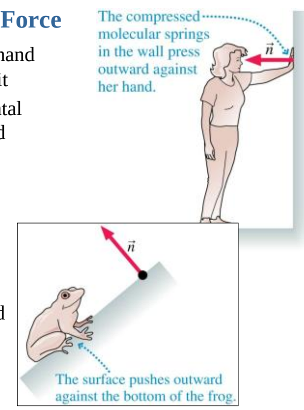
Normal Force

- When an object sits on a table, the table surface exerts an upward contact force on the object
- This pushing force is directed *perpendicular* to the surface, and thus is called the **normal force**
- A table is made of *atoms* joined together by *molecular bonds* which can be modeled as springs
- Normal force is a result of many molecular springs being compressed ever so slightly



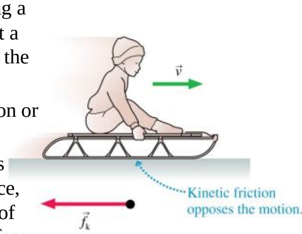
Examples of Normal Force

- Suppose you place your hand on a wall and lean against it
- The wall exerts a horizontal **normal force** on your hand
- Suppose a frog sits on an inclined surface
- The surface exerts a tilted **normal force** on the frog



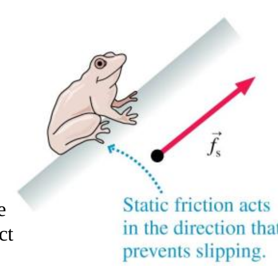
Kinetic Friction

- When an object slides along a surface, the surface can exert a contact force which opposes the motion
- This is called sliding friction or **kinetic friction**
- The kinetic friction force is directed *tangent* to the surface, and opposite to the velocity of the object relative to the surface
- Kinetic friction tends to slow down the sliding motion of an object in contact with a surface



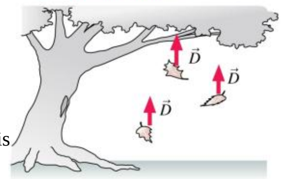
Static Friction

- **Static friction** is the contact force that keeps an object "stuck" on a surface, and prevents relative motion
- The static friction force is directed *tangent* to the surface
- Static friction points opposite the direction in which the object *would* move if there were no static friction



Drag

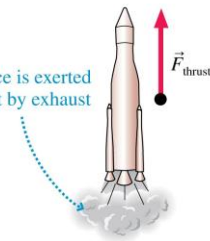
- Kinetic friction is a *resistive force*, which opposes or resists motion
- Resistive forces are also experienced by objects moving through fluids
- The resistive force of a fluid is called **drag**
- Drag points opposite the direction of motion



- For heavy and compact objects in air, drag force is fairly small
- **You can neglect air resistance in all problems unless a problem explicitly asks you to include it**

Thrust

- A jet airplane or a rocket has a **thrust** force pushing it forward during takeoff
- Thrust occurs when an engine expels gas molecules at high speed
- This exhaust gas exerts a contact force on the engine
- The direction of thrust is opposite the direction in which the exhaust gas is expelled



Electric and Magnetic Forces

- Electricity and magnetism, like gravity, exert long-range forces
- Atoms and molecules are made of electrically charged particles
- Molecular bonds are due to the electric force between these particles
- Most forces, such as normal force and tension, are actually caused by electric forces between the charged particles in the atoms

Section 5.3

Symbols for Forces:

Force	Notation
General force	$\vec{F}$
Gravitational force	$\vec{F}_G$
Spring force	$\vec{F}_{sp}$
Tension	$\vec{T}$
Normal force	$\vec{n}$
Static friction	$\vec{f}_s$
Kinetic friction	$\vec{f}_k$
Drag	$\vec{D}$
Thrust	$\vec{F}_{thrust}$

Tactics: Identifying forces

TACTICS BOX 5.2 Identifying forces MP

1. **Identify the object of interest.** This is the object whose motion you wish to study.
2. **Draw a picture of the situation.** Show the object of interest and all other objects—such as ropes, springs, or surfaces—that touch it.
3. **Draw a closed curve around the object.** Only the object of interest is inside the curve; everything else is outside.

Exercises 3–8

Tactics: Identifying forces

TACTICS BOX 5.2 Identifying forces

❹ **Locate every point on the boundary of this curve where other objects touch the object of interest.** These are the points where *contact forces* are exerted on the object.

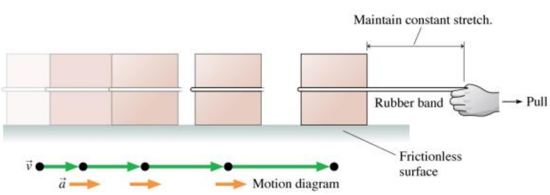
❺ **Name and label each contact force acting on the object.** There is at least one force at each point of contact; there may be more than one. When necessary, use subscripts to distinguish forces of the same type.

Please read Section 5.3

Section 5.4

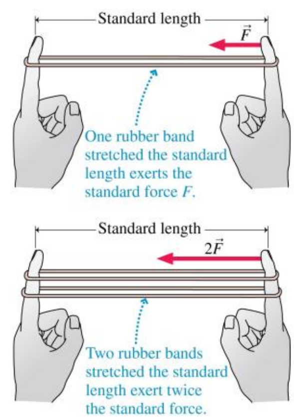
What Do Forces Do? A Virtual Experiment

- Attach a stretched rubber band to a 1 kg block
- Use the rubber band to pull the block across a horizontal, frictionless table
- Keep the rubber band stretched by a fixed amount
- We find that the block moves with a **constant acceleration**



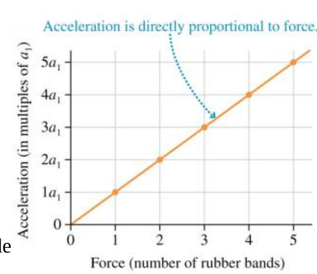
What Do Forces Do? A Virtual Experiment

- A standard rubber band can be stretched to some standard length
- This will exert a reproducible spring force of magnitude F on whatever it is attached to
- N side-by-side rubber bands exert N times the standard force: $F_{net} = NF$



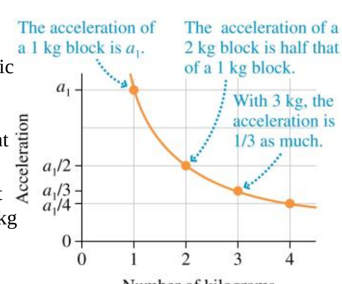
What Do Forces Do? A Virtual Experiment

- When a 1 kg block is pulled on a frictionless surface by a single elastic band stretched to the standard length, it accelerates with *constant acceleration* a_1
- Repeat the experiment with 2, 3, 4, and 5 rubber bands attached side-by-side
- **The acceleration is directly proportional to the force**



What Do Forces Do? A Virtual Experiment

- When a 1 kg block is pulled on a frictionless surface by a single elastic band stretched to the standard length, it accelerates with constant acceleration a_1
- Repeat the experiment with a 2 kg, 3 kg and 4 kg block
- **The acceleration is inversely proportional to the mass**



What Do Forces Do? A Virtual Experiment

- Force causes an object to *accelerate!*
- The result of the experiment is: $a = \frac{F}{m}$
- The basic unit of force is the **newton** (N)
- 1 N = 1 kg m/s^2

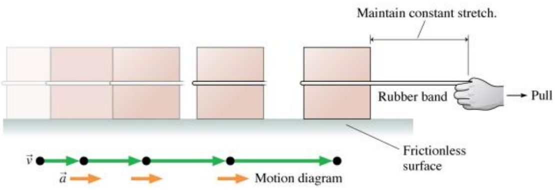


TABLE 5.1 Approximate magnitude of some typical forces

Force	Approximate magnitude (newtons)
Weight of a U.S. quarter	0.05
Weight of a 1 pound object	5
Weight of a 110 pound person	500
Propulsion force of a car	5,000
Thrust force of a rocket motor	5,000,000

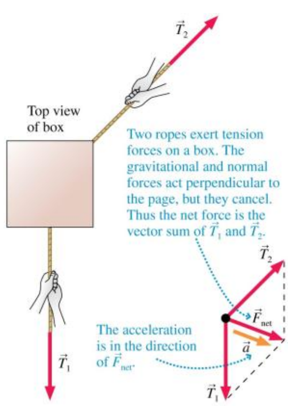
Inertial Mass

- An object with twice the amount of matter accelerates only half as much in response to the same force
- The more matter an object has, the more it *resists* accelerating in response to the same force
- The tendency of an object to resist a *change* in its velocity is called **inertia**
- The mass used in $a = F/m$ is called **inertial mass**

Section 5.5

Newton's Second Law

- When more than one force is acting on an object, the object accelerates in the direction of the net force vector $\vec{F}_{net}$



Newton's Second Law

Newton's second law An object of mass m subjected to forces $\vec{F}_1, \vec{F}_2, \vec{F}_3, \ldots$ will undergo an acceleration $\vec{a}$ given by

$$\vec{a} = \frac{\vec{F}_{net}}{m} \qquad (5.5)$$

where the net force $\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \cdots$ is the vector sum of all forces acting on the object. The acceleration vector $\vec{a}$ points in the same direction as the net force vector $\vec{F}_{net}$.

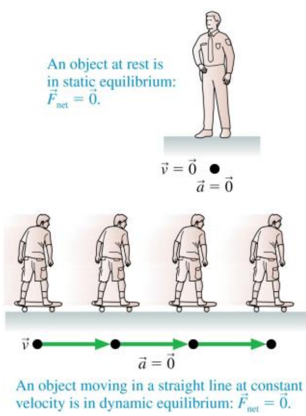
Section 5.6

Newton's first law An object that is at rest will remain at rest, or an object that is moving will continue to move in a straight line with constant velocity, if and only if the net force acting on the object is zero.

- Newton's first law is also known as the *law of inertia*
- If an object is at rest, it has a tendency to stay at rest
- If it is moving, it has a tendency to continue moving with the *same velocity*

Newton's First Law

- An object on which the net force is zero is said to be in **mechanical equilibrium**
- There are two forms of mechanical equilibrium:
  - If the object is at rest, then it is in **static equilibrium**
  - If the object is moving with constant velocity, it is in **dynamic equilibrium**



Inertial Reference Frames

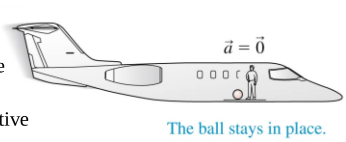
- If a car stops suddenly, you may be "thrown" forward
- You do have a forward acceleration *relative to the car*
- However, there is no force pushing you forward

This guy thinks there's a force hurling him into the windshield. What a dummy!

- We define an **inertial reference frame** as one in which Newton's laws are valid
- The interior of a crashing car is *not* an inertial reference frame!

Inertial Reference Frames

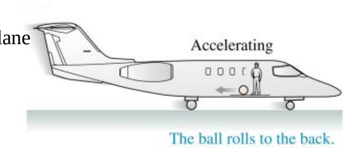
- A physics student cruises at a constant velocity in an airplane
- A ball placed on the floor stays at rest relative to the airplane



- There are no horizontal forces on the ball, so $\vec{a} = 0$ when $\vec{F}_{net} = 0$
- Newton's first law is satisfied, so this airplane is an inertial reference frame

Inertial Reference Frames

- A physics student is standing up in an airplane during takeoff
- A ball placed on the floor rolls toward the back of the plane



- There are no horizontal forces on the ball, and yet the ball accelerates *in the plane's reference frame*
- Newton's first law is violated, therefore this airplane is *not* an inertial reference frame
- In general, **accelerating reference frames are not inertial reference frames**

Thinking About Force

- Every force has an agent which causes the force
- Forces exist at the point of contact between the agent and the object (except for the few special cases of long-range forces)
- Forces exist due to interactions happening *now*, not due to what happened in the past
- Consider a flying arrow
- A pushing force was required to accelerate the *arrow as it was shot*
- However, *no force* is needed to keep the arrow moving forward as it flies
- It continues to move because of inertia

Please read
Section 5.7

Tactics: Drawing a free-body diagram

TACTICS BOX 5.3 Drawing a free-body diagram

❶ **Identify all forces acting on the object.** This step was described in Tactics Box 5.2.
❷ **Draw a coordinate system.** Use the axes defined in your pictorial representation.
❸ **Represent the object as a dot at the origin of the coordinate axes.** This is the particle model.

Exercises 24–29

Tactics: Drawing a free-body diagram

TACTICS BOX 5.3 Drawing a free-body diagram

❹ **Draw vectors representing each of the identified forces.** This was described in Tactics Box 5.1. Be sure to label each force vector.
❺ **Draw and label the *net force* vector $\vec{F}_{net}$.** Draw this vector beside the diagram, not on the particle. Or, if appropriate, write $\vec{F}_{net} = \vec{0}$. Then check that $\vec{F}_{net}$ points in the same direction as the acceleration vector $\vec{a}$ on your motion diagram.

Exercises 24–29