Lecture 7

Physics I

Chapter 5

Dynamics: Forces and Newton's Laws of Motion

Course website:
http://faculty.uml.edu/Andriy_Danylov/Teaching/PhysicsI

Today we are going to discuss:

Chapter 5:

- ***Force, Mass:*** *Section 5.1*
- ***Weight—the Force of Gravity; and the Normal Force/Tension:*** *Section 5.2-5.4*
- ***Newton's First Law of Motion:*** *Section 5.6*
- ***Newton's Second Law of Motion:*** *Section 5.5*
- ***Free-Body Diagram:*** *Section 5.7*

Transition from Kinematics to Dynamics

In Kinematics we studied

HOW things move

Motion ~~Forces~~

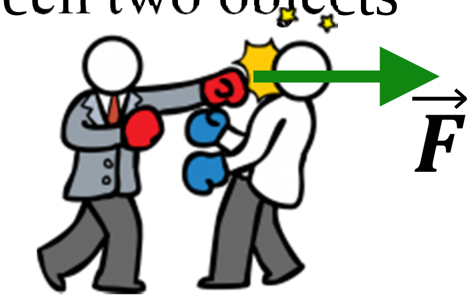
Now in Dynamics we will study

WHY things move

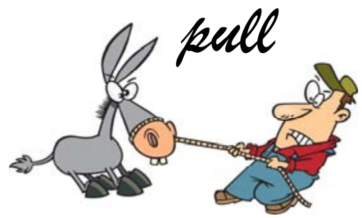
Motion Forces

Force

A force was introduced to describe interactions between two objects



A force is a push or pull



Force has magnitude and direction: ***VECTOR***! To quantify a push or pull, we need to specify both magnitude and a direction.

An object at rest needs a force to get it moving

A moving object needs a force to change its velocity

There are two types of forces

***Contact forces*:**

forces that act on an object by touching it at a point of contact.

Frictional Force
Tension Force
Normal Force
Spring Force

***Non-contact forces (Long-range forces)*:**

forces that act on an object without physical contact (gravity).

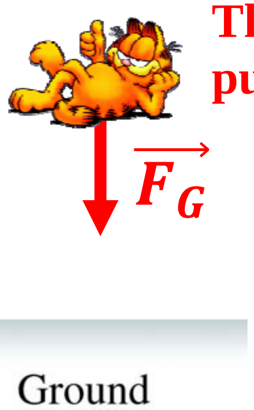
Gravity
Electric force
Magnetic force

The Major Forces

GRAVITY

The pull of a planet on an object near the surface is called the **gravitational force**. It comes from the entire planet

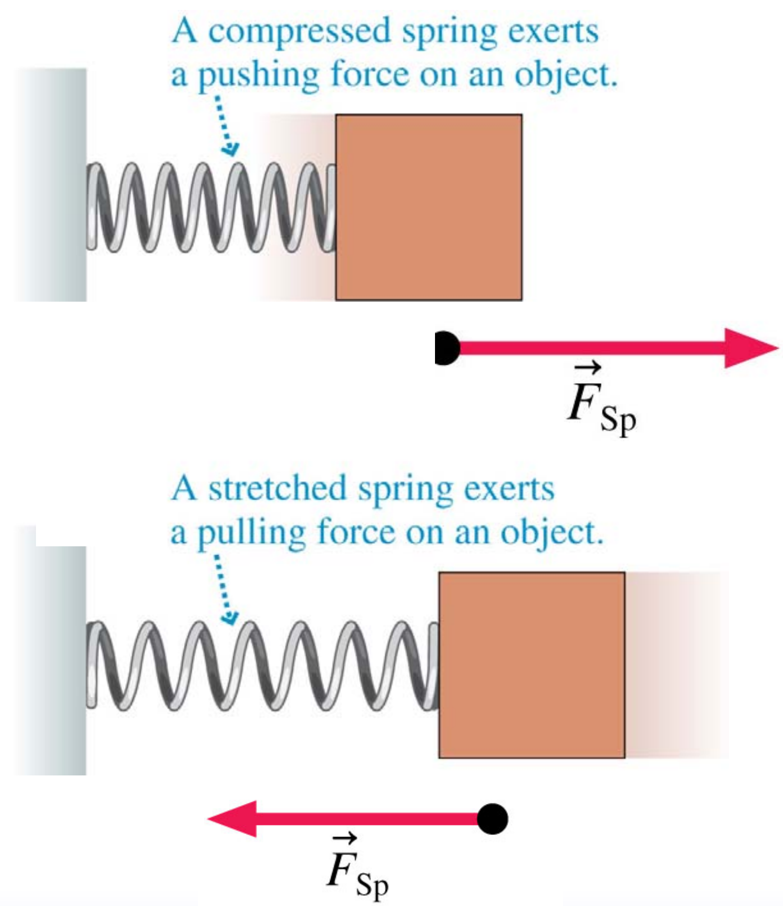
The gravitational force pulls the cat down



Gravity acts on all objects, whether moving or at rest.
The gravitational force vector always points vertically downward.

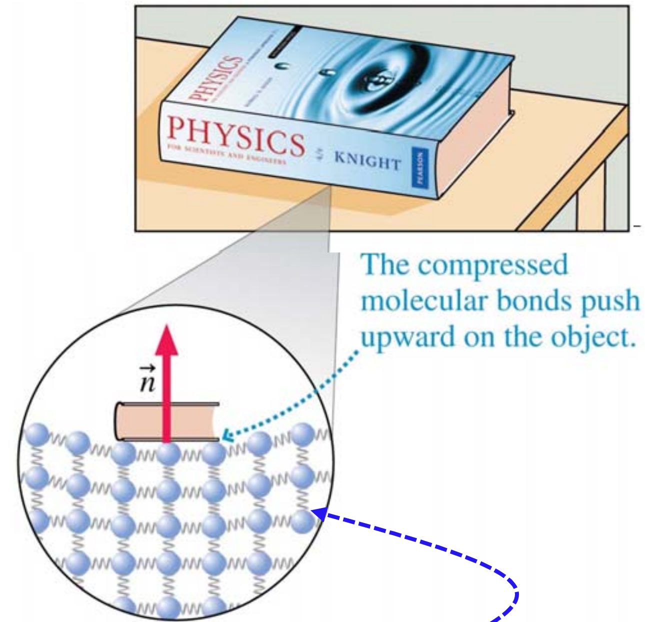
SPRING Force

A spring can either push (when compressed) or pull (when stretched).

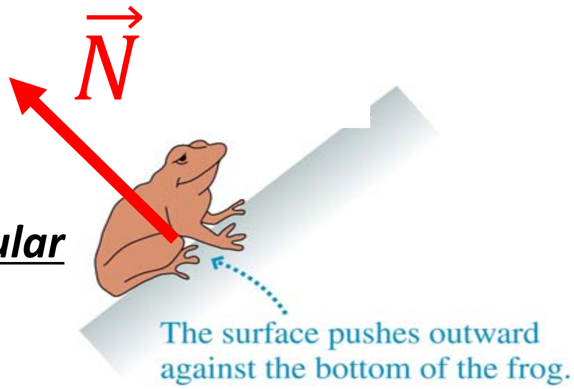


Normal Force

- 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**.



Always perpendicular



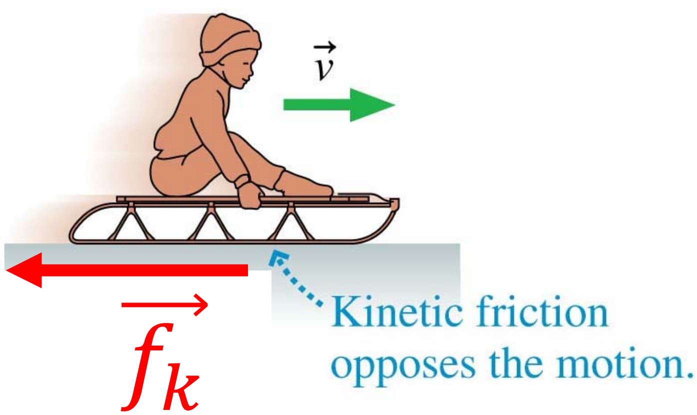
A table is made of atoms joined together by molecular bonds which can be modeled as springs.
Normal force is a result of many molecular springs being compressed ever so slightly.

Friction Force

Kinetic friction

When an object slides along a surface, the surface can exert a contact force which opposes the motion.

This is called **kinetic friction**.

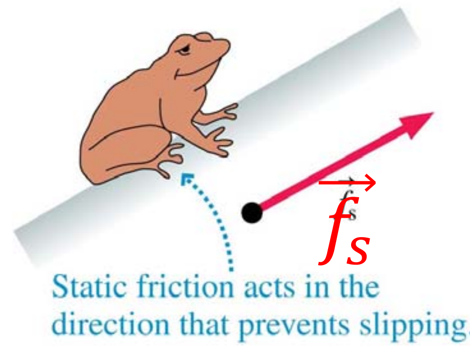


The kinetic friction force is directed **tangent to the surface, and opposite to the velocity** of the object relative to the surface.

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.

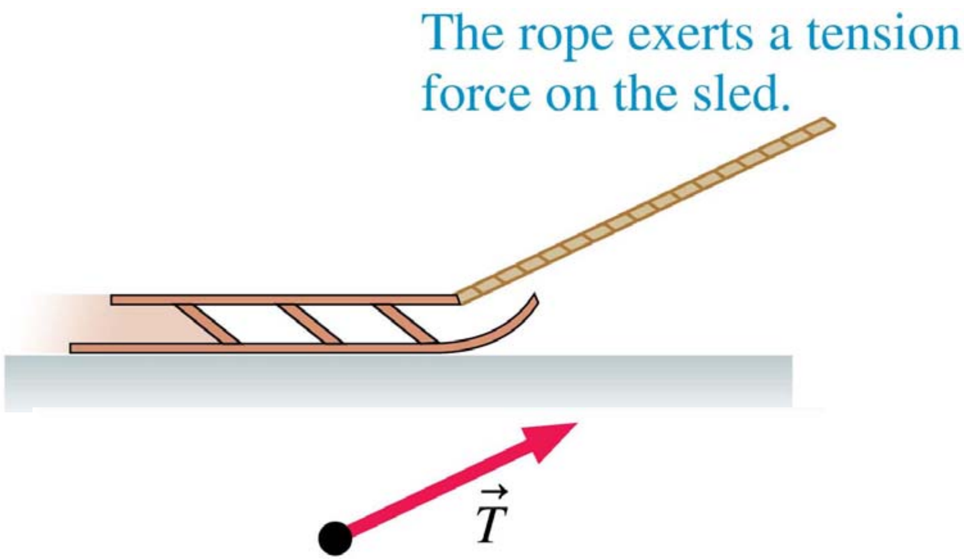


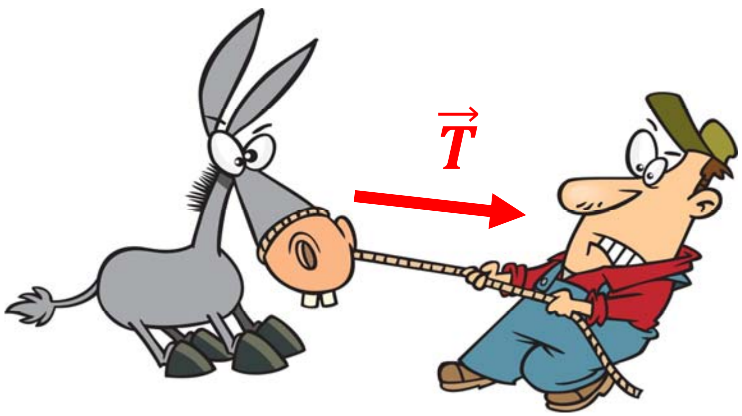
The static friction force is directed *tangent* to the surface.

Static friction points opposite the direction in which the object *would* move if there were no static friction.

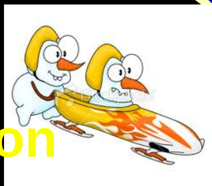
Tension Force

- 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.





ConcepTest Forces



A bobsledder pushes her sled across horizontal snow to get it going, then jumps in. After she jumps in, the sled gradually slows to a halt. What forces act on the sled just <u>after she's jumped in</u>?

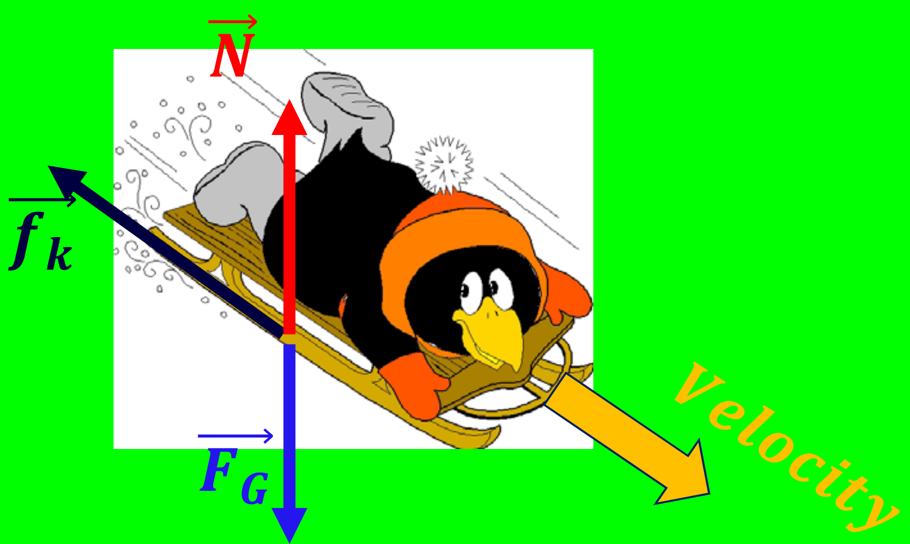
A) Gravity and kinetic friction

B) Gravity and a normal force.

C) Gravity and the force of the push.

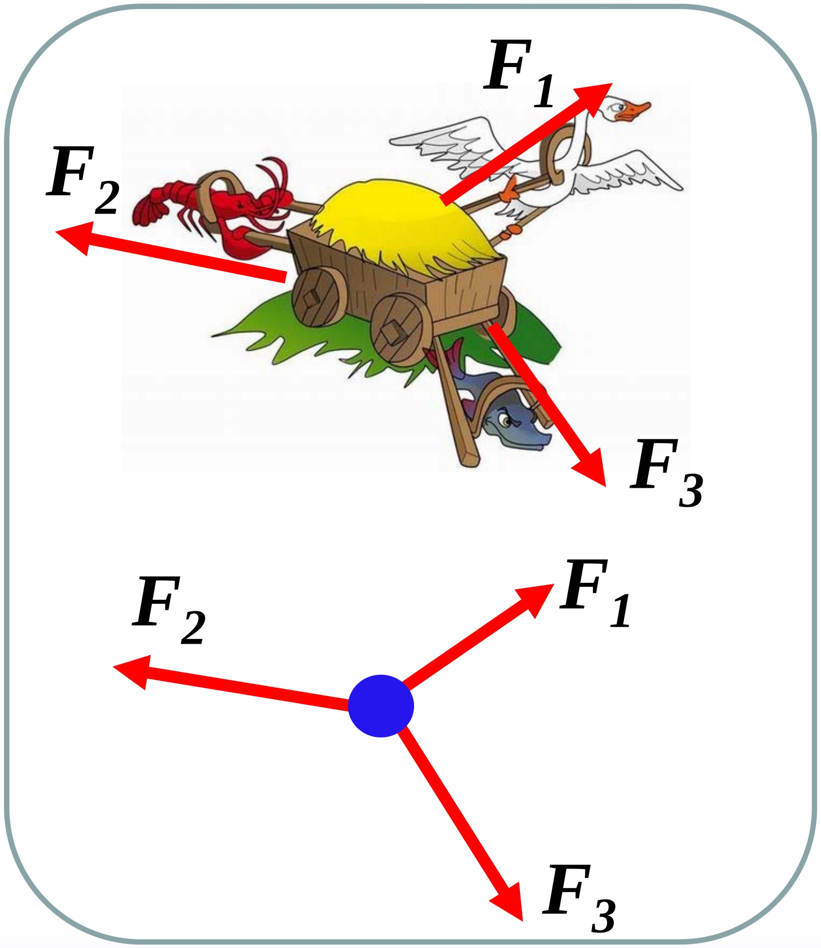
D) Gravity, a normal force, and kinetic friction.

E) Gravity, a normal force, kinetic friction, and the force of the push.



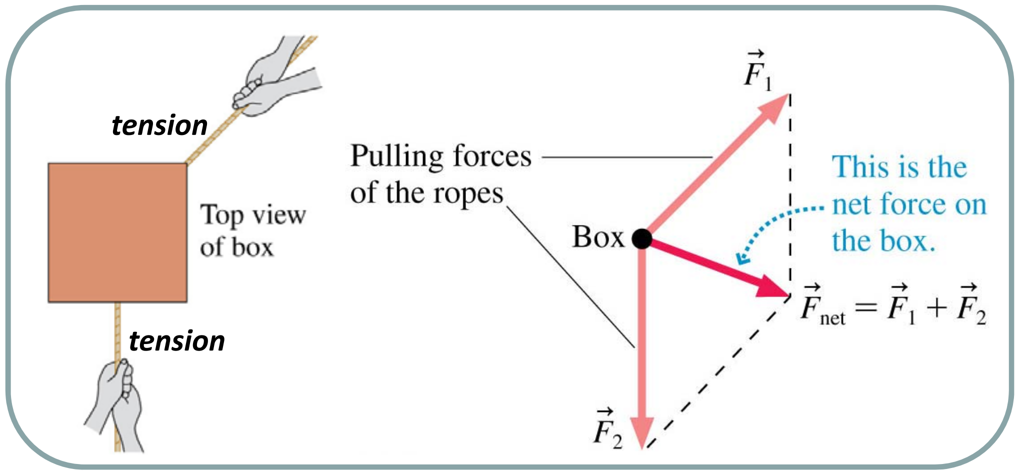
Principle of superposition

If multiple forces are present, the net force on an object is given by the vector sum of all the forces



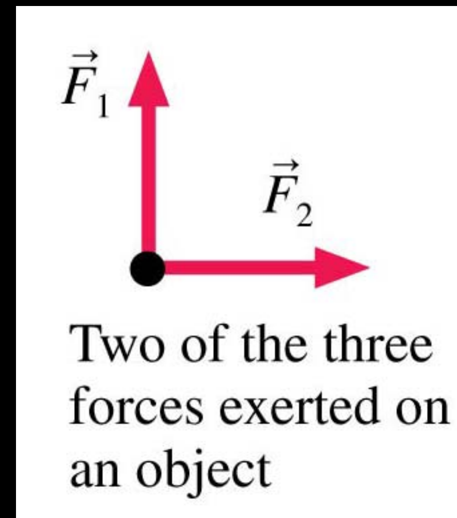
$$\vec{F} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \vec{F}_4$$

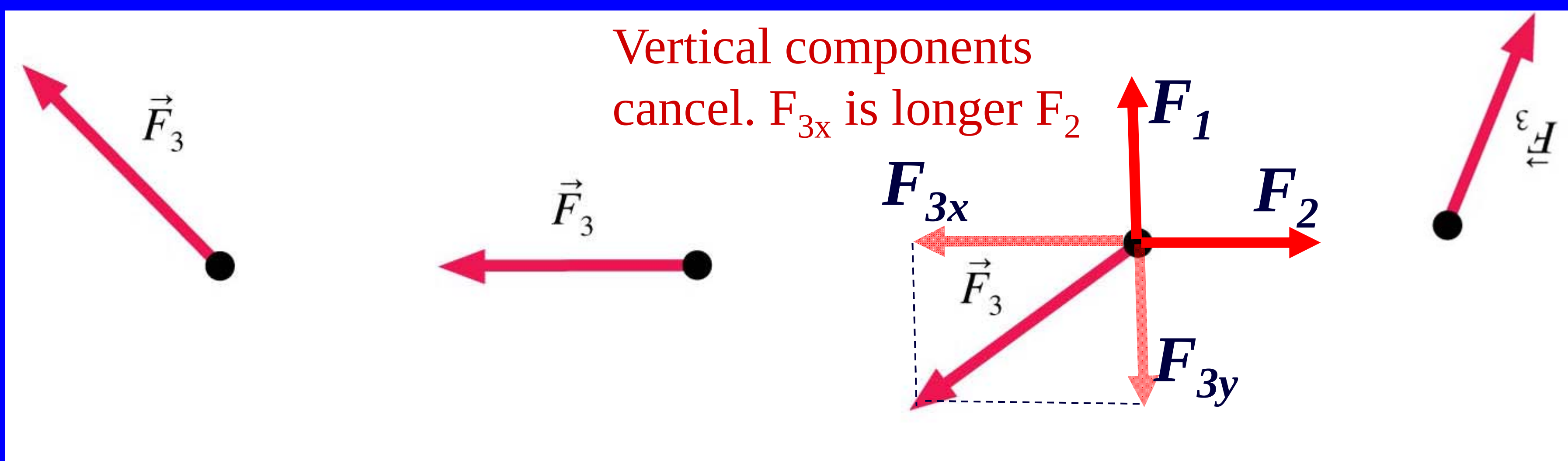
$$\vec{F} = \sum \vec{F}_n$$



ConcepTest — *Net Force*

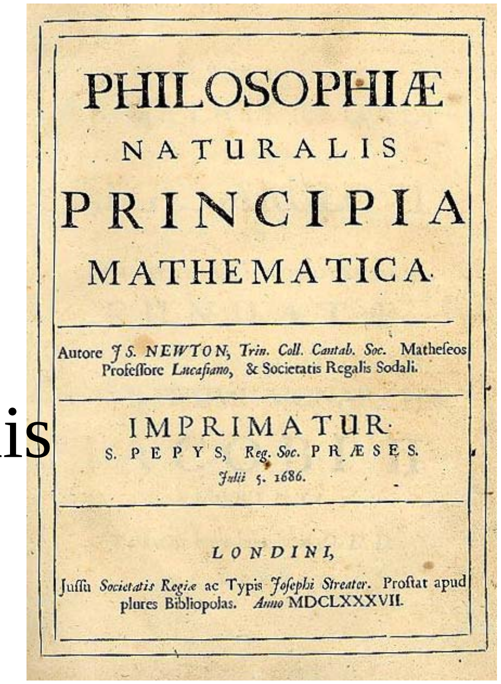
- ***The net force on an object points to the left. Two of three forces are shown. Which is the missing third force?***





A. **B.** **C.** **D.**

Newton’s laws



PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore J S. NEWTON, Trin. Coll. Cantab. Soc. Matheseos Professore Lucasiano, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, Reg. Soc. PRÆSES.
Julii 5. 1686.

LONDINI,
Jussu Societatis Regiæ ac Typis Josephi Streater. Prostat apud plures Bibliopolas. Anno MDCLXXXVII.

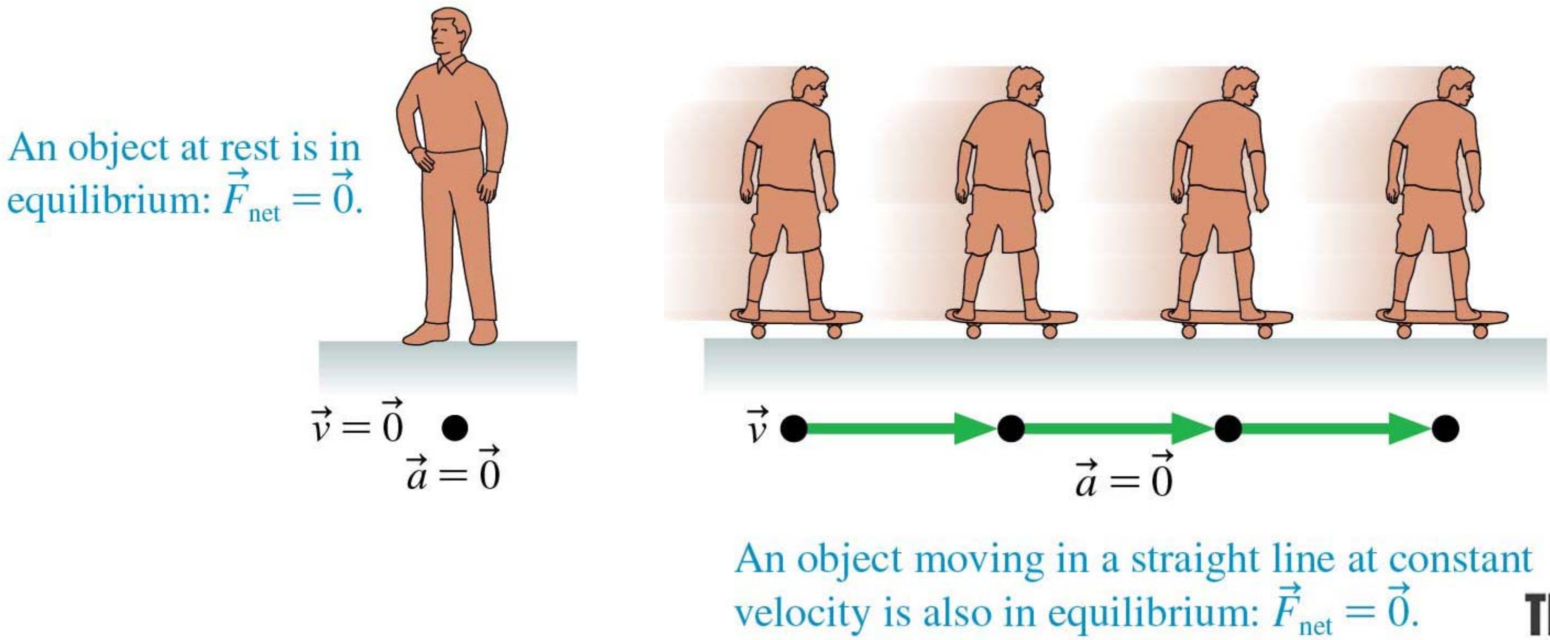
In 1687 Newton published his three laws in his ***Principia Mathematica***.

These intuitive laws are remarkable intellectual achievements and work spectacular for everyday physics

Newton's 1st Law (*Law of Inertia)*

In the absence of force, objects continue in their state of rest or of uniform velocity in a straight line

i.e. objects want to keep on doing what they are already doing



It helps to find ***inertial reference frames***

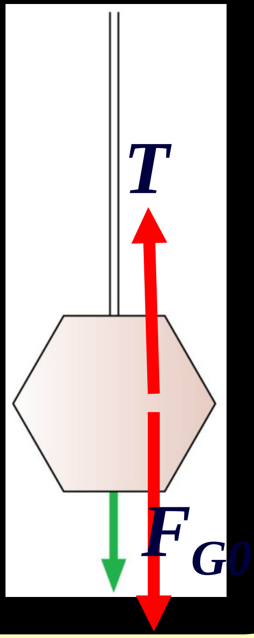
ConcepTest *N.1st Law*

- ***An object on a rope is lowered at constant speed. Which is true?***

Constant velocity

$$\vec{F}_{\text{net}} = \vec{0}$$

Vertical components cancel. $F_G = T$



A. **The rope tension is greater than the object’s weight.**

B. **The rope tension equals the object’s weight.**

C. **The rope tension is less than the object’s weight.**

D. **The rope tension can’t be compared to the object’s weight.**

Inertial reference frame

The end of the class

Inertial reference frame

- A reference frame at rest
- Or one that moves with a constant velocity

An ***inertial reference frame*** is one in which Newton's first law is valid.

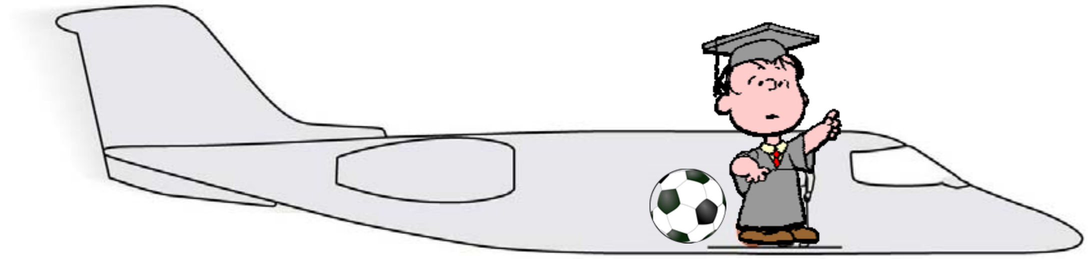
This excludes rotating and accelerating frames ***(non-inertial reference frames),*** where Newton's first law does not hold.

How can we tell if we are in an inertial reference frame?
- By checking if Newton's first law holds!

Inertial Reference Frame (*Example*)

A physics student cruises at a constant velocity in an airplane.

A ball placed on the floor stays at rest relative to the airplane.



The ball stays in place; the airplane is an inertial reference frame.

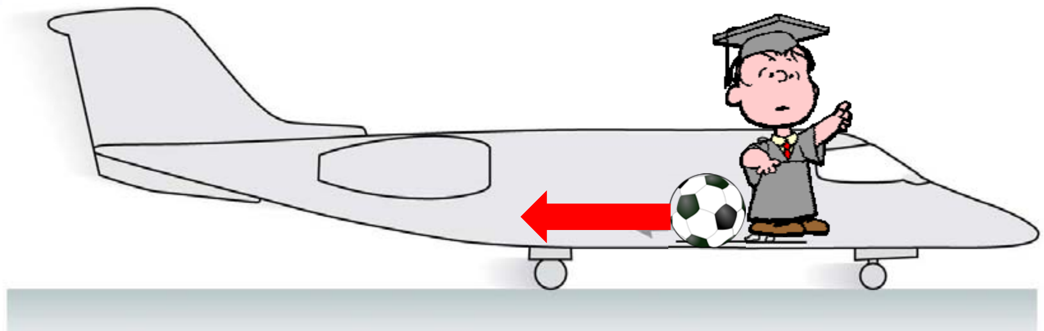
There are no horizontal forces on the ball, so $\vec{a} = 0$ when $\vec{F}_{\text{net}} = 0$.

Newton's first law is satisfied, so this airplane is an inertial reference frame.

Non-Inertial Reference Frames (*Example*)

A physics student is standing up in an airplane during takeoff.

A ball placed on the floor rolls toward the back of the plane.



The ball accelerates toward the back even though there are no horizontal forces; the airplane is *not* an inertial reference frame.

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**.

Newton’s Second Law of Motion

Newton’s second law is the relation between acceleration and force.

Acceleration is proportional to force and inversely proportional to mass.

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

New unit of force Newton

$$N = kg \cdot \frac{m}{s^2}$$

- It takes a force to change either the direction or the speed of an object.
- More force means more acceleration;
- the same force exerted on a more massive object will yield less acceleration.

Mass

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

Proportionality defines mass of object.

Mass is the measure of inertia of an object, sometimes understood as the quantity of matter in the object.
In the SI system, mass is measured in kilograms.

Mass is not weight.

Mass is a property of an object.
Weight is the force exerted on that object by gravity.

If you go to the Moon (gravitational acceleration is about 1/6 *g)*, you will weigh much less.
Your mass, however, will be the same.

Drawing a Free-body Diagram

TACTICS BOX 5.3

MP

Drawing a free-body diagram

1. **Identify all forces acting on the object.** This step was described in Tactics Box 5.2.
2. **Draw a coordinate system.** Use the axes defined in your pictorial representation.
3. **Represent the object as a dot at the origin of the coordinate axes.** This is the particle model.
4. **Draw vectors representing each of the identified forces.** This was described in Tactics Box 5.1. Be sure to label each force vector.
5. **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.

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.

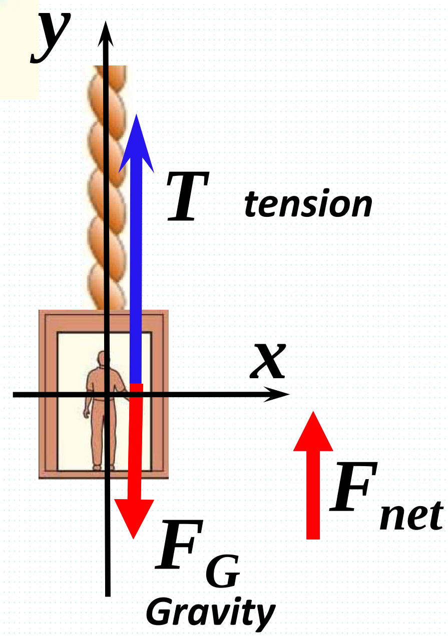
Draw a coordinate system.

$$F_{net} = ma$$

$$F_{net} = T - F_G = ma > 0$$

$$F_{net} > 0 \text{ (upward)}$$

$$\boxed{\therefore\ T > F_G}$$

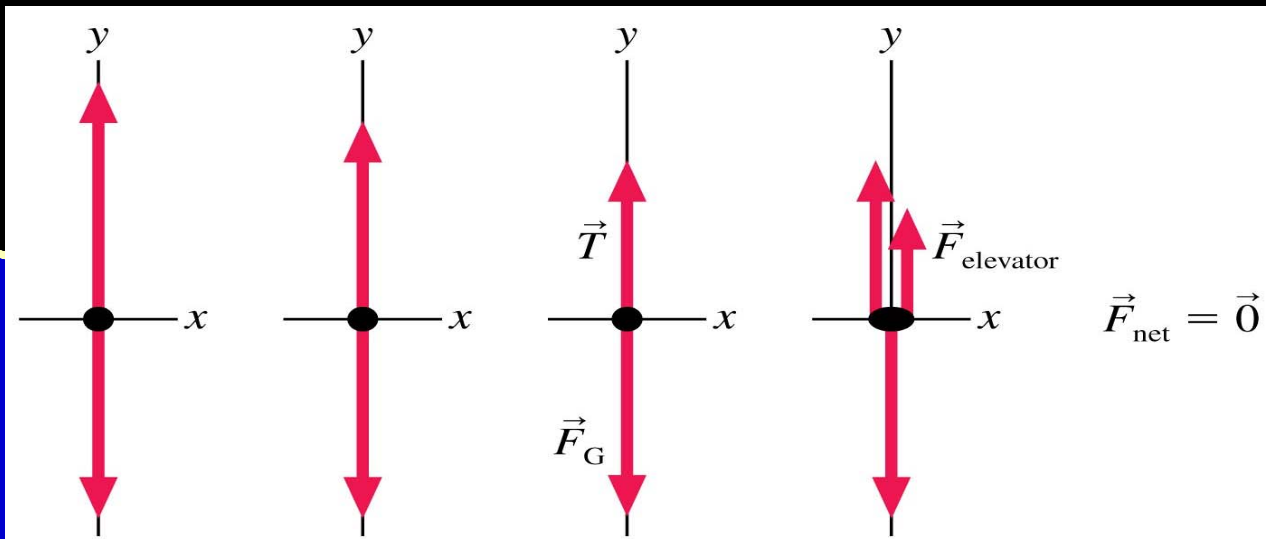


Draw and label $\vec{F}_{net}$ beside the diagram.

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.

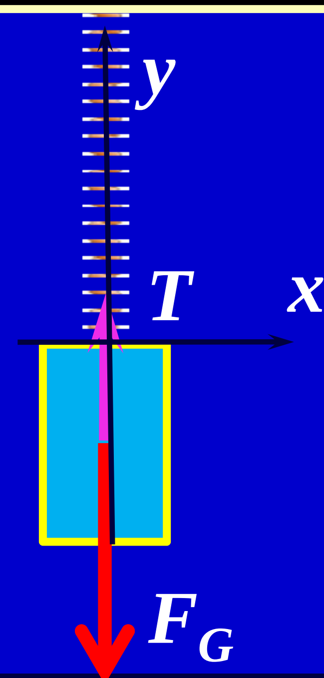
ConcepTest

An elevator, lifted by a cable, is moving upward and slowing. Which is the correct free-body diagram?



A. ***B.*** ***C.*** ***D*** ***E.***

The elevator is slowing down (acceleration is downward), so it *must* have a net downward force. The forces on it are *T* (up) and *mg* (down), so *T* must be <u>smaller</u> than *mg* in order to give the net downward force!

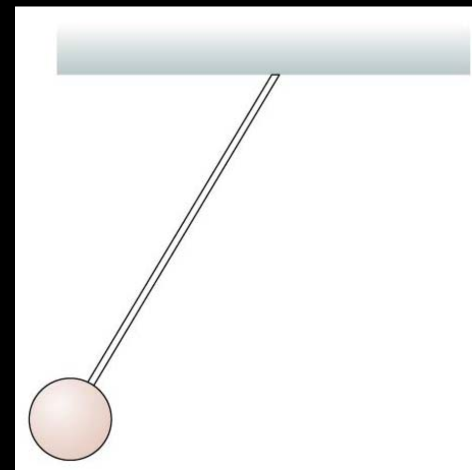


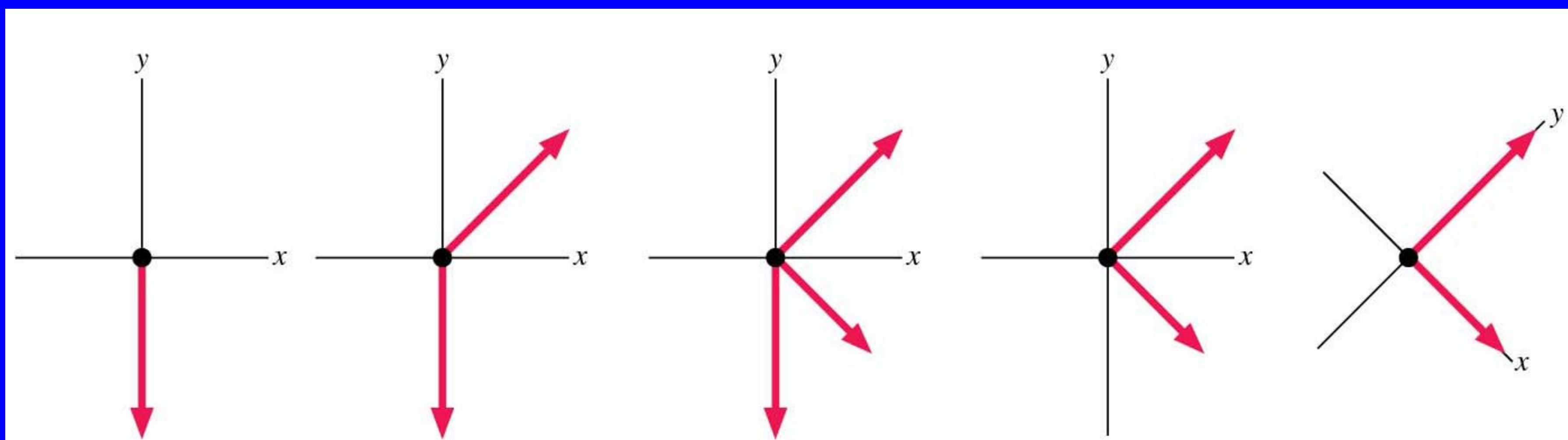
$$\Sigma F = T - F_G = ma < 0$$

$$\therefore \quad T < F_G$$

ConcepTest  *Free-body Diagram*

- ***A ball, hanging from the ceiling by a string, is pulled back and released. Which is the correct free-body diagram just after its release?***





A. **B.** **C.** **D.** **F.**

Thank you
See you on Monday