Kinematics: how the objects move?

Dynamics: why do they move? What makes an object at rest begin to move?
what changes the object velocity?

- a force is required

Force has magnitude and direction – is a VECTOR

Aristotle (384-322 B.C) vs. Galileo (1564 – 1642)

- Natural for an object to be at rest
- As natural for an object to be in motion with constant velocity as it is for it to be at rest

Galileo: imagine a world with no friction – if no force is applied to a moving object, it will continue to move with constant speed in a straight line

Pushing force cancels the force of friction - constant velocity (net force is zero)
Newton’s First Law of Motion

On top of Galileo’s work, Newton built his theory of motion.

In the *Principia*, Newton’s analysis of motion is summarized in his “three laws of motion”

**First Law of Motion** (also called Law of Inertia)

*Every object continues in its state of rest, or uniform velocity in a straight line, as long as no net force acts on it.*

The tendency of an object to maintain its state of rest or uniform motion in a straight line is called **inertia**.

![Net force equation](http://books.google.com/books?q=principia)

**Inertial reference frame**: any reference frame where Newton’s first law holds.
Mass

Mass: is the quantity of matter
is the **inertia** of an object
how much it resists any change in motion

Truck has more inertia than a soccer ball
It is more to difficult to speed up or change direction of motion of a truck

Mass is a **SCALAR**
In SI units the unit of mass is kilogram (kg)

Mass is different from weight
property of force
an object VECTOR
SCALAR
Newton’s Second Law of Motion

The acceleration of an object is directly proportional to the net force acting on it, and is inversely proportional to its mass. The direction of the acceleration is in the direction of the net force acting on the object.

\[ \sum \vec{F} = m \vec{a} \]

**Force** is an action capable of accelerating an object, is a VECTOR, its direction is the same as the acceleration.

For the motion along a line (one dimension):

\[ \sum F = ma \]

**Unit of force:**

In SI units: **newton** (N)

1 N = 1 kg m/s²

In cgs units: **dyne**

1 dyne = 1 g cm/s²

\[ \sum F_x = ma_x \]
\[ \sum F_y = ma_y \]
\[ \sum F_z = ma_z \]
Problem 4.3

What average net force is required to bring a 1500-kg car to rest from 28 m/s within a distance of 55 m?

\[ v^2 = v_0^2 + 2a(x - x_0) \]

\[ a = \frac{v^2 - v_0^2}{2(x - x_0)} = -7.1 \text{ m/s}^2 \]

\[ \sum F = ma = (1500 \text{ kg})(-7.1 \text{ m/s}^2) = -1.1 \times 10^4 \text{ N} \]
Newton’s Third Law of Motion

Force is the interaction between objects.

*Whenever on object exerts a force on a second object, the second exerts an equal force in the opposite direction on the first.*

“to every action there is an equal and opposite reaction”

\[ \vec{F}_{12} = -\vec{F}_{21} \]

3rd Law’s forces act on different objects!
Newton’s Third Law of Motion

Read Ex. 4.5
Ex. A
A massive truck collides head-on with a small car. (a) Which vehicle experiences the greater force of impact? (b) Which experiences the greater acceleration? (c) Which of Newton’s laws is useful to obtain the correct answer for each item?

(a) The same; (b) the car; (c) third law for (a) and second law for (b)
All objects dropped on Earth fall with constant acceleration. The force causing this acceleration is the **force of gravity** or **gravitational force**. EARTH exerts the gravitational force on an object.

Newton’s second law:

\[ \vec{F}_G = m\vec{g} \]

**Direction** is down toward the center of Earth
**Magnitude** is called **WEIGHT**

Weight on Earth vs. weight on the Moon
The Normal Force

Force of gravity acts on an object when it is falling. It ALSO acts on an object when it is at rest on Earth, but the object does not move because of the contact force.

Contact force perpendicular to the surface = normal force

At rest:

$$\sum \vec{F} = \vec{F}_G + \vec{F}_N = 0$$

$$|\vec{F}_G| = -|\vec{F}_N|$$

Weight is the gravitational force on the object.

Normal force is the force exerted by the support on the object.
Ex. 4-6 A box of mass 10.0 kg rests on a smooth (frictionless) horizontal surface of a table. (a) What is its weight and normal force exerted by the table? (b) If you push it down with force 40.0 N, what is the normal force exerted by the table? (c) If you pull it upward with force 40.0 N, what is normal force exerted by the table?

\[ \Sigma F_y = ma_y \]

(a) \( F_G = 98.0 \text{N} \) downward, \( F_N = 98.0 \text{N} \) upward

(b) 138 N  

(c) 58.0 N

Ex. 4-7 If you pull it upward with force 100.0 N, what is the acceleration upwards?

Net force = 2.00 N upward, \( a = \frac{2.00}{10.0 \text{kg}} = 0.20 \text{m/s}^2 \)
Weight and Scale

**At rest:**

\[ \ddot{a} = 0 \Rightarrow \Sigma \vec{F} = 0 \]

\[ \vec{F}_N + \vec{F}_g = 0 \quad \Rightarrow \quad F_N - mg = 0 \Rightarrow F_N = mg \]

**At motion with uniform acceleration:**

\[ \Sigma \vec{F} = m \ddot{a} \]

\[ \vec{F}_N + \vec{F}_g = m \ddot{a} \]

\[ F_N - mg = ma \Rightarrow F_N = m(g + a) \]

- If \( a = 0 \), scale gives a reading of \( mg \)
- If \( a > 0 \), the reading is larger
- If \( a < 0 \), the reading is smaller
Problems

Ex. 4.9 Calculate the magnitude of the resultant force exerted on the boat by workers A and B. (no friction)

\[ F_x = 52.3 \text{N}, \quad F_y = 10.2 \text{N} \]

\[ F_R = 53.3 \text{N} \quad \tan(\theta) = 0.195 \]

\[ \theta = 11.0^\circ \]

Ex. 4.10 Frictionless surface. The object moves with constant velocity. Which figure correctly describes the motion?

(a)  
(b)
1. Draw a **free-body diagram** for each object. (show ALL forces ON the object alone)

2. Apply **Newton’s second law** to the x and y **components** separately.

3. Solve the equations for the unknowns

Ex. 4.11 The mass is 10.0 kg. The surface is frictionless. Find (a) the acceleration of the box and (b) the magnitude of the normal force.

(a) $a_x = 3.46 \text{ m/s}^2$

(b) $F_N = 78.0 \text{N}$
Ex.4-12. Find (a) the acceleration of each box and (b) the tension in the cord connecting the boxes.

(a) $a = 1.82 \text{ m/s}^2$

(b) $F_T = 21.8.0\text{ N}$
Atwood’s machine and pulley

Ex. 4-14 What force must be exerted on the rope to lift the piano with constant velocity?

Advantage of a pulley

Ex. 4-13 Find (a) the acceleration of the elevator and (b) the tension in the cable (choose upward positive)

Atwood’s machine

\[
F_T - m_E g = -m_E a_E
\]

\[
F_T - m_C g = +m_C a_C
\]

\[
a_E = a_C
\]

\[
F_T = m_C g + m_C a
\]

\[
m_C g + m_C a - m_E g = -m_E a
\]

\[
(m_C + m_E) a = (m_E - m_C) g
\]

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CHECKPOINT 4

The suspended body in Fig. 5-9c weighs 75 N. Is $T$ equal to, greater than, or less than 75 N when the body is moving upward (a) at constant speed, (b) at increasing speed, and (c) at decreasing speed?
What are the three Newton’s law?

**First law**
\[ \Sigma \vec{F} = 0 \]

*Every object continues in its state of rest, or uniform velocity in a straight line*

**Second law**
\[ \Sigma \vec{F} = m \vec{a} \]

*What is the difference between mass and weight?*

**Third law**
\[ \vec{F}_{12} = -\vec{F}_{21} \]

*Examples?*

1. Draw a **free-body diagram** for each object.  
   (show ALL forces ON the object alone)

2. Apply **Newton’s second law** to the x and y **components** separately.

3. Solve the equations for the unknowns
Friction

Object at rest:

\[
F_{fr} = 0
\]

Object at motion:

\[
F_A - F_{fr} = ma_x
\]

\[
F_A - F_{fr} = 0
\]
Experiments show that the **magnitude** of the **friction force** is proportional to the **normal force**

\[ F_{fr} = \mu F_N \]

Friction force is parallel to the surface
while
Normal force is perpendicular to the surface
<table>
<thead>
<tr>
<th>Surfaces</th>
<th>Coefficient of Static Friction, $\mu_s$</th>
<th>Coefficient of Kinetic Friction, $\mu_k$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood on wood</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>Ice on ice</td>
<td>0.1</td>
<td>0.03</td>
</tr>
<tr>
<td>Metal on metal (lubricated)</td>
<td>0.15</td>
<td>0.07</td>
</tr>
<tr>
<td>Steel on steel (unlubricated)</td>
<td>0.7</td>
<td>0.6</td>
</tr>
<tr>
<td>Rubber on dry concrete</td>
<td>1.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Rubber on wet concrete</td>
<td>0.7</td>
<td>0.5</td>
</tr>
<tr>
<td>Rubber on other solid surfaces</td>
<td>1–4</td>
<td>1</td>
</tr>
<tr>
<td>Teflon® on Teflon in air</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Teflon on steel in air</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Lubricated ball bearings</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Synovial joints (in human limbs)</td>
<td>0.01</td>
<td>0.01</td>
</tr>
</tbody>
</table>

† Values are approximate and intended only as a guide.
Experiments show that the **magnitude** of the **friction force** is proportional to the **normal force**

\[ F_{fr} = \mu F_N \]

Friction force is parallel to the surface while Normal force is perpendicular to the surface

When at rest:
- Coefficient of **static** friction \( \mu_S \)
- Coefficient of **kinetic** friction \( \mu_K \)

Generally

\[ \mu_S > \mu_K \]

Why?
Surface on a microscopic scale: bumps
Atoms of different surfaces - bonds
Friction at Rest vs. at Motion

Object at rest: \[ 0 \leq F_{fr} \leq \mu_S F_N \] (static friction force)

Object at motion: \[ F_{fr} = \mu_K F_N \] (kinetic friction force)

Ex. 4-16 A box of mass \( m = 10.0 \text{ kg} \) rests on a horizontal floor. The coefficient of static friction is 0.40 and the coefficient of kinetic friction is 0.30. In a graph, show the values of the friction force when there is a horizontal external force of magnitude 0, 10N, 20N, 38N, 40N, 50N, 60N

\[ F_N = 98N \]
\[ F_{fr}^{\text{max (static)}} = \mu_S F_N = 39N \]
\[ F_{fr}^{\text{(kinetic)}} = \mu_K F_N = 29N \]
Ex. 4-19  Mass of the box=10.0 kg, the applied force is 40.0N, and the coefficient of kinetic friction is 0.30. Calculate the acceleration.

\[ F_N = 78.0N \]
\[ F_{fr} = \mu_k F_N = 23.4N \]
\[ a = 1.1m/s^2 \]

Ex. 4-20  The coefficient of kinetic friction is 0.20. As box B moves down, box A moves to the right. Calculate the acceleration. (positive to the right and positive downward)

\[ F_N = 49.0N \]
\[ F_{fr} = \mu_k F_N = 9.8N \]
\[ a = 1.4m/s^2 \]
Ex. 4.21  Given the slope and the coefficient of kinetic friction, calculate the acceleration

\[ a = (\sin \theta - \mu \cos \theta)g \]