PHY115

Newton's Laws Of Motion

Digipen

Spring 2023

NEWTON'S LAWS OF MOTION

- Kinematics $\rightarrow$ describer motion
- Dynamics $\rightarrow$ describes the relationship of motion to the forces that cause it.

Newton deduced the three laws from a multitude of experiments performed by other scientists, especially Galileo Galilei.

What is a force?

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There are different kinds of forces,

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- Contact forces: normal force, friction force
- Long range forces: Gravity, Electromagnetic

(a) **Normal force $\vec{n}$:** When an object rests or pushes on a surface, the surface exerts a push on it that is directed perpendicular to the surface.

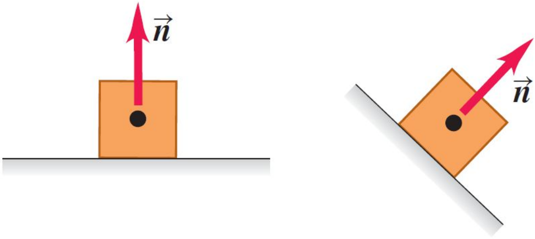
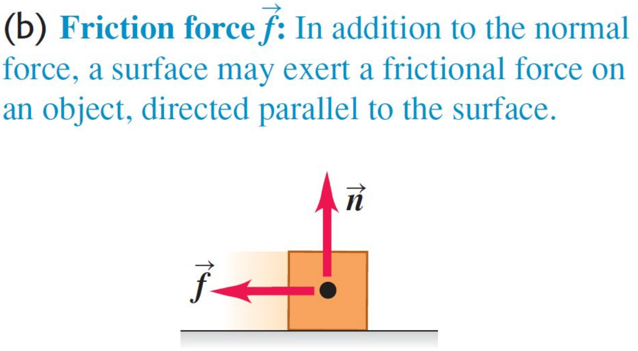


Figure: Figures from Sears and Zemansky's University Physics with Modern Physics, 13th Edition.



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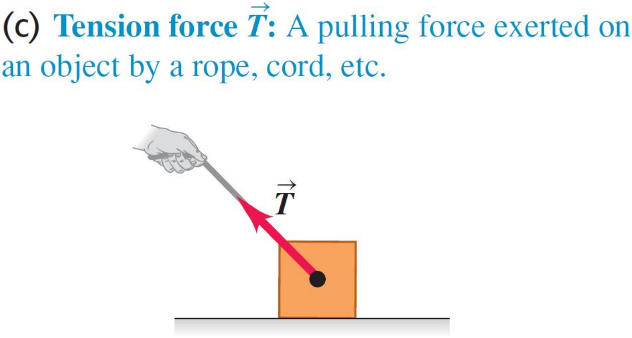
http://mw.concord.org/modeler1.3/mirror/materials/friction.html



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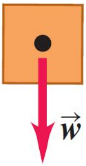
(d) **Weight $\vec{w}$:** The pull of gravity on an object is a long-range force (a force that acts over a distance).



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The units of force are Newtons.

Table 4.1 Typical Force Magnitudes

Sun's gravitational force on the earth	3.5×10^{22} N
Thrust of a space shuttle during launch	3.1×10^{7} N
Weight of a large blue whale	1.9×10^{6} N
Maximum pulling force of a locomotive	8.9×10^{5} N
Weight of a 250-lb linebacker	1.1×10^{3} N
Weight of a medium apple	1 N
Weight of smallest insect eggs	2×10^{-6} N
Electric attraction between the proton and the electron in a hydrogen atom	8.2×10^{-8} N
Weight of a very small bacterium	1×10^{-18} N
Weight of a hydrogen atom	1.6×10^{-26} N
Weight of an electron	8.9×10^{-30} N
Gravitational attraction between the proton and the electron in a hydrogen atom	3.6×10^{-47} N

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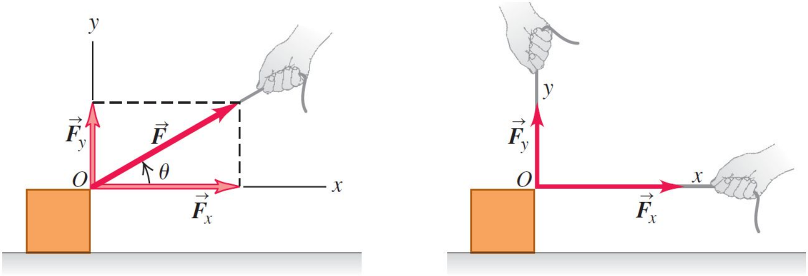
Superposition of Forces



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$$\vec{R} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \cdot = \sum \vec{F} \tag{1}$$

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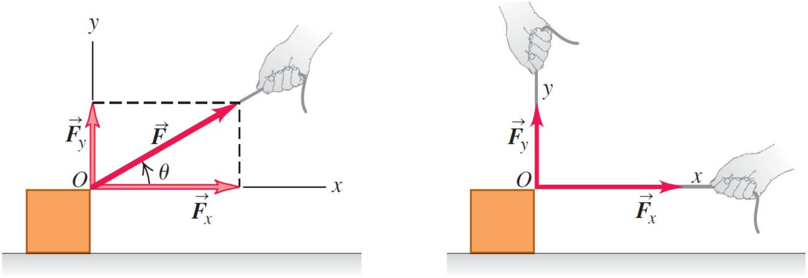

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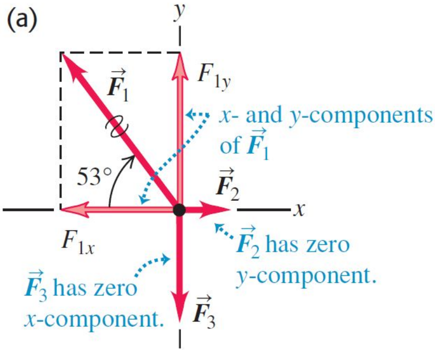
In 2D:

Example: What bis the resultant Force?



$F_1 = 250$ N $F_2 = 50$ N $F_3 = 120$ N

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Example: What bis the resultant Force?

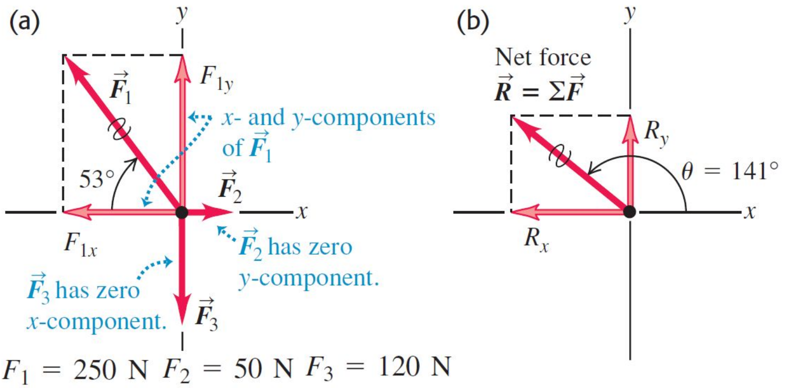
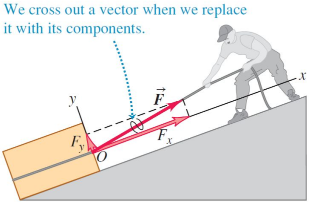


Figure: Figures from Sears and Zemansky's University Physics with Modern Physics, 13th Edition.

With the x- and y-axes shown in the figure, which statement about the components of the gravitational force that the earth exerts on the crate (the crate's weight) is correct?

1. The x- and y-components are both positive.
2. The x-component is zero and the y-component is positive.
3. The x-component is negative and the y-component is positive.
4. The x- and y-components are both negative.
5. The x-component is zero and the y-component is negative.
6. The x-component is positive and the y-component is negative.



How do the forces that act on a body affect its motion?

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THIS STATEMENT IS WRONG !!

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The tendency of a body to keep moving once it is set in motion results from a property called **inertia**.

Equilibrium

When a body is either at rest or moving with constant velocity (in a straight line with constant speed), we say that the body is in **equilibrium**.

$$\sum \vec{F} = \mathbf{0} \rightarrow \sum F_x = 0 \; and \; \sum F_y = 0$$

Inertial Frame of Reference

This concept is central to Newton's laws of motion.

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Let's see this example of motion inside the International Space Station:

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In the Previous example, Newton's First law seems not to be working!

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An inertial frame of reference is a frame of reference that is not undergoing acceleration.

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The earth is at least approximately an inertial frame of reference,

An inertial frame of reference is a frame of reference that is not undergoing acceleration.

We name the apparent forces that act on bodies in a non-inertial reference frame, **Fictitious Forces**.

Non-Inertial Frames of References

- Rotating surfaces.
- Accelerating cars.
- ...

There are many inertial frames...

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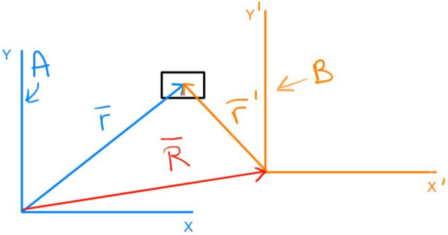
If we have an inertial frame of reference A, in which Newton's first law is obeyed, then any second frame of reference B will also be inertial if it moves relative to A with constant velocity.



$$\vec{r} = \vec{R} + \vec{r'} \rightarrow \vec{v} = \vec{V} + \vec{v'}$$

$$\rightarrow \vec{a} = \vec{A} + \vec{a'}$$

$$if \;\; \vec{A} = \vec{0} \rightarrow \vec{a} = \vec{a'}$$

Test Your Understanding

In which of the following situations is there zero net force on the body?

1. an airplane flying due north at a steady 120 m/s and at a constant altitude;
2. a car driving straight up a hill with a 3 deg slope at a constant 90 km/h:
3. a hawk circling at a constant speed at a constant height of 15 m above an open field;
4. a box with slick, frictionless surfaces in the back of a truck as the truck accelerates forward on a level road at $5 m/s^2$.

Newton's Second Law

Experiments shows that a net force acting on a body causes the body to accelerate in the same direction as the net force.

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Then, the relation between the acceleration and Force that produces it, must be something like...

$$\sum \vec{F} = (positive\ number) \cdot \vec{a} \tag{3}$$

Mass and Force

Then for a given body, we have:

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$$\boxed{m = \frac{|\sum \vec{F}|}{|\vec{a}|}} \tag{4}$$

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$$\boxed{1\ N = 1\ kg \cdot m/s^2} \tag{5}$$

Stating Newton's Second law

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If a net external force acts on a body, the body accelerates. The direction of acceleration is the same as the direction of the net force. The mass of the body times the acceleration of the body equals the net force vector.

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$$\boxed{\sum \vec{F} = m \cdot \vec{a}} \tag{6}$$

$$\sum F_x = ma_x, \; \sum F_y = ma_y, \; \sum F_z = ma_z$$

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Example: https://www.youtube.com/watch?v=sPZ2bjW53c8

$\boxed{CAUTION}$

$m \cdot \vec{a}$ is not a force. You must keep in mind that even though the vector is equal to the vector sum of all the forces acting on the body, the vector is not a force. Acceleration is a result of a nonzero net force; it is not a force itself.

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Mass and Weight

- Mass characterizes the inertial properties of a body.
- The greater the mass, the greater the force needed to cause a given acceleration.
- Weight, on the other hand, is a force exerted on a body by the pull of the earth.

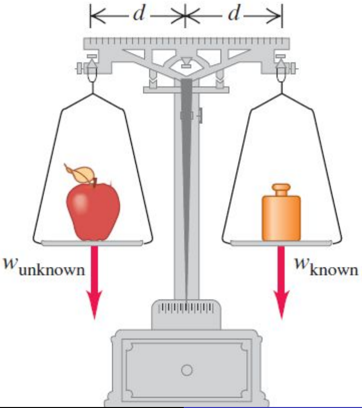
$$\vec{w} = m\vec{g} \tag{7}$$

If the mass is 1 kg, then

$$w = ma = (1\ kg)(9.8\ m/s^2) = 9.8\ N \tag{8}$$

Measuring Mass and Weight

We can measure mass comparing its weight to a known weight. The standard mass is defined as the mass f a cylinder of platinum–iridium alloy kept in a vault near Paris.



Newton's Third Law

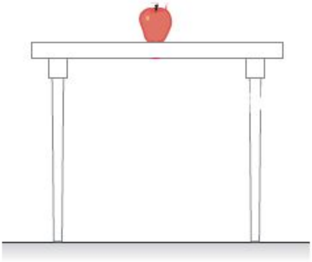
If body A exerts a force on body B (an "action"), then body B exerts a force on body A (a "reaction"). These two forces have the same magnitude but are opposite in direction. These two forces act on different bodies.

$$\vec{F}_{A\ on\ B} = -\vec{F}_{B\ on\ A} \tag{9}$$

Example `https://www.youtube.com/watch?v=ZkVU-bj9bDk`

Example, what is wrong in this scene?
https://www.youtube.com/watch?v=dKJa-KQNjQU

An apple sits at rest on a table, in equilibrium. What forces act on the apple? What is the reaction force to each of the forces acting on the apple? Which are the action–reaction pairs?



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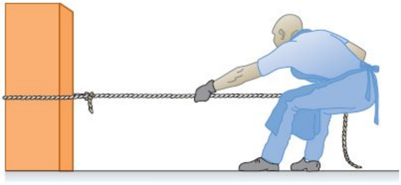
Identify the forces that act when a mason pulls on a rope attached to a block.



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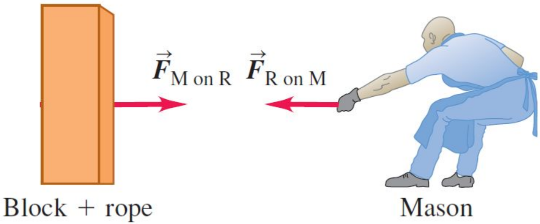
The stonemason pulls as hard on the rope–block combination as that combination pulls back on him. Why, then, does the block move while the stonemason remains stationary?



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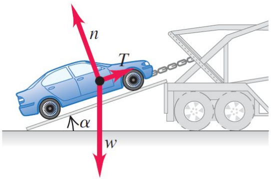
- Choose a body, identify all the forces acting on it.
- Draw them as vectors
- Apply Newton's Second Law $\sum \vec{F} = m\vec{a}$

Example, which force makes you walk?

`https://www.youtube.com/watch?v=G8Veye-N0A4`

Example, an inclined plane.

A car of weight w rests on a slanted ramp attached to a trailer. Only a cable running from the trailer to the car prevents the car from rolling off the ramp. (The car's brakes are off and its transmission is in neutral.) Find the tension in the cable and the force that the ramp exerts on the car's tires.



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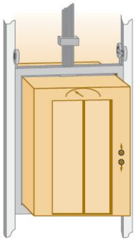
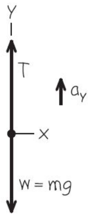
Example, tension in an elevator cable

An elevator and its load have a combined mass of 800 kg. The elevator is initially moving downward at 10 m/s it slows to a stop with constant acceleration in a distance of 25m. What is the tension T in the supporting cable while the elevator is being brought to rest?





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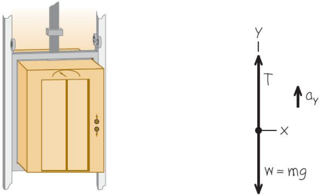
What happend when $a_y = -g$?



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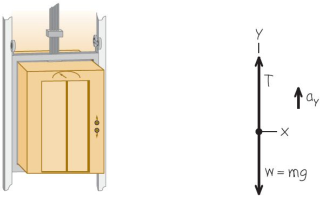

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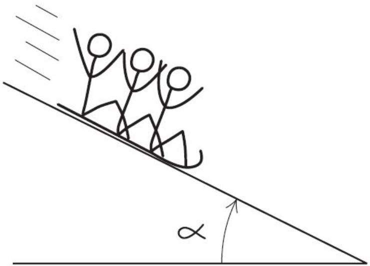
Apparent weightlessness

A toboggan loaded with students (total weight w) slides down a snow-covered slope. The hill slopes at a constant angle, and the toboggan is so well waxed that there is virtually no friction. What is its acceleration?



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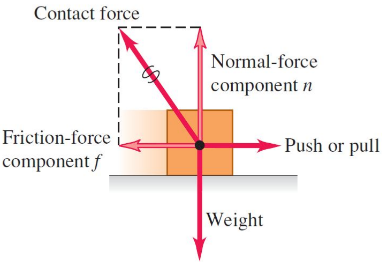
Frictional Forces

- The friction force arises from interactions between molecules on the surfaces of two bodies.
- The higher the normal force, the higher are the interactions $\rightarrow$ the higher is the friction force.



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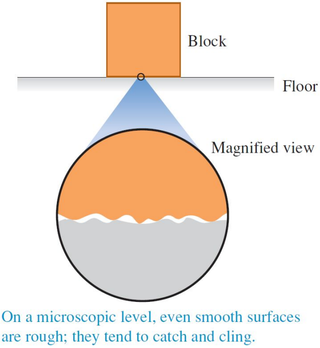
Frictional Forces

$$f_k = \mu_k N \tag{10}$$



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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

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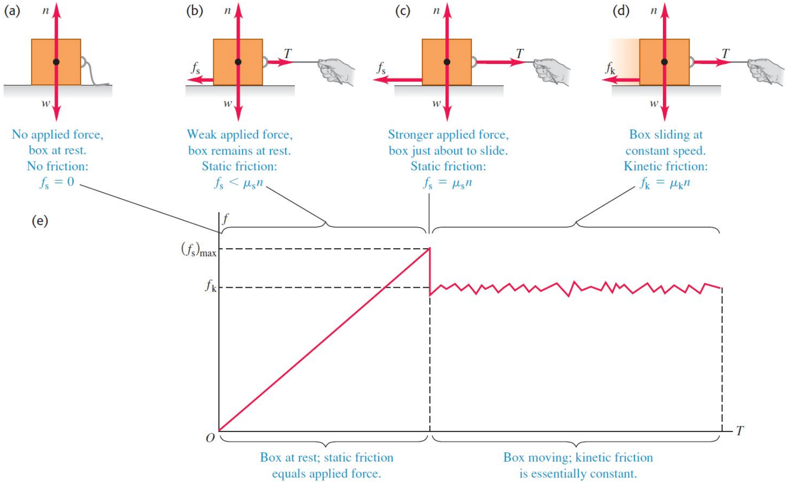

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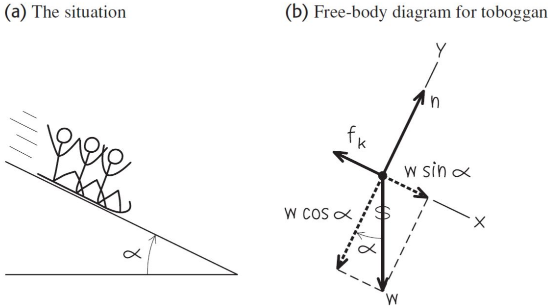
Frictional Forces

$$f_k \leq \mu_k N \tag{11}$$

Toboggan ride with friction

Let's go back to the toboggan we studied before. There is now a nonzero coefficient of kinetic friction μ_k . Find the acceleration.



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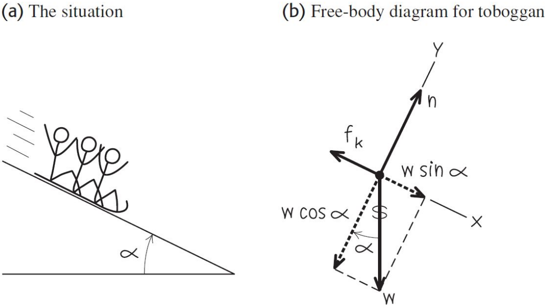
Toboggan ride with friction

Let's go back to the toboggan we studied before. There is now a nonzero coefficient of kinetic friction μ_k The slope has just the right angle to make the toboggan slide with constant velocity. Find this angle in terms of w and μ_k



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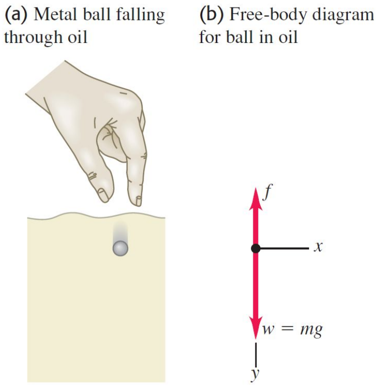
Fluid Resistance and Terminal Speed



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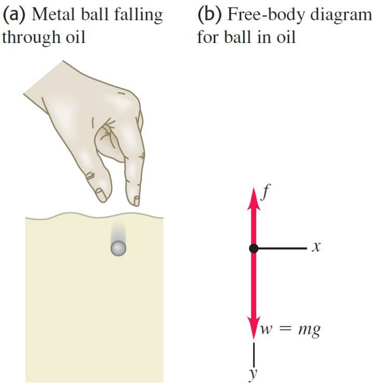
- The **fluid resistance** is the force that a fluid exerts on a body moving through it.

Fluid Resistance and Terminal Speed



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- The direction of the fluid resistance force is always opposite the direction of the motion.

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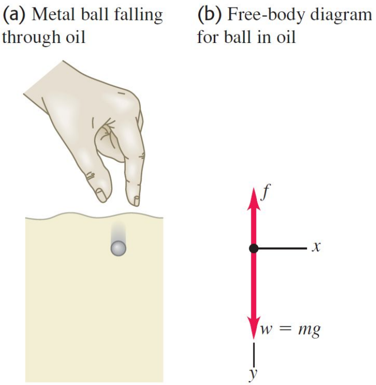

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- The direction of the fluid resistance force is always opposite the direction of the motion.
- $f = kv$ (fluid resistance at low speed).

Fluid Resistance and Terminal Speed

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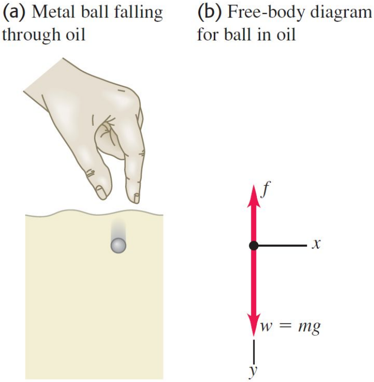
- To solve the problem we need to solve a differential equation $\rightarrow$ beyond the scope of this course.
- At some point the system reaches an equilibrium, there is a terminal speed.

Fluid Resistance and Terminal Speed



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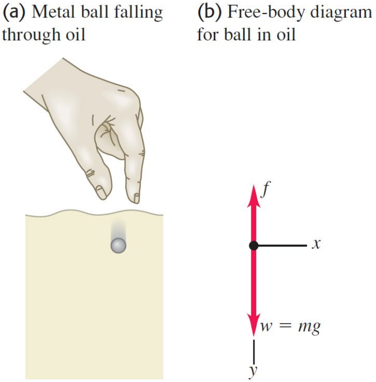
Second Newton's law:

$$\sum F_y = mg - kv = ma \quad (12)$$

Fluid Resistance and Terminal Speed



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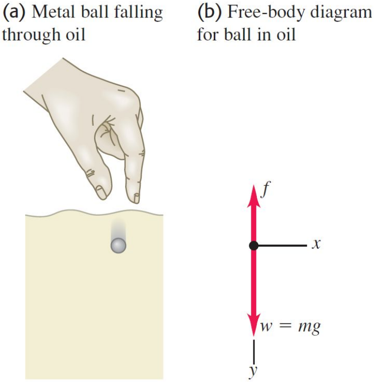
Terminal speed?

Fluid Resistance and Terminal Speed



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Second Newton's law:

$$\sum F_y = mg - kv = ma \quad (12)$$

Terminal speed?

$$a = 0 \rightarrow v = \frac{mg}{k}$$

Fluid Resistance and Terminal Speed

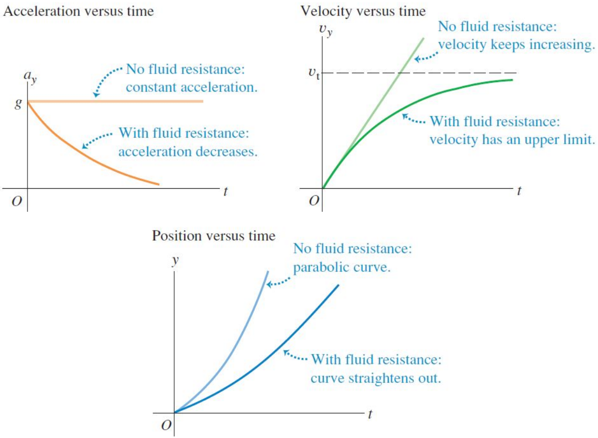


Figure: Figure from Sears and Zemansky's University Physics with Modern Physics, 13th Edition.

Rounding a banked curve

For a car traveling at a certain speed, it is possible to bank a curve at just the right angle so that no friction at all is needed to maintain the car's turning radius. Then a car can safely round the curve even on wet ice. At what angle should the curve be banked?

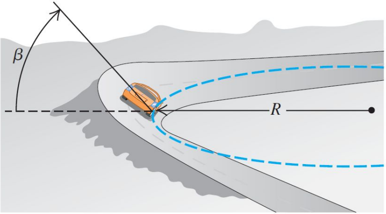
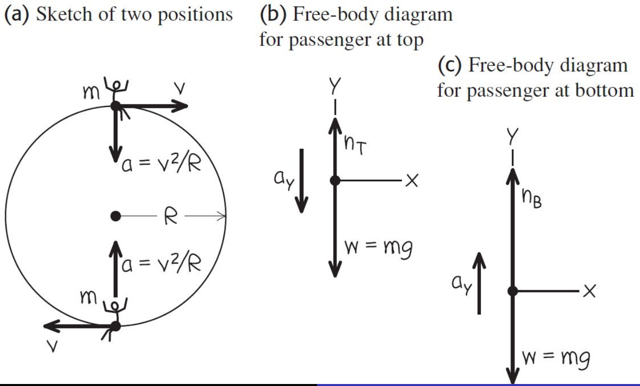


Figure: Figure from Sears and Zemansky's University Physics with Modern Physics, 13th Edition.

Motion in a vertical circle.

A passenger on a carnival Ferris wheel moves in a vertical circle of radius R with constant speed The seat remains upright during the motion. Find expressions for the force the seat exerts on the passenger at the top of the circle and at the bottom.



Test Your Understanding

Satellites are held in orbit by the force of our planet's gravitational attraction. A satellite in a small-radius orbit moves at a higher speed than a satellite in an orbit of large radius. Based on this information, what you can conclude about the earth's gravitational attraction for the satellite?

- It increases with increasing distance from the earth.
- It is the same at all distances from the earth.
- It decreases with increasing distance from the earth.
- This information by itself isn't enough to answer the question.