Conceptual Physics
Newton's 1st and 2nd Laws

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Last time

- graphing motional quantities
- free fall
- vectors
- relative motion and reference frames

Overview

- one last relative motion example
- Newton's first law
- equilibrium
- friction
- Newton's second law
- mass
- air resistance and falling objects (nonfree fall)

Relative Motion and Components of Velocity

Hewitt, page 79, ranking question 4.

Three motorboats crossing a river.

Forces

Galileo's idea of inertia:

A body moving on a level surface will continue in the same direction at a constant speed unless disturbed / interfered with.

What do we mean by "disturbed" or "interfered with"?

Forces

Galileo's idea of inertia:

A body moving on a level surface will continue in the same direction at a constant speed unless disturbed / interfered with.

What do we mean by "disturbed" or "interfered with"?

The body must interact with something else. That something-else affects the body.

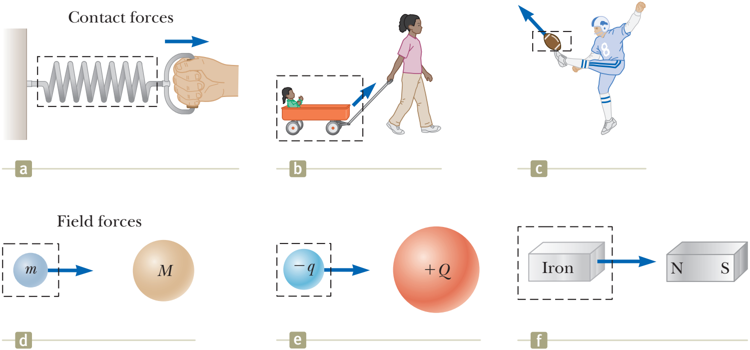
The effect is called a **force**.

The units we measure force in are called Newtons (N).
1 N = 1 kg m/s/s.

Forces

Forces are a "push" or "pull" that an object experiences because of an interaction.

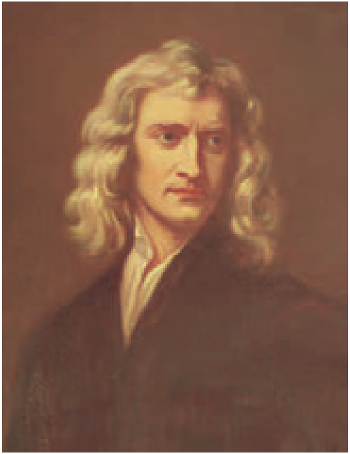
Force type examples:



[1]Serway & Jewett

Newton

Newton was able to articulate simple rules that govern the way in which forces act and effect motion.



Newton's First Law

Newton's first and second laws of motion hold in intertial reference frames.

Newton I (as commonly stated)

An object in motion tends to stay in motion with constant velocity and an object at rest tends to stay at rest, unless acted upon by a net force.

An "object" for these purposes is something with mass.

The net force on an object is the total force on the object.

Velocity and Newton's First Law

If an object is in motion and there is no net force on the object, does the speed or velocity have to be constant?

Velocity and Newton's First Law

If an object is in motion and there is no net force on the object, does the speed or velocity have to be constant?

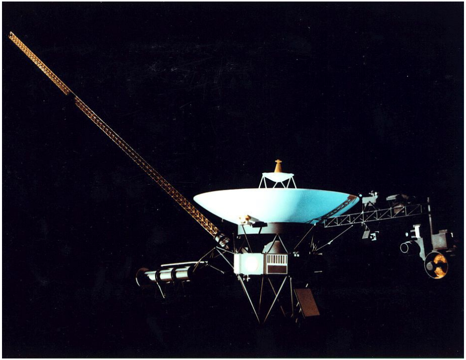
Both are constant!

Neither the speed or the direction of motion can change.

Newton's First Law

This was still a radical idea in the late 1600s. In our everyday environment, everything seems to naturally slow to a stop.

But we now know of other environments where we see this behavior.



[1]Figure from JPL.

Newton's First Law

Newton I (another way to state it)

If an object does not interact with other objects, it is possible to identify a reference frame in which the object has zero acceleration.

A zero-acceration reference frame is called an *inertial reference frame*.

Net Force

If two people push a heavy box in the same direction, the box experiences the combined force of both pushes.

However, if the people push in opposite directions, the pushing forces can cancel out.

This means that the **direction** of the forces that act on an object matter.

Forces are vectors!

Net Force

The *net force* is the vector sum of all of the forces acting on an object.

We can write it:

$$\mathbf{F}_{\text{net}} = \sum \mathbf{F}$$

The Greek letter sigma, $\sum$, is used to mean “sum over”.

Equilibrium

If the **net force** on an object is zero, we say the object is in **mechanical equilibrium**.

This means the sum of all the forces acting on the object is zero.

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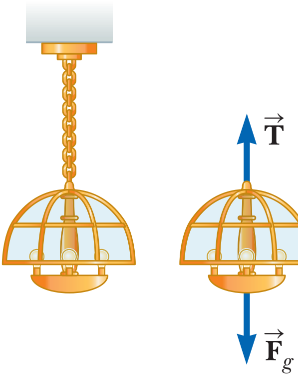
If an object is in equilibrium, what does Newton's First Law tell us about the motion of the object?

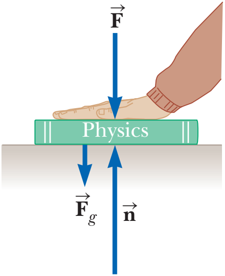
Equilibrium

$$\mathbf{F}_{\text{net}} = \sum_i \mathbf{F}_i = 0$$



Equilibrium Example

Consider a physics textbook resting on a table.



Does the book accelerate?

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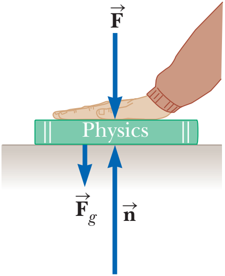

Does the book accelerate? No.

Then we know $\mathbf{F}_{\text{net}} = 0$. Then we can conclude from the weight and the applied force what the normal force must be:

$$\mathbf{n} + \mathbf{F}_g + \mathbf{F} = 0 \;\Rightarrow\; \mathbf{n} = (F_g + F)\mathbf{j}$$

Net Force - Equilibrium

Problem 3, page 34. ("What is the weight of the scaffold?")

A painter's scaffold in mechanical equilibrium.

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$$\sum F_x = 0 \qquad \text{and} \qquad \sum F_y = 0$$

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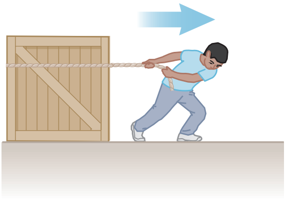
$$\sum F_x = 0 \qquad \text{and} \qquad \sum F_y = 0$$

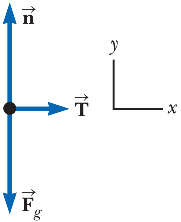
All the forces are pointing up or down. We can just consider this one direction, the y direction.

$$\begin{aligned}
F_{y,\text{net}} &= (\text{upward forces}) - (\text{downward forces}) = 0 \\
0 &= (400 + 400) - (500 + w) \text{ [N]} \\
0 &= 300 - w \text{ [N]} \\
w &= 300 \text{ N}
\end{aligned}$$

Net Force - nonequilibrium

Imagine pulling a crate, and the crate (for some reason) has no friction with the floor.





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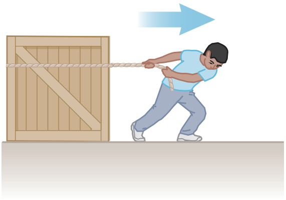

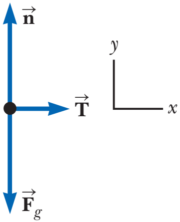

Here we can look at the forces in the x and y directions:

y direction:

$$\sum F_y = n - F_g = 0$$

x direction:

$$\sum F_x = T$$

There is a net force to the right (positive x direction): $\mathbf{F}_{\text{net}} = T\ \mathbf{i}$.

Newton's First Law Implications

Quick Quiz[1] Which of the following statements is correct?
I. It is possible for an object to have motion in the absence of forces on the object.
II. It is possible to have forces on an object in the absence of motion of the object.

A I. only

B II. only

C Neither I. or II.

D Both I. and II.

[2]Question from Serway & Jewett, Physics for Scientists and Engineers, p114

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When the coin is at the top of its path is it in equilibrium?

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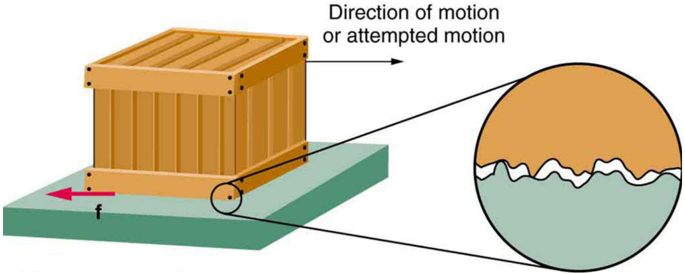
Galaxies have been moving through space for billions of years. What keeps them moving?

Question

Jen pushes on a heavy crate and moves it across the floor. However, if she stops pushing, the box stops moving. Why?

Does it violate the law of inertia?

Friction



Friction is a resistive force. It opposes motion.

Tiny defects in the surface of the floor and the crate catch on one another as the crate is pushed.

Air resistance is another resistive force.

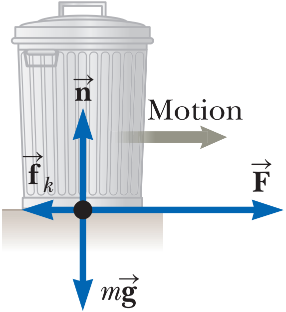
[1] Figure from boundless.com

Friction

There are actually two types of friction:

- kinetic (moving)
- static (stationary)

Kinetic Friction



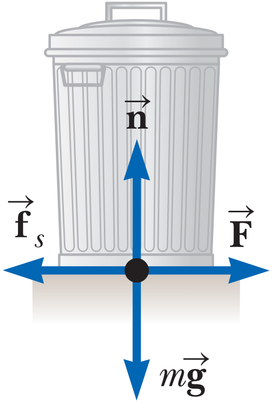
kinetic friction $\propto$ normal force

$$f_k = \mu_k n$$

μ_k is the coefficient of **kinetic** friction

Friction

Static Friction



max. static friction $\propto$ normal force

$$f_s \leqslant \mu_s n$$

μ_s is the coefficient of **static** friction

Newton's Second Law

Galileo proposed the concept of acceleration, but Newton realized:

$$\text{acceleration} \propto \text{net force}$$

(Remember net force is the sum of all the forces on an object)

If the net force on an object is doubled, the acceleration is twice as big also.

Mass and Inertia

Mass is also a measure of resistance to acceleration.

For a constant net applied force:

$$\text{acceleration} \propto \frac{1}{\text{mass}}$$

We can now relate force, mass, and acceleration.

Newton's Second Law

For objects with constant mass:

$$F_{\text{net}} = ma$$

F_{net} is net force, m is mass, a is acceleration.

This equation relates the units of force, N, to the units of mass and acceleration:

$$1 \text{ N} = 1 \text{ kg m s}^{-2}$$

Mass in this equation is sometimes called "inertial mass".

Newton's Second Law Example

Plug and Chug # 10, page 62.

Calculate the horizontal force that must be applied to produce and acceleration of $1.8g$ for a 1.2-kg puck on a horizontal friction-free air table.

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Calculate the horizontal force that must be applied to produce and acceleration of $1.8g$ for a 1.2-kg puck on a horizontal friction-free air table.

$$a = 1.8g = 1.8 \times 10 \text{ m/s/s} = 18 \text{ m/s/s}$$

There's no friction, so

$$\text{net force} = \text{normal force} + \text{weight} + \text{applied force}$$

The weight and normal force are equal in magnitude and opposite in direction, so

$$\mathbf{F}_{\text{net}} = \mathbf{F}_{\text{app}}$$

Newton's Second Law Example cont'd.

Plug and Chug # 10, page 62.

Calculate the horizontal force that must be applied to produce and acceleration of $1.8g$ for a 1.2-kg puck on a horizontal friction-free air table.

$$\begin{aligned}\mathbf{F}_{\text{net}} &= m\,\mathbf{a} \\ \mathbf{F}_{\text{app}} &= (1.2\text{ kg})(18\text{ m/s/s}) \\ &= 21.6\text{ N} \\ &= \underline{22\text{ N}} \qquad (2\text{ sig. fig.})\end{aligned}$$

Mass vs. Weight

mass

A measure of the amount of matter in an object. Also, a measure of the inertia of an object, that is, its resistance to changes in its motion. Also, a measure of how strong the force will be on an object in a gravitational field.

weight

The force due to gravity on an object.

Weight is a force. It is measured in Newtons (N) as are all forces.

$$\text{weight} = \text{mass} \times g$$

g is the strength of the gravitational field, measured in N/kg.

Mass vs. Weight

On Earth's surface $g \approx 10$ N/kg.

Knowing the mass of an object, we can quickly find its weight.

A 5-kg object has a weight of 50 N (about 11 pounds):

$$W = mg = (5\text{kg})(10 \text{ N/kg}) = 50 \text{ N}$$

Because of this relationship, sometimes kilograms are thought of as a proxy for weight.

However, the kilogram is the unit for mass. A 5-kg object would have a different weight on another planet.

Weight and acceleration

Let the weight of an object be written W.

$$W = mg$$

Mass in this equation is sometimes called "gravitational mass".

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$$a = \frac{W}{m} = \frac{mg}{m} = g$$

As we would expect! This is because the inertial mass is the same as the gravitational mass.

That is why all objects, no matter their mass, fall at the same rate (with the same acceleration).

Nonfree fall

However, the acceleration of a falling object can be less than g. When?

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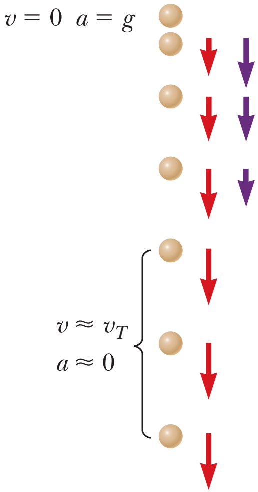
Skydivers, for example, reach a terminal velocity as they fall from an airplane, before they deploy their parachutes.

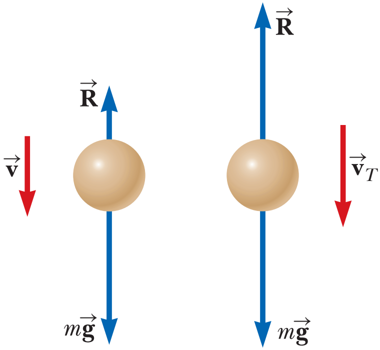
They stop accelerating once they reach this velocity.

Air resistance and nonfree fall



[1] Figure from Serway & Jewett, 9th ed.

Air resistance and nonfree fall



The drag force R depends on the velocity.

It gets bigger as $\mathbf{v}$ gets bigger, until $R = mg$.

Then the net force is zero, and the object stops accelerating.

[1] Figure from Serway & Jewett, 9th ed.

Air resistance and nonfree fall

At any point in the motion, we can still write an equation for the acceleration:

$$a = \frac{F_{\text{net}}}{m} = \frac{mg - R}{m} = g - \frac{R}{m}$$

It is something smaller than g, once $R > 0$.

Review Questions

Gravity on the surface of the Moon is only 1/6 as strong as on the surface of the Earth. What is the weight of a 10 kg object on the Moon and on the Earth? What is its mass on each?

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Gravity on the surface of the Moon is only 1/6 as strong as on the surface of the Earth. What is the weight of a 10 kg object on the Moon and on the Earth? What is its mass on each?

Can Newton's first law be considered a consequence of Newton's second law?

Review Questions

What is the net force on a falling 1 kg ball if it encounters 2 N of air resistance?

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(A) 0 N
(B) 2 N upwards
(C) 1 N downwards
(D) 8 N downwards

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Summary

- Newton's laws
- net force
- equilibrium
- nonfree fall

Homework

- 2 worksheets (set on Thurs, due tomorrow)
- 1 new worksheet (relative motion) due Thurs

Hewitt,

- Read up through Chapter 4.
- Ch 2, onward from page 31. Ranking: 1, 3. Exercises: 13, 17, Problems: 1, 3
- Ch 4, onward from page 61, Review Questions: 11, 23; Plug and Chug: 7; Exercises: 1, 17, 27, 47