Conceptual Physics
Mechanics
Units, Motion, and Inertia

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Last time

- Scientific facts, hypotheses, theories, and laws
- Measurements
- Physics as modeling the natural world

Overview

- Units
- More about size and scale
- Motion of objects
- Inertia
- quantities related to motion

Quantities, Units, Measurement

If we want to make *quantitative* statements we need to agree on measurements: standard reference units.

We will mostly use SI (Système International) units:

Length	meter, m
Mass	kilogram, kg
Time	second, s

and many more!

Physicists now strive to chose definitions for units that are based on **fundamental physical phenomena** - things anyone, anywhere could in principle observe consistently.

Units: Time

The SI unit of time is the *second*, s.

The second was originally defined (via the minute and hour) as 1/86,400-th of a day.

All clocks are based on oscillating systems - systems that repeat the same motion over and over again.

It is now more precisely defined in terms of the behavior of Cesium atoms. (Rubiduim and other elements are also used.)

Units: Time

Measuring time accurately is very important for navigation.

Accurate clocks were needed to help ships determine their longitude (East-West position) in the 1700s.

This lead to the development of clocks that worked based on the oscillations of springs rather than pendulums.

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[1] Harrison H5 naval chronometer. Photo from user Racklever, Wikipedia.

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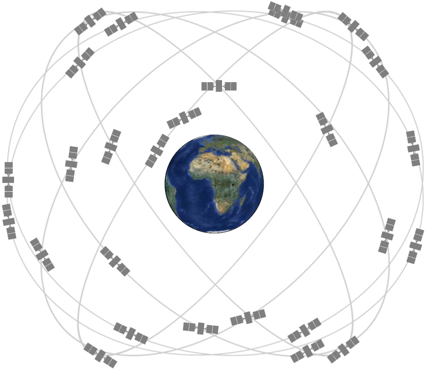

Now most navigation systems use the Global Positioning System (GPS) a constellation of satellites carrying atomic clocks.

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[1] Image from GPS.gov.

Units: Mass

The *kilogram*, kg, is the SI unit of mass.

Loosely speaking, mass is a measure of the amount of matter in an object.

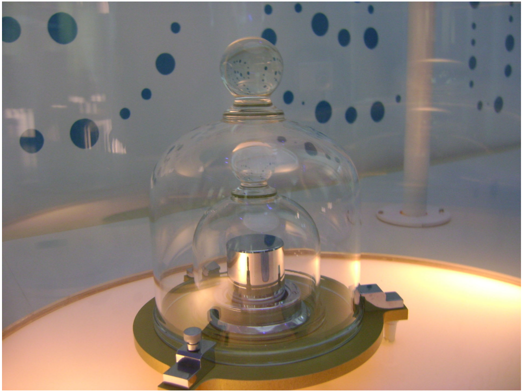
The kilogram currently does not have a definition in terms of natural phenomena.

1 kilogram is 1,000 grams.

Originally, the gram was defined to be the mass of one cubic centimeter of water at the melting point of water.

Units: Mass

Now the official 1-kilogram sample, the *international prototype kilogram* is a cylinder of platinum and iridium stored near Paris.



An alternative definition of the kilogram in terms of a fundamental constant has been proposed and will be adopted officially in 2018.

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[1] Photo: A replica of the prototype kilogram, Wikipedia.

Scale of Units

Scale	Prefix	Symbol
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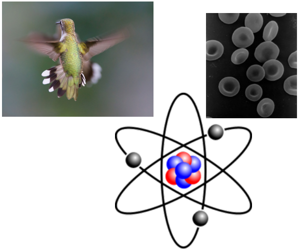
10^{15}	peta	P
10^{12}	tera-	T
10^{9}	giga-	G
10^{6}	mega-	M
10^{3}	kilo-	k
10^{2}	hecto-	h
10^{1}	deka-	da
10^{0}	—	—
10^{-1}	deci-	d
10^{-2}	centi-	c
10^{-3}	milli-	m
10^{-6}	micro-	μ
10^{-9}	nano-	n
10^{-12}	pico-	p
10^{-15}	femto-	f



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$$(3\ \text{g/cm}^3) \times \left(\frac{1\ \text{kg}}{1000\ \text{g}}\right) \times \left(\frac{100\ \text{cm}}{1\ \text{m}}\right)^3 = 3000\ \text{kg/m}^3.$$

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This is the same thing.

$$10^8 = 100,000,000$$

so,

$$3.0 \times 100{,}000{,}000 = 300{,}000{,}000 \text{ m/s}$$

Scientific Notation vs Unit Scaling Prefixes

In scientific notation,

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where 1 Mm is one mega-meter,
or use kilometers:

$$300,000 \text{ km/s}$$

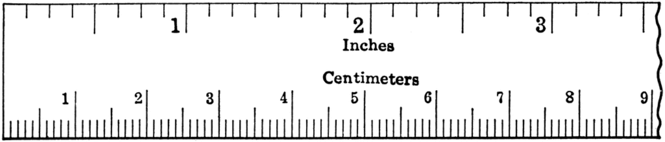
or use a prefix with scientific notation:

$$3.0 \times 10^{5} \text{ km/s}$$

Measurement Uncertainty and Significant Figures

All measuring devices are only so accurate.

For example, a ruler has millimeter (mm) marks, but not micrometer (μm) marks.



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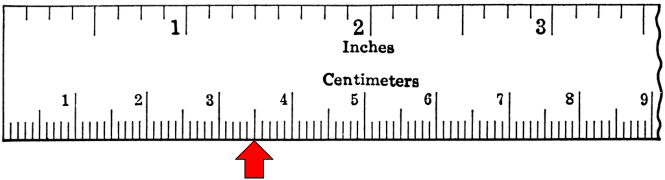

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The uncertainty in this ruler measurement is ±0.5 mm.

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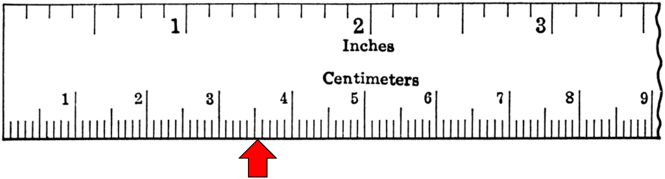

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A simple rule: if inputs to a problem or experiment are given to 3 significant figures, give the output to 3 significant figures.

Unit Conversion

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It is sometimes necessary to change units.

Example: what is 9 inches (in) in feet (ft)?

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Example: what is 9 inches (in) in feet (ft)?

3/4 of a foot, or 0.75 feet.

12 in = 1 ft.

$$(9\ \cancel{\text{inches}}) \times \left(\frac{1\ \text{foot}}{12\ \cancel{\text{inches}}}\right) = \frac{3}{4}\ \text{ft}$$

Unit Conversion Examples

To solve that problem, we again multiplied the value we wished to convert by 1.

$$(9 \text{ inches}) \times \underbrace{\left(\frac{1 \text{ foot}}{12 \text{ inches}}\right)}_{\substack{\uparrow \\ \mathbf{1}}} = 0.75 \text{ ft}$$

Any number times 1 remains unchanged.

The value remains the same, but the units change, in this case, from inches to feet.

Unit Conversion Examples

The distance between two cities is 100 mi. What is the number of kilometers between the two cities?

A smaller than 100
B larger than 100
C equal to 100

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Example: **how many seconds are there in a day?**

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$$(1 \text{ day}) \left(\frac{24 \text{ hr}}{1 \text{ day}}\right) \left(\frac{60 \text{ min}}{1 \text{ hr}}\right) \left(\frac{60 \text{ s}}{1 \text{ min}}\right)$$

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$$= 1 \times 24 \times 60 \times 60\ \text{s}$$

$$= 86,400\ \text{s}$$

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$$(60.0\ \mathrm{mi/hr})\left(\frac{1.609\ \mathrm{km}}{1\ \mathrm{mi}}\right)\left(\frac{1000\ \mathrm{m}}{1\ \mathrm{km}}\right)\left(\frac{1\ \mathrm{hr}}{60\ \mathrm{min}}\right)\left(\frac{1\ \mathrm{min}}{60\ \mathrm{s}}\right)$$

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$$= \frac{60.0 \times 1.609 \times 1000}{60 \times 60}\ \text{m/s}$$

$$= 26.8\ \text{m/s}$$

Scale of Units

Scale	Prefix	Symbol
10^{15}	peta	P
10^{12}	tera-	T
10^{9}	giga-	G
10^{6}	mega-	M
10^{3}	kilo-	k
10^{2}	hecto-	h
10^{1}	deka-	da
10^{0}	—	—
10^{-1}	deci-	d
10^{-2}	centi-	c
10^{-3}	milli-	m
10^{-6}	micro-	μ
10^{-9}	nano-	n
10^{-12}	pico-	p
10^{-15}	femto-	f

Motion of Objects

Aristotle (384 – 322 BCE) was one of the earliest *natural philosophers* (proto-physicists).

He was interested in describing the motion of objects and celestial bodies.

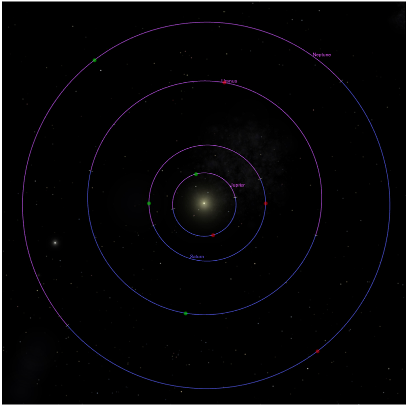
His ideas had a profound effect on thinkers for the next 1800+ years. (And they still do.)

However, his physics ideas were not quantitative, and were fairly often wrong: for example, he thought the Earth does not move.

Motion of the Earth

Nicolaus Copernicus (1473-1543) discovered that the most convenient model for the solar system has the Earth in motion.

It orbits the Sun, just as the other planets do.



Motion of the Planets

After Copernicus's proposal, Tycho Brahe gathered a lot of data about the positions of stars and planets.

Johannes Kepler inherited Brahe's data and did the calculations to deduce a complete heliocentric model.

Galileo gathered additional data that supported the heliocentric model and popularized it.

Galileo and the Leaning Tower of Pisa

Galileo also disproved another of Aristotle's ideas.

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Any two massive objects accelerate at the same rate.

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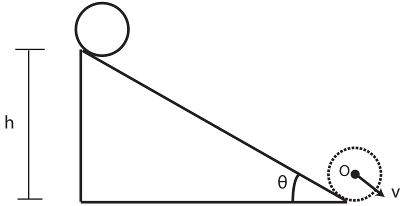
This has even been tested on the Moon!

Galileo and Inertia

Galileo studied the motion of objects by **experiment**, as well as by abstract reasoning.

He considered balls rolling on inclined surfaces...



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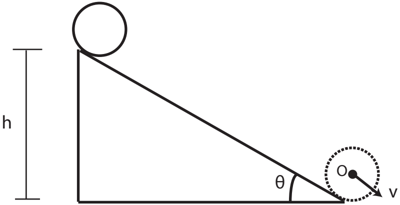


...and developed the notion of *inertia*.

Inertia is the tendency of objects to stay in whatever state of motion they already have, unless they are interfered with.

Galileo and Inertia

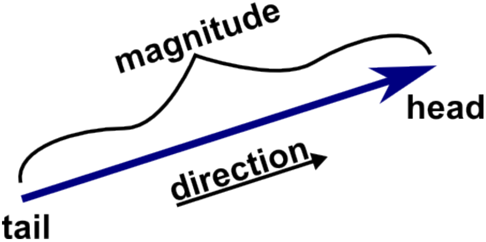
Galileo's idea of inertia:

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

To make quantitative statements about inertia, we need to first define some quantities.

Vectors

A vector is a mathematical quantity with a magnitude (amount, size) *and a direction*.



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[1] Diagram from mathinsight.org

Distance vs Displacement

How far are two points from one another?

Distance is the length of a path that connects the two points.

Displacement is the length together with the direction of a straight line that connects the two points.

Displacement is a vector.

Speed

We need a measure how fast objects move.

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

If an object goes 100 m in 1 second, its speed is 100 m/s.

Speed

Speed can change with time.

For example, driving. Sometimes you are on the highway, sometime you wait at a stoplight.

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Average speed is the average of the object's speed over a period of time:

$$\text{average speed} = \frac{\text{total distance traveled}}{\text{time interval}}$$

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Is its velocity constant?

Acceleration

Speed and velocity can change with time.

Acceleration is the rate of change of velocity with time.

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If an object is moving with constant speed in a circular path, is it accelerating?

Summary

- units
- scale of space and time
- Galileo and inertia
- motion
- speed, velocity, acceleration

Homework

Worksheets,

- 2 unit conversion worksheets (due Mon)

Hewitt,

- read Ch2
- Ch 2, onward from page 31. Exercise: 3