Preliminary Concepts

ASTR 101

August 22, 2018

- Scientific notation of numbers
- Units, dimensions
- Speed of light
- Light year, the astronomical unit
- Angular measures.

Scientific notation of numbers

- 1000,000 $= \mathbf{10^6}$ $(10 \times 10 \times 10 \times 10 \times 10 \times 10 = 10^6)$
- 299,000,000 $= 2.99 \times 100{,}000{,}000 = \mathbf{2.99 \times 10^8}$
- 0.0001 $= 1/10{,}000 = 1/10^4 = \mathbf{10^{-4}}$
- 0.0000412 $= 4.12/100000 = 4.12/10^5 = \mathbf{4.12 \times 10^{-5}}$

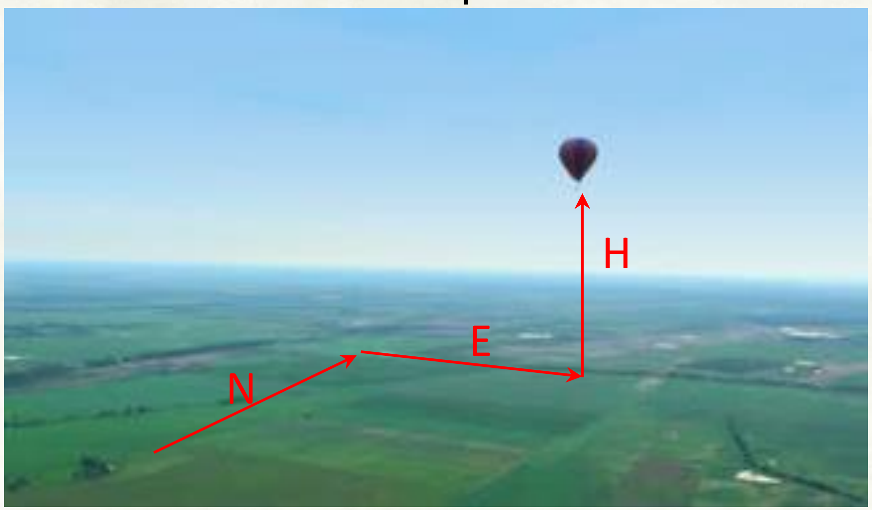
- Thousand 10^3 kilo (k)
- Million 10^6 mega (M)
- Billion 10^9 giga (G)
- Trillion 10^{12} tera (T)
- Quadrillion 10^{15} peta (P)

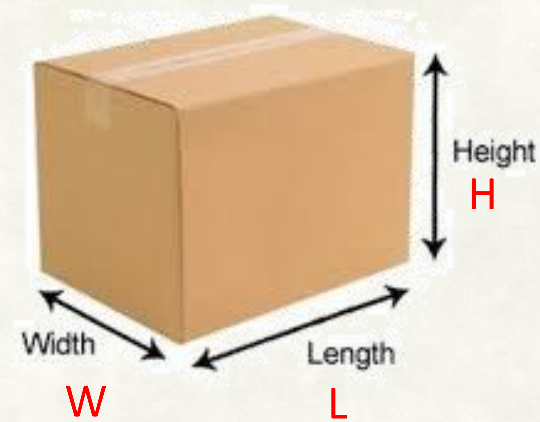
- hundredth $\frac{1}{100} = 10^{-2}$ centi(c)
- thousandth $\frac{1}{1000} = 10^{-3}$ milli (m)
- millionth 10^{-6} micro (μ)
- billionth 10^{-9} nano (n)
- trillionth 10^{-12} pico (p)
- quadrillionth 10^{-15} femto (f)

Examples: centimeter 1 cm = 1/100 m, milligram 1 mg = 10^{-3} g
1TB = 1 tera byte = 10^{12} bytes micrometer μm = 10^{-6} m

Space and time

- We live in a 3 dimensional world
  - Need 3 spatial dimensions (lengths) to specify the size of an object, or a location.
    - Any object has a length, width and a height
    - Also need 3 spatial dimensions to specify a location





- Also we need to specify the time T:
  - Like the balloon is at a certain location at a given time.

- So we need 3 lengths to give the location in space and time to specify an event.
- Often we also have to give other physical characteristics like mass and the temperature of an object to fully describe it.

Units

International System of Units (SI) is the preferred system of units used in science. It is a modern form of the metric system.

- length meter (m)
- time second (s)
- mass kilogram (kg) = 1000 g (grams)

1m = 39.37 inches = 3 feet 3.4 inches; 1 foot= 30.5cm=0.305m

1km = 0.62 miles 1 mile =1.61 km

1kg = 2.205 lbs 1 lbs = 0.454 kg

Temperature

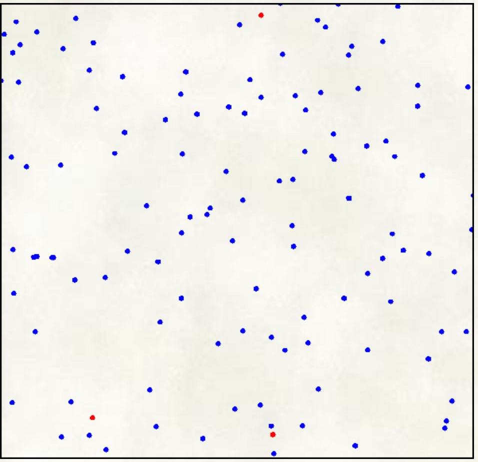
- temperature Kelvin (K) ; Kelvin = Celsius +273.15
  - 0 Kelvin (0K) = -273.15 °C:

Example: boiling point of water = 100 °C = 373.15 K ≃ 373K
freezing point of water = 0 °C = 273.15 K ≃ 273K
absolute zero temperature = -273.15 °C = 0K

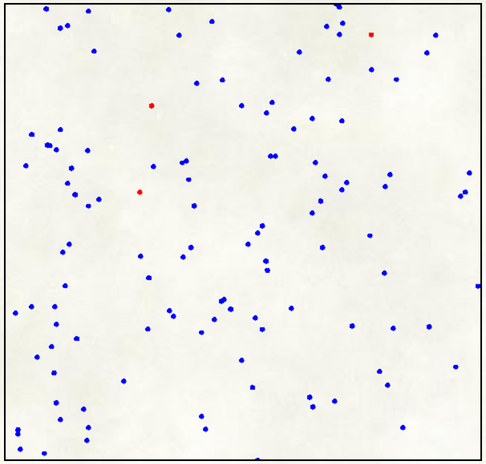
<u>Why Kelvin scale?</u>

- Temperature is a measure of the motion (more correctly energy) of microscopic particles of matter (atoms, molecules, electrons…)
- When something is heated (supply energy to it) microscopic particles of that material moves at faster speeds, which we perceive as an increase in its' temperature.
  - At 0°C average speed of an air molecule ~490 m/s
  - At 100°C average speed of an air molecule ~575 m/s

What is Temperature?

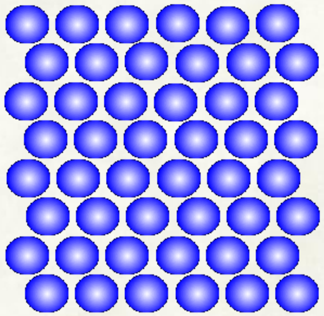


cold

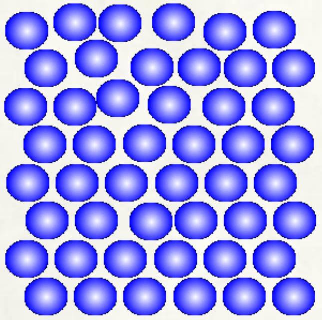


hot

gas molecules are in constant motion in random directions (thermal motion) at speeds determined by the temperature



cold



hot

In a solid atoms are held firmly by inter atomic forces so cannot move freely. But they can vibrate within a limited range which is determined by the temperature.

- When temperature is lowered molecular motions slow down.
- If temperature is lowered further, at a certain stage all molecular motions of the material would cease (almost). Temperature cannot be lowered any further, it is the coldest possible temperature.
- **This is the 0 Kelvin (absolute zero) temperature, lowest temperature anything can have.**
  - Theoretically it is not possible to cool down to absolute zero temperature. Only temperatures very close to 0K (billionth of K) have been achieved.

Basic Dimensions

length, mass, time and temperature are basic dimensions.

All other measureable quantities can be expressed as a combination of them. They are "derived dimensions".

Examples:

1) speed $= \dfrac{distance}{time} = \dfrac{a\ length}{time}$ like 50 m/s = 50 ms^{-1}

2)volume of a box with dimensions 1m,2m, 3m = 1mx2mx3m= = $6m^3$ (6 cubic meters)

Volume can be measured in cubic meters - no other unit is necessary. but we use units like gallons or liters for convenience

3) density $= \dfrac{mass}{volume}$

e.g: density of water

1 gram per cubic centimeter = 1 g/cm^3 = 1 gcm^{-3}

or 1000 kg per cubic meter or 1000 kg m^{-3}

The Speed of Light

- In daily life, light seems to travel instantaneously.
  - But light has a finite speed, first shown by Romer in 1676CE

Speed of light: ~ 300,000,000 m/s = 300,000 kms^{-1}

time takes to travel 1 foot (0.3m)

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

$$\Rightarrow \text{time} = \frac{distance}{speed} = \frac{0.3\ m}{3\times10^{8}\ m/s} = \frac{1}{10^{9}}$$ = billionth of a second = 1ns

time takes to travel 1km $= \frac{1}{300{,}000}$ = $3.3\text{x}10^{-6}$ second = 3.3 μs

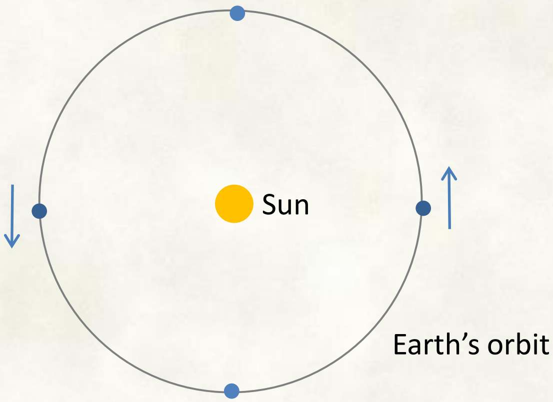
This is the speed of light in vacuum (in empty space).

– Speed of light depends on the medium.
  - In air it is slightly lower, but we ignore this tiny difference most of the time.
  - In water speed of light is 25% slower.
  - In glass 33% slower.

The Speed of Light: History

- There had been various ideas about the nature of light and speed it travels since ancient (Greek) times.
  - General consensus was that light propagated instantaneously (infinite speed).
- Galileo suspected that the light traveled at a finite speed. He tried to measure its speed, but failed.
- He concluded that if not instantaneous, light traveled extraordinarily fast, at least 10 times faster than sound.

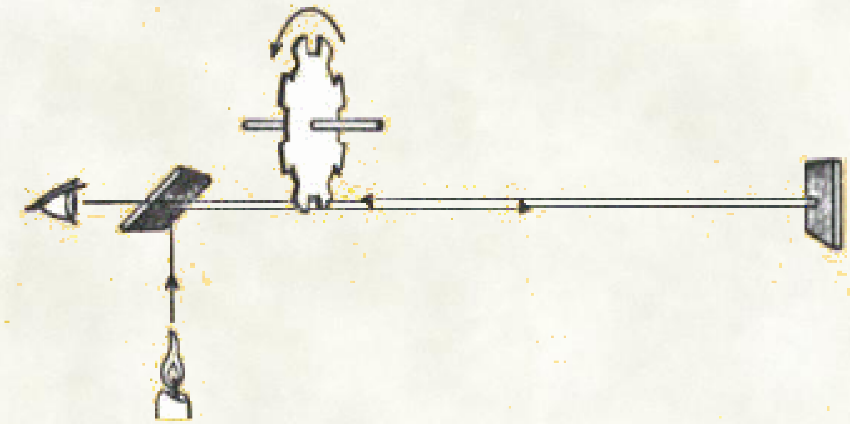
The Speed of Light: History

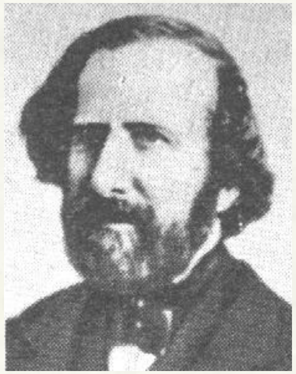


- Ole Rømer in 1676, by observing the motion Jupiter’s satellites showed that light must be traveling at a finite speed.
    - As the distance from the Earth to Jupiter increases Jupiter’s satellite Io seemed to take a longer time to go around Jupiter.
- He estimated that light took 22 minutes to travel a distance equal to the diameter of Earth's orbit (distance to Sun was not accurately known then).

(modern measurements: diameter of Earth’s orbit 300 million km,
time light take to travel Earth diameter ~17 minutes)

Speed of Light





- First terrestrial measurement of the speed of light was done by a French physicist, Louis Fizeau in 1849.
  - He measured the time it takes for a light beam to reflect back from a mirror placed 8km away.
    - His estimate of the speeed of light was 313,300 Km/s.
- Speed of light is one of the important parameters of nature.
  - It has been measured very precisely (299 792 458 m/s).
- According to Einstein's Theory of Relativity, speed of light is the fastest speed information can be sent, or the maximum speed an object can travel.

(Extra credit topic: history of the speed of light measurement)

Speed of Light

- Although we don't experience the finite speed of light in daily life, on astronomical scales it is noticeable.

  e.g. Distance to the Sun is 150 million km =1.5 x10^8 km

  Time light takes to travel from the Sun to the Earth =

$$\frac{distance}{speed} = \frac{1.5\times10^8 km}{3\times10^5\ km/s}$$

= 500 s =8m 20s

  - What we see is the Sun as it was 8m20s ago.
  - Similarly for more distance objects, light takes a longer time to reach us as a result we see them as they were further back in time.
    - millions or billions of yeas for distant galaxies
  - Telescopes are like time machines!

The Light-year

Distance to the nearest star, alpha Century, is 40 trillion km (4×10^{13} km)

It is awkward to work with such large numbers,

We can use the time light takes to travel to express large distances.

e.g.: Sun is 500 "**light seconds**" away

For larger distances we use the "**light year**".

Light Year = distance light travels in one year in empty space

= speed of light in km/s x number of seconds in a year

= 9.46×10^{12} km.

Distance to alpha Century (nearest star) is 4.3 ly.

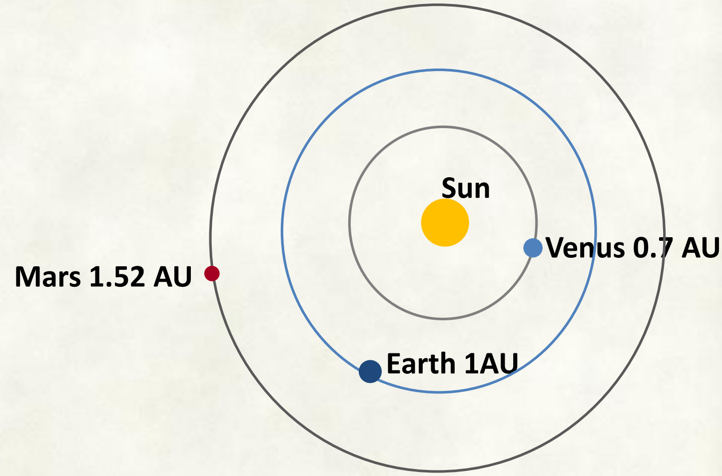
It takes 4.3 years for light from alpha Century to reach us.

Another astronomical unit often used is the **parsec**

1 parsec = 3.3 light years.

The Astronomical Unit (AU)

For objects in the solar system another unit called " the **Astronomical Unit**" is used.



1 Astronomical unit (AU) = average distance from Earth to the Sun

=150 million km (93,000,000miles)

e.g. Venus is 0.7AU from the Sun, Mars is 1.5 AU from the Sun

This is more convenient than kilometers, and gives an immediate sense of the scale.

Saturn is ~10 AU from the Sun

$\Rightarrow$ Saturn is 10 times farther away from the Sun than the Earth.

- Mass of the Earth ($M_\oplus$): 6 x10^{24} kg — useful as a unit of mass for solar system objects.
- Mass of the Sun ($M_\odot$): $2\text{x}10^{30}$ kg — useful in expressing mass of stars, galaxies etc.

$=330000\ M_\oplus$

Few objects at different scales

10^{-15}m

electron
0.1 fm

10^{-10} m

atoms
0.1 nm

10^{-5}m

virus
100 nm

Human hair
(thickness
10-100 μm)

1 m

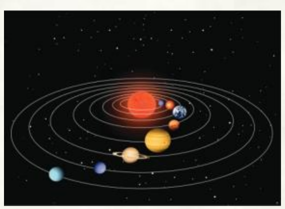
humans
~2 m

10^{5}m

lakes
1-100 km

10^{10}m

Earth
13000 km



Orbit of Neptune
10^{10} km

10^{15}m

star clusters
10^{15} km

10^{20}m

galaxies
10^{18} km

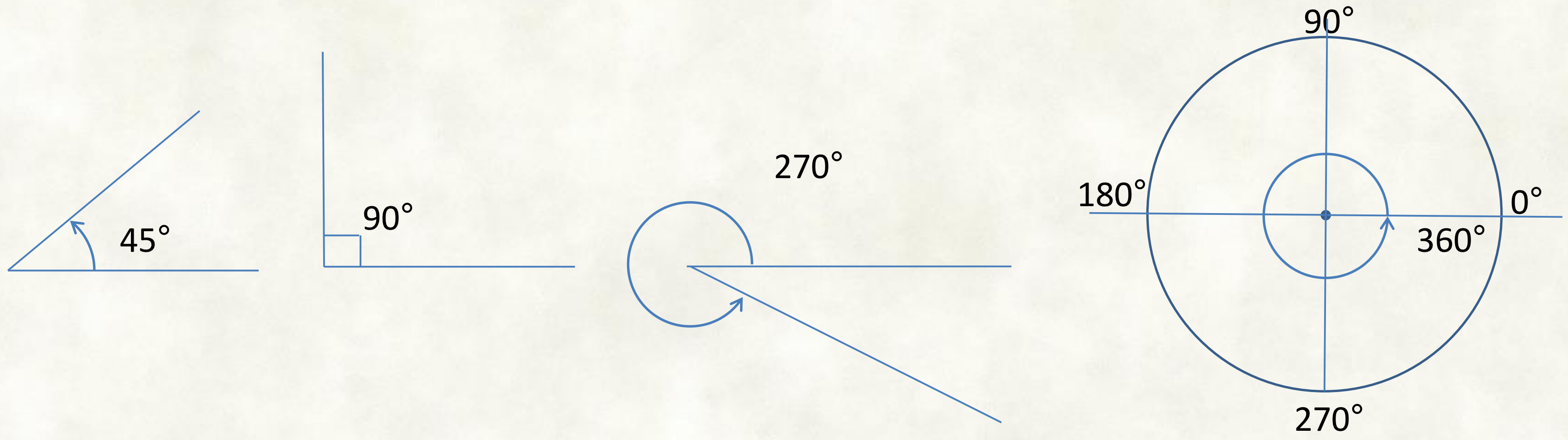
10^{25}m

Size of the observable
Universe 10^{22} km

Over 40 orders of magnitude: 10^{-16}m to 10^{26}m

Angles

- Although there is a SI unit for angles (radian) astronomers still use degrees to measure angles.
- Dividing the circle into 360 degrees dates back to ancient Babylonian times, 5 millennia ago.
  - 360° around a full circle/point



Sub divisions of a degree:

arc minute (′) $^1/_{60}$ of a degree, there are 60′ in a degree

arc second (″) $^1/_{60}$ of an arc minute, there are 60″ in an arc minute

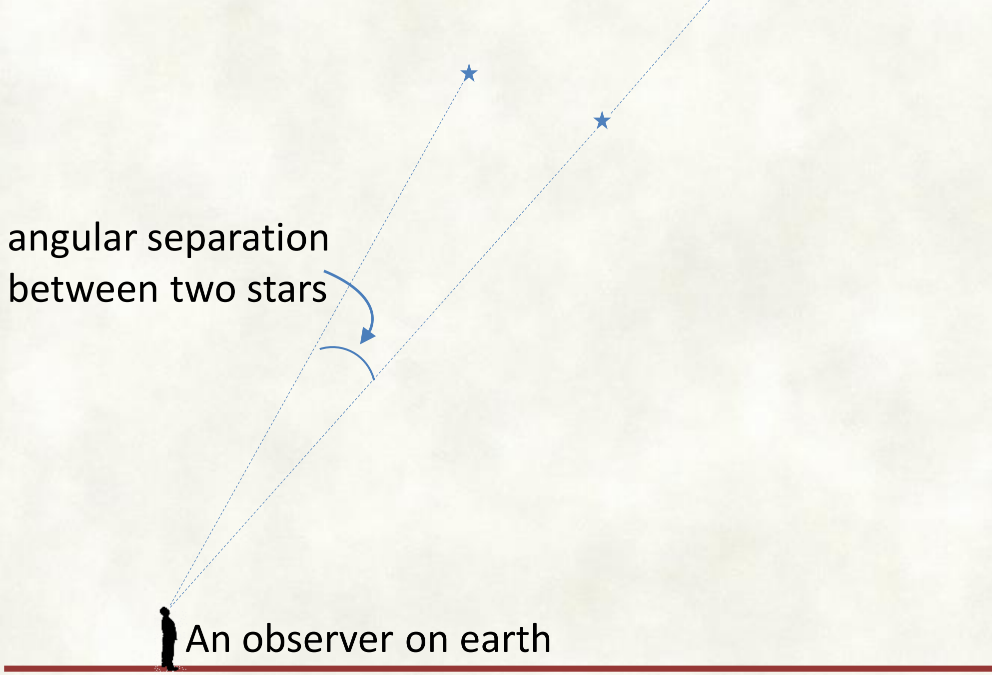
1′ =60″

1 degree = 60′ =60x60″ = 3600″

(1° = 3600″)

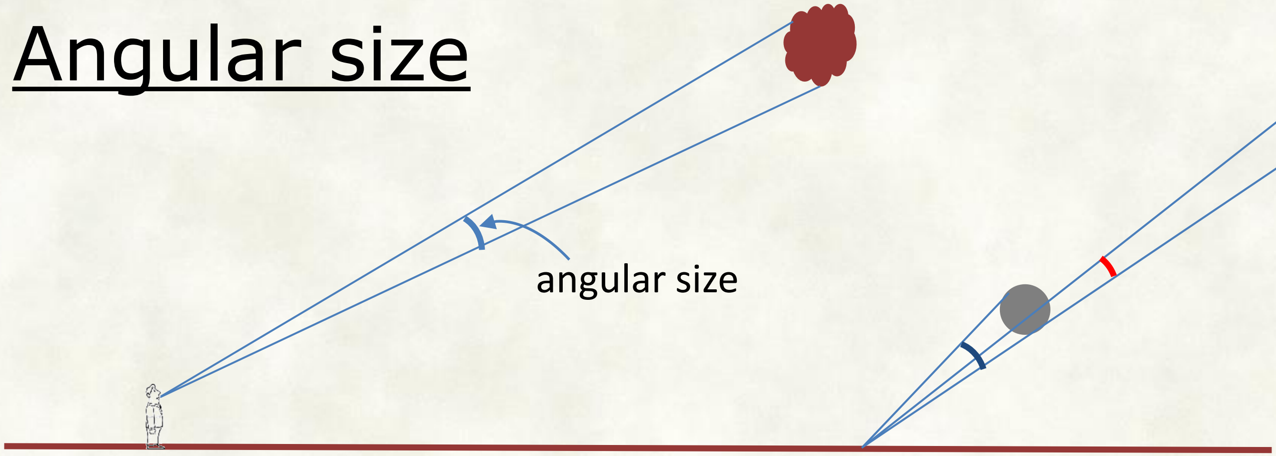
Angular separation

- Angular measurements play an important role in astronomy.
- In the sky we do not see physical distances, everything (sun, moon, stars, planets) seems to be at the same distance in the sky.
  - even a highflying airplane at night seems to move among stars
- We only see angular separations between them or angular sizes.



Angular separation (or Angular Distance): the angle between the lines of sight to two objects from the observer

Angular size



angular size changes with distance

- **Angular size:** angular separation between opposite edges of an object.

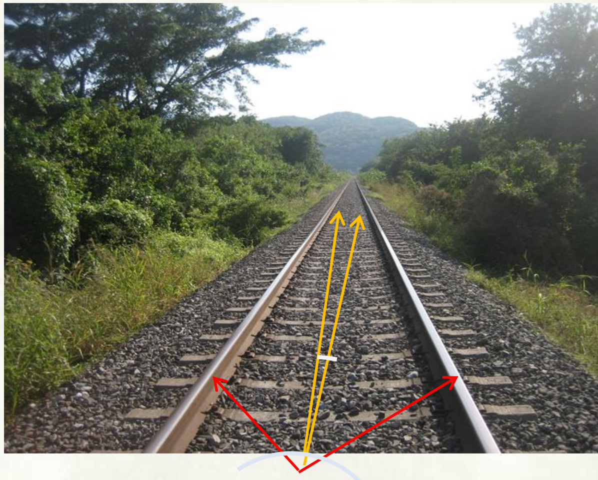
  Angular size depends on the size of the object and distance.

  – A larger object subtend a larger angle

  – As the distance increases angle becomes smaller.

- Angular diameters of the Sun and the Moon are about the same. (about half a degree ~0.5º)

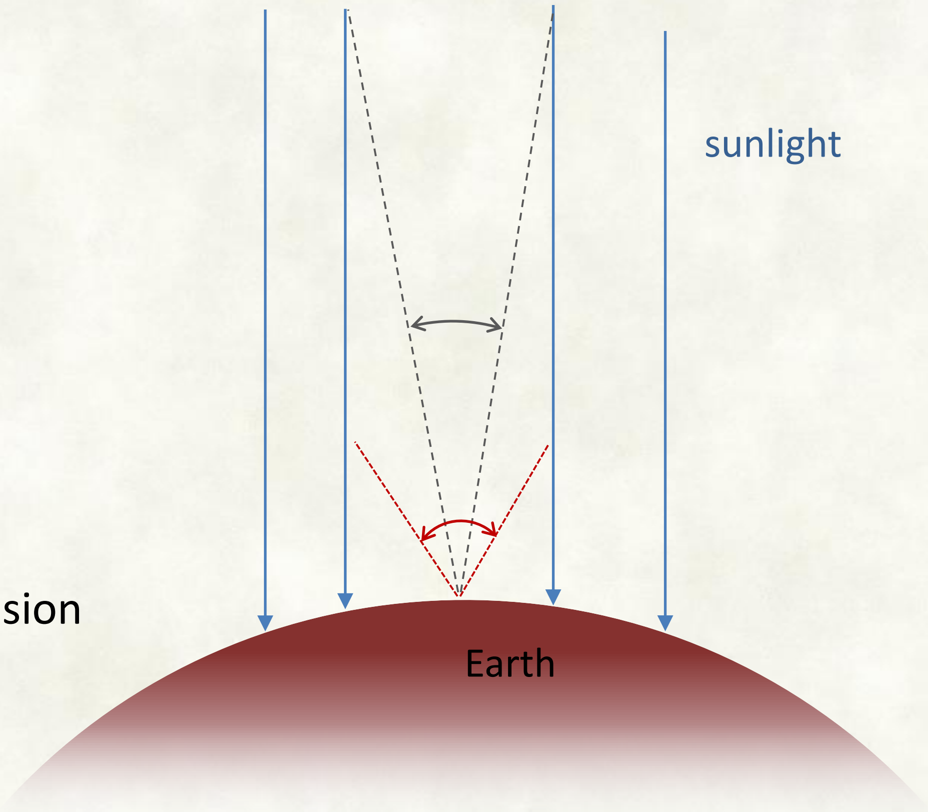
  – The sun is about 400 times larger than the moon, but it is also farther away.



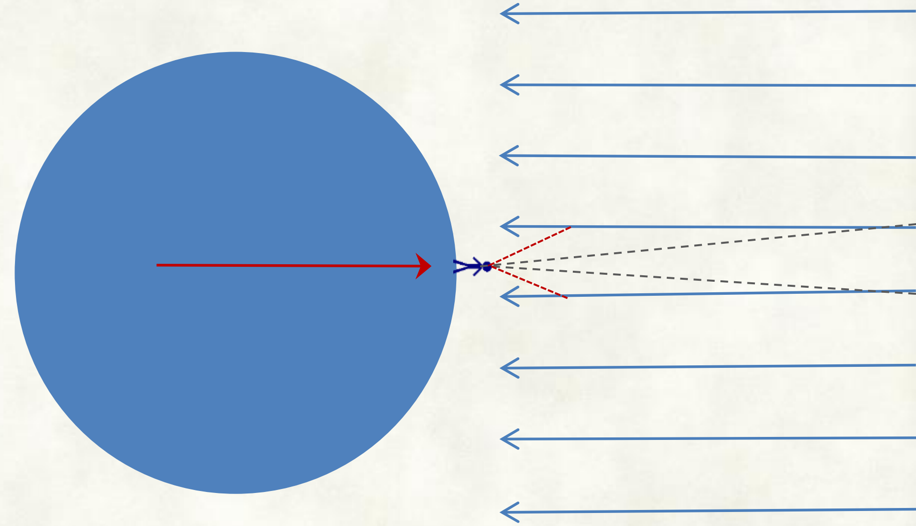
rails appear to converge because angular separation between them decreases with distance

apparent equal size of sun and moon during a solar eclipse

crepuscular rays/ converging sunbeams is an illusion



- The sun is 150 million km away, rays of sunlight reaching the earth are almost parallel to each other.
- But they appear to be converging to sun as if the sun is just above the clouds.
- It is an illusion caused by the decreasing angular separation between sun rays with distance (perspective).



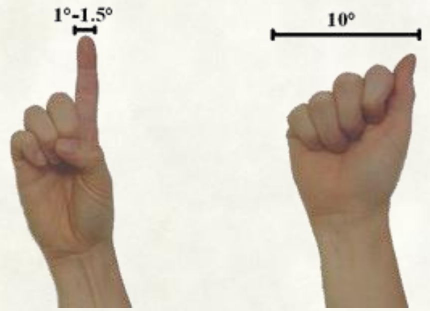
meteor trails
in the atmosphere

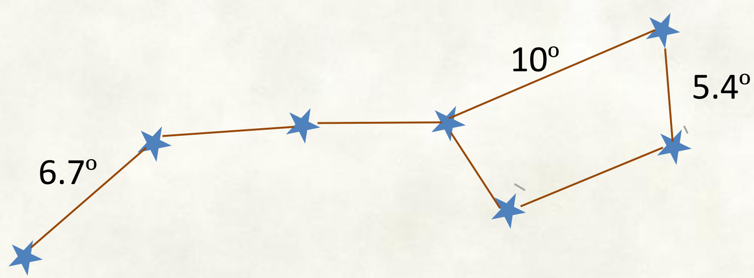
- A meteor shower occurs when the Earth moves through a derby field left by a comet. Debris enter the atmosphere and burn producing visible trails (shooting stars).

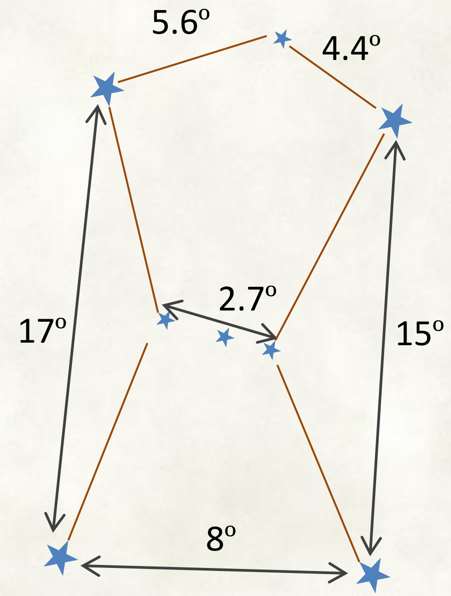
- They are all moving in the same direction, parallel to each other, in the atmosphere. But appear to be radiating from one point in the sky due to same reason.

Few angular sizes

- Moon 30′-34′
- Venus now 28″
- Mars now 5″
- Jupiter 30″-49″
- Neptune 2″
- Andromeda galaxy 1º
  (core visible to eye)
- Stars less than 0.01″
  - Alpha Centauri 0.007″
    (nearest star)

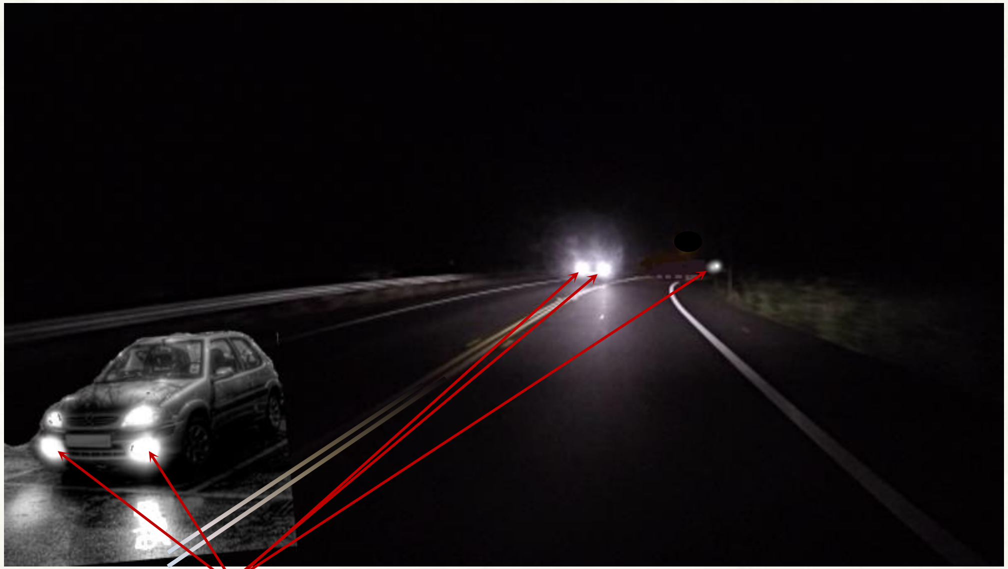






angular separations between stars in Big Dipper and Orion.

Resolving power of the Eye



If the angular separation between headlights is less than 1’ they will appear as a single light.

Castor is a multiple star system. Angular separation between two brightest stars is about 7”, well below the resolution of the eye. So it looks like a single star to the naked eye. Through a telescope three stars can be seen.

Angular resolution of the human eye is about one arc minute (1’).

This is the smallest detail eye can discern or see.

- If two objects are closer than one arc minute, we do not see them as separate objects.
- Or if the angular size of a bright object is less than 1’ it appears just as a point.

Stars look like points of light

Jupiter these days

Planet Mars and stars

double star Albireo, angular separation 35”. A telescope can resolve the pair into individual stars, but stars look like points.

- Angular diameter of stars are extremely small:
  - even through a telescope they are visible only as points of light.
  - Surface details are not visible.

e.g. angular size of Alpha Centauri is 0.007”,

magnify it 500 times: 0.0007” x 500 = 3.5”

still well below the resolution power of eye

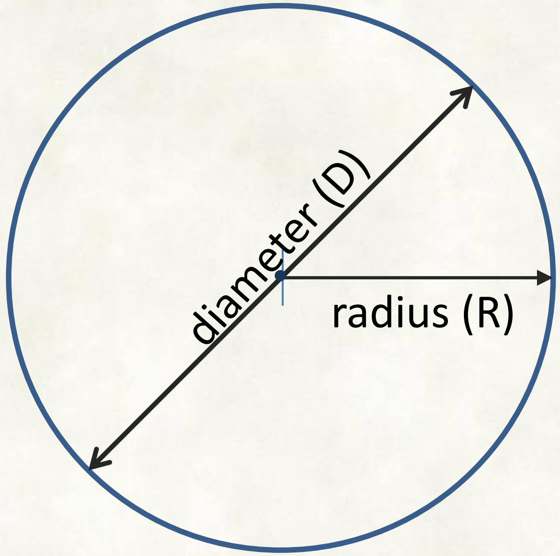
- A planet has a large enough angular size to show details through a telescope

e.g. angular size of Jupiter now =34”

a magnification of 100 gives = 3400” = 57’ (more than the resolution of eye)

- In astronomical images stars appear in different sizes.
  - Due to blooming (light diffusing) in the imaging sensor (or the photographic plate)
  - Size of the image of a star depends on the apparent brightness of the star, not its real size.

Geometric Shapes: Circle



Circle: all points on a circle are at the same distance from the center.

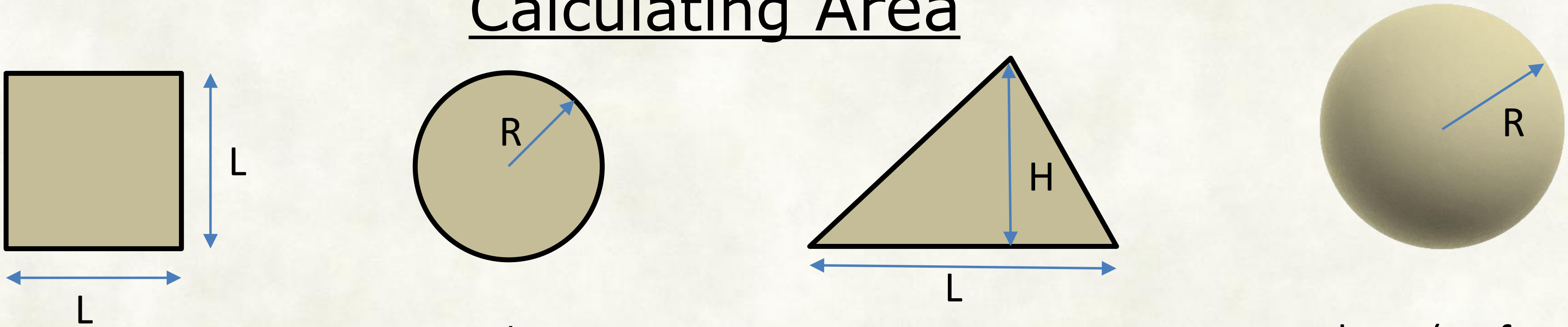
Diameter (D) = 2 x radius = 2R

Circumference = $\pi D = 2\pi R$

$\pi = 3.14169 \ldots$ 3.14 is good enough for most work

Area of the circle = πR^2

Calculating Area



square — circle — triangle — sphere (surface)

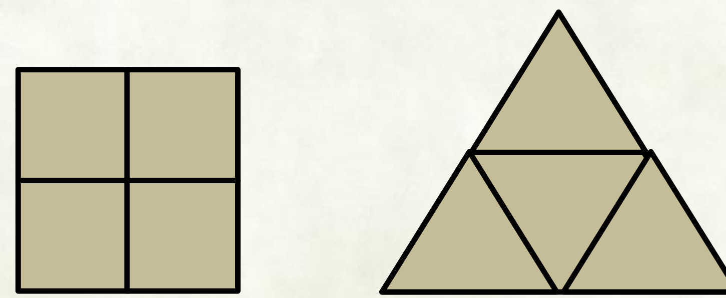
Area: L^2 — πR^2 — $\frac{1}{2}LH$ — $4\pi R^2$

Regardless of the shape, area is a product of two lengths

$\Rightarrow$ area is proportional to the square of the size.

e.g.: area of a room 4m x 3m = 12 m^2

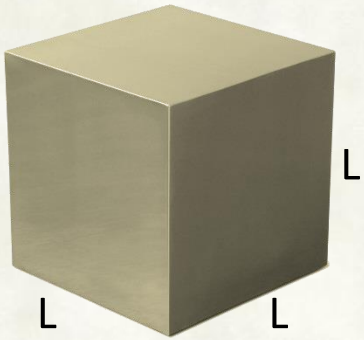
area of a room 8m x 6m = 48 m^2

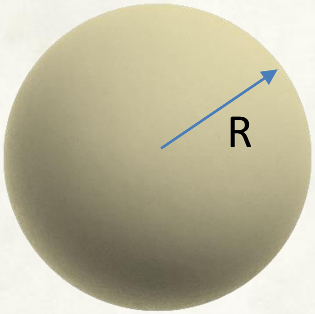


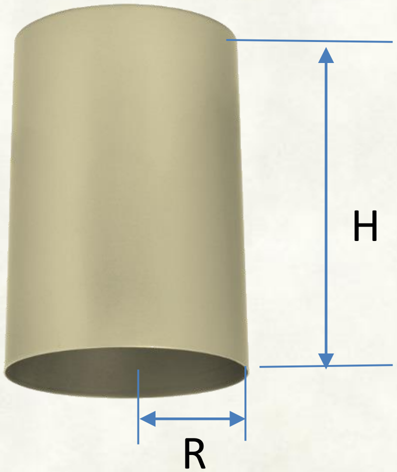
When size (length) changes by a factor of 2 area changes by a factor 4 (or 2^2)

In general area of a shape changes as the square of its size.

Volume







Volume:

cube of size L   sphere of radius R   cylinder: height H base R

L^3 $\frac{4}{3}\pi R^3$ $\pi R^2 H$

Volume is a product of three lengths:

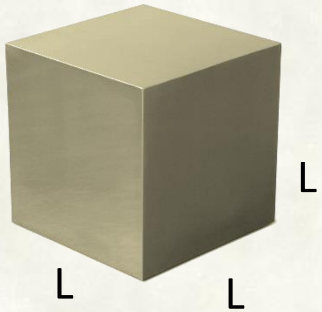
Volume is proportional to the 3rd power (cube) of the size

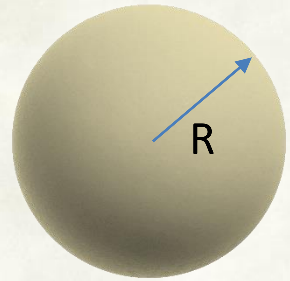
e.g.: volume of a cube 1m in size 1m x 1m x1m = 1 m^3

volume of a cube 2m in size 2m x 2m x 2m = 8 m^2

Volume of a solid changes as the 3rd power of its size.

Area:Volume





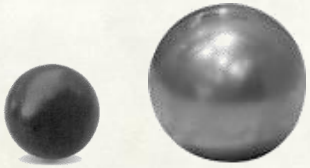
	cube	sphere
Volume:	L^3	$\frac{4}{3}\pi R^3$
Surface area	$6L^2$	$4\pi R^2$
$\frac{area}{volume}$	$\frac{6}{L}$	$\frac{3}{R}$

As the size increases the ratio of area to volume of any shape decreases.
A larger object has a smaller surface area compared to its volume

implications: an iceberg melts slower than an ice cube.
fine granulated sugar dissolves faster than large crystals.
coffee in a cup cools faster than coffee in a large pot
small twigs burns faster than logs

- Jupiter and Saturn emits more radiation than they receive from the Sun.
  - Due to their large size, they are still cooling down from their initial heat of formation (4.5 billion years ago)

- There are two iron balls, diameter of the larger ball is twice that of the smaller.



  - What is the weight of the larger ball

    2 times the smaller ball

    4 times the smaller ball

    6 times the smaller ball

    8 times the smaller ball

  - What is the surface area of the larger ball

    2 times the smaller ball

    4 times the smaller ball

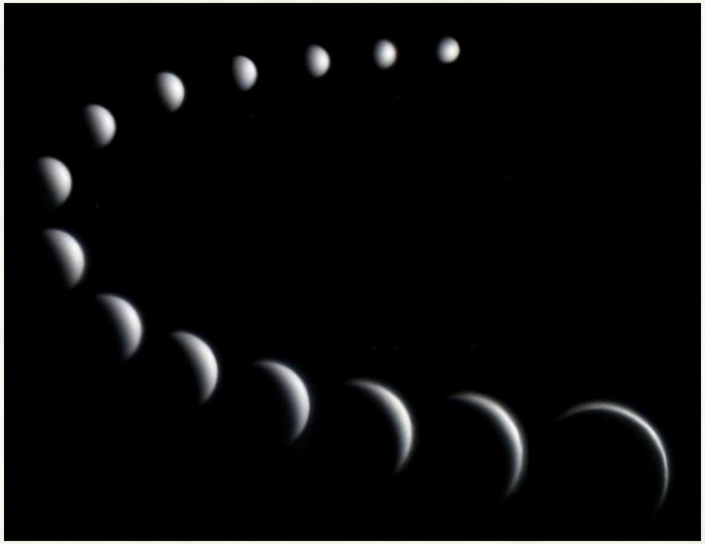
    6 times the smaller ball

    8 times the smaller ball

Review Questions

- What is the speed of light in empty space?
- What is the Astronomical Unit (AU) used for?
- What is the distance from the Earth to the Sun in astronomical units?
- What is a light year?
- How many kilometers is a light year?
- How many astronomical units is a light year?
- What is the angular diameter of the Moon.
- What is the angular diameter of the Sun.
- Angular diameter of Venus varies between 10” to 63”. What is the reason for that change.
- Why are the angular sizes of stars so small?
- Want is the resolution of the human eye? What does that mean?
- Why isn’t it possible to see surface details of stars through a telescope ?
- Can you use a telescope to see surface details of planets?
- What is the shape which has the smallest surface area for a given volume.

Jupiter and moons



phases of Venus

Saturn