I. Use of Scientific Methods

Measure everything that can be measured!

-Galileo-

Now let's talk about the scientific methods that we will use to arrive at these numbers and to make sense out of them! We'll browse through this chapter, which you will use as reference later. We will treat individual sections in more detail again, when they are actually needed! Because we will need geometry and motion right away, this will be more detailed now.

Galileo once said: Measure everything that can be measured!

What does it mean? To understand our world and the things within we have to measure them and put them into perspective. Let's try this with some facts that are easily accessible to our everyday imagination.

We will, however, integrate measurement into Scientific Methods immediately:

Let us start the more obvious way
First measure things then ask and derive: What does it mean?

This method is called Deduction

Before we elaborate on this, let us define what a measurement means:

Table 1: Scientific Methods

<table>
<thead>
<tr>
<th>Method</th>
<th>What is it?</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Measurement</strong></td>
<td>Comparison with known (size, amount, ....)</td>
<td>Length &lt;-&gt; meter stick</td>
</tr>
<tr>
<td><strong>Model</strong></td>
<td>Describe results with something that we can see, feel, or imagine</td>
<td>Geometric model: map of Earth small solar system model</td>
</tr>
<tr>
<td><strong>Scientific Reasoning</strong></td>
<td>i. Hypothesis how something works</td>
<td>i. Angle and distance of object are related</td>
</tr>
<tr>
<td></td>
<td>ii. Prediction what happens</td>
<td>ii. Smaller angle means farther away, or smaller object</td>
</tr>
<tr>
<td></td>
<td>iii. Test of prediction</td>
<td>iii. Measure size + distance</td>
</tr>
<tr>
<td><strong>Deduction</strong></td>
<td>i. Measure something</td>
<td>i. Measure Angle to object from the ends of a Baseline + Length of the Baseline</td>
</tr>
<tr>
<td></td>
<td>ii. Determine something else</td>
<td>ii. Determine Distance of object</td>
</tr>
</tbody>
</table>
1) To Measure Means to Compare

A. Powers of ten.
(already covered under 0.)

B. Geometry

a) Lengths:
Let us start with simple geometry. If I say something is 1 m long (do you still use feet?) I have developed an intuitive feeling what this means, but in science this is not enough. We want to communicate how big something is. Thus we have to compare it with a length that everybody agrees on. Do you know what the length of 1 Stadium is? This was used in ancient Greece, but we don’t know exactly how this compares to a meter.

Basic Unit: 1 m (cm, km) = 3.3 Feet
Compared with a meter stick (original meter, Paris)
something which everybody can compare with!!!
1 m = 1/10,000,000 of a quadrant of the Earth (Napoleon had his engineers derive this to get distances for his troops to march through Europe) This is not exact, so a better comparison is needed.

The meter stick is a Standard!
The Original is kept in Paris
A copy is kept by a National Institute in each country
US: NIST (National Institute of Standards)
Germany: PTB (Physikalisch Technische Bundesanstalt)
The standard is maintained to very high accuracy!!

We want to build up a system of units in which we measure everything.
simple: easy to remember, only few basic obvious units

You see immediately how we can measure the classroom: by comparing with the meter stick. The result is: from here to the rear end 15 m. You may have a good feeling for this length, but this is much harder with lengths and distances in the universe. You may find it much harder to have a feeling for the distance to Uranus, a planet which was only found with a telescope.

To help our imagination we often compare sizes and distances with objects and distances, which we know already:
-> we get a relative length (comparison with larger known objects)

To give you a feeling for distances and sizes in the universe I have brought the solar system to class (or better a Model of the Solar System) made to fit distance Earth-sun into the classroom of about 15 m length

Will talk a lot about models in this course, since this is what scientists do invent in order to understand the behavior of any object in the universe or even the entire universe! No matter how accurate we will become, we will never be able to see the universe as such, we will always have to make a model! Making a Model is another Scientific Method.

Here we just have a geometrical model:
The distance Sun-Earth:
150 million km or 1.5 x 10^{11} m shrunk by 1:10,000,000,000
is 15 m in the model:
Sun:
In the back of the room see the ball like the sun from earth
   Earth  head of shirtpin  ->
   Venus  head of shirtpin  ->
   Mercury little dot (poppy seed)
   Mars   dot
all of them are only points for your eyes!
   Jupiter marble collected from my kids
   Saturn " + quarter (size of rings)
   Uranus  size of bearing ball
   Neptune  size of bearing ball
   Pluto    poppy seed
The complete solar system fits within downtown Durham!!

But where is the closest star (Alpha Centauri) in this Model?
approx. in San Francisco!

<table>
<thead>
<tr>
<th>Reality</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Size in km</strong></td>
<td><strong>Distance in km</strong></td>
</tr>
<tr>
<td><strong>Size in cm</strong></td>
<td><strong>Distance in m</strong></td>
</tr>
<tr>
<td>Sun</td>
<td>1.4 ( \times ) 10^6</td>
</tr>
<tr>
<td>Mercury</td>
<td>4880</td>
</tr>
<tr>
<td></td>
<td>5.8 ( \times ) 10^7</td>
</tr>
<tr>
<td></td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>5.8</td>
</tr>
<tr>
<td></td>
<td>2 steps up</td>
</tr>
<tr>
<td>Venus</td>
<td>12100</td>
</tr>
<tr>
<td></td>
<td>1.0 ( \times ) 10^8</td>
</tr>
<tr>
<td></td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>10.8</td>
</tr>
<tr>
<td></td>
<td>7 steps up</td>
</tr>
<tr>
<td>Earth</td>
<td>12760</td>
</tr>
<tr>
<td></td>
<td>1.5 ( \times ) 10^8</td>
</tr>
<tr>
<td></td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>15.0</td>
</tr>
<tr>
<td></td>
<td>Rear of auditorium</td>
</tr>
<tr>
<td>Mars</td>
<td>6800</td>
</tr>
<tr>
<td></td>
<td>2.3 ( \times ) 10^8</td>
</tr>
<tr>
<td></td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>22.8</td>
</tr>
<tr>
<td></td>
<td>Lunch cart</td>
</tr>
<tr>
<td>Jupiter</td>
<td>143800</td>
</tr>
<tr>
<td></td>
<td>7.8 ( \times ) 10^8</td>
</tr>
<tr>
<td></td>
<td>1.44</td>
</tr>
<tr>
<td></td>
<td>77.8</td>
</tr>
<tr>
<td></td>
<td>Computer store</td>
</tr>
<tr>
<td>Saturn</td>
<td>120000</td>
</tr>
<tr>
<td></td>
<td>1.4 ( \times ) 10^9</td>
</tr>
<tr>
<td></td>
<td>1.20</td>
</tr>
<tr>
<td></td>
<td>143.</td>
</tr>
<tr>
<td></td>
<td>EOS (Morse Hall)</td>
</tr>
<tr>
<td>Uranus</td>
<td>50800</td>
</tr>
<tr>
<td></td>
<td>2.8 ( \times ) 10^9</td>
</tr>
<tr>
<td></td>
<td>0.51</td>
</tr>
<tr>
<td></td>
<td>287.</td>
</tr>
<tr>
<td></td>
<td>Hood House</td>
</tr>
<tr>
<td>Neptune</td>
<td>49500</td>
</tr>
<tr>
<td></td>
<td>4.5 ( \times ) 10^9</td>
</tr>
<tr>
<td></td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>450.</td>
</tr>
<tr>
<td></td>
<td>Tin Palace</td>
</tr>
<tr>
<td>Pluto</td>
<td>2300</td>
</tr>
<tr>
<td></td>
<td>5.9 ( \times ) 10^9</td>
</tr>
<tr>
<td></td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>590.</td>
</tr>
<tr>
<td></td>
<td>Young's Restaurant</td>
</tr>
</tbody>
</table>

Closest Star:
   LY
   \( \alpha \) Centauri  4.34 \( \times \) 4.1 \( \times \) 10^{13} 4,108,799 San Francisco

A direct comparison with a meter is impractical for such enormous distances (astronomical) \( \rightarrow \) many powers of ten
Therefore, we go to different length units to leap frog into the cosmos:

1 Astronomical unit (AU)  Earth-Sun Distance \( \approx \) 150 mio km
1 Light-year (l.y.)  distance light travels in 1 year \( \approx \) \( \times \) 10^{13} km
Surface of objects (e.g. planets):

\[ \text{Area} = \text{Length} \times \text{Length} \; \text{m}^2 \]

Volume of objects (e.g. stars):

\[ \text{Volume} = \text{Length} \times \text{Length} \times \text{Length} \; \text{m}^3 \]

How do we measure distances to planets and stars?

b) Angles:

We start (and this may be surprising) with angles and not with length. Angles is what we deal with first, although maybe unknowingly. If you look at something and try to judge its size, what do you see? It is the angular range, which is covered by the object. This is the primary information our eyes get, starting as a baby. Everything else is secondary and needs interpretation of our brain. Only later when we are able to move and touch things we get an idea of the real size and learn how to relate angle to size and separation (angular resolution).

The angle or "apparent" size varies of course with the distance from the object.

Definitions for angles:
Defined on the basis of the full circle
Angles (360 per circle).
Minutes (60 per degree).
Seconds (60 per minute).

for example: \( 1^\circ 15' 30'' = 1 + \frac{1}{4} \times 0.25 + \frac{1}{2} \times 0.008 = 1.258^\circ \)

right angle: \( 90^\circ \)
straight: \( 180^\circ \)

There is a simple protractor everyone has at "hand" that will be extremely useful for simple astronomical observations: our fist at arm’s length

\( \Rightarrow = 10^\circ \)

Whether tall or small, the ratio of arms length and fist remains constant and thus the angle under which you see the fist is approximately the same for every human.

For more quantitative purposes a Quadrant is used in astronomical angle determination

c) Distance determination
As already mentioned earlier in angles there is

size information the smaller the object the smaller the angle
distance information the further away the smaller the angle

This is the simplest example of Scientific Reasoning, yet another Scientific Method.

Length determination with an angle and a triangle:
In astronomy we always have a skinny triangle because objects are so far away:

\[ \theta \sim \frac{d}{r} = \frac{\theta \text{(in deg)} \times 2\pi}{360} = \frac{\theta \text{(in deg)}}{57.3} \]

"Parallax": basis of distance measurements.

Parallax is the difference in Angle under which an object is seen from two locations at the same time

This is a perfect use of Deduction:

Measure
Baseline + angle
Distance + angle

\( \Rightarrow \) Determine

Distance
Size
(Surface, volume)

Another practical unit:

1 Parsec = 3.26 l.y. = distance giving a parallax of 1 arcsec.
for a baseline of 1 AU (Earth - sun distance)

This is like a Nickel seen from 4 km distance
C. Action:
a) Time
   Basic unit: sec (second), hour, day

We measure time by comparing it with a regular motion
sun -> sun dial (position of shadow with time)  -> hours, days
sand flowing through an orifice -> sand clock  -> minutes
mechanical pendulum -> mechanical clock  -> seconds
oscillation of crystal -> quartz clock  -> fractions of second

Now we have already 2 Basic Units:

b) Velocity:

   Definition: Distance moved in a certain time

   Derived Unit: m/sec km/h

   We measure the distance and the time and can then calculate velocity. In the same way
   we can measure the:
   Change of velocity (acceleration, deceleration) during a fixed time

   Derived Unit: m/sec/sec m/sec^2

   For example a sports car may accelerate from rest to 100 km/hour is 6 sec.

This preliminary tool set will bring us through the first few sections of the course. We will
try to handle the limited set like a prudent craftsman and then add more tool and the skill to
handle them later. To describe the workings of the universe we will of course need much
more.

If you have a hard time now getting the first steps I should give some piece of
consolation: we will repeat the most important things in many disguises!!
Partly believe in learning as getting familiar with something
   -> by repetition
2) How do we measure all this in space?

We use
- Electromagnetic radiation: radio, microwave, IR, light, UV, X, gamma rays.
- Cosmic rays (sample of Milky Way Galaxy).
- Meteors (sample of early solar system).
- Comets (sample of early solar system).
- Solar wind (sample of sun).
- Lunar soil (sample of moon).

Forces: Gravity (the key to deducing masses).

3) We use Scientific Methods to derive what we can't touch or see

a) Deduction -- measure something to deduce something else:
   We have already used this method to derive distances or sizes from the measurement of angles:
   
   \[ \text{angle} \Rightarrow \text{size or distance} \]
   
   skinny triangle

b) Scientific Reasoning

Let us finally spend some time on a very important method, which we will encounter again and again in many disguises: Scientific Reasoning. In this case we turn the scientific arguments around:

Based on an idea we propose a measurement to answer the question, whether the idea is wrong.

First scientific idea then measurement to decide

We make an assumption about what is going on in the world and then we ask ourselves how we can observe whether there is some truth to this idea.