I. Physics & Measurement

Cartoon: "S*cience as Break from Vacation*"

- Syllabus
- Requirements
- Homework via Web Assign

1.1 Introduction

The first statement that our teacher made in the physics class in my Gymnasium in Germany was:

"Physics is the Art of Measurement"

In this way he captured one of the fundamental capstones of physics, i.e. the experimental approach to our physical world. In order to be able to deduce what is going on or to test a hypothesis about our surroundings we need to measure quantities, such as length, time, mass, force, pressure and many more. This goes back to the time, when quantitative science was in its infancy, when *Galileo*, among others, tried to put a quantitative base under the emerging sciences. He demanded:

Measure everything, that can be measured, and make accessible to measurement, what cannot yet be measured!

A pervading theme of the physics course will be to find new and to improve known methods to observe physical phenomena and to test predictions of models. To be quantitative, these observational aspects involve measurement in one way or another.

What does it mean, to measure something?

To Measure Means to Compare

with a known and accepted quantity.

In order to transfer results and to repeat them anywhere, anytime and to be able to judge, whether the results are the same under all circumstances we need an accepted system of "standards". With lots of different quantities to take care of this sounds very complicated and boring at the same time, as if we need to go through plenty of things to memorize. However, one good thing with physics is, we can minimize the number of things remember. We will see that we only need very few base quantities (*base standards*), and all the others can be derived from combinations. Only for convenience do we add names and thus units for other quantities. For each of the few base quantities we need standards that are:

- accessible (anywhere, anytime)
- do not change
- can be determined with very high precision

1.2 SI System

In 1971, the 14^{th} General Conference on weights and Measures picked 7 base standards, out of which we will only need 3 early on in the course: ***length, time and mass***. The units that were picked, ***meter, second and kilogram*** are now used almost all over the world. We will use them throughout the course, although you are still confronted with other units in your everyday life. How important it is to use a reliable and unique system of measures was emphasized relatively recently through the spectacular failure of one of the recent NASA Mars missions. The spacecraft probably crashed on Mars, because one important conversion between the American units and SI units was not made in the trajectory computations.

a) Length

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 today we don't know exactly how this compares to **1 meter**.

Basic Unit: **1 m (cm, km)** **= 3.3 Feet**

Compared with a meter stick (original meter, Paris) View I.1

Let me start to compile the units and their relationships in a table, which we will extend as needed.

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 means for precise comparison is needed.

The meter stick is our local Standard!

The Original is kept in Paris, which was used as the absolute Standard until recently.

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!!

Reflecting the progress in precision measurement, 1 m is redefined as a specific number of wavelengths of a spectral of krypton-86. The number is an awkward number because it was made to reflect the old m as precisely as possible. However, the new standard is much more precise and can be regenerated in any high precision laboratory without carrying the standard physically.

To measure very small sizes and astronomical distances, we make use of the scientific notation of numbers, i.e. we use powers of ten. An alternative method is the use of prefixes, such as deci, centi, milli etc. A full list is found in the book, not for memorization, but for reference. It helps, however, to know the most commonly used ones.

We want to build up a system of units in which we measure everything.

simple: easy to remember, only few basic obvious units View I.2

A simple extension of length is the determination of area and volume.

Surface of objects (e.g. planet surfaces):

-> **Area = Length * Length** $\mathbf{m^2}$

Volume of objects (e.g. stars):

-> **Volume = Length * Length * Length** $\mathbf{m^3}$

From this extension of the base unit we can immediately see a convenient shortcut that can be made in the determination of areas and volumes. If a body grows in its length dimensions by fixed factor, then the growth in area and volume can be found without any specific knowledge of a formula to calculate the area or volume, no matter how complicated the body may be. Slide 1

Class Question: Concept Question I.1

If the length dimension scales by a factor **A**, the area scales like $\mathbf{A^2}$, and the volume scales like $\mathbf{A^3}$.

System of Units

Basic Units

Length **1 Meter**
[m, cm, km]

Based on: *Wavelength of light of Kr atom*
(Original m in Paris)

Area = Length * Length **[1 m^2]**

Volume = Length * Length * Length **[1 m^3]**

Changing Units:

If you are asked to provide your result in units that are not the ones the original quantities are given in, you will have to change units in your computation. A very convenient and versatile method to this is the so-called **Chainlink Method**. Let's say you are told your room in the dorm is 12 feet long and 10 feet wide. Your European friend asks you, on how many m^2 you live. How long is a foot? 30 cm.

Area = 12 feet x 10 feet = (12 ~~feet~~)(30 ~~cm~~/1 ~~feet~~)(1 m/100 ~~cm~~) x (10 ~~feet~~)(30 ~~cm~~/1 ~~feet~~)(1 m/100 ~~cm~~) 3.6 m x 3 m = 10.8 m^2

By the way, it is always good practice to write all the units down in a problem. From the question, which quantity you are supposed to come with, you know the unit. If your unit doesn't match in the end, you know you are missing something. As far as accuracy of your answer is concerned, in this case it is clear. The answer has 3 digits, and that's it. However, you may at times need to use your calculator, and it gives you a very long result with plenty of digits after the decimal point. **3 digits are always good enough**, but for the results that you enter into the Web-Assign Homework you really **need 3 digits, i.e. 3 significant figures!**!

b) Time

In physics we often need to know, how long an event lasts. Thus we need to be able to pinpoint the time "when something happened" and from the difference of two markers to derive "what was the duration".

Basic unit: sec (second), hour, day

We **measure time** by **comparing** it **with a regular repetitive motion**

sun -> sun dial (position of shadow with time) -> hours, days **Slide 2**
sand flowing through an orifice -> sand clock-> minutes
mechanical pendulum -> mechanical clock -> seconds **Demo Pendulum**
oscillation of a crystal -> quartz clock -> fractions of second

Nowadays 1 second is taken as 9,192,631,770 oscillations of the light (of a specific spectral line) by a cesium-133 atom. Atomic clocks are based on these "atomic" oscillations. Two random atomic clocks would have to run for 6000 years (or approx. 3600 x 24 x 365 x 6000 sec $\approx 2\ 10^{11}$

sec), i.e. they have an accuracy of $1/10^{11}$. Compared with this accuracy the rotation of the earth, on which a sundial is based, is truly miserable. View I.3

Now we have already 2 Basic Units: View I.2_b

We will now build a system with these units and will see that we only need very few basic definitions.

Speed:

Definition: **Distance moved in a certain time**

Length/Time

Derived Unit: m/sec or km/h View I.2_c

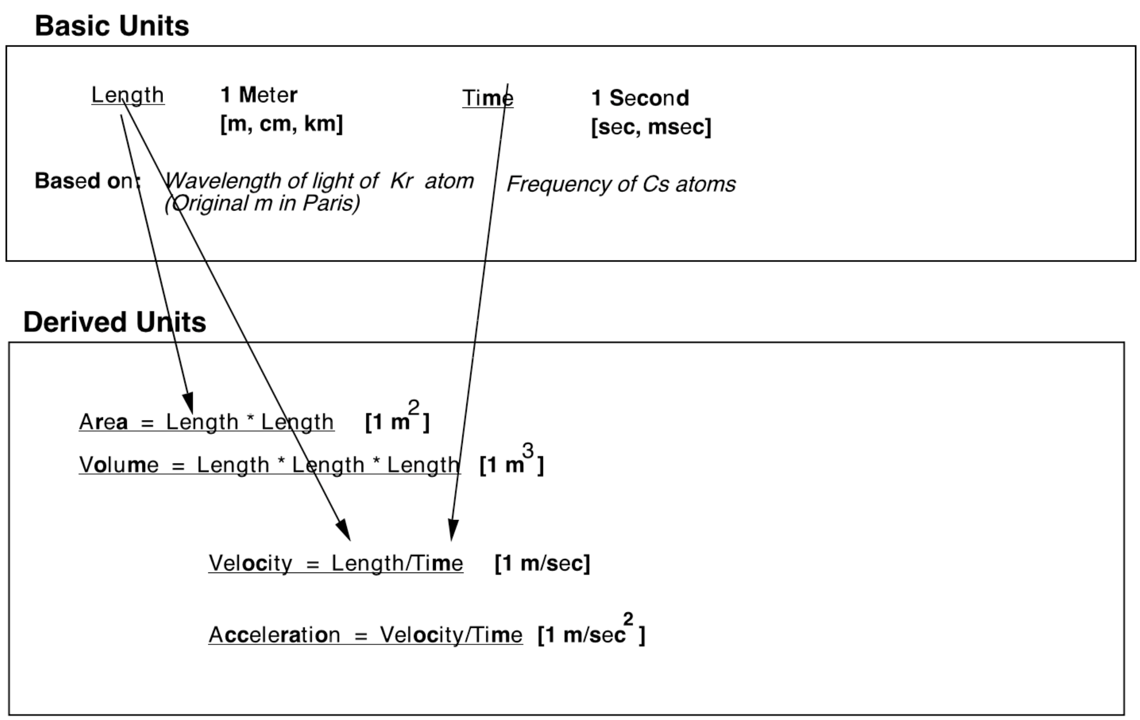
We measure the **distance** and the **time** and can then calculate **speed**. In the same way we can measure the:

Change of speed (**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 in 6 sec.

System of Units



c) Definition of Mass **"amount of material"**

Basic Unit: kg (kilogram) View I.6

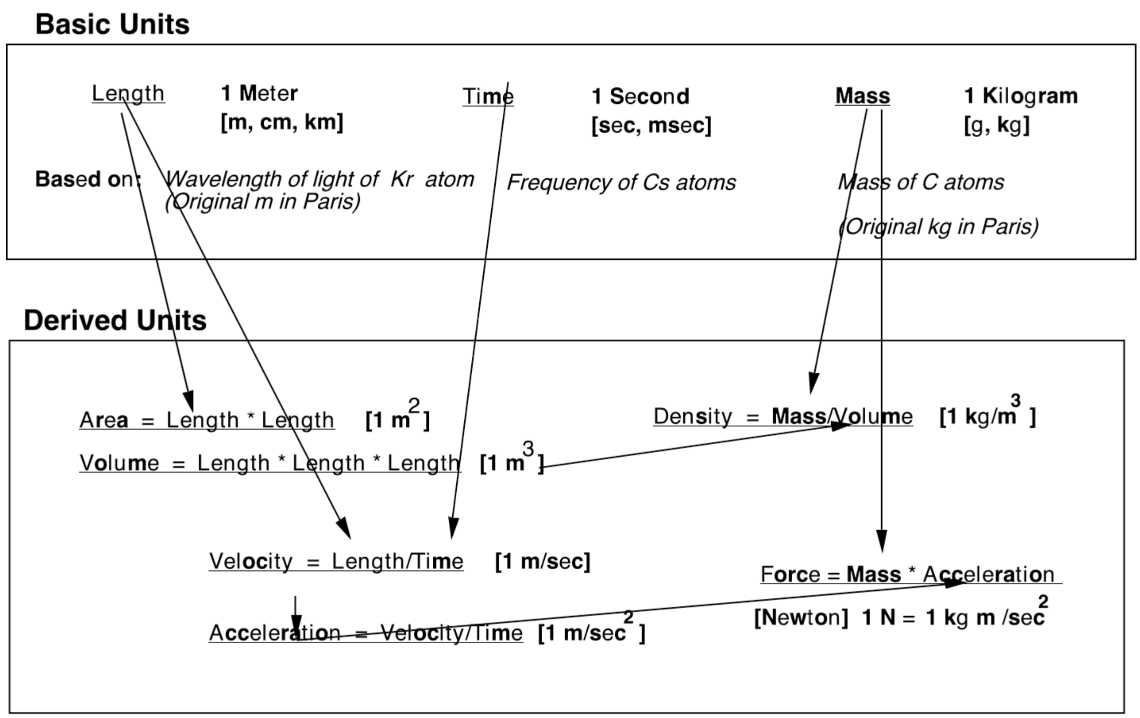
Compared with original kg (Paris) View I.2_d

A measurement of a mass therefore means a **comparison with a known mass**. That is what we do with scales **Demo Scales**

Again modern physics has enabled us to become much more precise with the mass of atoms than with the original standard. Therefore, the modern standard is based on the mass of carbon atoms. The C12 isotope has a mass of 12 atomic mass units (u) (6 protons and 6 neutrons). It is connected with the kg by:

$1 \text{ u} = 1.6605402\ (\pm 0.000001)\ 10^{-27} \text{ kg}$

System of Units



One important warning about the **definition of mass** is in order here:
<u>Do not mix Mass with Weight!!</u>

Weight means a force in a given gravitation (e.g., on Earth)
Mass of the same body remains the same, but its **Weight** may vary from location to location (on Earth, Moon or even in empty space)!!!

The effect of **weight** is sometimes used for spring based scales.
They produce the correct reading on Earth, but they will already produce a different result in an elevator!! The **weight** has changed, but not the **mass**!!

Weight is the result of a **force exerted on the mass**:

Force is action on an object to change its motion
Derived Unit: kg * m/sec^2 = Newton (N)
Mass * acceleration **View I.2_e**