1. Natural Constants for Time and Length

See also: https://www.mediatheque.lindau-nobel.org/videos/38527/si-units-iii-en

a) Definition of time

Since 1967, the measurement of the **second** has been defined as the transition between the two *hyperfine levels of the ground state of atoms of the Caesium isotope ^{133}Cs*. This means one second is equivalent to a multiple of 9,192,631,770 of the periodic time of the radiation thus emitted.

The **defined natural constant** here is the frequency $\Delta\nu = 9192631770\ s^{-1}$.

This results in the **definition of the base unit**: $1s = \frac{9192631770}{\Delta\nu(^{133}Cs)}$

b) Definition of length

In 1983, one **metre** was defined as the *speed of light* at exactly $c = 299792458\ m \cdot s^{-1}$. Consequently, one metre is the length of the path travelled by light in a vacuum during a time interval of 1/299,792,458 of a second.

Show with a calculation that the following figures result for the **definition of the base unit**:

$$1\,m = 30.663318\ldots \frac{c}{\Delta\nu(^{133}Cs)}$$

c) Demonstrate why the definitions of second and metre are connected by the natural constants c.

2. The Redefinition of the Kilogram

a) Problems with and because of the kilogram

Until 2019, the "International Prototype of the Kilogram", stored in a safe at the International Bureau of Weights and Measures (BIPM) on the outskirts of Paris (**Ill. 1**), as well as its official and numerous national copies, were the basis for all masses. But when the masses were compared, it was found that almost all the copies were heavier than the prototype – until now nobody can prove exactly why this was the case. However, it was clear that the prototype kilogram had to be replaced – after all, other units depend on the prototype kilogram, such as the *ampere* and *mole*, with the result that these units also had problems due to the kilogram.

Illustration 1: Photo: Japs 88 – wikipedia.org

b) Redefinition of the kilogram by defining the Planck constant h

See also: https://www.mediatheque.lindau-nobel.org/videos/38526/si-units-ii-en

To redefine the **kilogram**, a natural constant was selected whose unit includes the kg and whose measured value can be determined with extremely high precision – the decision was made to adopt the *Planck constant h*:

$$h = 6.62607015 \cdot 10^{-34} Js = 6.62607015 \cdot 10^{-34} \frac{kg \cdot m^2}{s}$$

Two experiments were conceived and implemented to realise a future stable kilogram:

- Using what is known as the *Kibble balance experiment*, the effect of gravity on a test object is compensated by an electro-magnetic force, which allows a figure for h to be deduced.
- In parallel, a perfectly polished crystal ball made of high-purity silicon was built from the mass of 21.442... quadrillion atoms, whose number can be counted with very high precision due to the crystal structure. This experiment, which is called the *Avogadro experiment,* results in the “Avogadro constant N_A”, from which the Planck constant can be calculated.
- This means that the results from the *Kibble balance experiment* and the silicon ball can be compared – as soon as the results from both experiments were consistent, the path to the new kilogram was clear.

Task: Research in textbooks and on the internet what is meant by the “Avogadro constant” and “Planck constant” and find out about the two experiments to redefine the kilogram.

Tip: The following YouTube video will provide initial explanations:

https://www.youtube.com/watch?v=m-fFRLWBzm8

c) The figure for the Planck constant is

$$Js = 6.62607015 \cdot 10^{-34} \frac{kg \cdot m^2}{s}.$$

Solve this equation for the unit kg and explain your result with reference to the Planck constant – also include **Ill. 2**.

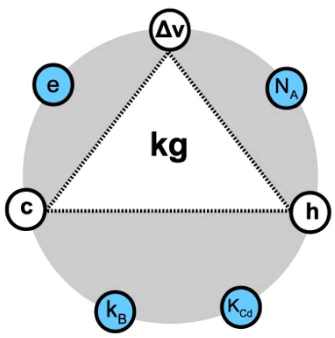

Illustration 2: Wolfgang Vogg