For an explanation of the definition of the unit ampere as well as the following definitions of kelvin, mole and candela **see also:**

https://www.mediatheque.lindau-nobel.org/videos/38528/si-units-iv-en

1. A New Basis for the Ampere

The **ampere** was chosen as the unit to measure the strength of electrical current – it is the only electrical base unit in the International System of Units. The version that has applied since 1948 is depicted in **Ill. 1**:

The base unit of 1 ampere is defined as the temporary constant current which, if maintained between two straight parallel conductors of infinite length, and placed 1 metre apart, generates a force equal to $2 \cdot 10^{-7}$ N per metre of length.

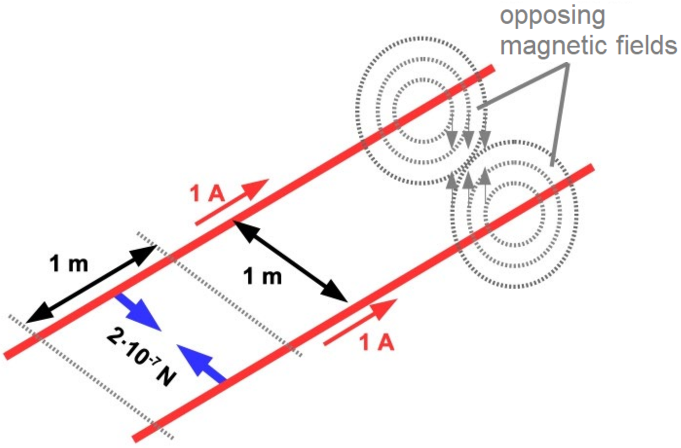

Illustration 1: Wolfgang Vogg

This arbitrarily chosen and unrealistic measurement specification could only be carried out approximately. In addition, it has the major disadvantage that it connects the ampere with the kilogram through force, with the problems that have already been mentioned.

For this reason, a different approach was taken decades ago:

In 1962, the British theoretical physicist and 1973 Nobel Laureate **Brian D. Josephson** had already predicted an **effect in superconductors** which made it possible to measure electrical currents with a high degree of accuracy. In addition, in 1980, the German physicist and 1985 Nobel Laureate **Klaus von Klitzing** discovered the **quantum Hall effect**, which enabled an exceedingly precise quantisation of electrical resistance.

a) Find out about the discoveries made by the two physicists and explain why their findings were not fully sufficient for a redefinition of the ampere.

Today, after the reform of the SI system, the ampere is also based on a natural constant – the elementary charge of the electron. In complex measurements, it has been possible to define the ampere through the electrical current of well above 1 trillion elementary charges per second.

The following applies to the elementary charge: $e = 1.602176634^{-19} A \cdot s$

b) Solve this equation for the unit A and calculate its value with the help of the corresponding natural constant.

2. Definition of the Remaining Base Units of Kelvin (K), Mole (Mol), Candela (cd)

a) The kelvin (K) as a unit of temperature

The **kelvin** is the SI unit of thermodynamic temperature. The *kelvin scale* is no different to the everyday *Celsius temperature scale* with a shifted absolute zero, meaning that -273.15 °C equals 0 K. Consequently, there are no negative temperatures when using the unit kelvin and one kelvin step equals one Celsius step.

The kelvin is defined as the natural constant k_B, which is called the *Boltzmann constant*:

$$k_B = 1.3806488 \cdot 10^{-23} \frac{J}{K}$$

α) Research how the “Boltzmann constant” was determined in your textbooks and on the internet.

β) Explain the significance of $k_B = 1.3806488 \cdot 10^{-23} \frac{J}{K}$, if the temperature is changed by1 K.

γ) Calculate the applicable relationship for 1 K. Also include **Ill.2**.

$$1K = 2.2666653 \ldots \frac{\Delta v(^{133}\,Cs)h}{k_B}$$

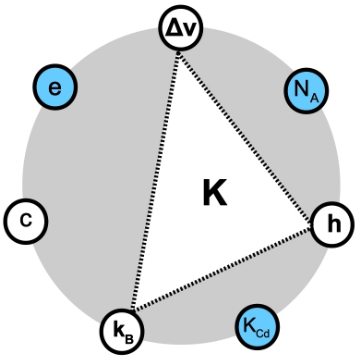

Illustration 2: Wolfgang Vogg

b) The mole (mol) as a unit of the amount of substance

By setting the kilogram on the Planck constant h, it was possible to determine the Avogadro constant N_A.

In turn, it became possible to relate the mole to a natural constant, so that the following applies today:

The **mole** is the unit of an amount of substance containing $6.02214076 \cdot 10^{23}$ particles of the same kind, which may relate to atoms, molecules, ions, electrons or other particles. Thus, the following applies to 1 mole:

1 mole = $\frac{6.02214076 \cdot 10^{23}}{N_A}$

c) The candela (cd) as the unit of luminous intensity

Luminous intensity – defined by the unit **candela** – hardly comes up in lessons in upper secondary school, but is extremely important as a unit in natural science and the resulting technical applications. Therefore, its definition and classification in the new SI system will only be introduced here – primarily to stimulate interest:

Luminous intensity was once derived from the flame of a candle with a certain wick height. By using such standardised candles, it was possible to determine how brightly a source of light was shining.

Since 1979, the unit candela (cd) – Latin for candle – has been defined by the luminous intensity of a green source of light with a frequency λ = 555 nanometres that at a certain output (1/683 watts) emits electro-magnetic radiation in a certain solid angle.

One candela corresponds approximately to the luminous intensity of one household candle. Using a conversion factor, the *photometric radiation equivalent* K_{cd}, the measurement, which is actually adjusted to the light sensitivity of the human eye, is connected to electro-magnetic radiation physics. The fact that the candela has survived as a unit is a concession to the lighting industry. Therefore, the definition will not be changed in the future.

There is the following correlation for 1 cd: $1cd = \left(\frac{K_{cd}}{683}\right) kg \cdot m^2 \cdot s^{-3} \cdot sr^{-1}$ *

* *Steradian (sr)* is a unit of measurement for the solid angle – projected onto a sphere with a radius of 1 m, a steradian encloses an area of 1 m^2 on the surface of the sphere.

Additional natural constants are included as follows:

$$1cd = \frac{1}{(6.62607015 \cdot 10^{-34}) \cdot (9192631770)^2} \left[\Delta v(^{133}\,Cs)\right]^2 h\, K_{cd}$$

$$1cd = 2.614830 \ldots \cdot 10^{10} \left[\Delta v(^{133}\,Cs)\right]^2 h\, K_{cd}$$

Thus, one candela is the luminous intensity of a source of radiation in a particular direction that emits a frequency of 540·10^{12} Hz and has a radiant intensity in this direction of 1/683 W sr^{-1}.

3. Overview of All Base Units and the Associated Natural Constants

Ill. 3 shows to which natural constant the respective base unit refers and the relationship between the individual units of measurement.

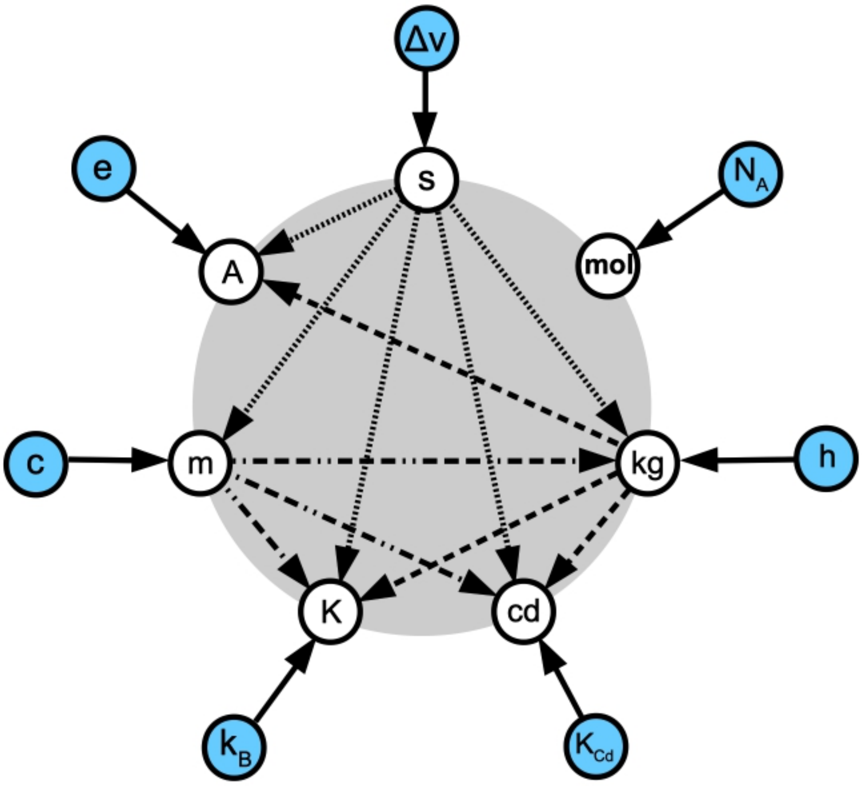

Illustration 3: Wolfgang Vogg

Disentangle the linkage using the differently labelled arrows and discover the connections between the individual base units and their associated natural constants.