Beauty of Physical Chemistry – Part 2

New definitions of SI Units and Physical Chemistry

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Learning physical chemistry is equally important as other areas in Chemistry. Unfortunately, lot of students (and also lecturers) give less attention to it. However, concepts in physical chemistry such as quantum mechanics, thermodynamics, kinetics, statistical mechanics, etc. are really important to understand the fascinating world of Chemistry. Considering this, I wish to make this series of articles an eye opener and to boost your curiosity in learning physical chemistry.

In the previous article we learnt how fixed values of hyperfine transition frequency of Cs, speed of light, Planck constant, and Avogadro constant are used to define SI units of time, length, mass and amount of substances (mole) respectively under the new definitions. In this article we will discuss the remaining three new definitions of SI units.

First let me explain little more about Silicon spheres which are used for the determination of Avogadro constant and Planck constant. Though silicon is the second most abundant element in the earth it is very rarely found in its pure form and mostly exists as silica (SiO_2) or silicate (SiO_4) crystalline forms. In addition, silicon spheres are made of isotopically pure ^{28}Si which is the most abundant and stable isotope of silicon. The silicon spheres made this way for SI unit definitions are the purest silicon ever created.

Quiz on Silicon Spheres

Referring to the unit cell shown in the diagram one can determine the number of silicon atoms in the unit cell silicon spheres (n) as $8\times\frac{1}{8}+6\times\frac{1}{2}+4=8$

Length of each side of the unit cell given above is a (m)

atomic mass of silicon is m (m =28.09 Da)

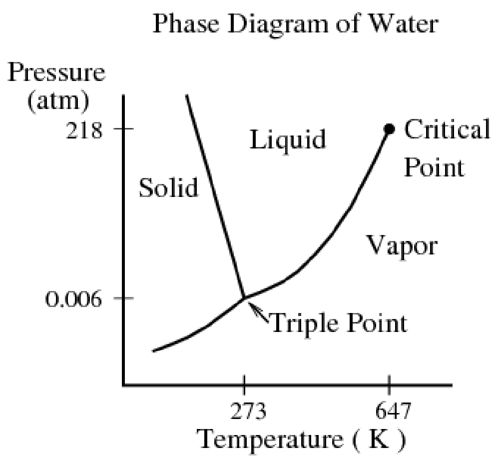
Density (d) of silicon sphere $\frac{nm}{a^3N_A}$

Density of this silicon spheres can express in terms of mass of the sphere and radius of sphere. Thus,

$$d=\frac{3}{4\pi r^3}=\frac{nm}{a^3N_A}$$

Temperature (Kelvin)

The temperature used to be measured in Fahrenheit and Celsius scales. However, the SI unit for Temperature is Kelvin and is applied widely in physical sciences. In 1954, the Kelvin was defined as 1/273.16 of the thermodynamic temperature of water. The triple point of water is the temperature and pressure at which water exists in equilibrium with ice, water and water vapor. The temperature at the triple point of water is exactly 273.16 K. Since it is problematic to extrapolate very high and very low temperatures only by the triple point of water measurement, scientists specified 21 other points between the freezing point of He and freezing point of Cu to define kelvin temperature scale.



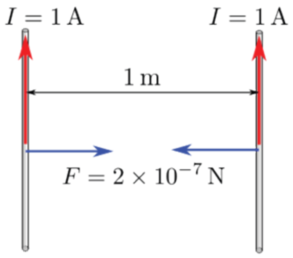
Under the new revision in 2019, Kelvin was redefined in terms of the Boltzmann constant. The Boltzmann constant (k_B) is set be exactly equal to 1.380469 $\times10^{-23}$ J K^{-1}. This value is accurately measured using the speed of sound in a gaseous medium which directly depends on the temperature known as acoustic thermometry. This definition of Kelvin is truly universal, when compared to the previously mentioned definition.

Current (Ampere)

Ampere is the SI base unit of electric current which has been internationally recognized since 1908. Previous (old) definition of ampere is as follows

The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 meter apart in vacuum, would produce between these conductors a force equal to 2x10^{-7} N m^{-1} of length.

The experiment carried out to realize this definition is depicted in the diagram below.



This definition in fact specifies a hypothetical situation since infinitely long wires are unavailable. Force is a derived unit (kg m s^{-2}), therefore measurement of force also has to be correctly calibrated.

According to the new definition given in 2019, the ampere is defined by the elementary charge of an electron which is equal to 1.602176634 ×10^{-19} C. One ampere is the current generated when one coulomb of charge travels across a given point in 1 second. You may know this equation; $I=Q/t$.

Therefore,

$$1A = \frac{Q}{.602176634\times10^{-19}}\frac{1}{s} = \frac{Q}{.602176634\times10^{-19}}\frac{\Delta v_{Cs}}{9192631770} = 18.06492806\ Q\ \Delta v_{Cs} - (5)$$

Hence, the ampere is defined in terms of electron charge and frequency of Cs.

Luminous intensity (Candela)

Candela is the base unit for photometry or to measure the luminous intensity. It is the only SI unit that involves human perception. Candela measures the light intensity in the visible region that can be perceived by the human eye (Not other regions such as UV or IR).

According to the new definition, a candela is the luminous intensity in a given direction of a source that emits monochromatic radiation of frequency 540 ×10^{12} Hz and has a radiant intensity in that direction of 1/683 watt per steradian. We will not go into much detail of this definition since chemistry students are not very familiar with the terms mentioned in this definition. However, you must notice that now candela is also defined without using any artifacts similar to the definitions of rest of the other SI base units.

Those who are interested about this subject please go through the following references.

https://www.nist.gov/si-redefinition

https://www.bipm.org/en/home

http://hyperphysics.phy-astr.gsu.edu/hbase/acloc.html