# FAQs, Frequently Asked Questions about the New SI

(Revised October 2011)

**Q1: Are the seven base quantities and base units in the current SI going to change in the New SI?**

A1: No, the seven base quantities and base units will remain unchanged.

**Q2: Are the 22 coherent derived units with special names and symbols going to change?**

A2: No, the 22 coherent derived units with special names and symbols will remain unchanged in the New SI.

**Q3: Are the names and symbols of the multiple and sub-multiple prefixes (kilo for $10^3$, milli for $10^{-3}$, etc.) going to change in the New SI?**

A3: No, the names and symbols for the prefixes will remain unchanged.

**Q4: Will the magnitudes of any of the units change in the New SI?**

A4: No.

**Q5: In that case what is going to change?**

A5: The kilogram, kg, ampere, A, kelvin, K, and mole, mol, will have new definitions, but they will be so chosen that at the moment of change the magnitudes of the new units will be identical to those of the old units.

**Q6: So what is the point of changing to new definitions?**

A6: Defining the kilogram in terms of fundamental physical constants will ensure its long-term stability, and hence its reliability, which is at present in doubt. The new definitions of the ampere and kelvin will significantly improve the accuracy with which mass, electrical, and radiometric temperature measurements can be made. The impact on electrical measurements will be immediate: the most precise electrical measurements are always made using the Josephson and quantum Hall effects, and fixing the numerical values of $h$ and $e$ in the new units will lead to exactly known values for the Josephson and von Klitzing constants. This will eliminate the current need to use conventional electrical units rather than SI units to express the results of electrical measurements. The conversion factor between measured radiance and thermodynamic temperature (the Stefan-Boltzmann constant) will be exact using the new definitions of the kelvin and kilogram, leading to improved temperature metrology as technology improves. The revised definition of the mole is simpler than the current definition, and it will help users of the SI to better understand the nature of the quantity "amount of substance" and its unit, the mole.

**Q7: What about the definitions of the second, s, metre, m, and candela, cd?**

A7: The definitions of the second, s, metre, m, and candela, cd, will not change, but the way they are expressed will be revised to make them consistent in form with the new definitions for the kilogram, kg, ampere, A, kelvin, K, and mole, mol.

**Q8: How can you fix the value of a fundamental constant like *h* to define the kilogram, and *e* to define the ampere, and so on? How do you know what value to fix them to? What if it emerges that you have chosen the wrong value?**

A8: We do not fix – or change – the *value* of any constant that we use to define a unit. The values of the fundamental constants are constants of nature, and we only fix the *numerical value* of each constant when expressed *in the New SI unit*. By fixing its numerical value we define the magnitude of the unit in which we measure that constant.

Example: If $c$ is the *value* of the speed of light, $\{c\}$ is its *numerical value*, and $[c]$ is the *unit*, so that

$$c = \{c\}\ [c] = 299\ 792\ 458\ \mathrm{m/s}$$

then the value $c$ is the product of the number $\{c\}$ times the unit $[c]$, and the value never changes. However the factors $\{c\}$ and $[c]$ may be chosen in different ways such that the product $c$ remains unchanged.

In 1983 it was decided to fix the number $\{c\}$ to be exactly 299 792 458, which then defined the unit of speed $[c]$ = m/s. Since the second, s, was already defined, the effect was to define the metre, m. The number $\{c\}$ in the new definition was chosen so that the magnitude of the unit m/s was unchanged, thereby ensuring continuity between the new and old units.

**Q9: OK, you actually only fix the *numerical value* of the constant expressed in the *new unit*. For the kilogram, for example, you choose to fix the numerical value $\{h\}$ of the Planck constant expressed in the new unit $[h] = \mathrm{kg\ m^2\ s^{-1}}$. But the question remains: suppose a new experiment shortly after you change the definition suggests that you chose a wrong numerical value for $\{h\}$, what then?**

A9: After making the change, the mass of the international prototype of the kilogram (the IPK), which defines the current kilogram, has to be determined by experiment. If we have chosen a "wrong value" it simply means that the new experiment will tell us that the mass of the IPK is not exactly 1 kg in the New SI.

Although this situation might seem to be problematic, it would only affect macroscopic mass measurements; the masses of atoms and the values of other constants related to quantum physics would not be affected. But if we were to retain the current definition of the kilogram, we would be continuing the unsatisfactory practice of using a reference constant (i.e. the mass of the IPK) that considerable evidence suggests to be changing with time compared to a true invariant such as the mass of an atom or the Planck constant. Although the magnitude of this change is not known exactly, it could be as much as a part in $10^7$ since the IPK was sanctioned as the definition of the kilogram in 1889.

The advantage of the new definition would be that we will know that the reference constant used to define the kilogram is a true invariant.

**Q10: Each of the fundamental constants used to define a unit has an uncertainty; its value is not known exactly. But it is proposed to fix its numerical value exactly. How can you do that? What has happened to the uncertainty?**

A10: The present definition of the kilogram fixes the mass of the IPK to be one kilogram exactly with zero uncertainty, $u_\mathrm{r}(m_\mathrm{IPK}) = 0$. The Planck constant is at present experimentally determined, and has a relative standard uncertainty of 4.4 parts in $10^8$, $u_\mathrm{r}(h) = 4.4 \times 10^{-8}$. In the new definition the value of $h$ would be known exactly in the new units with zero uncertainty, $u_\mathrm{r}(h) = 0$. But the mass of the IPK would have to be experimentally determined, and it would have a relative uncertainty of about $u_\mathrm{r}(m_\mathrm{IPK}) = 4.4 \times 10^{-8}$. Thus the uncertainty is not lost in the new definition, but it moves to become the uncertainty of the previous reference that is no longer used, as in the table below.

| *constant used* | *current SI* | | *New SI* | |
|---|---|---|---|---|
| *to define the kilogram* | *status* | *uncertainty* | *status* | *uncertainty* |
| mass of the IPK, $m(\mathcal{K})$ | exact | 0 | expt | $4.4 \times 10^{-8}$ |
| Planck constant, $h$ | expt | $4.4 \times 10^{-8}$ | exact | 0 |

**Q11: The unit of the Planck constant is equal to the unit of action, J s = kg m$^2$ s$^{-1}$. How does fixing the numerical value of the Planck constant define the kilogram?**

A11: Fixing the numerical value of $h$ actually defines the unit of action, J s = kg m$^2$ s$^{-1}$. But if we have already defined the second, s, to fix the numerical value of the caesium hyperfine splitting frequency $\Delta\nu(^{133}\mathrm{Cs})_\mathrm{hfs}$, and the metre, m, to fix the numerical value of the speed of light in vacuum, $c$, then fixing the magnitude of the unit kg m$^2$ s$^{-1}$ has the effect of defining the unit kg.

**Q12: Are not the proposed definitions of the base units in the New SI circular definitions, and therefore unsatisfactory?**

A12: No, they are not circular. A circular definition is one that makes use of the result of the definition in formulating the definition. The words for the individual definitions of the base units in the New SI specify the *numerical value* of each chosen reference constant to define the corresponding unit, but this does not make use of the result to formulate the definition.

**Q13: In the New SI the reference constant for the kilogram is the Planck constant *h*, with unit J s = kg m$^2$ s$^{-1}$. It would be much easier to comprehend if the reference constant had the unit of mass, the kg. Then we could say: "The kilogram is the mass of <*something*>", such as perhaps the mass of a specified number of carbon or silicon atoms. Would that not be a better definition?**

A13: This is to some extent a matter of subjective judgement. However note that the reference constant used to define a unit does not *have* to be dimensionally the same as the unit (even though it may be conceptually simpler when this is the case). We already use several reference constants in the current SI that have a different unit to that being defined. For example the metre is defined using as reference constant the speed of light $c$ with unit m/s, not a specified length in m. This definition has not been found unsatisfactory.

Although it may seem intuitively simpler to define the kilogram using a mass as the reference constant, using the Planck constant has other advantages. For example if both $h$ and $e$ are exactly known as proposed in the New SI, then both the Josephson and von Klitzing constants $K_\mathrm{J}$ and $R_\mathrm{K}$ will be exactly known, with great advantages for electrical metrology.

**Q14: Despite the answer to Q13 above, there are still people who question the wisdom of defining the kilogram by using *h* as a reference rather than by using $m(^{12}\mathrm{C})$. One of the arguments they use is that the watt balance (WB) experiment to determine *h* uses a complex apparatus that is difficult to use and expensive to build, in comparison with the XRCD (x-ray crystal density) experiment to measure the mass of a silicon 28 atom, and hence the mass of a carbon 12 atom. What are the principal reasons for choosing *h* rather than $m(^{12}\mathrm{C})$ as the reference constant for the kilogram?**

A14: These are really two unrelated questions: (I) why choose $h$ rather than $m(^{12}\mathrm{C})$ as the reference constant for the kilogram? (II) The question assumes that the choice of $h$ or $m(^{12}\mathrm{C})$ determines whether the kilogram will be realized in practice by a WB experiment or by the XRCD experiment; is that correct?

(I): Once the numerical value of a constant is given a fixed value, the constant need not, indeed cannot, be measured subsequently. For example, in 1983 when the SI was modified by making the speed of light in vacuum, $c$, the reference constant for the metre, the long history of measuring $c$ abruptly ended. This was an enormous benefit to science and technology, in part because $c$ enters into so many domains of science and technology that every time there was a change to the recommended SI value of $c$, the values of numerous constants and conversion factors related to $c$ needed to be updated. The decision to define the numerical value of $c$ as exact was obviously correct.

Similarly, $h$ is the fundamental constant of quantum physics and consequently its SI value is used in many diverse fields of modern science and technology. Changes to the recommended value of $h$ as experiments improve are at best annoying and at worst confusing. The rationale for defining the numerical value of $h$ is similar to that for defining $c$, but has the specific advantages in electrical metrology given in A6.

Of course $m(^{12}\mathrm{C})$ is undeniably a constant and is undeniable important, especially for chemistry and the physics of atoms. This is because atomic weights (if you are a chemist), also known as relative atomic masses (if you are a physicist), are all based on

$m(^{12}\mathrm{C})$. Nevertheless, atomic weights do not depend on the present definition of the kilogram and, of course, they will be unaffected by a new definition.

(II): No. The choice of which reference constant is used to define the kilogram does not imply any particular method to realize the kilogram, and none is mentioned in Resolution 1. We do know that any realization must be traceable to $h$ since $h$ will be the reference constant for the new kilogram. However, it is also known that $h/m(^{12}\mathrm{C}) = Q$, where $Q$ represents a collection of exact numerical factors and experimentally determined constants. The relative standard uncertainty of $Q$ is only $7 \times 10^{-10}$ based on the current recommended values of the constants involved. An apparatus, such as the WB, which measures a 1 kg mass standard directly in terms of $h$ and auxiliary measurements of length, time, voltage, and resistance, can be used to realize the kilogram. However, an experiment that measures a 1 kg mass standard in terms of $m(^{12}\mathrm{C})$, as in the XRCD project, also has the potential to realize the kilogram. This is because $m(^{12}\mathrm{C})Q = h$, and thus the price to pay for arriving at $h$ by way of $m(^{12}\mathrm{C})$ is the uncertainty of $Q$, which is negligible in the context of realizing the new definition. It is premature to speculate whether one type of realization will prevail in the long run or whether different types will coexist. At present, all such experiments are difficult and expensive.

**Q15: Can we still check the consistency of physics if we fix the values of all the fundamental constants?**

A15: We are not fixing the values of all the fundamental constants, only the *numerical values* of a small subset and combinations of the constants in this subset. This has the effect of changing the definitions of the units, but not the equations of physics, and it cannot prevent researchers from checking the consistency of the equations.

**Q16: Will I get my standard of mass, or my thermometer, calibrated under the New SI in the same way as I do now?**

A16: Yes. You will send it to your NMI for calibration, just as you do now. Your NMI will establish its own realization of the unit using the new definition, either by constructing an appropriate apparatus locally, or by any other method that proves to be convenient such as, in the case of 1 kg mass standards, by going to the BIPM for calibration. The BIPM intends to maintain traceability to the definition of the kilogram through a weighted mean of all available realizations.