The papers in this Discussion Meeting Issue of Philosophical Transactions A are based on the presentations given at a Discussion Meeting held at the Royal Society in London on 24 and 25 January 2011 entitled ‘The new SI: units of measurement based on fundamental constants’. The meeting was organized by the writer (Terry Quinn) in collaboration with Ian Mills FRS and Patrick Gill. The programme of lectures along with the biographies of lecturers and chairpersons can be found on the Royal Society website at http://royalsociety.org/new-SI/. The meeting was opened by the Minister for Universities and Science, the Right Honourable David Willetts MP. The PowerPoint presentations of all the lectures were subsequently placed on the website of the International Bureau of Weights and Measures (Bureau International des Poids et Mesures, BIPM) at www.bipm.org/en/si/new_si/discussion_meeting.html.

The International System of Units (SI) was formally adopted by the 11th General Conference on Weights and Measures (Conférences Générales des Poids et Mesures, CGPM) in 1960 to meet the need for a comprehensive system of units suitable for the twentieth century. It was founded on six base units, the metre, kilogram, second, ampere, kelvin and candela. At the time, the metre and kilogram were both still based on artefacts, with the International Prototypes of the metre and kilogram being kept at the BIPM, Sévres, France. The ampere and candela were also linked to these artefacts because of the dependence of their definitions on those of the metre and kilogram. The second, previously taken to be the fraction 1/86400 of the mean solar day, had only recently been redefined in 1956 as a fraction of the period of the orbit of the Earth around the Sun, the tropical year. The 11th CGPM in 1960, however, in addition to adopting the name SI (Système International d’Unités), redefined the metre in terms of the wavelength of the orange light of the krypton atom. By so doing, it took the first step towards a system of units that would meet the precept of James Clerk Maxwell, who famously said at the 1870 meeting of the British Association for the Advancement of Science (Maxwell, J. C. 1870 Report of the 1870 BA Meeting, Notices and Abstracts of Misc. Comm., Mathematics and Physics, pp. 1–9):

Yet, after all, the dimensions of our earth and its time of rotation, though, relatively to our present means of comparison, very permanent, are not so by physical necessity. The Earth might contract by cooling, or it might be enlarged by a layer of meteorites falling on it, or its rate of revolution might slowly slacken, and yet it would continue to be as much a planet as before. But a molecule, say of hydrogen, if either its mass or its time of vibration were to be altered in the least, would no longer be a molecule of hydrogen.

One contribution of 15 to a Discussion Meeting Issue ‘The new SI based on fundamental constants’.
If, then we wish to obtain standards of length, time, and mass which shall be absolutely permanent, we must seek them not in the dimensions, or the motion, or the mass of our planet, but in the wavelength, the period of vibration, and the absolute mass of these imperishable and unalterable and perfectly similar molecules.

In 1870, science and technology were not yet ready to allow this to happen, and indeed it took nearly 100 years before the 11th CGPM took this first step towards such a system by redefining the metre not in terms of an artefact, but in terms of the wavelength of the krypton atomic line. The next step was taken soon after; when, in 1967, the 13th CGPM adopted the present atomic definition of the second some 12 years after the first caesium atomic clock had been operated at the National Physical Laboratory. Although in 1983, the 17th CGPM redefined the metre in terms of a fixed numerical value for the speed of light, no further progress has been made since then in implementing Maxwell’s precept. The obstacle has been the difficulty in finding a way to redefine the kilogram in terms of a fundamental constant or an invariant of nature. Today, however, this problem has been solved and we have two alternative definitions based on invariants: one based on a fixed numerical value of the Planck constant; and the other based on the mass of a specified number of $^{12}$C or $^{28}$Si atoms (often described as a fixed numerical value of the Avogadro constant). These may be realized by either of two experiments: the so-called watt balance experiment; or the X-ray crystal density experiment using a single-crystal sphere of pure $^{28}$Si. The two definitions, and the two methods of realization, are closely related through an equation that relates either of the atomic masses to the Planck constant, in which the other factors are all known to better than one part in $10^9$.

The International Committee for Weights and Measures (Comité International des Poids et Mesures, CIPM) has made an outline proposal to the 24th CGPM, due to take place in October 2011, to redefine the kilogram, ampere, mole and kelvin in terms of fixed numerical values for the Planck constant $h$, the elementary charge $e$, the Avogadro constant $N_A$ and the Boltzmann constant $k$, respectively. This proposal has been extensively discussed in the national metrology institutes and by the various technical Consultative Committees of the CIPM. One of the aims of the Discussion Meeting was to present it to the wider scientific community. The first paper in this issue gives an overall view of the scientific basis for the proposal. In the papers that follow, detailed accounts are given of the various experimental aspects related to the new definitions of each unit. As is always the case in any such wide-ranging proposal, there have been different views on how best to proceed, and the present plan to redefine the base units of the SI is no exception. What is now proposed represents a broad consensus within the metrology community.

The January 2011 Discussion Meeting was the second to take place on this general topic, the first having been in February 2005, for which the papers appeared in issue 1834 in September that year (Phil. Trans. R. Soc. A 363, 2097–2327). An interested reader can compare the papers presented then with those here, and the progress made in the intervening 6 years will be evident. Full details of the CIPM proposal to the 24th CGPM and the decisions of the Conference can be found on the BIPM website, www.bipm.org.

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