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Scientific notation

Scientific notation (also referred to as **scientific form** or **standard index form**, or **standard form** in the UK) is a way of expressing numbers that are too big or too small to be conveniently written in decimal form. It is commonly used by scientists, mathematicians and engineers, in part because it can simplify certain arithmetic operations. On scientific calculators it is usually known as "SCI" display mode.

In scientific notation, all numbers are written in the form

$$m \times 10^n$$

(m times ten raised to the power of n), where the exponent n is an integer, and the coefficient m is any real number. The integer n is called the order of magnitude and the real number m is called the *significand* or *mantissa*.[1] However, the term "mantissa" may cause confusion because it is the name of the fractional part of the common logarithm. If the number is negative then a minus sign precedes m (as in ordinary decimal notation). In normalized notation, the exponent is chosen so that the absolute value (modulus) of the significand m is at least 1 but less than 10.

Decimal notation	Scientific notation
2	2×10^0
300	3×10^2
4,321.768	$4.321\,768 \times 10^3$
−53,000	-5.3×10^4
6,720,000,000	6.72×10^9
0.2	2×10^{-1}
987	9.87×10^2
0.000 000 007 51	7.51×10^{-9}

Decimal floating point is a computer arithmetic system closely related to scientific notation.

Contents

Normalized notation

Any given real number can be written in the form $m \times 10^n$ in many ways: for example, 350 can be written as 3.5×10^2 or 35×10^1 or 350×10^0.

In *normalized* scientific notation (called "standard form" in the UK), the exponent n is chosen so that the absolute value of m remains at least one but less than ten ($1 \leq |m| < 10$). Thus 350 is written as 3.5×10^2. This form allows easy comparison of numbers, as the exponent n gives the number's order of magnitude. In normalized notation, the exponent n is negative for a number with absolute value between 0 and 1 (e.g. 0.5 is written as 5×10^{-1}). The 10 and exponent are often omitted when the exponent is 0.

Normalized scientific form is the typical form of expression of large numbers in many fields, unless an unnormalized form, such as engineering notation, is desired. Normalized scientific notation is often called **exponential notation**—although the latter term is more general and also applies when m is not restricted to the range 1 to 10 (as in engineering notation for instance) and to bases other than 10 (for example, 3.15×2^{20}).

Engineering notation

Engineering notation (often named "ENG" display mode on scientific calculators) differs from normalized scientific notation in that the exponent n is restricted to multiples of 3. Consequently, the absolute value of m is in the range $1 \leq |m| < 1000$, rather than $1 \leq |m| < 10$. Though similar in concept, engineering notation is rarely called scientific notation. Engineering notation allows the numbers to explicitly match their corresponding SI prefixes, which facilitates reading and oral communication. For example, 12.5×10^{-9} m can be read as "twelve-point-five nanometers" and written as 12.5 nm, while its scientific notation equivalent 1.25×10^{-8} m would likely be read out as "one-point-two-five times ten-to-the-negative-eight meters".

Significant figures

A significant figure is a digit in a number that adds to its precision. This includes all nonzero numbers, zeroes between significant digits, and zeroes indicated to be significant. Leading and trailing zeroes are not significant because they exist only to show the scale of the number. Therefore, 1,230,400 usually has five significant figures: 1, 2, 3, 0, and 4; the final two zeroes serve only as placeholders and add no precision to the original number.

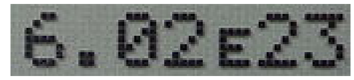
When a number is converted into normalized scientific notation, it is scaled down to a number between 1 and 10. All of the significant digits remain, but the place holding zeroes are no longer required. Thus 1,230,400 would become 1.2304×10^6. However, there is also the possibility that the number may be known to six or more significant figures, in which case the number would be shown as (for instance) 1.23040×10^6. Thus, an additional advantage of scientific notation is that the number of significant figures is clearer.

Estimated final digit(s)

It is customary in scientific measurements to record all the definitely known digits from the measurements, and to estimate at least one additional digit if there is any information at all available to enable the observer to make an estimate. The resulting number contains more information than it would without that extra digit(s), and it (or they) may be considered a significant digit because it conveys some information leading to greater precision in measurements and in aggregations of measurements (adding them or multiplying them together).

Additional information about precision can be conveyed through additional notations. It is often useful to know how exact the final digit(s) are. For instance, the accepted value of the unit of elementary charge can properly be expressed as $1.602\,176\,6208(98) \times 10^{-19}$ C,[2] which is shorthand for $(1.602\,176\,6208 \pm 0.000\,000\,0098) \times 10^{-19}$ C.

E-notation



A calculator display showing the Avogadro constant in E-notation

Most calculators and many computer programs present very large and very small results in scientific notation, typically invoked by a key labelled EXP (for *exponent*), EEX (for *enter exponent*), EE, EX, E, or ×10^x depending on vendor and model. Because superscripted exponents like 10^7 cannot always be conveniently displayed, the letter *E* (or *e*) is often used to represent "times ten raised to the power of" (which would be written as "$\times\ 10^n$") and is followed by the value of the exponent; in other words, for any two real numbers *m* and *n*, the usage of "*m*E*n*" would indicate a value of $m \times 10^n$. In this usage the character *e* is not related to the mathematical constant *e* or the exponential function e^x (a confusion that is unlikely if scientific notation is represented by a capital *E*). Although the *E* stands for *exponent*, the notation is usually referred to as *(scientific) E-notation* rather than *(scientific) exponential notation*. The use of E-notation facilitates data entry and readability in textual communication since it minimizes keystrokes, avoids reduced font sizes and provides a simpler and more concise display, but it is not encouraged in some publications.[3]

Examples and other notations

- In most popular programming languages, `6.022E23` (or `6.022e23`) is equivalent to 6.022×10^{23}, and 1.6×10^{-35} would be written `1.6E-35` (e.g. Ada, Analytica, C/C++, FORTRAN (since FORTRAN II as of 1958), MATLAB, Scilab, Perl, Java,[4] Python, Lua, JavaScript, and others).
- After the introduction of the first pocket calculators supporting scientific notation in 1972 (HP-35, SR-10) the term *decapower* was sometimes used in the emerging user communities for the power-of-ten multiplier in order to better distinguish it from "normal" exponents. Likewise, the letter "D" was used in typewritten numbers. This notation was proposed by Jim Davidson and published in the January 1976 issue of Richard J. Nelson's Hewlett-Packard newsletter *65 Notes*[5] for HP-65 users, and it was adopted and carried over into the Texas Instruments community by Richard C. Vanderburgh, the editor of the *52-Notes* newsletter for SR-52 users in November 1976.[6]
- FORTRAN (at least since FORTRAN IV as of 1961) also uses "D" to signify double precision numbers in scientific notation.[7]
- Similar, a "D" was used by Sharp pocket computers PC-1280, PC-1470U, PC-1475, PC-1480U, PC-1490U, PC-1490UII, PC-E500, PC-E500S, PC-E550, PC-E650 and PC-U6000 to indicate 20-digit double-precision numbers in scientific notation in BASIC between 1987 and 1995.[8][9][10][11][12][13]
- The ALGOL 60 (1960) programming language uses a subscript ten "$_{10}$" character instead of the letter E, for example: $6.022_{10}23$.[14][15]
- The use of the "$_{10}$" in the various Algol standards provided a challenge on some computer systems that did not provide such a "$_{10}$" character. As a consequence Stanford University Algol-W required the use of a single quote, e.g. `6.02486'+23`,[16] and some Soviet Algol variants allowed the use of the Cyrillic character "ю" character, e.g. 6.022ю+23.
- Subsequently, the ALGOL 68 programming language provided the choice of 4 characters: E, e, \, or $_{10}$. By examples: `6.022E23`, `6.022e23`, `6.022\23` or $6.022_{10}23$.[17]

- *Decimal Exponent Symbol* is part of the Unicode Standard,[18] e.g. `6.022⏨23`. It is included as `U+23E8` ⏨ DECIMAL EXPONENT SYMBOL to accommodate usage in the programming languages Algol 60 and Algol 68.
- The TI-83 series and TI-84 Plus series of calculators use a stylized **E** character to display *decimal exponent* and the $_{10}$ character to denote an equivalent ×10^ operator.[19]
- The Simula programming language requires the use of & (or && for long), for example: `6.022&23` (or `6.022&&23`).[20]
- The Wolfram Language (utilized in Mathematica) allows a shorthand notation of `6.022*^23`. (Instead, `E` denotes the mathematical constant *e*).

Order of magnitude

Scientific notation also enables simpler order-of-magnitude comparisons. A proton's mass is 0.000 000 000 000 000 000 000 000 001 6726 kg. If written as 1.6726×10^{-27} kg, it is easier to compare this mass with that of an electron, given below. The order of magnitude of the ratio of the masses can be obtained by comparing the exponents instead of the more error-prone task of counting the leading zeros. In this case, −27 is larger than −31 and therefore the proton is roughly four orders of magnitude (10,000 times) more massive than the electron.

Scientific notation also avoids misunderstandings due to regional differences in certain quantifiers, such as *billion*, which might indicate either 10^9 or 10^{12}.

In physics and astrophysics, the number of orders of magnitude between two numbers is sometimes referred to as "dex", a contraction of "decimal exponent". For instance, if two numbers are within 1 dex of each other, then the ratio of the larger to the smaller number is less than 10. Fractional values can be used, so if within 0.5 dex, the ratio is less than $10^{0.5}$, and so on.

Use of spaces

In normalized scientific notation, in E-notation, and in engineering notation, the space (which in typesetting may be represented by a normal width space or a thin space) that is allowed *only* before and after "×" or in front of "E" is sometimes omitted, though it is less common to do so before the alphabetical character.[21]

Further examples of scientific notation

- An electron's mass is about 0.000 000 000 000 000 000 000 000 000 000 910 938 356 kg.[22] In scientific notation, this is written $9.109\,383\,56 \times 10^{-31}$ kg (in SI units).
- The Earth's mass is about 5 972 400 000 000 000 000 000 000 kg.[23] In scientific notation, this is written 5.9724×10^{24} kg.
- The Earth's circumference is approximately 40 000 000 m.[24] In scientific notation, this is 4×10^7 m. In engineering notation, this is written 40×10^6 m. In SI writing style, this may be written 40 Mm (*40 megameters*).
- An inch is defined as *exactly* 25.4 mm. Quoting a value of 25.400 mm shows that the value is correct to the nearest micrometer. An approximated value with only two significant digits would be 2.5×10^1 mm instead. As there is no limit to the number of significant digits, the length of an inch could, if required, be written as (say) $2.540\,000\,000\,00 \times 10^1$ mm instead.

Converting numbers

Converting a number in these cases means to either convert the number into scientific notation form, convert it back into decimal form or to change the exponent part of the equation. None of these alter the actual number, only how it's expressed.

Decimal to scientific

First, move the decimal separator point sufficient places, n, to put the number's value within a desired range, between 1 and 10 for normalized notation. If the decimal was moved to the left, append "$\times 10^n$"; to the right, "$\times 10^{-n}$". To represent the number 1,230,400 in normalized scientific notation, the decimal separator would be moved 6 digits to the left and "$\times 10^6$" appended, resulting in 1.2304×10^6. The number −0.004 0321 would have its decimal separator shifted 3 digits to the right instead of the left and yield -4.0321×10^{-3} as a result.

Scientific to decimal

Converting a number from scientific notation to decimal notation, first remove the × 10^n on the end, then shift the decimal separator n digits to the right (positive n) or left (negative n). The number 1.2304×10^6 would have its decimal separator shifted 6 digits to the right and become 1,230,400, while -4.0321×10^{-3} would have its decimal separator moved 3 digits to the left and be −0.004 0321.

Exponential

Conversion between different scientific notation representations of the same number with different exponential values is achieved by performing opposite operations of multiplication or division by a power of ten on the significand and an subtraction or addition of one on the exponent part. The decimal separator in the significand is shifted x places to the left (or right) and x is added to (or subtracted from) the exponent, as shown below.

$$1.234 \times 10^3 = 12.34 \times 10^2 = 123.4 \times 10^1 = 1234$$

Basic operations

Given two numbers in scientific notation,

$$x_0 = m_0 \times 10^{n_0}$$

and

$$x_1 = m_1 \times 10^{n_1}$$

Multiplication and division are performed using the rules for operation with exponentiation:

$$x_0 x_1 = m_0 m_1 \times 10^{n_0+n_1}$$

and

$$\frac{x_0}{x_1} = \frac{m_0}{m_1} \times 10^{n_0-n_1}$$

Some examples are:

$$5.67 \times 10^{-5} \times 2.34 \times 10^2 \approx 13.3 \times 10^{-5+2} = 13.3 \times 10^{-3} = 1.33 \times 10^{-2}$$

and

$$\frac{2.34 \times 10^2}{5.67 \times 10^{-5}} \approx 0.413 \times 10^{2-(-5)} = 0.413 \times 10^7 = 4.13 \times 10^6$$

Addition and subtraction require the numbers to be represented using the same exponential part, so that the significand can be simply added or subtracted:

$$x_0 = m_0 \times 10^{n_0} \text{ and } x_1 = m_1 \times 10^{n_1} \text{ with } n_0 = n_1$$

Next, add or subtract the significands:

$$x_0 \pm x_1 = (m_0 \pm m_1) \times 10^{n_0}$$

An example:

$$2.34 \times 10^{-5} + 5.67 \times 10^{-6} = 2.34 \times 10^{-5} + 0.567 \times 10^{-5} = 2.907 \times 10^{-5}$$

Other bases

While base ten is normally used for scientific notation, powers of other bases can be used too,[25] base 2 being the next most commonly used one.

For example, in base-2 scientific notation, the number 1001_b in binary ($=9_d$) is written as $1.001_b \times 2_d^{11_b}$ or $1.001_b \times 10_b^{11_b}$ using binary numbers (or shorter 1.001×10^{11} if binary context is obvious). In E-notation, this is written as $1.001_b\mathrm{E}11_b$ (or shorter: 1.001E11) with the letter *E* now standing for "times two (10_b) to the power" here. In order to better distinguish this base-2 exponent from a base-10 exponent, a base-2 exponent is sometimes also indicated by using the letter *B* instead of *E*,[26] a shorthand notation originally proposed by Bruce Alan Martin of Brookhaven National Laboratory in 1968,[27] as in $1.001_b\mathrm{B}11_b$ (or shorter: 1.001B11). For comparison, the same number in decimal representation: 1.125×2^3 (using decimal representation), or 1.125B3 (still using decimal representation). Some calculators use a mixed representation for binary floating point numbers, where the exponent is displayed as decimal number even in binary mode, so the above becomes $1.001_b \times 10_b^{3_d}$ or shorter 1.001B3.[26]

This is closely related to the base-2 floating-point representation commonly used in computer arithmetic, and the usage of IEC binary prefixes (e.g. 1B10 for 1×2^{10} (kibi), 1B20 for 1×2^{20} (mebi), 1B30 for 1×2^{30} (gibi), 1B40 for 1×2^{40} (tebi)).

Similar to *B* (or *b*[28]), the letters *H*[26] (or *h*[28]) and *O*[26] (or *o*,[28] or *C*[26]) are sometimes also used to indicate *times 16 or 8 to the power* as in $1.25 = 1.40_h \times 10_h^{0_h}$ = 1.40H0 = 1.40h0, or $98000 = 2.7732_o \times 10_o^{5_o}$ = 2.773205 = 2.7732C5.[26]

Another similar convention to denote base-2 exponents is using a letter *P* (or *p*, for "power"). In this notation the significand is always meant to be hexadecimal, whereas the exponent is always meant to be decimal.[29] This notation can be produced by implementations of the *printf* family of functions following the C99 specification and (Single Unix Specification) IEEE Std 1003.1 POSIX standard, when using the *%a* or *%A* conversion specifiers.[29][30][31] Starting with C++11, C++ I/O functions could parse and print the P-notation as well. Meanwhile, the notation has been fully adopted by the language standard since C++17.[32] Apple's Swift supports it as well.[33] It is also required by the IEEE 754-2008 binary floating-point standard. Example: 1.3DEp42 represents $1.3\mathrm{DE}_h \times 2^{42}$.

Engineering notation can be viewed as a base-1000 scientific notation.

See also

- Binary prefix
- Positional notation
- Variable scientific notation
- Engineering notation
- Floating point
- ISO 31-0
- ISO 31-11
- Significant figure
- Suzhou numerals are written with order of magnitude and unit of measurement below the significand
- RKM code

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