Scale of the Universe

Distant galaxies

When we describe the structure of the Universe we are using very large numbers. There are billions of galaxies and their average separation is about a million light years. The Big Bang theory says that the Universe began expanding about 14 billion years ago. The Sun formed about 5 billion years ago. These numbers and larger numbers can be expressed in standard form, and using prefixes.

USING STANDARD FORM

The diameter of the Earth is 13 000 km. 13 000 km = $1.3 \times 10\,000$ km = 1.3×10^4 km. In standard form the number is written with one digit in front of the decimal point and multiplied by the appropriate power of 10.

The distance to the Andromeda galaxy is 2 200 000 light years = $2.2 \times 1\,000\,000$ ly = 2.2×10^6 ly.

PRACTICE QUESTION

1 Write these measurements in standard form:

a 1350 W
b 503 N
c 130 000 Pa
d 86 400 s
e 696×10^6 s
f 9315×10^5 eV
g 0.176×10^{12} C kg^{-1}

ORDER OF MAGNITUDE CALCULATIONS

If a number is rounded to the nearest power of ten we say we are giving an order of magnitude value.

The average separation of the galaxies is $\sim 10^6$ light years. The symbol $\sim$ is used to mean 'to within an order of magnitude.'

The wavelength of red light is 700 nm and of violet light is 400 nm. They are both a few hundred nanometres so they are the same 'within an order of magnitude'.

PRACTICE QUESTIONS

2 Scientists estimate that the Big Bang occurred 13.7×10^9 years ago. Write this time as an order of magnitude.

3 Which planets are the same size, to within an order of magnitude? Radii: Mercury 2.4×10^6 m, Venus 6.09×10^6 m, Earth 6.4×10^6 m, Mars 3.4×10^6 m, Jupiter 7.1×10^7 m, Saturn 6.0×10^7 m, Uranus 2.4×10^7 m, Neptune 2.2×10^7 m.

PREFIXES

As an alternative to standard form, these prefixes are used with SI units. Drax power station has an output of 3.96×10^9 W. This can be written as 3960 MW or 3.96 GW.

Prefix	Symbol	Value	Prefix	Symbol	Value
kilo	k	10^3	giga	G	10^9
mega	M	10^6	tera	T	10^{12}

REMEMBER: Except for k, the symbols are all upper case. The factors increase in threes, that is 3, 6, 9, 12.

Particle theory

At the other end of the scale, the diameter of an atom is about a tenth of a billionth of a metre. The particles that make up an atomic nucleus are much smaller. These measurements are represented using negative powers of ten, and more prefixes.

POWERS OF TEN

One way to understand the negative powers of ten (or any number) is to write out a series and look at the pattern:

$1000 = 10^3, 100 = 10^2, 10 = 10^1, 1 = 10^0, 0.1 = \frac{1}{10} = 10^{-1}, 0.01 = \frac{1}{100} = 10^{-2}, 0.001 = \frac{1}{1000} = 10^{-3}$

To multiply powers of ten, add the indices: $1000 \times 100 = 100\,000$ becomes $10^3 \times 10^2 = 10^{(3+2)} = 10^5$.

To divide powers of ten, subtract the indices: $\frac{1000}{100} = 10$ becomes $\frac{10^3}{10^2} = 10^{(3-2)} = 10^1$.

To understand why $10^0 = 1$, think of $\frac{100}{100} = \frac{10^2}{10^2} = 10^{(2-2)} = 10^0 = 1$.

Dividing by 100 (or 10^2) is the same as multiplying by 0.01 (or 10^{-2}).

REMEMBER: $10^3 \times 10^{-2} = 10^{(3-2)} = 10^1 = 10$ but $10^3 + 10^{-2} = 1000.01$
You can only add and subtract the indices when you are multiplying or dividing the numbers, not adding or subtracting them.

PRACTICE QUESTION

4 The speed of light is $3.0 \times 10^8\,m\,s^{-1}$. Use the equation $v = f\lambda$ to calculate the frequency of:
- a ultraviolet, wavelength $3.0 \times 10^{-7}\,m$
- b radio waves, wavelength 1000 m
- c X-rays, wavelength $1.0 \times 10^{-10}\,m$

SMALL NUMBERS: STANDARD FORM, ORDERS OF MAGNITUDE AND PREFIXES

In standard form the Planck constant $\lambda = 6.63 \times 10^{-34}\,J\,s$.
The charge on an electron $= 1.6 \times 10^{-19}\,C$.
As an order of magnitude, the diameter of an atom is $\sim 10^{-10}\,m$ and of a nucleus is $\sim 10^{-14}\,m$.

Prefix	Symbol	Value	Prefix	Symbol	Value
centi	c	10^{-2}	nano	n	10^{-9}
milli	m	10^{-3}	pico	p	10^{-12}
micro	μ	10^{-6}	femto	f	10^{-15}

PRACTICE QUESTIONS

5 Write these measurements in standard form:
- a 0.0025 m
- b 0.60 kg
- c $160 \times 10^{-17}\,m$
- d $0.01 \times 10^{-6}\,J$
- e $0.005 \times 10^6\,m$
- f $911 \times 10^{-33}\,kg$
- g $0.00062 \times 10^3\,N$

6 The charge on an electron is $1.6 \times 10^{-19}\,C$. Write this as an order of magnitude.

7 Write the measurements for question 1a, b, c, f, g on page 10 and question 5a, d, e above using suitable prefixes.