Tip of the month/No. 8

Units for expressing the helium leakage rate

Question:
How come the rather odd unit mbar · l/s is used to quantify leakage rates? Is there any explanation for this?

Answer:
With liquids, a statement of the volume is sufficient to describe the amount of liquid. When a faucet drips, for instance, the amount of water going down the drain within a given time can be stated quite simply in l/h (liters per hour). In contrast to fluids however, gases are compressible or decompressible. Assuming the temperature remains constant, a quantity of gas can be expressed as the product of pressure multiplied by volume. In the unit in question "mbar · l" tells us the quantity of gas that is lost within the period of time "s".

Background:
"Rate" expresses something as a "per time unit". So the birth rate tells us how many children are born per year. The repayment rate for a new car tells us how much money has to be paid out per month. Accordingly, a leakage rate tells us how much gas is flowing out of a leak per unit of time.

Let us take the example of a single liter of gas which is held in a container under a pressure of 10 bars. After it has flowed through a leak in the wall of the container to the outside world then, under normal atmospheric conditions (1 bar absolute pressure), it will take up a volume of 10 liters. The ideal gas law states that the product of pressure and volume stays the same when the gas goes from one state (internal, 10 bar · 1 l = 10 bar · l = 10,000 mbar · l) to another (external, 1 bar · 10 l = 10 bar · l = 10,000 mbar · l). If this is considered in terms of time, then this becomes a "rate" and the unit used in Europe is mbar · l/s.

Another leakage rate which can be thought of is the rate of $1 \cdot 10^{-4}$ mbar · l/s, generally considered as "watertight", which corresponds to a volume of gas equal to the size of a fine grain of salt with a diameter of just under 0.5 mm per second.

A good way of picturing a small leakage rate is to think of it as the time which it would take for a given volume of gas to escape from a known object. For example a leakage rate of as little as $1 \cdot 10^{-11}$ mbar · l/s can be measured with Pfeiffer Vacuum helium leak detectors. At this rate it would take 3,170 years at atmospheric pressure for a gas bubble with a volume of 1 cm^3 to form.

The units “mbar”, “liter” and “second” are widely used and easy to picture, but only the “second” as a unit of time is in fact included as one of the seven base units in the International System of Units (Système International d’Unités, symbol: SI). The seven base units are:

Base unit	Quantity symbol	Unit	Unit symbol
length	l	meter	m
mass	m	kilogram	kg
time	t	second	s
electric current	I	ampere	A
thermodynamic temperature	T	kelvin	K
amount of substance	n	mol	mol
luminous intensity	I_V	candela	cd

In vacuum technology the most important physical magnitude is pressure. The unit of pressure can be derived from the SI units. Pressure is by definition the same as force (unit newton = m · kg/s^2) per unit area (unit square meters). The resulting unit for pressure is therefore newtons per square meter (N/m^2), which also goes by the name pascal. 100 pascals are the same as one millibar. To enable us to work with a familiar numerical value, the unit pascal is prefixed by “hecto” meaning 100. This now makes it possible for the pressure to be expressed as the same numerical value in both mbar and hPa.

“Liter” is not an SI unit either. To express a leak rate in SI units we need to express it in Pa m^3 s^{-1}. This unit has established itself in Japan, for instance, while Europe and the English-speaking world are in a transition period. The same is true of the expression for leak rate which according to DIN EN 1330-8 is really called “leakage” rate.

To make it easier for you, we have compiled two small tables showing pressures, leakage rates and the mathematical basis.

mbar l/s	Pa m^3/s	mbar l/s	hPa l/s	mbar	hPa	Pa	bar	MPa	kPa	hPa
$1 \cdot 10^{3}$	$1 \cdot 10^{2}$	$1 \cdot 10^{3}$	$1 \cdot 10^{3}$	$1 \cdot 10^{3}$	$1 \cdot 10^{3}$	$1 \cdot 10^{5}$	1000	100		
$1 \cdot 10^{2}$	$1 \cdot 10^{1}$	$1 \cdot 10^{2}$	$1 \cdot 10^{2}$	$1 \cdot 10^{2}$	$1 \cdot 10^{2}$	$1 \cdot 10^{4}$	500	50		
$1 \cdot 10^{1}$	$1 \cdot 10^{0}$	$1 \cdot 10^{1}$	$1 \cdot 10^{1}$	$1 \cdot 10^{1}$	$1 \cdot 10^{1}$	$1 \cdot 10^{3}$	200	20		
$1 \cdot 10^{0}$	$1 \cdot 10^{-1}$	$1 \cdot 10^{0}$	$1 \cdot 10^{0}$	$1 \cdot 10^{0}$	$1 \cdot 10^{0}$	$1 \cdot 10^{2}$	100	10		
$1 \cdot 10^{-1}$	$1 \cdot 10^{-2}$	$1 \cdot 10^{-1}$	$1 \cdot 10^{-1}$	$1 \cdot 10^{-1}$	$1 \cdot 10^{-1}$	$1 \cdot 10^{1}$	50	5		
$1 \cdot 10^{-2}$	$1 \cdot 10^{-3}$	$1 \cdot 10^{-2}$	$1 \cdot 10^{-2}$	$1 \cdot 10^{-2}$	$1 \cdot 10^{-2}$	$1 \cdot 10^{0}$	20	2		
$1 \cdot 10^{-3}$	$1 \cdot 10^{-4}$	$1 \cdot 10^{-3}$	$1 \cdot 10^{-3}$	$1 \cdot 10^{-3}$	$1 \cdot 10^{-3}$	$1 \cdot 10^{-1}$	10	1	1000	
$1 \cdot 10^{-4}$	$1 \cdot 10^{-5}$	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$	$1 \cdot 10^{-2}$	5	0.5	500	
$1 \cdot 10^{-5}$	$1 \cdot 10^{-6}$	$1 \cdot 10^{-5}$	$1 \cdot 10^{-5}$	$1 \cdot 10^{-5}$	$1 \cdot 10^{-5}$	$1 \cdot 10^{-3}$	2	0.2	200	
$1 \cdot 10^{-6}$	$1 \cdot 10^{-7}$	$1 \cdot 10^{-6}$	$1 \cdot 10^{-6}$	$1 \cdot 10^{-6}$	$1 \cdot 10^{-6}$	$1 \cdot 10^{-4}$	1	0.1	100	1000
$1 \cdot 10^{-7}$	$1 \cdot 10^{-8}$	$1 \cdot 10^{-7}$	$1 \cdot 10^{-7}$	$1 \cdot 10^{-7}$	$1 \cdot 10^{-7}$	$1 \cdot 10^{-5}$	0.5		50	500
$1 \cdot 10^{-8}$	$1 \cdot 10^{-9}$	$1 \cdot 10^{-8}$	$1 \cdot 10^{-8}$	$1 \cdot 10^{-8}$	$1 \cdot 10^{-8}$	$1 \cdot 10^{-6}$	0.2		20	200
$1 \cdot 10^{-9}$	$1 \cdot 10^{-10}$	$1 \cdot 10^{-9}$	$1 \cdot 10^{-9}$	$1 \cdot 10^{-9}$	$1 \cdot 10^{-9}$	$1 \cdot 10^{-7}$	0.1		10	100
$1 \cdot 10^{-10}$	$1 \cdot 10^{-11}$	$1 \cdot 10^{-10}$	$1 \cdot 10^{-10}$	$1 \cdot 10^{-10}$	$1 \cdot 10^{-10}$	$1 \cdot 10^{-8}$			5	50
$1 \cdot 10^{-11}$	$1 \cdot 10^{-12}$	$1 \cdot 10^{-11}$	$1 \cdot 10^{-11}$	$1 \cdot 10^{-11}$	$1 \cdot 10^{-11}$	$1 \cdot 10^{-9}$			2	20
$1 \cdot 10^{-12}$	$1 \cdot 10^{-13}$	$1 \cdot 10^{-12}$	$1 \cdot 10^{-12}$	$1 \cdot 10^{-12}$	$1 \cdot 10^{-12}$	$1 \cdot 10^{-10}$			1	10

billion			million	hundred thousand	ten thousand	thousand	hundred	ten	one	tenths	hundredths	thousandths	ten thousandths	hundred thousandths	millionths			billionths	Prefix	Exponential notation
1	0	0	0	0	0	0	0	0	0										giga	$1 \cdot 10^{9}$
			1	0	0	0	0	0	0										mega	$1 \cdot 10^{6}$
				1	0	0	0	0	0											$1 \cdot 10^{5}$
					1	0	0	0	0											$1 \cdot 10^{4}$
						1	0	0	0										kilo	$1 \cdot 10^{3}$
							1	0	0										hecto	$1 \cdot 10^{2}$
								1	0										deka	$1 \cdot 10^{1}$
									1											$1 \cdot 10^{0}$
									0.	1									deci	$1 \cdot 10^{-1}$
									0.	0	1								centi	$1 \cdot 10^{-2}$
									0.	0	0	1							milli	$1 \cdot 10^{-3}$
									0.	0	0	0	1							$1 \cdot 10^{-4}$
									0.	0	0	0	0	1						$1 \cdot 10^{-5}$
									0.	0	0	0	0	0	1				micro	$1 \cdot 10^{-6}$
									0.	0	0	0	0	0	0	0	0	1	nano	$1 \cdot 10^{-9}$

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