Units of
Power, Pressure, Force and Mass

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Chapter-1

Watt

The **watt** (symbol: **W**) is a derived unit of power in the International System of Units (SI), named after the Scottish engineer James Watt (1736–1819). The unit, defined as one joule per second, measures the rate of energy conversion.

Definition

- In terms of classical mechanics, one watt is the rate at which work is done when an object's velocity is held constant at one meter per second against constant opposing force of one newton.

$$W = \frac{J}{s} = \frac{N \cdot m}{s} = \frac{kg \cdot m^2}{s^3}$$

- In terms of electromagnetism, one watt is the rate at which work is done when one ampere (A) of current flows through an electrical potential difference of one volt (V).

$$W = V \cdot A$$

Two additional unit conversions for watt can be found using the above equation and Ohm's Law.

$$W = \frac{V^2}{\Omega} = A^2 \cdot \Omega$$

Where ohm (Ω) is the SI derived unit of electrical resistance.

Examples

A person having a mass of 100 kilograms who climbs a 3 meter high ladder in 5 seconds is doing work at a rate of about 600 watts. Mass times acceleration due to gravity times height divided by the time it takes to lift the object to the given height gives the *rate of doing work* or *power*. A laborer over the course of an 8-hour day can sustain an average output of about 75 watts; higher power levels can be achieved for short intervals and by athletes.

A medium-sized passenger automobile engine is rated at 50–100 kW (kilowatts) – while cruising it will typically yield half that amount. Larger or high performance vehicles have more powerful engines.

A typical household incandescent light bulb has a power rating of 25 to 100 watts; fluorescent lamps typically consume 5 to 30 watts to produce a similar amount of light.

A typical coal powered power station produces around 600-700 MW (megawatts).

Origin and adoption as an SI unit

The watt is named after James Watt for his contributions to the development of the steam engine. The unit was recognized by the Second Congress of the British Association for the Advancement of Science in 1882. The 11th General Conference on Weights and Measures in 1960 adopted it for the measurement of power into the International System of Units (SI).

Multiples

<div align="center">SI multiples for watt (W)</div>

Submultiples			Multiples		
Value	Symbol	Name	Value	Symbol	Name
10^{-1} W	dW	deciwatt	10^{1} W	daW	decawatt
10^{-2} W	cW	centiwatt	10^{2} W	hW	hectowatt
10^{-3} W	**mW**	**milliwatt**	10^{3} W	**kW**	**kilowatt**
10^{-6} W	**μW**	**microwatt**	10^{6} W	**MW**	**megawatt**
10^{-9} W	**nW**	**nanowatt**	10^{9} W	**GW**	**gigawatt**
10^{-12} W	**pW**	**picowatt**	10^{12} W	**TW**	**terawatt**
10^{-15} W	fW	femtowatt	10^{15} W	PW	petawatt
10^{-18} W	aW	attowatt	10^{18} W	EW	exawatt
10^{-21} W	zW	zeptowatt	10^{21} W	ZW	zettawatt
10^{-24} W	yW	yoctowatt	10^{24} W	YW	yottawatt

<div align="center">Common multiples are in **bold** face</div>

Femtowatt

The femtowatt is equal to one quadrillionth (10^{-15}) of a watt. Technologically important powers that are measured in femtowatts are typically found in reference(s) to radio and radar receivers. For example, FM tuner performance figures for sensitivity/quieting and signal-to-noise require that the RF energy applied to the antenna input be specified in order to be meaningful. These input levels are often stated in dBf (decibels referenced to 1 femtowatt which is equal to 0.2739 microvolt across a 75 ohm load or 0.5477 microvolt

across a 300 ohm load) so that the specification takes into account the RF input impedance of the tuner.

Picowatt

The picowatt is equal to one trillionth (10^{-12}) of a watt. Technologically important powers that are measured in picowatts are typically used in reference to radio and radar receivers, and also in the science of radio astronomy.

Nanowatt

The nanowatt is equal to one billionth (10^{-9}) of a watt. A surface area of one square meter on Earth receives one nanowatt of power from a single star of apparent magnitude +3.5. Important powers that are measured in nanowatts are also typically used in reference to radio and radar receivers.

Microwatt

The microwatt is equal to one millionth (10^{-6}) of a watt. Important powers that are measured in microwatts are typically stated in medical instrumentation systems such as the EEG and the EKG, in a wide variety of scientific and engineering instruments and also in reference to radio and radar receivers. Compact solar cells for devices such as calculators and watches are typically measured in microwatts.

Milliwatt

The milliwatt is equal to one thousandth (10^{-3}) of a watt. A typical laser pointer outputs about five milliwatts of light power, whereas a typical hearing aid for people consumes less than one milliwatt.

Kilowatt

The kilowatt is equal to one thousand (10^{3}) watts. This unit is typically used to express the output power of engines and the power consumption of electric motors, tools, machines, and heaters. It is also a common unit used to express the electromagnetic power output of broadcast radio and television transmitters.

One kilowatt of power is approximately equal to 1.34 horsepower. A small electric heater with one heating element can use 1.0 kilowatt. The average annual electrical energy consumption of a household in the United States is about 8,900 kilowatt-hours (cf the average UK household's approx 4,700 kilowatt-hours for example), equivalent to a steady power consumption of about 1 kW for an entire year. Also, kilowatts of light power can be measured in the output pulses of some lasers.

Megawatt

The megawatt is equal to one million (10^6) watts. Many events or machines produce or sustain the conversion of energy on this scale. For example: lightning strikes, large electric motors, large warships, such as aircraft carriers, cruisers, and submarines, engineering hardware, large Server farms or data centers and some scientific research equipment, such as supercolliders, and in the output pulses of very large lasers. A large residential or commercial building may consume several megawatts in electric power and heat.

The productive capacity of electrical generators operated by a utility company is often measured in MW. On railways, modern high-powered electric locomotives typically have a peak power output of 5 or 6 MW although some produce much more—the Eurostar, for example, consumes more than 12 MW—while heavy diesel-electric locomotives typically consume 3 to 5 MW. U.S. nuclear power plants have net summer capacities between about 500 and 1300 MW.

The earliest citing of the megawatt in the Oxford English Dictionary (OED) is a reference in the 1900 Webster's International Dictionary of English Language. The OED also states that megawatt appeared in a 28 November 1947 article in the journal *Science* (506:2).

Gigawatt

The gigawatt is equal to one billion (10^9) watts or 1 gigawatt = 1000 megawatts. This unit is sometimes used for large power plants or power grids. For example, by the end of 2010 power shortages in China's Shanxi province were expected increase to 5–6 GW and the installed capacity of wind power in Germany was 25.8 GW. The largest unit (out of four) of the Belgian Nuclear Plant Doel has a peak output of 1.04 GW.

Though obscure, the "j" sound is still an accepted pronunciation.

Terawatt

The terawatt is equal to one trillion (10^{12}) watts. The total power used by humans worldwide (about 16 TW in 2006) is commonly measured in this unit. The most powerful lasers from the mid-1960s to the mid-1990s produced power in terawatts, but only for nanosecond time frames. The average stroke of lightning peaks at 1 terawatt, but these strokes only last for 30 microseconds.

Petawatt

The petawatt is equal to one quadrillion (10^{15}) watts and can be produced by the current generation of lasers for time-scales of the order of femtoseconds (10^{-15} s). Based on the average of 1.366 kW/m^2 of total solar irradiance the total energy flow of sunlight striking Earth's atmosphere is estimated at 174 PW (cf. Solar Constant).

Electrical and thermal watts

In the electric power industry, *megawatt electrical* (abbreviation: MW_e or MWe) is a term that refers to electric power, while *megawatt thermal* or *thermal megawatt* (abbreviations: MW_t, MW_{th}, MWt, or MWth) refers to thermal power produced. Other SI prefixes are sometimes used, for example *gigawatt electrical* (GW_e).

For example, the Embalse nuclear power plant in Argentina uses a fission reactor to generate 2109 MW_t of heat, which creates steam to drive a turbine, which generates 648 MW_e of electricity. The difference is due to the inefficiency of steam-turbine generators and the limitations of the theoretical Carnot Cycle.

Confusion of watts, watt-hours, and watts per hour

The terms power and energy are frequently confused. Power is the rate at which energy is generated and consumed.

For example, when a light bulb with a power rating of 100W is turned on for one hour, the energy used is 100 watt-hours (W•h), 0.1 kilowatt-hour, or 360 kJ. This same amount of energy would light a 40-watt bulb for 2.5 hours, or a 50-watt bulb for 2 hours. A power station would be rated in multiples of watts, but its annual energy sales would be in multiples of watt-hours. A kilowatt-hour is the amount of energy equivalent to a steady power of 1 kilowatt running for 1 hour, or 3.6 MJ.

Terms such as *watts per hour* are often misused. Watts per hour properly refers to the *change* of power per hour. Watts per hour (W/h) might be useful to characterize the ramp-up behavior of power plants. For example, a power plant that reaches a power output of 1 MW from 0 MW in 15 minutes has a ramp-up rate of 4 MW/h. Hydroelectric power plants have a very high ramp-up rate, which makes them particularly useful in peak load and emergency situations.

Major energy production or consumption is often expressed as terawatt-hours for a given period that is often a calendar year or financial year. One terawatt-hour is equal to a sustained power of approximately 114 megawatts for a period of one year.

Chapter-2

Horsepower

Horsepower (**HP**) is the name of several units of measurement of power. The most common definitions equal between 735.5 and 750 watts. Horsepower was originally defined to compare the output of steam engines with the power of draft horses. The unit was widely adopted to measure the output of piston engines, turbines, electric motors, and other machinery. The definition of the unit varied between geographical regions. Most countries now use the SI unit *watt* for measurement of power. With the implementation of the EU Directive 80/181/EEC on January 1, 2010, the use of horsepower in the EU is only permitted as supplementary unit.

The definition of the horsepower also has varied between different applications:

- The *mechanical horsepower*, also known as *imperial horsepower*, of exactly 550 foot-pounds per second is approximately equivalent to 745.7 watts.
- The *metric horsepower* of 75 kgf-m per second is approximately equivalent to 735.499 watts.
- The *boiler horsepower* is used for rating steam boilers and is equivalent to 34.5 pounds of water evaporated per hour at 212 degrees Fahrenheit, or 9,809.5 watts.
- One horsepower for rating electric motors is equal to 746 watts.
- Continental European electric motors used to have dual ratings, using conversion rate 0.735 kW for 1 HP
- The *Pferdestärke* PS (German translation of horsepower) is a name for a group of similar power measurements used in Germany around the end of the 19th century, all of about one metric horsepower in size.
- The Royal Automobile Club (RAC) horsepower or British tax horsepower is an estimate based on several engine dimensions.

History of the unit

The development of the steam engine provided a reason to compare the output of horses with that of the engines that could replace them. In 1702, Thomas Savery wrote in The Miner's Friend: "So that an engine which will raise as much water as two horses, working together at one time in such a work, can do, and for which there must be constantly kept

ten or twelve horses for doing the same. Then I say, such an engine may be made large enough to do the work required in employing eight, ten, fifteen, or twenty horses to be constantly maintained and kept for doing such a work…" The idea was later used by James Watt to help market his improved steam engine. He had previously agreed to take royalties of one third of the savings in coal from the older Newcomen steam engines. This royalty scheme did not work with customers who did not have existing steam engines but used horses instead. Watt determined that a horse could turn a mill wheel 144 times in an hour (or 2.4 times a minute). The wheel was 12 feet in radius; therefore, the horse travelled $2.4 \times 2\pi \times 12$ feet in one minute. Watt judged that the horse could pull with a force of 180 pounds. So:

$$power = \frac{work}{time} = \frac{force \times distance}{time} = \frac{(180\ \text{lbf})(2.4 \times 2\pi \times 12\ \text{ft})}{1\ \text{min}} = 32,572\frac{\text{ft} \cdot \text{lbf}}{\text{min}}.$$

This was rounded to an even 33,000 ft·lbf/min.

Others recount that Watt determined that a pony could lift an average 220 lbf (0.98 kN) 100 ft (30 m) per minute over a four-hour working shift. Watt then judged a horse was 50% more powerful than a pony and thus arrived at the 33,000 ft·lbf/min figure.

Engineering in History recounts that John Smeaton initially estimated that a horse could produce 22,916 foot-pounds per minute. John Desaguliers increased that to 27,500 foot-pounds per minute. "Watt found by experiment in 1782 that a 'brewery horse' was able to produce 32,400 foot-pounds per minute." James Watt and Matthew Boulton standardized that figure at 33,000 the next year.

Most observers familiar with horses and their capabilities estimate that Watt was either a bit optimistic or intended to underpromise and overdeliver; few horses can maintain that effort for long. Regardless, comparison with a horse proved to be an enduring marketing tool.

A healthy human can produce about 1.2 hp briefly and sustain about 0.1 hp indefinitely; trained athletes can manage up to about 2.5 hp briefly and 0.3 hp for a period of several hours.

Horsepower from a horse

In 1993, R. D. Stevenson and R. J. Wassersug published an article calculating the upper limit to an animal's power output. The peak power over a few seconds has been measured to be as high as 14.9 hp. However, Stevenson and Wassersug observe that for sustained activity, a work rate of about 1 hp per horse is consistent with agricultural advice from both 19th and 20th century sources.

Current definitions

The following definitions have been widely used:

Mechanical horsepower hp(I)	≡ 33,000 ft-lb$_f$/min
	= 550 ft·lb$_f$/s
	= 745.699872 W
Metric horsepower hp(M)	≡ 75 kg$_f$·m/s
	≡ 735.49875 W
Electrical horsepower hp(E)	≡ 746 W
Boiler horsepower hp(S)	≡ 33,475 BTU/h
	= 9,809.5 W
Hydraulic horsepower	= flow rate (US gal/min) × pressure (psi) × 7/12,000
	or
	= flow rate (US gal/min) × pressure (psi) / 1714
	= 550 ft·lb$_f$/s
	= 745.699872 W

In certain situations it is necessary to distinguish between the various definitions of horsepower and thus a suffix is added: hp(I) for mechanical (or imperial) horsepower, hp(M) for metric horsepower, hp(S) for boiler (or steam) horsepower and hp(E) for electrical horsepower.

Hydraulic horsepower is equivalent to mechanical horsepower. The formula given above is for conversion to mechanical horsepower from the factors acting on a hydraulic system.

Mechanical horsepower

Assuming the third CGPM (1901, CR 70) definition of standard gravity, g_n=9.80665 m/s^2, is used to define the pound-force as well as the kilogram force, and the international avoirdupois pound (1959), one mechanical horsepower is:

$\frac{1}{HP}$	≡ 33,000 ft·lb$_f$/min	by definition
	= 550 ft·lb$_f$/s	since 1 min = 60 s
	= 550×0.3048×0.45359237 m·kg$_f$/s	since 1 ft = 0.3048 m and
	= 76.0402249068 kg$_f$·m/s	1 lb = 0.45359237 kg

$$= 76.0402249068 \times 9.80665 \ \text{kg·m}^2/\text{s}^3 \qquad g = 9.80665 \ \text{m/s}^2$$

$$= 745.69987158227022 \ \text{W} \qquad \text{since} \quad 1 \ \text{W} \equiv \frac{1 \ \text{J/s} = 1 \ \text{N·m/s}}{1 \ (\text{kg·m/s}^2)\cdot(\text{m/s})} =$$

Or given that 1 hp = 550 ft·lb$_f$/s, 1 ft = 0.3048 m, 1 lb$_f \approx$ 4.448 N, 1 J = 1 N·m, 1 W = 1 J/s: 1 hp = 746 W

Metric horsepower

Metric horsepower began in Germany in the 19th century and became popular across Europe and Asia. The various units used to indicate this definition (*PS, CV, hk, pk, ks* and *ch*) all translate to *horse power* in English, so it is common to see these values referred to as *horsepower* or *hp* in the press releases or media coverage of the German, French, Italian, and Japanese automobile companies. British manufacturers often intermix metric horsepower and mechanical horsepower depending on the origin of the engine in question. Sometimes the metric horsepower rating of an engine is conservative enough so that the same figure can be used for both 80/1269/EEC with metric hp and SAE J1349 with imperial hp.

Metric horsepower, as a rule, is defined as 0.73549875 kW, or roughly 98.6% of mechanical horsepower. This was a minor issue in the days when measurement systems varied widely and engines produced less power, but has become a major sticking point today. Exotic cars from Europe like the McLaren F1 and Bugatti Veyron are often quoted using the wrong definition, and their power output is sometimes even converted twice because of confusion over whether the original *horsepower* number was metric or mechanical.

PS

This unit (German: *Pferdestärke* = horse strength) is no longer a statutory unit, but is still commonly used in Europe, South America, Japan and India especially by the automotive and motorcycle industry. It was adopted throughout continental Europe with designations equivalent to the English *horsepower*, but mathematically different from the British unit.

DIN 66036 defines one horsepower to lift a mass of 75 kilograms within one second against the earth gravitation over a distance of one metre. Similar definitions were already common to the time of James Watt.

The PS was adopted by the Deutsches Institut für Normung (DIN) and then by the automotive industry throughout most of Europe, under varying names. In 1992, the PS was rendered obsolete by EEC directives, when it was replaced by the kilowatt as the official power measuring unit. It is still in use for commercial and advertising purposes, in addition to the kW rating, as many customers are still not familiar with the use of kilowatts for engines.

pk, ch, hk, hv, LE, k/ks, KS, KM, CP, PS

The Dutch *paardenkracht* (pk), the French *chevaux* (ch), the Swedish *hästkraft* (hk), the Finnish *hevosvoima* (hv), the Norwegian and Danish *hestekraft* (hk), the Hungarian *lóerő* (LE), the Czech *koňská síla* and Slovak *koňská sila* (k or ks), the Croatian and Serbian *konjska snaga* (KS), the Macedonian *Којнска сила* (KC), the Polish *koń mechaniczny* and Slovenian *konjska moč* (KM) and the Romanian *cal-putere* (CP) all equal the German *Pferdestärke* (PS), and are approximately equal to 735.5 W.

CV and cv

In Italian (*Cavalli*), Spanish (*Caballos de vapor*), and Portuguese (*Cavalo-vapor*), *CV* is the equivalent to the German, *PS*. It is also used as the French term for the Pferdestärke, but in French, this should be written in lowercase letters as *cv*.

In addition, the capital form *CV* is used in Italy and France as a unit for tax horsepower, short for, respectively, *cavalli vapore* and *chevaux vapeur* (*steam horses*). CV is a non-linear rating of a motor vehicle for tax purposes. The CV rating, or fiscal power, is $\left(\frac{P}{40}\right)^{1.6} + \frac{U}{45}$, where P is the maximum power in kilowatts and U is the amount of CO_2 emitted in grams per kilometre. The term for CO_2 measurements has only been included in the definition since 1998, so older ratings in CV are not directly comparable. The fiscal power has found its way into naming of automobile models, such as the popular Citroën deux-chevaux. The cheval-vapeur (ch) unit should not be confused with the French cheval fiscal (CV).

In the 19th century, the French had their own unit, which they used instead of the CV or horsepower. It was called the poncelet and was abbreviated *p*.

Boiler horsepower

A boiler horsepower is used for boilers in various industrial applications; however, it is considered an antiquated term and is not used in modern power plants except in North America, where it persists in industrial boiler engineering. One boiler horse power unit or BHP is equal to a boiler thermal output of 33,475 BTU/h (9.8095 kW), which is the energy rate needed to evaporate 34.5 lb (15.65 kg) of water at 212 °F (100 °C) in one hour.

The term was originally developed at the Philadelphia Centennial Exhibition in 1876, where the best steam engines of that period were tested. The average steam consumption of those engines (per output horsepower) was determined to be the evaporation of 30 lb/h of water, based on feedwater at 100 °F (38 °C), and saturated steam generated at 70 psi (480 kPa) gauge pressure. This original definition is equivalent to a boiler heat output of 33,485 BTU/h. In 1884, the ASME redefined the boiler horsepower as the thermal output equal to the evaporation of 34.5 lb/h of water "from and at" 212 °F. This considerably simplified boiler testing, and provided more accurate comparisons of the boilers at that

time. This revised definition is equivalent to a boiler heat output of 33,469 BTU/hr. Present industrial practice is to define *boiler horsepower* as a boiler thermal output equal to 33,475 BTU/h, which is very close to the original and revised definitions.

The amount of power that can be obtained by a steam engine or steam turbine based on *boiler horsepower* varies so widely that use of the term is entirely obsolete for these purposes. The term makes no distinction as to the steam pressure or temperature which is produced (both of which significantly influence engine/turbine output); it merely defines a thermal output of a boiler. Smaller steam engines often require several *boiler horsepower* to make one horsepower, and modern steam turbines can make power with as little as about 0.15 hp (boiler) thermal output per actual horsepower developed.

Electrical horsepower

The horsepower used for electrical machines is defined as exactly 746 W. The nameplates on electrical motors show their power output, not their power input

Relationship with torque

For a given torque and speed, the power may be calculated; the relationship between torque in foot-pounds, rotational speed in rpm and horsepower is:

$$P/\mathrm{hp} = \frac{\tau/(\mathrm{ft \cdot lbf}) \times f/(\mathrm{rpm})}{5252}$$

Where *P* is power, τ is torque, and *f* is rotations per minute. The constant 5252 comes from (33,000 ft·lbf/min)/(2π rad/rev).

The standard equation relating torque in inch pounds, rotational speed in rpm and horsepower is:

$$P/\mathrm{hp} = \frac{\tau/(\mathrm{in \cdot lbf}) \times f/(\mathrm{rpm})}{63,025}$$

Where *P* is power, τ is torque, and *f* is rotations per minute. The constant 63,025 comes from (33,000 ft·lbf/min) × (12 in/ft)/(2π rad/rev).

Drawbar horsepower

Drawbar horsepower (dbhp) is the power a railway locomotive has available to haul a train or an agricultural tractor to pull an implement. This is a measured figure rather than a calculated one. A special railway car called a dynamometer car coupled behind the locomotive keeps a continuous record of the drawbar pull exerted, and the speed. From these, the power generated can be calculated. To determine the maximum power

available, a controllable load is required; it is normally a second locomotive with its brakes applied, in addition to a static load.

If the drawbar force (F) is measured in pounds-force (lbf) and speed (v) is measured in miles per hour (mph), then the drawbar power (P) in horsepower (hp) is:

$$P/\mathrm{hp} = \frac{(F/\mathrm{lbf})(v/\mathrm{mph})}{375}$$

Example: How much power is needed to pull a drawbar load of 2,025 pounds-force at 5 miles per hour?

$$P/\mathrm{hp} = \frac{2025 \times 5}{375} = 27$$

The constant 375 is because 1 hp = 375 lbf·mph. If other units are used, the constant is different. When using a coherent system of units, such as SI (watts, newtons, and metres per second), no constant is needed, and the formula becomes $P = Fv$.

RAC horsepower (taxable horsepower)

This measure was instituted by the Royal Automobile Club in Britain and was used to denote the power of early 20th century British cars. Many cars took their names from this figure (hence the Austin Seven and Riley Nine), while others had names such as "40/50 hp", which indicated the RAC figure followed by the true measured power.

Taxable horsepower does not reflect developed horsepower; rather, it is a calculated figure based on the engine's bore size, number of cylinders, and a (now archaic) presumption of engine efficiency. As new engines were designed with ever-increasing efficiency, it was no longer a useful measure, but was kept in use by UK regulations which used the rating for tax purposes.

$$RACh.p. = D^2 * n/2.5$$
where
D is the diameter (or bore) of the cylinder in inches
n is the number of cylinders

This is equal to the displacement in cubic inches divided by 10π then divided again by the stroke in inches.

Since taxable horsepower was computed based on bore and number of cylinders, not based on actual displacement, it gave rise to engines with 'undersquare' dimensions (i.e., relatively narrow bore), but long stroke; this tended to impose an artificially low limit on rotational speed (rpm), hampering the potential power output and efficiency of the engine.

The situation persisted for several generations of four- and six-cylinder British engines: for example, Jaguar's 3.4-litre XK engine of the 1950s had six cylinders with a bore of 83 mm (3.27 in) and a stroke of 106 mm (4.17 in), where most American automakers had long since moved to oversquare (wide bore, short stroke) V-8s (see, for example, the early Chrysler Hemi).

Measurement

The power of an engine may be measured or estimated at several points in the transmission of the power from its generation to its application. A number of names are used for the power developed at various stages in this process, but none is a clear indicator of either the measurement system or definition used.

In the case of an engine dynamometer, power is measured at the engine's flywheel (i.e., at the crankshaft output). With a chassis dynamometer or *rolling road*, power output is measured at the driving wheels. This accounts for the significant power loss through the drive train.

In general:

Nominal is derived from the size of the engine and the piston speed and is only accurate at a pressure of 48 kPa (7 psi).
Indicated or gross horsepower (theoretical capability of the engine) [PLAN/ 33000]
minus frictional losses within the engine (bearing drag, rod and crankshaft windage losses, oil film drag, etc.), equals
Brake / net / crankshaft horsepower (power delivered directly to and measured at the engine's crankshaft)
minus frictional losses in the transmission (bearings, gears, oil drag, windage, etc.), equals
Shaft horsepower (power delivered to and measured at the output shaft of the transmission, when present in the system)
minus frictional losses in the universal joint/s, differential, wheel bearings, tire and chain, (if present), equals
Effective, True (thp) or commonly referred to as wheel horsepower (whp)

All the above assumes that no power inflation factors have been applied to any of the readings.

Engine designers use expressions other than horsepower to denote objective targets or performance, such as brake mean effective pressure (BMEP). This is a coefficient of theoretical brake horsepower and cylinder pressures during combustion.

Nominal horsepower

Nominal horsepower (nhp) is an early Nineteenth Century rule of thumb used to estimate the power of steam engines.

nhp = 7 x area of piston x equivalent piston speed/33,000

For paddle ships the piston speed was estimated as 129.7 x (stroke)$^{1/3.35}$

For the nominal horsepower to equal the actual power it would be necessary for the mean steam pressure in the cylinder during the stroke to be 48 kPa (7 psi) and for the piston speed to be of the order of 54–75 m/min.

Indicated horsepower

Indicated horsepower (ihp) is the theoretical power of a reciprocating engine if it is completely frictionless in converting the expanding gas energy (piston pressure × displacement) in the cylinders. It is calculated from the pressures developed in the cylinders, measured by a device called an *engine indicator* – hence indicated horsepower. As the piston advances throughout its stroke, the pressure against the piston generally decreases, and the indicator device usually generates a graph of pressure vs stroke within the working cylinder. From this graph the amount of work performed during the piston stroke may be calculated. It was the figure normally used for steam engines in the 19th century but is misleading because the actual power output may only be 70% to 90% of the indicated horsepower.

Brake horsepower

Brake horsepower (bhp) is the measure of an engine's horsepower before the loss in power caused by the gearbox, alternator, differential, water pump, and other auxiliary components such as power steering pump, muffled exhaust system, etc. *Brake* refers to a device which was used to load an engine and hold it at a desired RPM. During testing, the output torque and rotational speed were measured to determine the *brake horsepower*. Horsepower was originally measured and calculated by use of the indicator (a James Watt invention of the late 18th century), and later by means of a De Prony brake connected to the engine's output shaft. More recently, an engine dynamometer is used instead of a De Prony brake. The output delivered to the driving wheels is less than that obtainable at the engine's crankshaft.

British horsepower

The abbreviation *bhp* may also be used for *British horsepower* (though the usual use is Brake Horse Power), which has the same definition as the American SAE gross brake horsepower: 33,000 lb·ft/min. More information on American SAE horsepower measurements is below.

Shaft horsepower

Shaft horsepower (shp) is the power delivered to the propeller shafts of a steamship (or one powered by diesel engines or nuclear power), or an aircraft powered by a piston engine or a gas turbine engine. This shaft horsepower can be measured with instruments,

or estimated from the indicated horsepower and a standard figure for the losses in the transmission (typical figures are around 10%). This measure is uncommonly used in the automobile industry, because there, drive train losses can become significant.

Engine power test codes

Engine power test codes determine how the power and torque of an automobile engine is measured and corrected. Correction factors are used to adjust power and torque measurements to standard atmospheric conditions to provide a more accurate comparison between engines as they are affected by the pressure, humidity, and temperature of ambient air. There exist several standards for this purpose, some described below.

Society of Automotive Engineers

SAE gross power

Prior to the 1972 model year, American automakers rated and advertised their engines in brake horsepower (bhp), frequently referred to as SAE gross horsepower, because it was measured in accord with the protocols defined in SAE standards J245 and J1995. As with other brake horsepower test protocols, SAE gross hp was measured using a stock test engine, generally running with few belt-driven accessories and sometimes fitted with long tube (test headers) in lieu of the OEM exhaust manifolds. The atmospheric correction standards for barometric pressure, humidity and temperature for testing were relatively idealistic.

SAE net power

In the United States, the term *bhp* fell into disuse in 1971-72, as automakers began to quote power in terms of SAE net horsepower in accord with SAE standard J1349. Like SAE gross and other brake horsepower protocols, SAE Net hp is measured at the engine's crankshaft, and so does not account for transmission losses. However, the SAE net power testing protocol calls for standard production-type belt-driven accessories, air cleaner, emission controls, exhaust system, and other power-consuming accessories. This produces ratings in closer alignment with the power produced by the engine as it is actually configured and sold.

SAE certified power

In 2005, the SAE introduced "SAE Certified Power" with SAE J2723. This test is voluntary and is in itself not a separate engine test code but a certification of either J1349 or J1995 after which the manufacturer is allowed to advertise "Certified to SAE J1349" or "Certified to SAE J1995" depending on which test standard have been followed. To attain certification the test must follow the SAE standard in question, take place in a ISO9000/9002 certified facility and be witnessed by an SAE approved third party.

A few manufacturers such as Honda and Toyota switched to the new ratings immediately, with multi-directional results; the rated output of Cadillac's supercharged Northstar V8 jumped from 440 to 469 hp (330 to 350 kW) under the new tests, while the rating for Toyota's Camry 3.0 L *1MZ-FE* V6 fell from 210 to 190 hp (160 to 140 kW). The ES330 and Camry SE V6 were previously rated at 225 hp but the ES330 dropped to 218 hp (163 kW) while the Camry declined to 210 hp (160 kW). The first engine certified under the new program was the 7.0 L LS7 used in the 2006 Chevrolet Corvette Z06. Certified power rose slightly from 500 to 505 hp (370 to 377 kW).

While Toyota and Honda are retesting their entire vehicle lineups, other automakers generally are retesting only those with updated powertrains. For example, the 2006 Ford Five Hundred is rated at 203 horsepower, the same as that of 2005 model. However, the 2006 rating does not reflect the new SAE testing procedure as Ford is not going to spend the extra expense of retesting its existing engines. Over time, most automakers are expected to comply with the new guidelines.

SAE tightened its horsepower rules after some engineers noticed parts of the old test could be subjected to different interpretations. Under the old testing procedures, there were small factors that required a judgment call: how much oil was in the crankcase, how the engine controls were calibrated and whether a vehicle was tested with premium fuel. In some cases, such can add up to a change in horsepower ratings. A road test editor at Edmunds.com, John Di Pietro, said decreases in horsepower ratings for some '06 models are not that dramatic. For vehicles like a midsize family sedan, it is likely that the reputation of the manufacturer will be more important.

Deutsches Institut für Normung 70020

DIN 70020 is a standard from German DIN regarding road vehicles. Because the German word for *horsepower* is **P**fer*destärke*, in Germany it is commonly abbreviated to *PS*. DIN hp is measured at the engine's output shaft, and is usually expressed in metric (Pferdestärke) rather than mechanical horsepower.

Economic Commission for Europe R24

ECE R24 is a European standard for the approval of compression ignition engine emissions, installation and measurement of engine power. It is similar to DIN 70020 standard, but with different requirements for connecting an engine's fan during testing causing it to absorb less power from the engine.

80/1269/EEC

80/1269/EEC of 16 December 1980 is a European Union standard for road vehicle engine power.

International Organization for Standardization

- ISO 14396 specifies the additional and method requirement for determinating the power of reciprocating internal combustion engines when presented for an ISO 8178 exhaust emission test. It applies to reciprocating internal combustion engines for land, rail and marine use excluding engines of motor vehicles primarily designed for road use.

- ISO 1585 is an engine net power test code intended for road vehicles.

- ISO 2534 is an engine gross power test code intended for road vehicles

- ISO 4164 is an engine net power test code intended for mopeds.

- ISO 4106 is an engine net power test code intended for motorcycles.

- ISO 9249 is an engine net power test code intended for earth moving machines.

Japanese Industrial Standard D 1001

JIS D 1001 is a Japanese net, and gross, engine power test code for automobiles or trucks having a spark ignition, diesel engine, or fuel injection engine.

Chapter-3

Orders of Magnitude
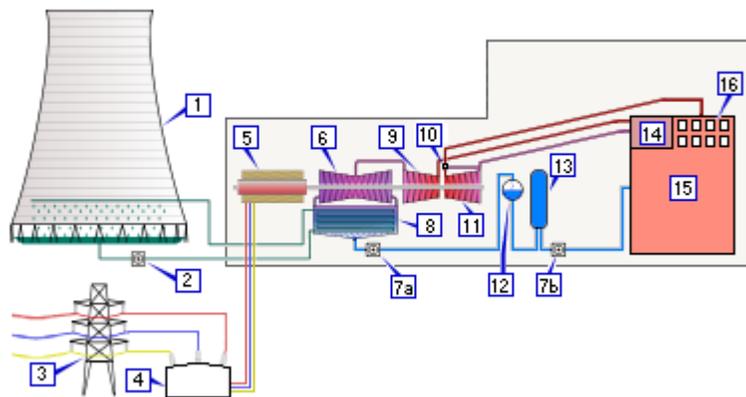
A thermal power plant generates electric power from thermal energy

This page lists examples of the power in watts produced by various different sources of energy. They are grouped by orders of magnitude, and each section covers three **orders of magnitude**, or a factor of one thousand.

Below 1 Watt

zeptowatt (10^{-21} watt)

- ~10 zW – *tech:* approximate power of Galileo space probe's radio signal (when at Jupiter) as received on earth by a 70-meter DSN antenna.

attowatt (10^{-18} watt)

- 1 aW – *phys:* approximate power scale at which operation of nanoelectromechanical systems are overwhelmed by thermal fluctuations.

- 100 aW The GPS signal strength measured at the surface of the Earth is about −160dBw (1 x 10–16 watts), which is roughly equivalent to viewing a 25-watt light bulb from a distance of 10,000 miles.

femtowatt (10^{-15} watt)

- 2.5 fW – *tech:* minimum discernible signal at the antenna terminal of a good FM radio receiver
- 10 fW (−110 dBm) – *tech:* approximate lower limit of power reception on digital spread-spectrum cell phones

picowatt (10^{-12} watt)

- 1 pW – *biomed:* average power consumption of a human cell
- 18.4 pW – *tech:* (1.84 x 10^{-11} watt) power lost by a proton in the Large Hadron Collider at 7000 GeV
- 150 pW – *biomed:* power entering a human eye from a 100-watt lamp 1 km away

nanowatt (10^{-9} watt)

- 2–15 nW – *tech:* power consumption of 8-bit PIC microcontroller chips when in "sleep" mode

microwatt (10^{-6} watt)

- 1 μW – *tech:* approximate consumption of a quartz wristwatch
- 3 μW – *astro:* cosmic microwave background radiation per square meter

milliwatt (10^{-3} watt)

- 5 mW – *tech:* laser in a CD-ROM drive
- 5-10 mW – *tech:* laser in a DVD player
- 70 mW - *tech:* antennae power in a typical consumer wireless router

Between 1 and 1000 Watts

watt

- 4 W – *tech:* the power consumption of an incandescent night light
- 5 W – *legal:* maximum power output of a CB or hand-held radio transceiver
- 14 W – *tech:* the power consumption of a typical household compact fluorescent light bulb
- 20–40 W – *biomed:* approximate power consumption of the human brain
- 30–40 W – *tech:* the power consumption of a typical household fluorescent tube light

- 60 W – *tech:* the power consumption of a typical household incandescent light bulb
- 100 W – *biomed:* approximate basal metabolic rate used by an adult human body
- 120 W – *tech:* power output of 1 m^2 solar panel in full sunlight (approx. 12% efficiency)[at sea level]
- 130 W – *tech:* peak power consumption of a Pentium 4 CPU
- 253 W (2,215 kWh/year) – *geo:* per capita average power use of the world in 2001
- 290 W – *units:* approximately 1000 BTU/hour
- 300–400 W – *tech:*PC GPU Nvidia Geforce Fermi 480 power consumption
- 400 W – *tech:* legal limit of power output of an amateur radio station in the United Kingdom
- 500 W – *biomed:* power output (useful work plus heat) of a person working hard physically
- 745.7 W – *units:* 1 horsepower
- 750 W – *astro:* approximately the amount of sunshine falling on a square metre of the Earth's surface on a clear day in March for northern temperate latitudes
- 909 W – *biomed*: peak output power of a healthy human (nonathlete) during a 30-second cycle sprint at 30.1 degree Celsius.

Above 1000 Watts

kilowatt (10^3 watts)

- 1.1 kW - *tech:* power of a microwave oven
- 1.366 kW – *astro:* power received from the sun at the earth's orbit per square metre
- 1.5 kW – *tech:* legal limit of power output of an amateur radio station in the United States
- up to 2 kW – *biomed:* approximate short-time power output of sprinting professional cyclists
- 1 kW to 3 kW – *tech:* heat output of a domestic electric kettle.
- 3.6 kW – *tech:* Synchrotron radiation power lost per ring in the Large Hadron Collider at 7000 GeV
- 3.3-6.6 kW – *eco:* average photosynthetic power output per square kilometer of ocean
- 30 kW – power generated by the four motors of GEN H-4 one-man helicopter
- 11.4 kW – average power consumption per person in the United States as of 2009
- 16-32 kW – *eco:* average photosynthetic power output per square kilometer of land
- 10 kW to 50 kW – *tech:* nominal power of clear channel AM
- 50 kW to 100 kW – *tech:* highest allowed ERP for an FM band radio station in the United States.
- 40 kW to 200 kW – *tech:* approximate range of power output of typical automobiles
- 167 kW – *tech:* power consumption of UNIVAC 1 computer

- 250 kW to 800 kW – *tech:* approximate range of power output of 'supercars'

megawatt (10^6 watts)

- 1.3 MW – *tech:* power output of P-51 Mustang fighter aircraft
- 1.5 MW – *tech:* peak power output of GE's standard wind turbine
- 2.5 MW – *biomed:* peak power output of a blue whale
- 3 MW – *tech:* mechanical power output of a diesel locomotive
- 10 MW – *tech:* highest ERP allowed for an UHF television station
- 10.3 MW – *geo:* electrical power output of Togo
- 16 MW – *tech:* rate at which a typical gasoline pump transfers chemical energy to a vehicle
- 17 to 80 MW – *tech:* approximate maximum power output of a Nd:YAG laser used in Particle Image Velocimetry (100mJ over 6ns to 400mJ over 5ns, both at 532 nm)
- 75 MW – *tech:* maximum power output of one GE90 jet engine as installed on the Boeing 777
- 140 MW – *tech:* average power consumption of a Boeing 747 passenger aircraft
- 190 MW – *tech:* peak power output of a Nimitz-class aircraft carrier
- 900 MW – *tech:* electric power output of a CANDU nuclear reactor
- 959 MW – *geo:* average electrical power consumption of Zimbabwe in 1998

The productive capacity of electrical generators operated by utility companies is often measured in MW. Few things can sustain the transfer or consumption of energy on this scale; some of these events or entities include: lightning strikes, naval craft (such as aircraft carriers and submarines), engineering hardware, and some scientific research equipment (such as supercolliders and large lasers).

For reference, about 10,000 100-watt lightbulbs or 5,000 computer systems would be needed to draw 1 megawatt. Also, 1 MW equals approximately 1360 horsepower. Modern high-powered diesel-electric railroad locomotives typically have a peak power output of 3–5 MW, whereas a typical modern nuclear power plant produces on the order of 500–2000 MW peak output.

gigawatt (10^9 watts)

- 1.3 GW – *tech:* electric power output of Manitoba Hydro Limestone hydroelectric generating station
- 2.074 GW – *tech:* peak power generation of Hoover Dam
- 2.1 GW – *tech:* peak power generation of Aswan Dam
- 4.116 GW – *tech:* installed capacity of Kendal Power Station, the world's largest coal-fired power plant.
- 8.21 GW – *tech:* capacity of the Kashiwazaki-Kariwa Nuclear Power Plant, the world's largest nuclear power plant.
- 12.6 GW – *tech:* electrical power generation of the Itaipu Dam
- 12.7 GW – *geo:* average electrical power consumption of Norway in 1998

- 18.3 GW – *tech:* current electrical power generation of the Three Gorges Dam the world's largest hydroelectric power plant of any type.
- 55 GW – *tech* peak daily electrical power consumption of Great Britain in November 2008.
- 74 GW – *tech:* total installed wind turbine capacity at end of 2006.
- 190 GW – *tech:* average power consumption of the first stage of the Saturn V rocket

terawatt (10^{12} watts)

- 2 TW – *astro:* approximate power generated between the surfaces of Jupiter and its moon Io due to Jupiter's tremendous magnetic field.
- 3.34 TW – *geo:* average total (gas, electricity, etc.) power consumption of the U.S. in 2005
- 15 TW – *geo:* average total power consumption of the human world in 2004
- 44 TW – *geo:* average total heat flux from earth's interior
- 75 TW – *eco:* global net primary production (= biomass production) via photosynthesis
- 50 to 200 TW – *weather:* rate of heat energy release by a hurricane
- 290 TW – *tech:* the power the Z machine reaches in 1 billionth of a second when it is fired
- 300 TW – *tech:* power reached by the extremely high-power Hercules laser from the University of Michigan.

petawatt (10^{15} watts)

- 1.1 PW – *tech:* world's most powerful laser pulses by laser still in operation (claimed on 31 March 2008 by Texas Center for High Intensity Laser Science at The University of Texas at Austin).
- 1.25 PW – *tech:* world's most powerful laser pulses (claimed on 23 May 1996 by Lawrence Livermore Laboratory).
- 1.4 PW – *geo:* estimated heat flux transported by the Gulf Stream.
- 4 PW – *geo:* estimated total heat flux transported by earth's atmosphere and oceans away from the equator towards the poles.
- 10–100 PW *geo:* estimated total power output of a Type-I civilization on the Kardashev scale.
- 174.0 PW – *astro:* total power received by the earth from the sun

zettawatt (10^{21} watts)

- 135 ZW – *astro:* approximate luminosity of Wolf 359
- 250 ZW - tech: z-machine electric discharge

yottawatt (10^{24} watts)

- 5.3 YW – *tech:* power produced by the Tsar Bomba fusion bomb, the most powerful man made device
- 384.6 YW – *astro:* luminosity of the sun
- 400 YW – *geo:* estimated total power output of a Type-II civilization on the Kardashev scale.

greater than one thousand yottawatts

- 3.31×10^{31}W – *astro:* approximate luminosity of Beta Centauri
- 1.23×10^{32}W – *astro:* approximate luminosity of Deneb
- 5×10^{36}W – *astro:* approximate luminosity of the Milky Way galaxy.
- 4×10^{37}W – *astro:* estimated total power output of a Type-III civilization on the Kardashev scale.
- 1×10^{40}W – *astro:* approximate luminosity of a quasar
- 1×10^{42}W – *astro:* approximate luminosity of the Local Supercluster
- 1×10^{45}W – *astro:* approximate luminosity of a gamma-ray burst
- 2×10^{49}W – *astro:* approximate total luminosity of all the stars in the observable universe
- 3.63×10^{52}W – *phys:* The Planck power, the basic unit of power in the Planck units.

Chapter-4

Diverse Units of Power

Airwatt

An **airwatt** or **air watt** is a unit of power very close to the watt which is used for various vacuum cleaning systems, such as vacuum cleaners. The airwatt is derived from English units. ASTM International defines the airwatt as 0.117354 * F * S, where F is the rate of air flow in ft^3/m and S is the pressure in inches of water. This makes one airwatt equal to 0.9983 watts.

The airwatt is useful measurement of vacuum power, since the power carried by a fluid flow (in the case of a typical house vacuum the fluid is air) is equal to pressure times volumetric flow rate. This could be a more useful figure than the electrical power drawn by the vacuum system's motor, since the efficiency of motor and vacuum systems varies.

Formula

cleaning power (air watts) = airflow (CFM) × suction (inches of water) / 8.5

$$= \text{airflow (m³/s)} \times \text{suction (Pa)}$$

Mercury (Hg) is heavier than water so, 1" of Hg= 13.5" of water. In other words, 10" Hg is the same vacuum level as 135" of H2O lift. The CFM figure can't be evaluated alone, any more than the lift figure can. The following shows why:

Lift vs. Airflow: These two factors are interdependent. They are tied to one another; if one goes up, the other goes down. This is called an inverse relationship.

Let's suppose that when you look at the vacuum gauge of your truck mount the reading is a level of 6" Hg. Looking at chart 1, we see that at this level of lift, the system is capable of moving about 175 CFM.

Now suppose you do something to the system such as add more hose or improve the wand seal. Now your gauge reads a level of 10" Hg. From the chart, you can see that you now hit the performance curve at point "B" and that the airflow has dropped to about 150

CFM. So, as one factor (lift) went up, another (airflow) came down. They have an inverse relationship. Fact: The most effective cleaning is accomplished when there is proper balance between lift and airflow.

Air watts measured at the vacuum's motor can differ by as much as 50% (depending on the type of vacuum) from the air watts measured at the end of the hose. This is most noted in central vacuums.

Nominal watt

Nominal wattage is used to simplify the measurement of the efficiency of a loudspeaker.

The impedance of a loudspeaker varies with frequency. This means that if different sine wave tones are fed into the loudspeaker at the same voltage (or the same current), the amount of electric power consumed will vary.

By convention, loudspeakers are designed to generate the same sound pressure level (SPL) at the listener for the same voltage at varying frequencies - regardless of the variation in electric power. This permits a loudspeaker to be used with an amplifier having a low internal impedance and a flat frequency response is realized for the combined amplifier/loudspeaker system.

However, an amplifier with a low internal impedance delivers more electrical output power when the load impedance reduces (until the impedances become approximately matched). Such high power levels could cause damage to either the amplifier or the amplifier's power supply, or the circuit connected to the amplifier's output (including the loudspeaker).

Therefore, an additional convention exists whereby loudspeaker manufacturers specify a conservative estimate of the average impedance that the loudspeaker will present while playing typical music. This is called the *nominal impedance*. Amplifiers can therefore be safely specified to operate into a load that has this *nominal impedance* (or higher, but not lower).

Typical nominal impedances for speakers include 4, 6, 8 and 16Ω (ohms), with 4Ω being most common in in-car loudspeakers, and 8Ω being most common elsewhere. A loudspeaker with an 8Ω nominal impedance may exhibit actual impedances ranging from approximately 5 to 100Ω depending on frequency.

In this context, the nominal wattage is the *theoretical* electric power that *would* be transferred from amplifier to speaker *if* the loudspeaker was actually exhibiting its nominal impedance. The actual electric power may vary from about twice the nominal power down to less than one tenth.

Loudspeaker efficiency is measured with respect to nominal power in order to emulate the situation outlined above where a low internal impedance amplifier is used with a loudspeaker. The convention is to supply one nominal watt during testing. If the nominal impedance is 4 ohms, the voltage would be 2 volts. If the nominal impedance is 8Ω, the voltage would be 2.83 volts.

Volt-ampere

A **volt-ampere** (VA) is the unit used for the apparent power in an electrical circuit, equal to the product of root-mean-square (RMS) voltage and RMS current. In direct current (DC) circuits, this product is equal to the real power (active power) in watts. Volt-amperes are useful only in the context of alternating current (AC) circuits (sinusoidal voltages and currents of the same frequency).
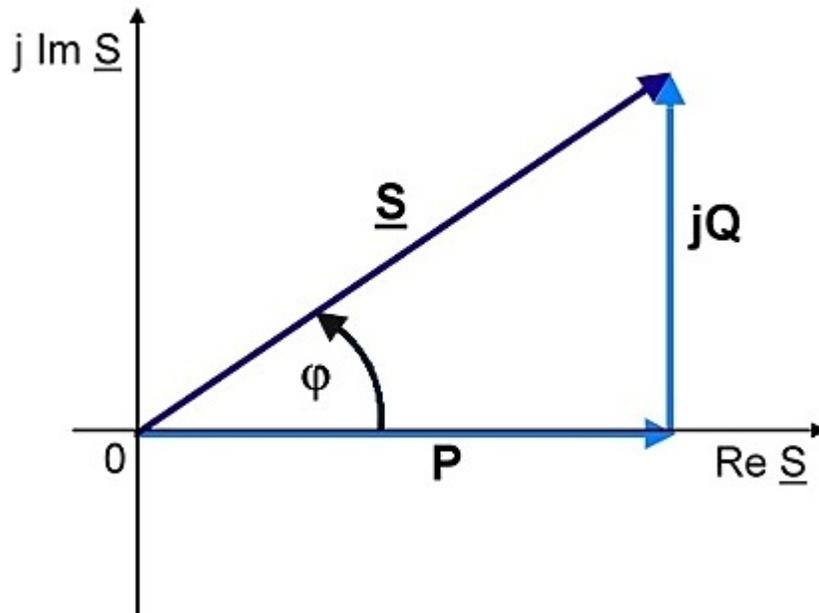
Apparent power is the vector sum of real (P) and reactive (jQ) AC power vectors

While both the volt-ampere (abbreviated VA) and the watt have the dimension of power (time rate of energy), they do not have the same meaning. Some devices, including Uninterruptible Power Supplies (UPSs), have ratings both for maximum VAs and maximum watts.

The VA rating is limited by the maximum permissible current, and the watt rating by the power-handling capacity of the device. When a UPS powers equipment which presents a reactive load with a low power factor (e.g., a computer), neither limit may safely be exceeded.

Volt-ampere reactive

In alternating current power transmission and distribution, **volt-ampere reactive** (**var**) is a unit used to measure reactive power in an AC electric power system. Reactive power exists in an ac circuit when the current and voltage are not changing at the same time. The correct symbol is var and not VAr or VAR, but the latter two terms are widely used. The term *var* was proposed by the Romanian electrical engineer Constantin Budeanu and introduced in 1930 by the IEC in Stockholm, which has adopted it as the unit for reactive power.

Vars may be considered as either the imaginary part of apparent power, or the power flowing into a reactive load, where voltage and current are specified in volts and amperes. The two definitions are equivalent.

Reactive power

A sinusoidally alternating voltage applied to a purely resistive load results in an alternating current that is fully in phase with the voltage. In many applications it is however common for there to be a reactive component to the system, that is, the system possesses capacitance, inductance, or both. These electrical properties cause the current to change phase with respect to the voltage: capacitance tending the current to lead the voltage in phase, and inductance to lag it.

For sinusoid currents and voltages at the same frequency, reactive power in vars is the product of the RMS voltage and current, or the apparent power, multiplied by the sine of the phase angle between the voltage and the current. The reactive power Q, (measured in units of volt-amperes reactive or var), is given by:

$$Q = V_{\mathrm{rms}} I_{\mathrm{rms}} \sin(\phi)$$

where φ is the phase angle between the voltage and current.

Only effective power, the actual power delivered to or consumed by the load, is expressed in watts. Imaginary power is properly expressed in volt-amperes reactive.

Watt-peak

Watt-peak (Wp) is a measure of the nominal power of a photovoltaic solar energy device under laboratory illumination conditions. Related units such as **kilowatt-peak** or **kilowatts-peak** (kWp) and **megawatts-peak** are also used, and in the context of domestic installations kWp is the most common unit encountered.

Measurement of Nominal Power

The nominal power of a photovoltaic module is determined by measuring current and voltage while varying resistance under defined illumination. The conditions are specified in standards such as IEC 61215, IEC 61646 and UL 1703; specifically the light intensity is $1000W/m^2$, with a spectrum similar to sunlight hitting the earth's surface at latitude 35°N in the summer (airmass 1.5) and temperature of the cells at 25°C. The power is measured while varying the resistive load on the module between open and closed circuit. The maximum power measured is the nominal power of the module in **"W_p"**. The nominal power divided by the light power that falls on the module (area x $1000W/m^2$) is the **efficiency**. Watts peak is a convenient measure because it enables one to compare one module with another and track industry capacities and shipments. Equivalent measures can be used for wind electricity generators, though obviously the specification of ideal conditions is different.

Power output in real conditions

The output of photovoltaic systems varies with the intensity of sunshine and other conditions. The more sun, the more power the PV module will generate. Losses will occur due to non-ideal alignment of the module in tilt and/or orientation, high temperature, module power mismatch, soiling and DC to AC conversion. Importantly the maximum power a module can generate can easily exceed the nominal power, anywhere where the intensity of sunlight exceeds $1000W/m^2$ (which corresponds roughly to midday in summer in, for example, Germany)

Cost-per-watt

Although watt-peak is a convenient measure, and is the standardized number in the photovoltaic industry on which prices, sales and growth numbers are based, it is arguably not the most important number for cost-effectiveness. Since a solar panel's job is to generate electric power, the amount of power that it generates under average conditions should be the most important number to evaluate. It can happen that a panel from brand A and a panel of brand B give exactly the same watt-peak in a laboratory test, but their power output is different in a real installation. This difference can be caused by the fact that the relation of performance to temperature or insulation is different for the two cells. For example, a low efficiency cell will become hotter, and with higher temperature

the efficiency will go down, reducing useful energy conversion further. The ratio of a power source's average to peak production is its capacity factor.

Solar luminosity

The **solar luminosity**, $L_\odot$, is a unit of luminosity or radiant power (power emitted in the form of photons) conventionally used by astronomers to give the luminosities of stars. One solar luminosity is equal to the current accepted luminosity of the Sun, which is 3.839×10^{26} W, or 3.839×10^{33} erg/s. The value is slightly higher, 3.939×10^{26} W (equivalent to 4.382×10^{9} kg/s or 2.107×10^{-15} $M_\odot$/d) if the solar neutrino radiation is included as well as electromagnetic radiation. The Sun is a weakly variable star and its luminosity therefore fluctuates. The major fluctuation is the eleven-year solar cycle (sunspot cycle), which causes a periodic variation of about ±0.1%. Any other variation over the last 200–300 years is thought to be much smaller than this.

Determination

The solar luminosity is related to the solar irradiance measured at the Earth or by satellites in Earth orbit. The mean irradiance at the top of the Earth's atmosphere is sometimes known as the solar constant, $I_\odot$. Irradiance is defined as power per unit area, so the solar luminosity (total power emitted by the Sun) is the irradiance received at the Earth (solar constant) multiplied by the area of the sphere whose radius is the mean distance between the Earth and the Sun:

$$L_\odot = 4\pi k I_\odot A^2$$

where A is the unit distance (the value of the astronomical unit in metres) and k is a constant (whose value is very close to one) that reflects the fact that the mean distance from the Earth to the Sun is not exactly one astronomical unit.

Chapter-5

Torr

The **torr** (symbol: **Torr**) is a non-SI unit of pressure with the ratio of 760 to 1 standard atmosphere, chosen to be roughly equal to the fluid pressure exerted by a millimeter of mercury, *i.e.* a pressure of 1 Torr is *approximately* equal to 1 mmHg. Note that the symbol is spelled exactly the same as the unit, but the symbol is capitalized, as is customary in metric units derived from names. It was named after Evangelista Torricelli, an Italian physicist and mathematician who discovered the principle of the barometer in 1644.

History

Torricelli attracted considerable attention when he demonstrated the first mercury barometer to the general public. He is credited with giving the first modern explanation of atmospheric pressure. Scientists at the time were familiar with small fluctuations in height that occurred in barometers. When these fluctuations were explained as a manifestation of changes in atmospheric pressure, the science of meteorology was born.

Over time, 760 millimeters of mercury (abbreviated mmHg) came to be regarded as the standard atmospheric pressure. In honor of Torricelli, the torr was defined as a unit of pressure equal to one mmHg.

In 1954, the definition of the *atmosphere* was revised by the *10e Conférence Générale des Poids et Mesures* (*10th CGPM*) to the currently accepted definition: one atmosphere is equal to 101,325 pascals. The torr was then re-defined as $\frac{1}{760}$ of one atmosphere. This was necessary in place of the definition of a torr as 1 mmHg, because the height of mercury changes at different temperatures and gravities.

SI units of pressure

The SI unit of pressure is the *pascal* (symbol: Pa), defined as one newton per square meter. Other units of pressure are defined in terms of SI units. These include:

- The bar (symbol: bar), defined as 100 kPa exactly.

- The atmosphere (symbol: atm), defined as 101.325 kPa exactly.
- The torr (symbol: Torr), defined as $\frac{1}{760}$ atm exactly.

These four pressure units are used in different settings. For example, the bar is used in meteorology to report atmospheric pressures. The torr, a more convenient unit for low pressures, is used in high-vacuum physics and engineering.

Pressure units

	Pascal (Pa)	Bar (bar)	Technical atmosphere (at)	Atmosphere (atm)	Torr (Torr)	Pound-force per square inch (psi)
1 Pa	$\equiv 1\ \mathrm{N/m^2}$	10^{-5}	1.0197×10^{-5}	9.8692×10^{-6}	7.5006×10^{-3}	145.04×10^{-6}
1 bar	100,000	$\equiv 10^6\ \mathrm{dyn/cm^2}$	1.0197	0.98692	750.06	14.5037744
1 at	98,066.5	0.980665	$\equiv 1\ \mathrm{kgf/cm^2}$	0.96784	735.56	14.223
1 atm	101,325	1.01325	1.0332	$\equiv 1$ atm	760	14.696
1 torr	133.322	1.3332×10^{-3}	1.3595×10^{-3}	1.3158×10^{-3}	$\equiv 1$ Torr; ≈ 1 mmHg	19.337×10^{-3}
1 psi	6.894×10^3	68.948×10^{-3}	70.307×10^{-3}	68.046×10^{-3}	51.715	$\equiv 1\ \mathrm{lbf/in^2}$

Example reading: $1\ \mathrm{Pa} = 1\ \mathrm{N/m^2} = 10^{-5}$ bar $= 10.197 \times 10^{-6}$ at $= 9.8692 \times 10^{-6}$ atm $= 7.5006 \times 10^{-3}$ torr $= 145.04 \times 10^{-6}$ psi
etc.

Manometric units of pressure

Manometric units are units such as *millimeters of mercury* or *centimeters of water* that depend on an assumed density of a fluid and an assumed acceleration of gravity. The use of these units is discouraged. Nevertheless, manometric units are used routinely in medicine and physiology, and they continue to be used in areas as diverse as weather reporting and scuba diving.

The *millimeter of mercury* (symbol: *mmHg*) is defined as the pressure exerted at the base of a column of fluid exactly 1 mm high, when the density of the fluid is exactly 13.5951 g/cm^3, at a place where the acceleration of gravity is exactly 9.80665 m/s^2. Under most conditions, 1 mmHg is approximately equal to 1 Torr.

There are several things to notice about this definition:

- A fluid density of 13.5951 g/cm^3 was chosen for this definition because this is the approximate density of mercury at 0 °C. The definition, therefore, assumes a particular value for the density of mercury. The density can depend on temperature, exogenous pressure, and other similar variables, so those have to assume certain conventional, normal values as well.

- The definition assumes a particular value for the acceleration of gravity: the standard gravity $g_0 = 9.80665$ m/s^2. In theory, the precise acceleration would vary, and the measurement would have to be recalibrated against the local value; in weightless conditions, this kind of measurement would not even make sense.
- The definition does not address the quality of the vacuum, including the vapor pressure of the mercury, above the column of fluid.

In practice, of course, measurements are made using local values, which vary little enough at the Earth's surface. These assumptions limit both the validity and the precision of the mmHg as a unit of pressure.

According to the UK's National Physical Laboratory (NPL):

The need to assume fixed and exact – but ultimately incorrect – values of liquid density and acceleration due to gravity will inherently limit knowledge of the relationship between [the millimeter of mercury] and the pascal.

By contrast, the magnitude of pressure values expressed in the SI pressure unit, the pascal, can flex (albeit not by much) to take account of technological improvements in the underlying definitions of mass, length and time – the SI base quantities from which pressure is derived.

The performance of modern transducers approaches the precision required to distinguish between the torr and the millimeter of mercury.

The NPL concludes

Thus, in the near future, the accuracy claims being made for otherwise state-of-the-art instruments scaled in manometric units will become inherently inferior.

Even now, confusion and large errors abound through the use of differing definitions, including alternative values of 'standard' gravity and varying assumptions about the density and temperature of the fluid.

Misunderstandings about temperature assumptions alone can lead to errors of several tenths of a percent and there are many stories of this leading to major mistakes in pressure measurement.

Manometric units in medicine and physiology

In medicine, the millimetre of mercury (measured with a sphygmomanometer) is the "gold standard" for blood pressure measurement.

In physiology, manometric units are used to measure Starling forces. Other applications include:

- Intraocular pressure (tonometry)
- Cerebrospinal fluid pressure
- Intracranial pressure
- Intramuscular pressure (compartment syndrome)
- Central venous pressure
- Pulmonary artery catheterization
- Mechanical ventilation

Manometric results in medicine are sometimes given in torr.

This is usually incorrect, since the torr and the millimetre of mercury are not the same thing.

Pressures obtained with a manometer (or its transducer equivalent) should be reported in millimetres of mercury.

Conversion factors

The mmHg is defined as (13.595 1 × 9.806 65) Pa = 133.322 387 415 Pa, which is approximated with known accuracies of density of mercury and gravitational acceleration. The torr is defined as 1/760 of one atmosphere, while the atmosphere is defined as 101.325 kPa. Therefore, one torr is equal to 101 325 / 760 Pa. The decimal form of this fraction (133.322 368 421...) is, unfortunately for practical use, an infinitely long, periodically repeating decimal, as is its reciprocal.

The relationship between the torr and the mmHg is:

- 1 Torr = 0.999 999 *857 533 699*... mmHg
- 1 mmHg = 1.000 000 *142 466 321*... Torr

The difference between one mmHg and one torr, as well as between one atmosphere (101.325 kPa) and 760 mmHg (101.325 014 435 4 kPa), is less than one part in seven million (or less than 0.000 015%). This small difference is negligible for most applications outside metrology.

The unit mmHg as used in medicine is in general given relative to the atmospheric pressure. This means that when a doctor tells you you have a blood pressure of 100 mmHg, this is 100mmHg above atmospheric. So on a day when the barometric pressure is 760 your absolute pressure is actually $760 + 100 = 860$ mmHg $= 860/760×10^5$ Pa.

Pascal and Pounds Per Square Inch

Pascal

Pascal

A pressure gauge reading in psi (red scale) and kPa (black scale)

Unit information	
Unit system:	SI derived unit
Unit of...	Pressure / Stress
Symbol:	Pa
Named after:	Blaise Pascal
In SI base units:	1 Pa = 1 kg/(m·s^2)

The **pascal** (symbol: **Pa**) is the SI derived unit of pressure, internal pressure, stress, Young's modulus and tensile strength, named after the French mathematician, physicist, inventor, writer and Catholic philosopher Blaise Pascal. It is a measure of force per unit area, defined as one newton per square metre. In everyday life, the pascal is perhaps best known from meteorological barometric pressure reports, where it occurs in the form of hectopascals (1 hPa ≡ 100 Pa) or kilopascals (1 kPa ≡ 1000 Pa). In other contexts, the

kilopascal is commonly used, for example on bicycle tire labels. One hectopascal corresponds to about 0.1% and one kilopascal to about 1% of atmospheric pressure (near sea level). One hectopascal is equivalent to one millibar; one standard atmosphere is exactly equal to 1013.25 hPa or 101325 Pa. The equivalent Imperial unit is pounds per square inch.

hPa = hectopascal where 1 hPa = 100 Pa

kPa = kilopascal where 1 kPa = 1000 Pa

MPa = megapascal where 1MPa = 1000000 Pa

Definition

The pascal can be expressed using SI derived units, or alternatively solely SI base units, as:

$$1 \text{ Pa} = 1 \ \frac{\text{N}}{\text{m}^2} = 1 \ \frac{\text{kg}}{\text{m} \cdot \text{s}^2}$$

Where N is the newton, m is the metre, kg is the kilogram, and s is the second.

Pressure units

	Pascal (Pa)	Bar (bar)	Technical atmosphere (at)	Atmosphere (atm)	Torr (Torr)	Pound-force per square inch (psi)
1 Pa	$\equiv 1 \text{ N/m}^2$	10^{-5}	1.0197×10^{-5}	9.8692×10^{-6}	7.5006×10^{-3}	145.04×10^{-6}
1 bar	100,000	$\equiv 10^6 \text{ dyn/cm}^2$	1.0197	0.98692	750.06	14.5037744
1 at	98,066.5	0.980665	$\equiv 1 \text{ kgf/cm}^2$	0.96784	735.56	14.223
1 atm	101,325	1.01325	1.0332	$\equiv 1 \text{ atm}$	760	14.696
1 torr	133.322	1.3332×10^{-3}	1.3595×10^{-3}	1.3158×10^{-3}	$\equiv 1 \text{ Torr};$ $\approx 1 \text{ mmHg}$	19.337×10^{-3}
1 psi	6.894×10^3	68.948×10^{-3}	70.307×10^{-3}	68.046×10^{-3}	51.715	$\equiv 1 \text{ lbf/in}^2$

Example reading: $1 \text{ Pa} = 1 \text{ N/m}^2 = 10^{-5} \text{ bar} = 10.197 \times 10^{-6} \text{ at} = 9.8692 \times 10^{-6} \text{ atm} = 7.5006 \times 10^{-3} \text{ torr} = 145.04 \times 10^{-6} \text{ psi}$
etc.

Origin

The unit is named after Blaise Pascal, the eminent French mathematician, physicist, and philosopher noted for his experiments with a barometer, an instrument to measure air pressure. The name *pascal* was adopted for the SI unit newton per square metre by the 14th CGPM in 1971.

This SI unit is named after Blaise Pascal. As with every SI unit whose name is derived from the proper name of a person, the first letter of its symbol is upper case (**Pa**). When an SI unit is spelled out in English, it should always begin with a lower case letter (**pascal**), except where *any* word would be capitalized, such as at the beginning of a sentence or in capitalized material such as a title. Note that "degree Celsius" conforms to this rule because the "d" is lowercase.
—Based on *The International System of Units*, section 5.2.

Miscellaneous

Standard atmospheric pressure is 101,325 Pa = 101.325 kPa = 1013.25 hPa = 1013.25 mbar = 760 Torr. This definition is used for pneumatic fluid power (ISO R554), and in the aerospace (ISO 2533) and petroleum (ISO 5024) industries.

In 1985, IUPAC recommended that standard atmospheric pressure should be harmonized to 100,000 Pa = 1 bar = 750 Torr. The same definition is used in the compressor and the pneumatic tool industries (ISO 2787).

The Unicode computer character set has dedicated symbols ㎩ (U+33A9) for Pa and ㎪ (U+33AA) for kPa, but these exist merely for backward-compatibility with some older ideographic character-sets and are therefore deprecated.

Uses

The pascal (Pa) or kilopascal (kPa) as a unit of pressure measurement is widely used throughout the world and largely replaces the pounds per square inch (psi) unit, except in some countries still using the Imperial measurement system.

Tectonophysicists use the gigapascal (GPa) in measuring or calculating tectonic forces within the earth.

In Solid Mechanics, megapascals (MPa = N/mm^2) or gigapascals (GPa = kN/mm^2) are commonly used to measure stiffness of materials.

Another unit for pressure measurement in common use today is millimetres of water (1 mm H_2O = 9.80665 Pa).

Meteorologists worldwide have for a long time measured atmospheric pressure in millibars. After the introduction of SI units, many preferred to preserve the customary

pressure figures. Therefore, meteorologists use hectopascals (hPa) today for air pressure, which are equivalent to millibars, while similar pressures are given in kilopascals in practically all other fields, where the hecto prefix is hardly ever used. Since official metrication, meteorologists in Canada use kilopascals (kPa), see for example CTV News, weather; current conditions in Montreal and Environment Canada weather, current conditions in Montreal, although in some other countries hectopascals are still in use, see for example KNMI, KMI, DWD, JMA, MDD and NOAA.

> 1 hectopascal (hPa) ≡ 100 Pa ≡ 1 mbar.
> 1 kilopascal (kPa) ≡ 1000 Pa ≡ 10 hPa ≡ 10 mbar.

In the cgs system, the unit of pressure is the barye (symbol **ba**), which is equal to one decipascal. The older kg(force)/cm^2 corresponds to 98.0665 kPa, but is often rounded to 100 kPa in practice.

In the former mts system, the unit of pressure is the pièze (symbol **pz**), which is equal to one kilopascal.

Vehicle owners' guides now specify tire inflation in kilopascals.

Airtightness testing of buildings is measured at 50 Pa or 0.2 inches of water.

Pounds per square inch

A pressure gauge reading in psi (red scale) and kPa (black scale)

The **pound per square inch** or, more accurately, **pound-force per square inch** (symbol: **psi** or **lbf/in^2** or **lb$_f$/in^2** or **lbf/sq in** or **lb$_f$/sq in**) is a unit of pressure or of stress based on avoirdupois units. It is the pressure resulting from a force of one pound-force applied to an area of one square inch:

1 psi approximately equals 6,894.757 Pa, where pascal (Pa) is the SI unit of pressure.

Relation to other measures

Other abbreviations are used that append a modifier to "psi". However, the US National Institute of Standards and Technology recommends that, to avoid confusion, any modifiers be instead applied to the quantity being measured rather than the unit of measure For example, "$P_g = 100$ psi" rather than "$P = 100$ psig".

- psia (pounds-force per square inch absolute) — gauge pressure plus local atmospheric pressure. Replace "x psia" with "$P_a = x$ psi".
- psid (psi difference) — difference between two pressures. Replace "x psid" with "$\Delta P = x$ psi".
- psig (pounds-force per square inch gauge) - pressure relative to the surrounding atmosphere. Replace "x psig" with "$P_g = x$ psi".
- psivg (psi vented gauge) — difference between the measuring point and the local pressure. Replace "x psivg" with "$P_{vg} = x$ psi".
- psisg (psi sealed gauge) — difference between a chamber of air sealed at atmospheric pressure and the pressure at the measuring point. Replace "x psisg" with "$P_{sg} = x$ psi".

Psig v. Psia

Psig (pound-force per square inch gauge) is a unit of pressure relative to the surrounding atmosphere. By contrast, *psia* (pound-force per square inch absolute) measures pressure relative to a vacuum (such as that in space).

At sea level, Earth's atmosphere actually exerts a pressure of 14.696 psi. Humans do not feel this pressure because the internal pressure of their bodies matches the external pressure. If a pressure gauge is calibrated to read zero in a vacuum, then at sea level on Earth it would read 14.7 psi. Thus, a reading of 30 psig on Earth represents an absolute pressure of 44.7 psi. More generally, x psia $= (x + 14.696$) psig.

Psi is often used instead of psig, possibly causing confusion.

ksi

The ksi ("kilo-pound[-force] per square inch") is 1000 psi, combining the prefix kilo with the psi abbreviation. It is occasionally used in materials science, civil and mechanical engineering to specify stress and Young's modulus.

Magnitude

- Blood Pressure Average human blood pressure (120/80): 2.32044psi/1.54696psi
- Boost Pressure Provided By an Automotive Turbocharger(common):$P_g = 6 - 15$psi
- Atmospheric pressure at sea level (standard): $P_a = 14.7$ psi
- Automobile tire overpressure (common): $P_g = 32$ psi

- Bicycle tire overpressure (common): $P_g = 65$ psi
- Workshop or garage air tools: $P_g = 90$ psi
- Air brake (rail) or Air brake (road vehicle) reservoir overpressure (common): 90 psi $\leq P_g \leq$ 120 psi
- Road racing bicycle tire overpressure: $P_g = 120$ psi
- Steam locomotive fire tube boiler (UK, 20th century): 150 psi $\leq P_g \leq$ 225 psi
- Union Pacific Big Boy steam locomotive boiler: 300 psi
- Natural gas pipelines: 800 to 1000 psi
- Full SCBA Self Contained Breathing Apparatus for toxic atmospheres: 2216 psi
- Full scuba tank overpressure (common): $P_g = 3000$ psi
- Commercial jet airliner hydraulic pressure: 3000 psi
- Airbus A380 hydraulic system: 5000 psi
- Water jet cutter: 40,000 psi - 100,000 psi

Conversions

Pressure units

	Pascal (Pa)	Bar (bar)	Technical atmosphere (at)	Atmosphere (atm)	Torr (Torr)	Pound-force per square inch (psi)
1 Pa	$\equiv 1$ N/m^2	10^{-5}	1.0197×10^{-5}	9.8692×10^{-6}	7.5006×10^{-3}	145.04×10^{-6}
1 bar	100,000	$\equiv 10^6$ dyn/cm^2	1.0197	0.98692	750.06	14.5037744
1 at	98,066.5	0.980665	$\equiv 1$ kgf/cm^2	0.96784	735.56	14.223
1 atm	101,325	1.01325	1.0332	$\equiv 1$ atm	760	14.696
1 torr	133.322	1.3332×10^{-3}	1.3595×10^{-3}	1.3158×10^{-3}	$\equiv 1$ Torr; ≈ 1 mmHg	19.337×10^{-3}
1 psi	6.894×10^3	68.948×10^{-3}	70.307×10^{-3}	68.046×10^{-3}	51.715	$\equiv 1$ lbf/in^2

Example reading: 1 Pa = 1 N/m^2 = 10^{-5} bar = 10.197×10^{-6} at = 9.8692×10^{-6} atm = 7.5006×10^{-3} torr = 145.04×10^{-6} psi
etc.

Chapter-7

Atmosphere (unit) and Bar (unit)

Atmosphere (unit)

The **standard atmosphere** (symbol: **atm**) is an international reference pressure defined as 101,325 Pa and formerly used as unit of pressure. For practical purposes it has been replaced by the bar which is 100,000 Pa. The difference of about 1% is not significant for many applications, and is within the error range of common pressure gauges.

History

In 1954 the 10th Conférence Générale des Poids et Mesures (CGPM) adopted *standard atmosphere* for general use and affirmed its definition of being precisely equal to 1,013,250 dynes per square centimeter (101 325 Pa). This value was intended to represent the mean atmospheric pressure at mean sea level at the latitude of Paris, France, and as a practical matter, truly reflects the mean sea level pressure for many of the industrialized nations (those with latitudes similar to Paris).

In chemistry, the original definition of "Standard Temperature and Pressure" (STP) was a reference temperature of 0 °C (273.15 K) and pressure of 101.325 kPa (1 atm). However, in 1982, the International Union of Pure and Applied Chemistry (IUPAC) recommended that for the purposes of specifying the physical properties of substances, "*the standard pressure*" should be defined as precisely 100 kPa (exactly 1 bar).

Pressure units and equivalencies

Pressure units

	Pascal (Pa)	Bar (bar)	Technical atmosphere (at)	Atmosphere (atm)	Torr (Torr)	Pound-force per square inch (psi)
1 Pa	$\equiv 1\ N/m^2$	10^{-5}	1.0197×10^{-5}	9.8692×10^{-6}	7.5006×10^{-3}	145.04×10^{-6}
1 bar	100,000	$\equiv 10^6\ dyn/cm^2$	1.0197	0.98692	750.06	14.5037744
1 at	98,066.5	0.980665	$\equiv 1\ kgf/cm^2$	0.96784	735.56	14.223
1 atm	101,325	1.01325	1.0332	$\equiv 1\ \mathbf{atm}$	760	14.696
1 torr	133.322	1.3332×10^{-3}	1.3595×10^{-3}	1.3158×10^{-3}	$\equiv 1\ Torr;$ $\approx 1\ mmHg$	19.337×10^{-3}
1 psi	6.894×10^3	68.948×10^{-3}	70.307×10^{-3}	68.046×10^{-3}	51.715	$\equiv 1\ lbf/in^2$

Example reading: $1\ Pa = 1\ N/m^2 = 10^{-5}$ bar $= 10.197\times10^{-6}$ at $= 9.8692\times10^{-6}$ atm $= 7.5006\times10^{-3}$ torr $= 145.04\times10^{-6}$ psi
etc.

A pressure of 1 atm can also be stated as:

$\equiv$ 1.013 25 bar
$\equiv$ 1013.25 hectopascal (hPa)
$\equiv$ 1013.25 millibars (mbar, also mb)
$\equiv$ 760 torr [B]
$\approx$ 760.001 mm-Hg, 0 °C, subject to revision as more precise measurements of mercury's density become available [B, C]
$\approx$ 29.9213 in-Hg, 0 °C, subject to revision as more precise measurements of mercury's density become available [C]
$\approx$ 1.033 227 452 799 886 kgf/cm²
$\approx$ 1.033 227 452 799 886 technical atmosphere
$\approx$ 1033.227 452 799 886 cm–H$_2$O, 4 °C [A]
$\approx$ 406.782 461 732 2385 in–H$_2$O, 4 °C [A]
$\approx$ 14.695 948 775 5134 pounds-force per square inch (psi)
$\approx$ 2116.216 623 673 94 pounds-force per square foot (psf)
Notes:
[A] This is the customarily-accepted value for cm–H$_2$O, 4 °C. It is precisely the product of 1 kg-force per square centimeter (one technical atmosphere) times 1.013 25 (bar/atmosphere) divided by 0.980 665 (one gram-force). It is not accepted practice to define the value for water column based on a true physical realization of water (which would be 99.997 495% of this value because the true maximum density of Vienna

Standard Mean Ocean Water is 0.999 974 95 kg/l at 3.984 °C). Also, this "physical realization" would *still* ignore the 8.285 cm–H_2O reduction that would actually occur in a true physical realization due to the vapor pressure over water at 3.984 °C.

[B] Torr and mm-Hg, 0°C are often taken to be identical. For most practical purposes (to 5 significant digits), they are interchangeable.

[C] NIST value of 13.595 078(5) g/ml assumed for the density of Hg at 0 °C

Other applications

Scuba divers and others use the word *atmosphere* and "atm" in relation to pressures that are relative to mean atmospheric pressure at sea level (1.013 bar). For example, a partial pressure of oxygen is calibrated typically using air at sea level, so is expressed in units of atm.

The old European unit technical atmosphere (at) is roughly equal to the gauge pressure under 10 m of water; 1 at = 98066.5 Pa.

Bar (unit)

The **bar** is a unit of pressure equal to 100 kilopascals, and roughly equal to the atmospheric pressure on Earth at sea level. Other units derived from the bar are the **megabar** (symbol: **Mbar**), **kilobar** (symbol: **kbar**), **decibar** (symbol: **dbar**), **centibar** (symbol: **cbar**), and **millibar** (symbol: **mbar** or **mb**). They are not SI units, nor are they cgs units, but they are accepted for use with the SI. The bar is widely used in descriptions of pressure because it is only about 1% smaller than the atmosphere, and is legally recognized in countries of the European Union.

Except for the power of ten, the definition of bar fits in the sequence of SI pressure units (Pa, kPa, MPa), namely, 1 bar ≡ 100,000 Pa = 100 kPa = 0.1 MPa. This is in contrast to the well-known unit of pressure, atmosphere, which now is *defined* to be 1.01325 bar exactly.

The bar and the millibar were introduced by the British meteorologist William Napier Shaw in 1909. William Napier Shaw was the director of the Meteorological Office in London from 1907 to 1920.

Barg is a unit of gauge pressure, i.e. pressure in bars above ambient or atmospheric pressure.

Definition

- 1 atm (atmosphere) = 1.01325 bar
- 1 kbar = 1000 bar = 100,000 kPa = 1,000,000,000 dyn/cm^2 = 100 MPa = 0.1 GPa

- 1 bar = 100 kPa = 1,000,000 dynes per square centimeter (baryes) = 0.987 atm (atmospheres) = 14.5038 psi = 29.53 inHg = 750.06 torr
- 1 dbar = 0.1 bar = 10 kPa = 100,000 dyn/cm^2
- 1 cbar = 0.01 bar = 1 kPa
- 1 mbar = 0.001 bar = 0.1 kPa = 1 hPa (hectopascal) = 1,000 dyn/cm^2

Example conversion: 1 atm pressure = 1.01325 bar = 1.01325 x 10^5 Pa = 1.01325 x 10^5 N/m^2

Origin

The word *bar* has its origin in the Greek word βάρος (baros), meaning weight. Its official symbol is "bar"; the earlier "b" is now deprecated, but still often seen especially in "mb" rather than the proper "mbar" for millibars.

The bar and millibar were introduced by Sir Napier Shaw in 1909 and internationally adopted in 1929.

Usage

Atmospheric air pressure is often given in millibars where "standard" sea level pressure (1 atm) is defined as 1013.25 mbar (hPa), equal to 1.01325 bar. Despite millibars not being an SI unit, meteorologists and weather reporters worldwide have long measured air pressure in millibars. After the advent of SI units, some meteorologists began using hectopascals (symbol hPa) which are numerically equivalent to millibars. For example, the weather office of Environment Canada uses kilopascals and hectopascals on their weather maps. In contrast, Americans are familiar with the use of the millibar in US reports of hurricanes and other cyclonic storms.

In water, there is an approximate numerical equivalence between the change in pressure in decibars and the change in depth from the sea surface in metres. Specifically, an increase of 1 decibar occurs for every 1.019716 metre increase in depth close to the surface. As a result, decibars are commonly used in oceanography.

Many engineers worldwide use the bar as a unit of pressure because, in much of their work, using pascals would involve using very large numbers.

In the automotive field, turbocharger boost is often described in the United Kingdom in terms of the bar.

Unicode has a character for "mb": mb, U+33D4, but it exists only for compatibility with legacy Asian encodings. There is also a character "bar": bar, U+3374.

The kilobar is commonly used in geological systems, particularly in experimental Petrology.

Absolute pressure and gauge pressure

Bourdon tube pressure gauges, vehicle tire gauges, and many other types of pressure gauges are zero referenced to atmospheric pressure, which means that they measure the pressure above atmospheric pressure (which is around 1 bar); this is *gauge* pressure and is often referred to as *barg* (spoken "bar gauge"). In contrast, absolute pressures are zero referenced to a complete vacuum and when expressed in bar are often referred to as *bara*. Thus, the absolute pressure of any system is the gauge pressure of the system plus atmospheric pressure. The usage of bara and barg is now deprecated, with qualification of the physical property being preferred, e.g., "The gauge pressure is 2.3 bar; the absolute pressure is 3.3 bar".

In the United States, where pressures are still often expressed in pounds per square inch (symbol *psi*), gauge pressures are referred to as *psig* and absolute pressures are referred to as *psia*. Gauge pressure is also sometimes spelled as *gage pressure*.

Sometimes, the context in which the word pressure is used helps to identify it as meaning either the absolute or gauge pressure. However, in truth, whenever a pressure is expressed in any units (bar, Pa, psi, atm, etc.), it should be denoted in some manner as being either absolute or gauge pressure to avoid any possible misunderstanding. One recommended way of doing so is to spell out what is meant, for example as *bar gauge* or *kPa absolute*.

Chapter-8

Kilogram

Kilogram

A computer-generated image of the *international prototype kilogram* (IPK). The IPK *is* the kilogram. The IPK, which is roughly the size of a golf ball, sits here alongside a ruler. The IPK is made of a platinum-iridium alloy and is stored in a vault at the International Bureau of Weights and Measures in Sèvres, France. Like the other prototypes, the edges of the IPK have a four-angle chamfer to minimize wear. For other kilogram-related images.

Unit information	
Unit system:	SI base unit
Unit of...	Mass
Symbol:	kg
Unit conversions	
1 kg in...	is equal to...
U.S. customary	$\approx$ 2.205 pounds
Natural units	$\approx$ 4.59×10^7 Planck masses $\approx 1.356392733(68) \times 10^{50}$ hertz

The **kilogram** (symbol: kg) is the base unit of mass in the International System of Units (**SI**, from the French *Système international d'unités*), which is the modern standard governing the metric system. The kilogram is defined as being equal to the mass of the *international prototype kilogram* (IPK), which is almost exactly equal to the mass of one liter of water. It is the only SI base unit with an SI prefix as part of its name. It is also the only SI unit that is still defined by an artifact, whereas all other SI units have been redefined using a fundamental physical property that can be reproduced in adequately equipped laboratories.

In everyday usage, the mass of an object is often referred to as its weight though these are in fact different concepts and quantities. In scientific contexts, mass refers to the amount of matter in an object, whereas weight refers to the force experienced by an object due to gravity once it has come to rest against another object. In other words, an object with a mass of one kilogram will weigh one kilogram on Earth, less on Mars, much more on Saturn, and nothing in space and in free fall close to planets and other objects. Throughout most of the world, force is measured with the SI unit newton and the non-SI unit kilogram-force. Similarly, the avoirdupois (or *international*) pound, used in both the imperial system and U.S. customary units, is a unit of mass and its related unit of force is the pound-force. The avoirdupois pound is defined as exactly 0.45359237 kg, making one kilogram approximately equal to 2.2046 avoirdupois pounds.

Many units in the SI system are defined relative to the kilogram, so its stability is important. After the international prototype kilogram had been found to vary in mass over time, the International Committee for Weights and Measures (known also by its French-language initials CIPM) recommended in 2005 that the kilogram be redefined in terms of a fundamental constant of nature. No final decision is expected before 2015.

Nature of mass

The chains on the swing hold all the child's weight. If one were to stand behind her at the bottom of the arc and try to stop her, one would be acting against her inertia, which arises purely from mass, not weight.

The kilogram is a unit of mass, the measurement of which corresponds to the general, everyday notion of how "heavy" something is. However, mass is actually an *inertial* property; that is, the tendency of an object to remain at constant velocity unless acted upon by an outside force. According to Sir Isaac Newton's 324-year-old laws of motion and an important formula that sprang from his work, $F = ma$, an object with a mass, *m,* of one kilogram will accelerate, *a,* at one meter per second per second (about one-tenth the acceleration due to earth's gravity) when acted upon by a force, *F,* of one newton.

While the *weight* of matter is entirely dependent upon the strength of gravity, the *mass* of matter is invariant. Accordingly, for astronauts in microgravity, no effort is required to hold objects off the cabin floor; they are "weightless". However, since objects in microgravity still retain their mass and inertia, an astronaut must exert ten times as much force to accelerate a 10-kilogram object at the same rate as a 1-kilogram object.

On earth, a common swing set can demonstrate the relationship of force, mass, and acceleration without being appreciably influenced by weight (downward force). If one were to stand behind a large adult sitting stationary in a swing and give him a strong push, the adult would accelerate relatively slowly and swing only a limited distance forwards before beginning to swing backwards. Exerting that same effort while pushing on a small child would produce much greater acceleration.

History

Early definitions

On 7 April 1795, the gram was decreed in France to be equal to "the absolute weight of a volume of water equal to the cube of the hundredth part of the meter, at the temperature of melting ice." The concept of using a specified volume of water to define a unit measure of mass was first advanced by the English philosopher John Wilkins in 1668.

Since trade and commerce typically involve items significantly more massive than one gram, and since a mass standard made of water would be inconvenient and unstable, the regulation of commerce necessitated the manufacture of a *practical realization* of the water-based definition of mass. Accordingly, a provisional mass standard was made as a single-piece, metallic artifact one thousand times more massive than the gram—the kilogram.

At the same time, work was commissioned to precisely determine the mass of a cubic decimeter (one liter) of water. Although the decreed definition of the kilogram specified water at 0 °C—its highly stable *temperature* point—the French chemist, Louis Lefèvre-Gineau and the Italian naturalist, Giovanni Fabbroni after several years of research chose to redefine the standard in 1799 to water's most stable *density* point: the temperature at which water reaches maximum density, which was measured at the time as 4 °C. They concluded that one cubic decimeter of water at its maximum density was equal to 99.9265% of the target mass of the provisional kilogram standard made four years earlier. That same year, 1799, an all-platinum kilogram prototype was fabricated with the objective that it would equal, as close as was scientifically feasible for the day, the mass of one cubic decimeter of water at 4 °C. The prototype was presented to the Archives of the Republic in June and on 10 December 1799, the prototype was formally ratified as the *kilogramme des Archives* (Kilogram of the Archives) and the kilogram was defined as being equal to its mass. This standard stood for the next ninety years.

International prototype kilogram

The Metre Convention was signed on 20 May 1875 and established the SI system, which since 1889 defines the magnitude of the kilogram to be equal to the mass of the *international prototype kilogram*, often referred to in the professional metrology world as the "IPK". The IPK is made of a platinum alloy known as "Pt-10Ir", which is 90% platinum and 10% iridium (by mass) and is machined into a right-circular cylinder

(height = diameter) of 39.17 millimeters to minimize its surface area. The addition of 10% iridium improved upon the all-platinum Kilogram of the Archives by greatly increasing hardness while still retaining platinum's many virtues: extreme resistance to oxidation, extremely high density (more than twice as dense as lead and more than 21 times as dense as water), satisfactory electrical and thermal conductivities, and low magnetic susceptibility. The IPK and its six sister copies are stored at the International Bureau of Weights and Measures (known by its French-language initials BIPM) in an environmentally monitored safe in the lower vault located in the basement of the BIPM's House of Breteuil in Sèvres on the outskirts of Paris. Three independently controlled keys are required to open the vault. Official copies of the IPK were made available to other nations to serve as their national standards. These are compared to the IPK roughly every 50 years.

The IPK is one of three cylinders made in 1879. In 1883, it was found to be indistinguishable from the mass of the Kilogram of the Archives made eighty-four years prior, and was formally ratified as *the* kilogram by the 1st CGPM in 1889.

Modern measurements of Vienna Standard Mean Ocean Water, which is pure distilled water with an isotopic composition representative of the average of the world's oceans, show it has a density of 0.999975 ±0.000001 kg/L at its point of maximum density (3.984 °C) under one standard atmosphere (760 torr) of pressure. Thus, a cubic decimeter of water at its point of maximum density is only 25 parts per million less massive than the IPK; that is to say, the 25 milligram difference shows that the scientists over 212 years ago managed to make the mass of the Kilogram of the Archives equal that of a cubic decimeter of water at 4 °C to within the mass of a single excess grain of rice.

Stability of the international prototype kilogram
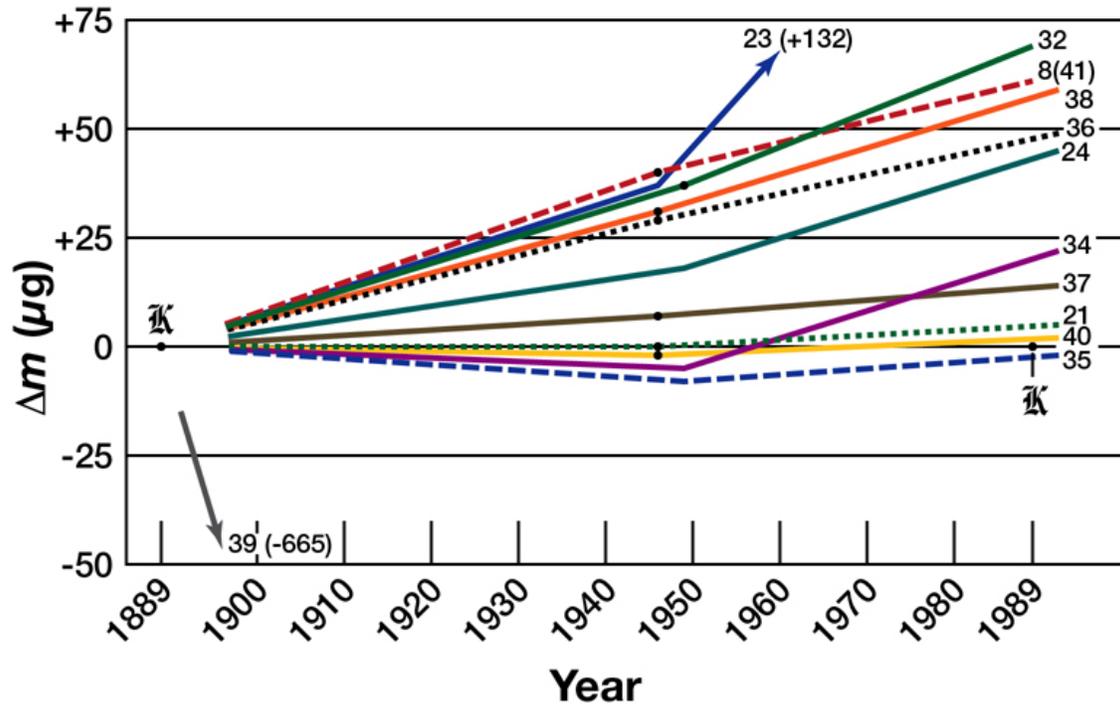
Mass drift over time of national prototypes K21–K40, plus two of the IPK's sister copies: K32 and K8(41). All mass changes are relative to the IPK. The initial 1889 starting-value offsets relative to the IPK have been nulled. The above are all *relative* measurements; no historical mass-measurement data is available to determine which of the prototypes has been most stable relative to an invariant of nature. There is the distinct possibility that *all* the prototypes gained mass over 100 years and that K21, K35, K40, and the IPK simply *gained less* than the others.

By definition, the error in the measured value of the IPK's mass is exactly zero; the IPK *is* the kilogram. However, any changes in the IPK's mass over time can be deduced by comparing its mass to that of its official copies stored throughout the world, a process called "periodic verification." For instance, the U.S. owns four 90% platinum / 10% iridium (Pt-10Ir) kilogram standards, two of which, K4 and K20, are from the original batch of 40 replicas delivered in 1884. The K20 prototype was designated as the primary national standard of mass for the U.S. Both of these, as well as those from other nations, are periodically returned to the BIPM for verification.

Note that none of the replicas has a mass precisely equal to that of the IPK; their masses are calibrated and documented as offset values. For instance, K20, the U.S.'s primary standard, originally had an official mass of 1 kg − 39 micrograms (μg) in 1889; that is to say, K20 was 39 μg less than the IPK. A verification performed in 1948 showed a mass of 1 kg − 19 μg. The latest verification performed in 1999 shows a mass precisely identical to its original 1889 value. Quite unlike transient variations such as this, the

U.S.'s check standard, K4, has persistently declined in mass relative to the IPK—and for an identifiable reason. Check standards are used much more often than primary standards and are prone to scratches and other wear. K4 was originally delivered with an official mass of 1 kg − 75 μg in 1889, but as of 1989 was officially calibrated at 1 kg − 106 μg and ten years later was 1 kg − 116 μg. Over a period of 110 years, K4 lost 41 μg relative to the IPK.

Beyond the simple wear that check standards can experience, the mass of even the carefully stored national prototypes can drift relative to the IPK for a variety of reasons, some known and some unknown. Since the IPK and its replicas are stored in air (albeit under two or more nested bell jars), they gain mass through adsorption of atmospheric contamination onto their surfaces. Accordingly, they are cleaned in a process the BIPM developed between 1939 and 1946 known as "the BIPM cleaning method" that comprises lightly rubbing with a chamois soaked in equal parts ether and ethanol, followed by steam cleaning with bi-distilled water, and allowing the prototypes to settle for 7–10 days before verification. Cleaning the prototypes removes between 5 and 60 μg of contamination depending largely on the time elapsed since the last cleaning. Further, a second cleaning can remove up to 10 μg more. After cleaning—even when they are stored under their bell jars—the IPK and its replicas immediately begin gaining mass again. The BIPM even developed a model of this gain and concluded that it averaged 1.11 μg per month for the first 3 months after cleaning and then decreased to an average of about 1 μg per year thereafter. Since check standards like K4 are not cleaned for routine calibrations of other mass standards—a precaution to minimize the potential for wear and handling damage—the BIPM's model of time-dependent mass gain has been used as an "after cleaning" correction factor.

K48, above, came from the second batch of kilogram replicas to be produced. It was delivered to Denmark in 1949 with an official mass of 1 kg $+$ 81 µg. Like all other replicas, it is stored under two nested bell jars virtually all the time. Still, its mass and that of the IPK diverged markedly in only 40 years; the mass of K48 was certified as 1 kg $+$ 112 µg during the 1988–1992 periodic verification.

Because the first forty official copies are made of the same alloy as the IPK and are stored under similar conditions, periodic verifications using a large number of replicas—especially the national primary standards, which are rarely used—can convincingly demonstrate the stability of the IPK. What has become clear after the third periodic verification performed between 1988 and 1992 is that masses of the entire worldwide ensemble of prototypes have been slowly but inexorably diverging from each other. It is also clear that the mass of the IPK lost perhaps 50 µg over the last century, and possibly

significantly more, in comparison to its official copies. The reason for this drift has eluded physicists who have dedicated their careers to the SI unit of mass. No plausible mechanism has been proposed to explain either a steady decrease in the mass of the IPK, or an increase in that of its replicas dispersed throughout the world. This *relative* nature of the changes amongst the world's kilogram prototypes is often misreported in the popular press, and even some notable scientific magazines, which often state that the IPK simply "lost 50 µg" and omit the very important caveat of *"in comparison to its official copies."* Moreover, there are no technical means available to determine whether or not the entire worldwide ensemble of prototypes suffers from even greater long-term trends upwards or downwards because their mass "relative to an invariant of nature is unknown at a level below 1000 µg over a period of 100 or even 50 years." Given the lack of data identifying which of the world's kilogram prototypes has been most stable in absolute terms, it is equally as valid to state that the first batch of replicas has, as a group, gained an average of about 25 µg over one hundred years in comparison to the IPK.

What *is* known specifically about the IPK is that it exhibits a short-term instability of about 30 µg over a period of about a month in its after-cleaned mass. The precise reason for this short-term instability is not understood but is thought to entail surface effects: microscopic differences between the prototypes' polished surfaces, possibly aggravated by hydrogen absorption due to catalysis of the volatile organic compounds that slowly deposit onto the prototypes as well as the hydrocarbon-based solvents used to clean them.

It has been possible to rule out many explanations of the observed divergences in the masses of the world's prototypes proposed by scientists and the general public. The BIPM's FAQ explains, for example, that the divergence is dependent on the amount of time elapsed between measurements and not dependent on the number of times the artifacts have been cleaned or possible changes in gravity or environment.

Scientists are seeing far greater variability in the prototypes than previously believed. The increasing divergence in the masses of the world's prototypes and the short-term instability in the IPK has prompted research into improved methods to obtain a smooth surface finish using diamond-turning on newly manufactured replicas and has intensified the search for a new definition of the kilogram.

Importance of the kilogram
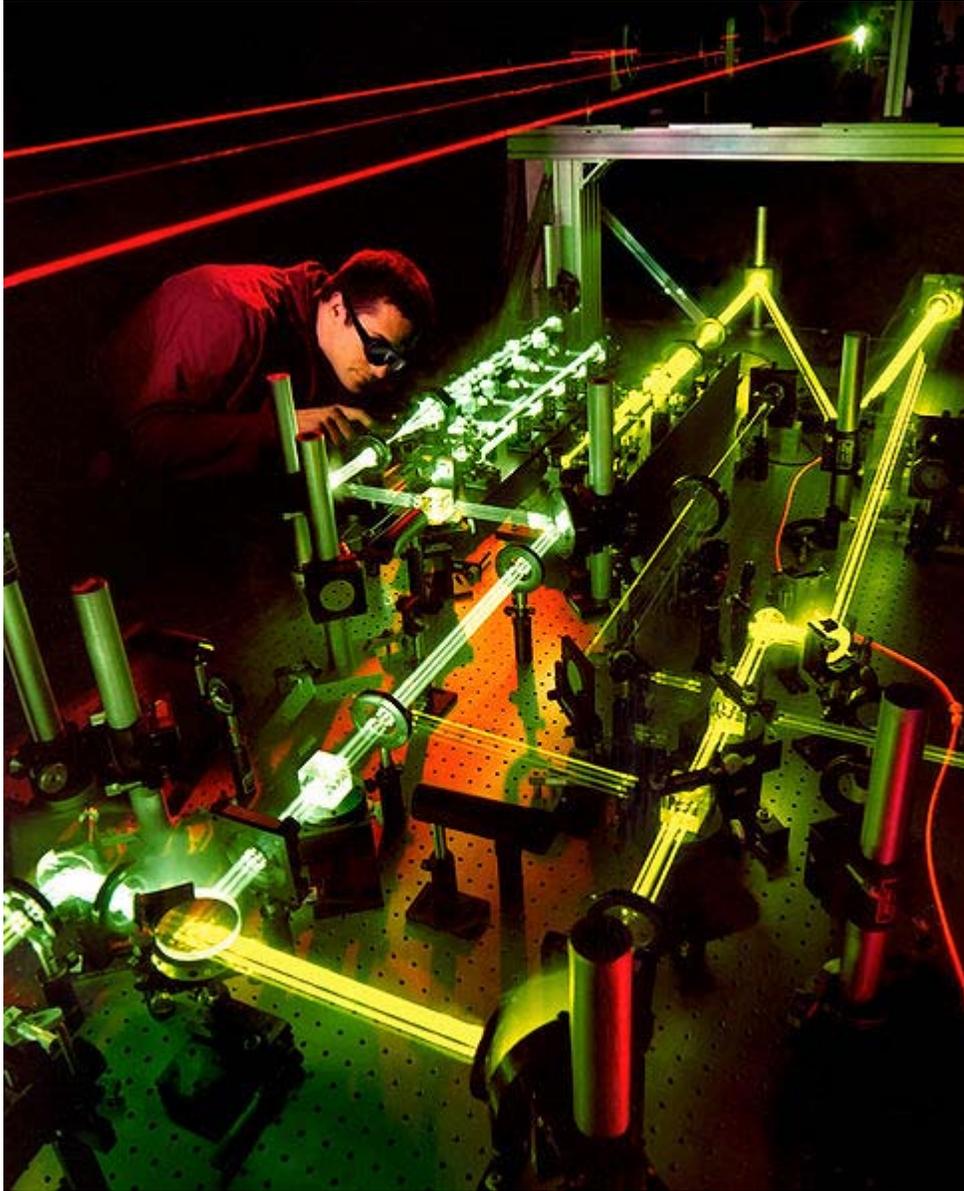
The magnitude of many of the units comprising the SI system of measurement, including most of those used in the measurement of electricity and light, are highly dependent upon the stability of a 132-year-old, golf ball-size cylinder of metal stored in a vault in France.

The stability of the IPK is crucial because the kilogram underpins much of the SI system of measurement as it is currently defined and structured. For instance, the newton is defined as the force necessary to accelerate one kilogram at one meter per second squared. If the mass of the IPK were to change slightly, so too must the newton by a proportional degree. In turn, the pascal, the SI unit of pressure, is defined in terms of the newton. This chain of dependency follows to many other SI units of measure. For instance, the joule, the SI unit of energy, is defined as that expended when a force of one newton acts through one meter. Next to be affected is the SI unit of power, the watt,

which is one joule per second. The ampere too is defined relative to the newton, and ultimately, the kilogram. With the magnitude of the primary units of electricity thus determined by the kilogram, so too follow many others; namely, the coulomb, volt, tesla, and weber. Even units used in the measure of light would be affected; the candela—following the change in the watt—would in turn affect the lumen and lux.

Because the magnitude of many of the units comprising the SI system of measurement is ultimately defined by the mass of a 132-year-old, golf ball-sized piece of metal, the quality of the IPK must be diligently protected to preserve the integrity of the SI system. Yet, in spite of the best stewardship, the average mass of the worldwide ensemble of prototypes and the mass of the IPK have likely diverged another 5.1 μg since the third periodic verification 22 years ago. Further, the world's national metrology laboratories must wait for the fourth periodic verification to confirm whether the historical trends persisted.

Fortunately, *definitions* of the SI units are quite different from their *practical realizations*. For instance, the meter is *defined* as the distance light travels in a vacuum during a time interval of $\frac{1}{299,792,458}$ of a second. However, the meter's *practical realization* typically takes the form of a helium-neon laser, and the meter's length is *delineated*—not defined—as 1,579,800.298728 wavelengths of light from this laser. Now suppose that the official measurement of the second was found to have drifted by a few parts per billion (it is actually extremely stable). There would be no automatic effect on the meter because the second—and thus the meter's length—is abstracted via the laser comprising the meter's practical realization. Scientists performing meter calibrations would simply continue to measure out the same number of laser wavelengths until an agreement was reached to do otherwise. The same is true with regard to the real-world dependency on the kilogram: if the mass of the IPK was found to have changed slightly, there would be no automatic effect upon the other units of measure because their practical realizations provide an insulating layer of abstraction. Any discrepancy would eventually have to be reconciled though because the virtue of the SI system is its precise mathematical and logical harmony amongst its units. If the IPK's value were definitively proven to have changed, one solution would be to simply redefine the kilogram as being equal to the mass of the IPK plus an offset value, similarly to what is currently done with its replicas; e.g., "the kilogram is equal to the mass of the IPK $+$ 42 parts per billion" (equivalent to 42 μg).

The long-term solution to this problem, however, is to liberate the SI system's dependency on the IPK by developing a practical realization of the kilogram that can be reproduced in different laboratories by following a written specification. The units of measure in such a practical realization would have their magnitudes precisely defined and expressed in terms of fundamental physical constants. While major portions of the SI system would still be based on the kilogram, the kilogram would in turn be based on invariant, universal constants of nature. While this is a worthwhile objective and much work towards that end is ongoing, no alternative has yet achieved the uncertainty of a couple parts in 10^8 (~20 μg) required to improve upon the IPK. However, as of April 2007, the U.S.'s National Institute of Standards and Technology (NIST) had an

implementation of the watt balance that was approaching this goal, with a demonstrated uncertainty of 36 μg.

Proposed future definitions

In the following sections, wherever numeric equalities are shown in 'concise form'—such as 1.85487(14)×1043
—the two digits between the parentheses denote the uncertainty at 1σ standard deviation (68% confidence level) in the two least significant digits of the significand.

The kilogram is the only SI unit that is still defined by an artifact. Note that the meter was also once defined as an artifact (a single platinum-iridium bar with two marks on it). However, it was eventually redefined in terms of invariant, fundamental constants of nature (the wavelength of light emitted by krypton, and later the speed of light) so that the standard can be reproduced in different laboratories by following a written specification. Today, physicists are investigating various approaches to doing the same with the kilogram.

In October 2010, the International Committee for Weights and Measures (known by its French-language initials CIPM) voted to submit a resolution for consideration at the General Conference on Weights and Measures (CGPM), to "take note of an intention" that the kilogram be defined in terms of the Planck constant, h. Such a definition would theoretically permit any apparatus that was capable of delineating the kilogram in terms of the Planck constant to be used as long as it possessed sufficient precision, accuracy and stability. The watt balance (discussed below) may be able to do this.

In getting to the threshold of replacing the last artifact that underpins much of the International System of Units (SI), a variety of other fundamentally different technologies were considered and explored over many years. Some of the approaches are fundamentally very different from each other. They too are covered below. Some of these now-abandoned approaches were based on equipment and procedures that would have enabled the reproducible production of new, kilogram-mass prototypes on demand (albeit with extraordinary effort) using measurement techniques and material properties that are ultimately based on, or traceable to, fundamental constants. Others were based on devices that measured either the acceleration or weight of hand-tuned, kilogram test masses and which expressed their magnitudes in electrical terms via special components that permit traceability to fundamental constants. All approaches depend on converting a weight measurement to a mass, and therefore require the precise measurement of the strength of gravity in laboratories. All approaches would have precisely fixed one or more constants of nature at a defined value.

The watt balance

The NIST's watt balance is a project of the U.S. Government to develop an "electronic kilogram." The vacuum chamber dome, which lowers over the entire apparatus, is visible at top.

The watt balance is essentially a single-pan weighing scale that measures the electric power necessary to oppose the weight of a kilogram test mass as it is pulled by earth's gravity. It is a variation of an ampere balance in that it employs an extra calibration step that nulls the effect of geometry. The electric potential in the watt balance is delineated by a Josephson voltage standard, which allows voltage to be linked to an invariant constant of nature with extremely high precision and stability. Its circuit resistance is calibrated against a quantum Hall resistance standard.

The watt balance requires exquisitely precise measurement of the local gravitational acceleration g in the laboratory, using a gravimeter. For instance, the NIST compensates for earth's gravity gradient of 309 μGal per meter when the elevation of the center of the gravimeter differs from that of the nearby test mass in the watt balance; a change in the weight of a one-kilogram test mass that equates to about 316 μg/m.

In April 2007, the NIST's implementation of the watt balance demonstrated a combined relative standard uncertainty (CRSU) of 36 μg and a short-term resolution of 10–15 μg. The UK's National Physical Laboratory's watt balance demonstrated a CRSU of 70.3 μg in 2007. That watt balance was disassembled and shipped in 2009 to Canada's Institute for National Measurement Standards (part of the National Research Council), where research and development with the device could continue.

If the CGPM adopts the new proposal and the new definition of the kilogram becomes part of the SI, the Planck constant (h), which is a measure that relates the energy of photons to their frequency, would be precisely fixed; for example, to $h = 6.626069 \times 10^{-34}$ J·s (from the 2006 CODATA value of $6.62606896(33) \times 10^{-34}$ J·s). Once agreed upon internationally, the kilogram would no longer be defined as the mass of the IPK. With the definition of the kilogram in terms of electric power and a frequency (the Planck constant's J·s), electric power would be directly identical to mechanical power by definition rather than being a derivative. All the remaining units in the International System of Units (the SI) that today have dependencies upon the kilogram and the joule would also fall in place, their magnitudes ultimately defined, in part, in terms of photon oscillations rather than a 132-year-old metal artifact stored in a vault.
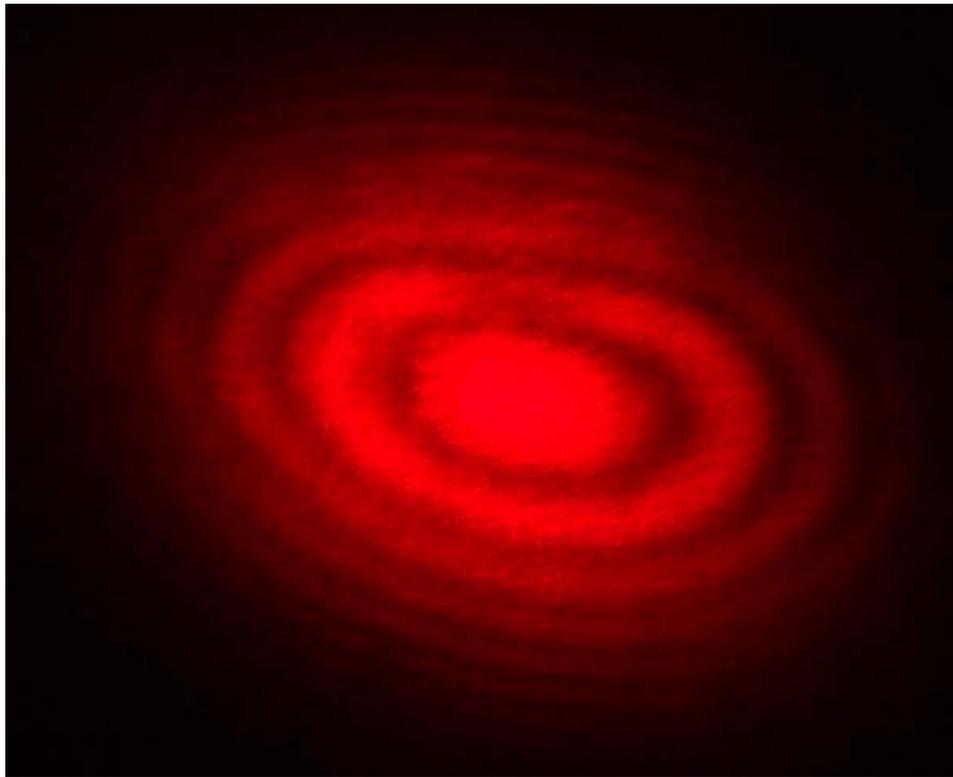
the local gravitational acceleration g is measured with exceptional precision with the help of a laser interferometer. The laser's pattern of interference fringes—the dark and light bands above—blooms at an ever faster rate as a free-falling corner reflector drops inside an absolute gravimeter. The pattern's frequency sweep is timed by an atomic clock.

Gravity and the nature of the watt balance, which oscillates test masses up and down against the local gravitational acceleration g, are exploited so that mechanical power is compared against electrical power, which is the square of voltage divided by electrical resistance. However, g varies significantly—nearly one percent—depending upon where on earth's surface the measurement is made. There are also subtle seasonal variations in g due to changes in underground water tables, and larger semimonthly and diurnal changes due to tidal distortions in the earth's shape caused by the moon. Although g would not be a term in the *definition* of the kilogram, it would be crucial in the *delineation* of the kilogram when relating energy to power. Accordingly, g must be measured with at least as much precision and accuracy as are the other terms, so measurements of g must also be traceable to fundamental constants of nature. For the most precise work in mass metrology, g is measured using dropping-mass absolute gravimeters that contain an iodine-stabilized helium–neon laser interferometer. The fringe-signal, frequency-sweep output from the interferometer is measured with a rubidium atomic clock. Since this type of dropping-mass gravimeter derives its accuracy and stability from the constancy of the speed of light as well as the innate properties of helium, neon, and rubidium atoms, the 'gravity' term in the delineation of an all-electronic kilogram is also measured in terms of invariants of nature—and with very high precision. For instance, in the basement of the NIST's Gaithersburg facility in 2009, when measuring the gravity acting upon Pt-10Ir test masses (which are denser, smaller, and have a slightly lower center of gravity inside the watt balance than stainless steel masses), the measured value was typically within 8 ppb of 9.80101644 m/s^2.

The virtue of electronic realizations like the watt balance is that the definition and dissemination of the kilogram would no longer be dependent upon the stability of kilogram prototypes, which must be very carefully handled and stored. It would free physicists from the need to rely on assumptions about the stability of those prototypes. Instead, hand-tuned, close-approximation mass standards would simply be weighed and documented as being equal to one kilogram plus an offset value. With the watt balance, while the kilogram would be *delineated* in electrical and gravity terms, all of which are traceable to invariants of nature; it would be *defined* in a manner that is directly traceable to just three fundamental constants of nature. The Planck constant defines the kilogram in terms of the second and the meter. By fixing the Planck constant, the *definition* of the kilogram would depend only on the *definitions* of the second and the meter. The definition of the second depends on a single defined physical constant: the ground state hyperfine splitting frequency of the caesium 133 atom $\Delta v(^{133}Cs)_{hfs}$. The meter depends on the second and on an additional defined physical constant: the speed of light c. If the Kilogram is redefined in this manner, mass artifacts—physical objects calibrated in a watt balance, including the IPK—would no longer be part of the definition, but would instead become *transfer standards*.

Scales like the watt balance also permit more flexibility in choosing materials with especially desirable properties for mass standards. For instance, Pt-10Ir could continue to be used so that the specific gravity of newly produced mass standards would be the same as existing national primary and check standards ($\approx$21.55 g/ml). This would reduce the relative uncertainty when making mass comparisons in air. Alternately, entirely different

materials and constructions could be explored with the objective of producing mass standards with greater stability. For instance, osmium-iridium alloys could be investigated if platinum's propensity to absorb hydrogen (due to catalysis of VOCs and hydrocarbon-based cleaning solvents) and atmospheric mercury proved to be sources of instability. Also, vapor-deposited, protective ceramic coatings like nitrides could be investigated for their suitability to isolate these new alloys.

The challenge with watt balances is not only in reducing their uncertainty, but also in making them truly *practical* realizations of the kilogram. Nearly every aspect of watt balances and their support equipment requires such extraordinarily precise and accurate, state-of-the-art technology that—unlike a device like an atomic clock—few countries would currently choose to fund their operation. For instance, the NIST's watt balance used four resistance standards in 2007, each of which was rotated through the watt balance every two to six weeks after being calibrated in a different part of NIST headquarters facility in Gaithersburg, Maryland. It was found that simply moving the resistance standards down the hall to the watt balance after calibration altered their values 10 ppb (equivalent to 10 μg) or more. Present-day technology is insufficient to permit stable operation of watt balances between even biannual calibrations. If the kilogram is defined in terms of the Planck constant, it is likely there will only be a few—at most— watt balances initially operating in the world.

Alternative approaches to redefining the kilogram that were fundamentally different from the watt balance were explored to varying degrees with some abandoned, as follows:

Atom-counting approaches

Carbon-12

Though not offering a practical realization, this definition would precisely define the magnitude of the kilogram in terms of a certain number of carbon-12 atoms. Carbon-12 (^{12}C) is an isotope of carbon. The mole is currently defined as "the quantity of entities (elementary particles like atoms or molecules) equal to the number of atoms in 12 grams of carbon-12." Thus, the current definition of the mole requires that $^{1000}/_{12}$ (83⅓) moles of ^{12}C has a mass of precisely one kilogram. The number of atoms in a mole, a quantity known as the Avogadro constant, is experimentally determined, and the current best estimate of its value is $6.02214179(30) \times 10^{23}$
entities per mole (CODATA, 2006). This new definition of the kilogram proposes to fix the Avogadro constant at precisely $6.02214179 \times 10^{23}$
with the kilogram being defined as "the mass equal to that of $^{1000}/_{12} \cdot 6.02214179 \times 10^{23}$ atoms of ^{12}C."

The accuracy of the measured value of the Avogadro constant is currently limited by the uncertainty in the value of the Planck constant—a measure relating the energy of photons to their frequency. That relative standard uncertainty has been 50 parts per billion (ppb) since 2006. By fixing the Avogadro constant, the practical effect of this proposal would be that the uncertainty in the mass of a ^{12}C atom—and the magnitude of the kilogram—

could be no better than the current 50 ppb uncertainty in the Planck constant. Under this proposal, the magnitude of the kilogram would be subject to future refinement as improved measurements of the value of the Planck constant become available; electronic realizations of the kilogram would be recalibrated as required. Conversely, an electronic *definition* of the kilogram, which would precisely fix the Planck constant, would continue to allow 83⅓ moles of ^{12}C to have a mass of precisely one kilogram but the number of atoms comprising a mole (the Avogadro constant) would continue to be subject to future refinement.

A variation on a ^{12}C-based definition proposes to define the Avogadro constant as being precisely 84,446,886^3 ($\approx 6.02214098 \times 10_{23}$
) atoms. An imaginary realization of a 12-gram mass prototype would be a cube of ^{12}C atoms measuring precisely 84,446,886 atoms across on a side. With this proposal, the kilogram would be defined as "the mass equal to 84,446,886^3 × 83⅓ atoms of ^{12}C." The value 84,446,886 was chosen because it has a special property; its cube (the proposed new value for the Avogadro constant) is evenly divisible by twelve. Thus with this definition of the kilogram, there would be an integer number of atoms in one gram of ^{12}C: 50,184,508,190,229,061,679,538 atoms.

Avogadro project

One of the master opticians at the Australian Centre for Precision Optics (ACPO) is holding a 1 kg, single-crystal silicon sphere for the Avogadro project. These spheres are among the roundest man-made objects in the world. If the best of these spheres were scaled to the size of earth, its high point—a continent-size area—would gently rise to a maximum elevation of only 2.4 meters above "sea level."

Another Avogadro constant-based approach, known as the *Avogadro project*, would define and delineate the kilogram as a softball-size (93.6 mm diameter) sphere of silicon atoms. Silicon was chosen because a commercial infrastructure with mature processes for creating defect-free, ultra-pure monocrystalline silicon already exists to service the semiconductor industry. To make a practical realization of the kilogram, a silicon boule (a rod-like, single-crystal ingot) would be produced. Its isotopic composition would be

measured with a mass spectrometer to determine its average relative atomic mass. The boule would be cut, ground, and polished into spheres. The size of a select sphere would be measured using optical interferometry to an uncertainty of about 0.3 nm on the radius—roughly a single atomic layer. The precise lattice spacing between the atoms in its crystal structure (≈192 pm) would be measured using a scanning X-ray interferometer. This permits its atomic spacing to be determined with an uncertainty of only three parts per billion. With the size of the sphere, its average atomic mass, and its atomic spacing known, the required sphere diameter can be calculated with sufficient precision and low uncertainty to enable it to be finish-polished to a target mass of one kilogram.

Experiments are being performed on the Avogadro Project's silicon spheres to determine whether their masses are most stable when stored in a vacuum, a partial vacuum, or ambient pressure. However, no technical means currently exist to prove a long-term stability any better than that of the IPK's because the most sensitive and accurate measurements of mass are made with dual-pan balances like the BIPM's FB-2 flexure-strip balance. Balances can only compare the mass of a silicon sphere to that of a reference mass. Given the latest understanding of the lack of long-term mass stability with the IPK and its replicas, there is no known, perfectly stable mass artifact to compare against. Single-pan scales, which measure weight relative to an invariant of nature, are not precise to the necessary long-term uncertainty of 10–20 parts per billion. Another issue to be overcome is that silicon oxidizes and forms a thin layer (equivalent to 5–20 silicon atoms) of silicon dioxide (quartz) and silicon monoxide. This layer slightly increases the mass of the sphere, an effect which must be accounted for when polishing the sphere to its finish dimension. Oxidation is not an issue with platinum and iridium, both of which are noble metals that are roughly as cathodic as oxygen and therefore don't oxidize unless coaxed to do so in the laboratory. The presence of the thin oxide layer on a silicon-sphere mass prototype places additional restrictions on the procedures that might be suitable to clean it to avoid changing the layer's thickness or oxide stoichiometry.

All silicon-based approaches would fix the Avogadro constant but vary in the details of the definition of the kilogram. One approach would use silicon with all three of its natural isotopes present. About 7.78% of silicon comprises the two heavier isotopes: ^{29}Si and ^{30}Si. As described in *Carbon-12* above, this method would *define* the magnitude of the kilogram in terms of a certain number of ^{12}C atoms by fixing the Avogadro constant; the silicon sphere would be the *practical realization.* This approach could accurately delineate the magnitude of the kilogram because the masses of the three silicon nuclides relative to ^{12}C are known with great precision (relative uncertainties of 1 ppb or better). An alternative method for creating a silicon sphere-based kilogram proposes to use isotopic separation techniques to enrich the silicon until it is nearly pure ^{28}Si, which has a relative atomic mass of 27.9769265325(19). With this approach, the Avogadro constant would not only be fixed, but so too would the atomic mass of ^{28}Si. As such, the definition of the kilogram would be decoupled from ^{12}C and the kilogram would instead be defined as $^{1000}/_{27.9769265325} \cdot 6.02214179 \times 1023$
atoms of ^{28}Si (≈35.74374043 fixed moles of ^{28}Si atoms). Physicists could elect to define the kilogram in terms of ^{28}Si even when kilogram prototypes are made of natural silicon (all three isotopes present). Even with a kilogram definition based on theoretically pure

[28]Si, a silicon-sphere prototype made of only nearly pure [28]Si would necessarily deviate slightly from the defined number of moles of silicon to compensate for various chemical and isotopic impurities as well as the effect of surface oxides.

Ion accumulation

Another Avogadro-based approach, ion accumulation, since abandoned, would have defined and delineated the kilogram by precisely creating new metal prototypes on demand. It would have done so by accumulating gold or bismuth ions (atoms stripped of an electron) and counted them by measuring the electrical current required to neutralize the ions. Gold ([197]Au) and bismuth ([209]Bi) were chosen because they can be safely handled and have the two highest atomic masses among the mononuclidic elements that is effectively non-radioactive (bismuth) or is perfectly stable (gold).

With a gold-based definition of the kilogram for instance, the relative atomic mass of gold could have been fixed as precisely 196.9665687, from the current value of 196.9665687(6). As with a definition based upon carbon-12, the Avogadro constant would also have been fixed. The kilogram would then have been defined as "the mass equal to that of precisely $^{1000}/_{196.9665687} \cdot 6.02214179 \times 10_{23}$ atoms of gold" (precisely 3,057,443,620,887,933,963,384,315 atoms of gold or about 5.07700371 fixed moles).

In 2003, German experiments with gold at a current of only 10 μA demonstrated a relative uncertainty of 1.5%. Follow-on experiments using bismuth ions and a current of 30 mA were expected to accumulate a mass of 30 g in six days and to have a relative uncertainty of better than 1 ppm. Ultimately, ion-accumulation approaches proved to be unsuitable. Measurements required months and the data proved too erratic for the technique to be considered a viable future replacement to the IPK.

Among the many technical challenges of the ion-deposition apparatus was obtaining a sufficiently high ion current (mass deposition rate) while simultaneously decelerating the ions so they could all deposit onto a target electrode embedded in a balance pan. Experiments with gold showed the ions had to be decelerated to very low energies to avoid sputtering effects—an phenomenon whereby ions that had already been counted ricochet off the target electrode or even dislodged atoms that had already been deposited. The deposited mass fraction in the 2003 German experiments only approached very close to 100% at ion energies of less than around 1 eV (<1 km/s for gold).

If the kilogram had been defined as a precise quantity of gold or bismuth atoms deposited with an electric current, not only would the Avogadro constant and the atomic mass of gold or bismuth have to have been precisely fixed, but also the value of the elementary charge (e), likely to 1.602176487×10−19
 C (from the present 2006 CODATA value of 1.602176487(40)×10−19
). Doing so would have effectively defined the ampere as a flow of $^{1}/_{1.602176487 \times 10-19}$ (6,241,509,647,120,417,390) electrons per second past a fixed point in an electric circuit. The SI unit of mass would have been fully defined by having precisely fixed the values of

the Avogadro constant and elementary charge, and by exploiting the fact that the atomic masses of bismuth and gold atoms are invariant, universal constants of nature.

Beyond the slowness of making a new mass standard and the poor reproducibility, there were other intrinsic shortcomings to the ion-accumulation approach that proved to be formidable obstacles to ion-accumulation-based techniques becoming a practical realization. The apparatus necessarily required that the deposition chamber have an integral balance system to enable the convenient calibration of a reasonable quantity of transfer standards relative to any single internal ion-deposited prototype. Furthermore, the mass prototypes produced by ion deposition techniques would have been nothing like the freestanding platinum-iridium prototypes currently in use; they would have been deposited onto—and become part of—an electrode imbedded into one pan of a special balance integrated into the device. Moreover, the ion-deposited mass wouldn't have had a hard, highly polished surface that can be vigorously cleaned like those of current prototypes. Gold, while dense and a noble metal (resistant to oxidation and the formation of other compounds), is extremely soft so an internal gold prototype would have to be kept well isolated and scrupulously clean to avoid contamination and the potential of wear from having to remove the contamination. Bismuth, which is an inexpensive metal used in low-temperature solders, slowly oxidizes when exposed to room-temperature air and forms other chemical compounds and so would not have produced stable reference masses unless it was continually maintained in a vacuum or inert atmosphere.

Ampere-based force

A magnet floating above a superconductor bathed in liquid nitrogen demonstrates perfect diamagnetic levitation via the Meissner effect. Experiments with an ampere-based definition of the kilogram flipped this arrangement upside-down: an electric field accelerated a superconducting test mass supported by fixed magnets.

This approach would define the kilogram as "the mass which would be accelerated at precisely 2×10^{-7} m/s^2 when subjected to the per-meter force between two straight parallel conductors of infinite length, of negligible circular cross section, placed one meter apart in vacuum, through which flow a constant current of $\frac{1}{1.602176487\times10^{-19}}$ ($\approx$6,241,509,647,120,417,390) elementary charges per second."

Effectively, this would define the kilogram as a derivative of the ampere rather than present relationship, which defines the ampere as a derivative of the kilogram. This redefinition of the kilogram would specify elementary charge (e) as precisely

1.602176487×10−19
coulomb rather than the current 2006 CODATA value of 1.602176487(40)×10−19
. Effectively, the coulomb would be the sum of 6,241,509,647,120,417,390 elementary charges. It would necessarily follow that the ampere (one coulomb per second) would also become an electrical current of this precise quantity of elementary charges per second passing a given point in an electric circuit. The virtue of a practical realization based upon this definition is that unlike the watt balance and other scale-based methods, all of which require the careful characterization of gravity in the laboratory, this method delineates the magnitude of the kilogram directly in the very terms that define the nature of mass: acceleration due to an applied force. Unfortunately, it is extremely difficult to develop a practical realization based upon accelerating masses. Experiments over a period of years in Japan with a superconducting, 30 g mass supported by diamagnetic levitation never achieved an uncertainty better than ten parts per million. Magnetic hysteresis was one of the limiting issues. Other groups performed similar research that used different techniques to levitate the mass.

SI multiples

Because SI prefixes may not be concatenated (serially linked) within the name or symbol for a unit of measure, SI prefixes are used with the *gram*, not the kilogram, which already has a prefix as part of its name. For instance, one-millionth of a kilogram is 1 mg (one milligram), not 1 μkg (one microkilogram).

SI multiples for gram (g)

Value	Symbol	Name	Value	Symbol	Name
Submultiples			**Multiples**		
10^{-1} g	dg	decigram	10^{1} g	dag	decagram
10^{-2} g	cg	centigram	10^{2} g	hg	hectogram
10^{-3} g	**mg**	**milligram**	10^{3} g	**kg**	**kilogram**
10^{-6} g	**μg**	**microgram (mcg)**	10^{6} g	Mg	megagram (tonne)
10^{-9} g	**ng**	**nanogram**	10^{9} g	Gg	gigagram
10^{-12} g	**pg**	**picogram**	10^{12} g	Tg	teragram
10^{-15} g	fg	femtogram	10^{15} g	Pg	petagram
10^{-18} g	ag	attogram	10^{18} g	Eg	exagram
10^{-21} g	zg	zeptogram	10^{21} g	Zg	zettagram
10^{-24} g	yg	yoctogram	10^{24} g	Yg	yottagram

Common prefixes are in bold face.

- When the Greek lowercase "μ" (mu) in the symbol of microgram is typographically unavailable, it is occasionally—although not properly—replaced by Latin lowercase "u".

- The microgram is often abbreviated "mcg", particularly in pharmaceutical and nutritional supplement labeling, to avoid confusion since the "µ" prefix is not well recognized outside of technical disciplines. Note however, that the *abbreviation* "mcg", is also the *symbol* for an obsolete CGS unit of measure known as the "millicentigram", which is equal to 10 µg.
- The unit name "megagram" is rarely used, and even then, typically only in technical fields in contexts where especially rigorous consistency with the units of measure is desired. For most purposes, the unit "tonne" is instead used. The tonne and its symbol, t, were adopted by the CIPM in 1879. It is a non-SI unit accepted by the BIPM for use with the SI. According to the BIPM, "In English speaking countries this unit is usually called 'metric ton'." Note also that the unit name "megatonne" or "megaton" (Mt) is often used in general-interest literature on greenhouse gas emissions whereas the equivalent value in scientific papers on the subject is often the "teragram" (Tg).

Glossary

- **Abstracted**: Isolated and its effect changed in form, often simplified or made more accessible in the process.
- **Artifact**: A simple human-made object used directly as a comparative standard in the measurement of a physical quantity.
- **Check standard**:
    1. A standard body's backup replica of the international prototype kilogram (IPK).
    2. A secondary kilogram mass standard used as a stand-in for the primary standard during routine calibrations.
- **Definition**: A formal, specific, and exact specification.
- **Delineation**: The physical means used to mark a boundary or express the magnitude of an entity.
- **Disseminate**: To widely distribute the magnitude of a unit of measure, typically via replicas and transfer standards.
- **IPK**: Abbreviation of "international prototype kilogram" (CG image), *the* mass artifact in France internationally recognized as having the defining mass of precisely one kilogram.
- **Magnitude**: The extent or numeric value of a property
- **National prototype**: A replica of the IPK possessed by a nation.
- **Practical realization**: A readily reproducible apparatus to conveniently delineate the magnitude of a unit of measure.
- **Primary national standard**:
    1. A replica of the IPK possessed by a nation
    2. The least used replica of the IPK when a nation possesses more than one.
- **Prototype**:
    1. A human-made object that serves as the defining comparative standard in the measurement of a physical quantity.
    2. A human-made object that serves as *the* comparative standard in the measurement of a physical quantity.

3. The IPK and any of its replicas

- **Replica**: An official copy of the IPK.
- **Sister copy**: One of six official copies of the IPK that are stored in the same safe as the IPK and are used as check standards by the BIPM.
- **Transfer standard**: An artifact or apparatus that reproduces the magnitude of a unit of measure in a different, usually more practical, form.

Chapter-9

Ton and Tonne

Ton

The **ton** is a unit of measure. It has a long history and has acquired a number of meanings and uses over the years. It is used principally as a unit of weight, and as a unit of volume. It can also be used as a measure of energy, for truck classification, or as a colloquial term.

It is derived from the *tun*, the term applied to a barrel of the largest size. This could contain a volume between 210 and 256 gallons (800 to 1000 L), which could weigh around 2,000 pounds (900 kg) and occupy some 60 cubic feet (1700 L) of space.

In the United Kingdom, the ton is a unit of measure which, when it ceased to be legal for trade in 1985, was defined in British legislation as being a weight or mass equal to 2,240 pounds (1,016 kg) (avoirdupois pounds). In the United States and Canada, however, a ton is defined to be 2,000 pounds (907 kg). To avoid confusion, the former is more specifically referred to as a "long ton" and the latter, a "short ton"; neither should be confused with the *metric ton* (tonne), which is 1,000 kilograms (2,205 lb). While they do vary, a ton is generally one of the heaviest units of weight or mass referred to in colloquial speech.

The term "ton" is also used to refer to a number of units of *volume*, ranging from 35 to 100 cu ft (around 1000 to 2800 L) in capacity.

It can also be used as a unit of *energy*, expressed as an equivalent of coal burnt, TNT detonated, or in refrigeration, ice melted.

Units of mass/weight

There are several similar units of mass or volume called the **ton**:

Full name(s)	Common name	Quantity	Notes

long ton, weight ton, gross ton	"ton" (UK)	2,240 lb (1,016.047 kg)	Used in countries such as the United Kingdom that formerly used the Imperial system
short ton, net ton	"ton" (US)	2,000 lb (907.1847 kg)	Used in North America
metric ton, tonne	"tonne" or "metric ton"	1,000 kg (2,204.623 lb)	In the UK, Canada, Australia, and other areas that had used the Imperial system, the metric ton is the form of ton legal in trade. Conveniently, it is less than 2% different from the long ton.
ton shortweight		2240 lb	Used in the iron industry in the 17th and 18th centuries.
ton longweight		2400 lb	Used in the iron industry in the 17th and 18th centuries.

Note 1: The longweight and shortweight tons were used as a means of making an allowance for wastage in an industrial process. The workman is provided with a longweight ton and is expected to return a shortweight ton of processed product. These measures were particulary used in the operation of hammering iron blooms into shape. Note 2: In other industries, a different longweight ton might be used. Coal miners delivered coal to the surface in longweight tons but were paid only for a shortweight ton. This was supposedly to allow for "dirt" (non-coal rocks) in the output. Mine owners, however, were free to set the value of the longweight ton at a value of their own choosing, and in at least some cases, it was set to 25 cwt (2800 lb) compared to the 20 cwt shortweight ton. This was a source of discontent amongst the miners who saw the practice as unfairly in favour of the mine owners.
Others

- The long ton is used for petroleum products such as aviation fuel.
- **Deadweight ton** (abbreviation 'DWT' or 'dwt') is a measure of a ship's carrying capacity, including bunker oil, fresh water, ballast water, crew and provisions. It is expressed in tonnes (1000 kg) or long tons (2240 pounds, about 1016 kg). This measurement is also used in the U.S. tonnage of naval ships.
- Increasingly, tonnes are being used rather than long tons in measuring the displacement of ships.
- **Harbour ton** used in South Africa in the 20th century, 2000 pounds or one short ton.

Both the long ton and the short ton are composed of 20 hundredweight, being 112 and 100 pounds respectively. Prior to the 15th century in England, the ton was composed of 20 hundredweight, each of 108 lb, giving a ton of 2,160 pounds (980 kg).

Assay ton (abbreviation 'AT') is not a unit of measurement, but a standard quantity used in assaying ores of precious metals; it is $29\frac{1}{6}$ grams (short assay ton) or $32\frac{2}{3}$ grams (long assay ton), the amount which bears the same ratio to a milligram as a short or long

ton bears to a troy ounce. In other words, the number of milligrams of a particular metal found in a sample of this size gives the number of troy ounces contained in a short or long ton of ore.

In documents that predate 1960 the word *ton* is sometimes spelled *tonne*, but in more recent documents *tonne* refers exclusively to the metric ton.

In nuclear power plants **tHM** and **MTHM** mean tonnes of heavy metals, and MTU means tonnes of uranium. In the steel industry, the abbreviation **THM** means 'tons/tonnes hot metal', which refers to the amount of liquid iron or steel that is produced, particularly in the context of blast furnace production or specific consumption.

A **dry ton** or **dry tonne** has the same mass value, but the material (sludge, slurries, compost, and similar mixtures in which solid material is soaked with or suspended in water) has been dried to a relatively low, consistent moisture level (dry weight). If the material is in its natural, wet state, it is called a **wet ton** or **wet tonne**.

Units of volume

The **displacement ton** is a unit of volume used for calculating the displacement of a ship. While displacement is a measure of a ships weight, being the volume of water displaced multiplied by its density and measured in long tons (**tons displacement**), the displacement ton is the standard volume of water representing one ton displacement. It equates to 35 cubic feet (0.9911 m^3) of sea water at average density, being slightly less than the 224 imperial gallons, of the **water ton** (*qv*). It is usually abbreviated as **DT**.

One **measurement ton** or **freight ton** is equal to 40 cubic feet (1.133 m^3), but historically it has had several informal definitions. It is sometimes abbreviated as "MTON". The freight ton represents the volume of a truck, train or other freight carrier. In the past it has been used for a cargo ship but the register ton is now preferred. It is correctly abbreviated as "FT" but some users are now using freight ton to represent a weight of 1 tonne (1,000 kg; 2,205 lb), thus the more common abbreviations are now **M/T**, **MT**, or **MTON** (for measurement ton), which still cause it to be confused with the tonne, or even the megatonne.

The **register ton** is a unit of volume used for the cargo capacity of a ship, defined as 100 cubic feet (2.832 m^3). It is often abbreviated **RT** or **GRT** for **gross registered ton** (The former providing confusion with the refrigeration ton). It is known as a *tonneau de mer* in Belgium, but, in France, a *tonneau de mer* is 1.44 cubic metres (50.85 cu ft).

The **Panama Canal/Universal Measurement System (PC/UMS)** is based on net tonnage, modified for Panama Canal billing purposes. PC/UMS is based on a mathematical formula to calculate a vessel's total volume; a **PC/UMS net ton** is equivalent to 100 cubic feet of capacity.

The **water ton** was formerly used in Great Britain and is equal to 224 imperial gallons (35.96 cu ft; 1.018 m^3), the volume occupied by a mass of 1 long ton (2,240 lb; 1,016 kg) under the conditions that define 1 imperial gallon (1.201 US gal; 4.546 L).

Units of energy and power

Ton of TNT

- A **ton of TNT** or *tonne of TNT* is a unit of energy equal to 10^9 (thermochemical) calories, also known as a gigacalorie (Gcal), equal to 4.184 gigajoules (GJ).
- A **kiloton of TNT** or *kilotonne of TNT* is a unit of energy equal to 10^{12} calories, also known as a teracalorie (Tcal), equal to 4.184 terajoules (TJ).
- A **megaton of TNT** (1,000,000 metric tonnes) or *megatonne of TNT* is a unit of energy equal to 10^{15} calories, also known (infrequently) as a petacalorie (Pcal), equal to 4.184 petajoules (PJ).

Note that these are small calories (cal). The dietary calorie (Cal) is distinct and equal to one kilocalorie (Kcal), and is gradually being replaced by the latter correct term.

Early values for the explosive energy released by trinitrotoluene (TNT) ranged from 900 to 1100 calories per gram. In order to standardise the use of the term *TNT* as a unit of energy, an arbitrary value was assigned based on 1000 calories (1 kcal or 4.184 kJ) per gram. Thus there is no longer a direct connection to the chemical TNT itself. It is now merely a unit of energy that happens to be expressed using words normally associated with mass (e.g., kilogram, tonne, pound). The definition applies for both spellings: *ton of TNT* and *tonne of TNT*.

Measurements in tons of TNT have been used primarily to express nuclear weapon yields, though they have also been used since in seismology as well.

Ton of coal equivalent

- A **ton of coal equivalent** or *tonne of coal equivalent* (TCE), a conventional value of 7 Gcal (IT) = 29.3076 GJ.

Refrigeration

The unit *ton* is used in refrigeration and air conditioning to measure heat absorption. Prior to the introduction of mechanical refrigeration, cooling was accomplished by delivering ice. Installing one ton of refrigeration replaced the daily delivery of one ton of ice.

- In North America, a **standard ton of refrigeration** is 12,000 BTU/h (3,517 W). "The heat absorption per day is approximately the heat of fusion of 1 *ton* of ice at 32 °F (0 °C)." This is approximately the power required to melt one short ton (2,000 lb or 907 kg) of ice at 0 °C (32 °F) in 24 hours, thus representing the delivery of 1 ton of ice per day.

- A less common usage is the power required to cool 1 long ton (2,240 lb or 1,016 kg) of water by 1 °F (0.556 °C) every 10 minutes = 13,440 BTU/h ≈ 3939 W.

A Refrigeration Ton should be regarded as power produced by a chiller when operating in standard ARI conditions, which are typically 44 °F (7 °C) for chilled water unit, and 95 °F (35 °C) air entering the condenser. This is commonly referred to as "true ton". Manufacturers can also provide tables for chillers operating at other chilled water temperature conditions (as 65 °F or 18 °C) which can show more favorable data, which are not valid when making performance comparisons among units unless conversion rates are applied.

The refrigeration ton is commonly abbreviated as **RT**.

Informal tons

- **Ton** is also used informally, often as slang, to mean a large amount of something (material or not), for example, "Man, I just ate a ton of french fries back there".
- In Britain, a ton is colloquially used to refer to 100 of a given unit. Ton can thus refer to a speed of 100 miles per hour, and in this instance is always prefixed by the definite article, e.g. "Lee was doing the ton down the motorway"; to money e.g. "How much did you pay for that?" "A ton" (£100); to 100 points in a game e.g. "Eric just threw a ton in our darts game" (in some games, e.g. cricket, more commonly called a century); or to a hundred of pretty much anything else.

Tonne

The **tonne** (unit symbol **t**) or **metric ton** (U.S.), often written tautologously as **metric tonne**, is a unit of mass equal to 1,000 kg (2,204.62 lb) or approximately the mass of one cubic metre of water at four degrees Celsius. It is sometimes abbreviated to *mt* in the United States, although this conflicts with other SI symbols. The tonne is not a unit in the International System of Units (SI), but is accepted for use with the SI. In SI units and prefixes, the tonne is a **megagram** (**Mg**). The spelling *tonne* pre-dates the introduction of the SI in 1960; it has been used with this meaning in France since 1842 (when there were no metric prefixes for multiples of 10^6 and above), and is now used as the standard spelling for the metric mass measurement in most English-speaking countries. In the United States, the unit was originally referred to using the French words *millier* or *tonneau*, but these terms are now obsolete. The Imperial and US customary units comparable to the tonne are both spelled *ton* in English, though they differ in mass. Pronunciation of tonne (the word used in the UK) and ton is usually identical.

Derived units

Multiple	Name	Symbol	Multiple (SI)	Name	Symbol
10^0	tonne	t	10^6	megagram	Mg
10^3	kilotonne	kt	10^9	gigagram	Gg
10^6	megatonne	Mt	10^{12}	teragram	Tg
10^9	gigatonne	Gt	10^{15}	petagram	Pg
10^{12}	teratonne	Tt	10^{18}	exagram	Eg
10^{15}	petatonne	Pt	10^{21}	zettagram	Zg
10^{18}	exatonne	Et	10^{24}	yottagram	Yg

Origin

Ton and *tonne* are both derived from a Germanic word in general use in the North Sea area since the Middle Ages (cf. Old English and Old Frisian *tunne*, Old High German and Medieval Latin *tunna*, German and French *tonne*) to designate a large cask, or *tun*. A full tun, standing about a metre high, could easily weigh a tonne. The old English wine cask volume measurement known as a tun is close to a metric tonne in weight as it defines about 954 litres which for many commonly used liquids (aqueous solutions) approximates to as many kilograms.

Conversions

One tonne is equivalent to:

- One megagram (exactly);
    - This is the official SI term, but generally not used in industry or shipping, nor colloquially
- $\frac{1000}{0.453\ 592\ 37}$ pounds (exactly by definition), giving approximately
    - 2205 lb (to four significant digits)
- 98.42% of a long ton
    - One long ton (2,240 lb) is 101.605% of a tonne
- 110.23% of a short ton
    - One short ton (2,000 lb) is 90.72% of a tonne

Explanation

The unit symbol for the tonne is *t*. *T* and *mT* and *mt* (especially in the combination *mmt* for *million metric tons* compare to Mt for megatonne) are also occasionally used, but all of these are deprecated since they conflict with internationally agreed SI symbols. (T is the SI symbol for the tesla and m is SI prefix 'milli', meaning 0.001.) *Te* is also sometimes used, particularly in the offshore and nuclear industries.

In France and the English-speaking countries that are predominantly metric, the spelling *tonne* is widespread. This is generally true in Britain; however, the ton used prior to

metrication was the long ton of 2,240 pounds (1,016 kg) and this is so close to the tonne that some people draw little distinction and continue to use the old spelling. For example, even the Guinness Book of World Records accepts metrication without marking this by changing the spelling. For the United States, *metric ton* is the name for this unit used and recommended by NIST. In the U.S. an unqualified mention of a ton almost invariably refers to a short ton of 2,000 pounds (907 kg).

Like the gram and the kilogram, the tonne gave rise to a (now obsolete) force unit of the same name, the tonne-force, equivalent to about 9.8 kilonewtons: a unit also often called simply "tonne" or "metric ton" without identifying it as a unit of force. Note that it is only the tonne as a unit of mass (an exact decimal multiple of the SI unit of mass, the kilogram) which is accepted for use with SI: the tonne-force or metric ton-force is not acceptable for use with SI, partly because it is not an exact multiple of the SI unit of force, the newton.

Use of mass as proxy for energy

The *tonne of trinitrotoluene (TNT)* is used as a proxy for energy, usually of explosions (TNT is a common high explosive). Prefixes are used: kiloton(ne), megaton(ne), gigaton(ne), especially for expressing nuclear weapon yield, based on a specific combustion energy of TNT of about 4.2 MJ/kg (or one thermochemical calorie per milligram). Hence, 1 kt TNT = 4.2 TJ, 1 Mt TNT = 4.2 PJ.

The SI unit of energy is the joule. Assuming that a TNT explosion releases 1,000 small (thermochemical) calories per gram (4.2 kJ/g), one tonne of TNT is equivalent to 4.2 gigajoules.

Alternate usage

A metric ton unit (MTU) can mean 10 kilograms (22 lb) within metal (e.g. tungsten, manganese) trading, particularly within the USA. It traditionally referred to a metric ton of ore containing 1% (i.e. 10 kg) of metal.

In the case of uranium, the acronym *MTU* is sometimes considered to be *metric ton of uranium*, meaning 1,000 kg.

Ounce and Grain

Ounce

The **ounce** (abbreviated: **oz**, the old Italian word *onza*, now spelled *oncia*; apothecary symbol: ℥) is a unit of mass with several definitions, the most commonly used of which are equal to approximately 28 grams. The ounce is used in a number of different systems, including various systems of mass that form part of the imperial and United States customary systems. Its size can vary from system to system. The most commonly used ounces today are the international avoirdupois ounce and the international troy ounce.

Etymology

Ounce derives from Latin *uncia*, a unit that was one twelfth (1/12) of the Roman pound (*libra*). *Ounce* was borrowed twice: first into Old English as *ynsan* or *yndsan* from an unattested Vulgar Latin form with *ts* for *c* before *i* (palatalization) and second into Middle English through Anglo-Norman and Middle French (*unce*, *once*, *ounce*).

Inch comes from the same Latin word, but is different because it was borrowed into Old English and underwent i-mutation or umlaut ($u \to y$) and palatalization ($k \to ch$).

Definitions

Historically, in different parts of the world, at different points in time, and for different, the ounce (or its translation) has referred to broadly similar but different standards of mass.

Summary of ounce units

ounce variant	equivalent in grams	equivalent in grains
International avoirdupois ounce	28.3495231	437.5
International troy ounce Apothecaries' ounce	31.1034768	480

Maria Theresa ounce	28.0668
Spanish ounce	28.75
Dutch metric ounce	100
Chinese metric ounce	50

International avoirdupois ounce

The avoirdupois ounce is the most commonly used ounce today. It is defined to be one sixteenth of an avoirdupois pound. The avoirdupois pound is defined as 7000 grains; one ounce is therefore equal to 437.5 grains.

In 1958 the United States and countries of the Commonwealth of Nations agreed to define the international avoirdupois ounce to be exactly $^{0.45359237}/_{16}$ kg (28.349523125 g) by definition.

The ounce is commonly used as a unit of mass in the United States.

On January 1, 2000, it ceased to be a legal unit of measure within the United Kingdom for economic, health, safety or administrative purposes but remains a familiar unit, especially amongst older people.

International troy ounce

A troy ounce (abbreviated as t oz) is equal to 480 grains. Consequently, the **international troy ounce** is equal to exactly 31.1034768 grams. There are 12 troy ounces in the now obsolete troy pound.

Today, the troy ounce is used only to express the mass of precious metals such as gold, platinum, palladium or silver. Bullion coins are the most common products produced and marketed in troy ounces, but precious metal bars also exist in gram and kilogram(kg) sizes. (A kilogram bullion bar contains 32.15074657 troy ounces.)

For historical measurement of gold,

- a **fine ounce** is a troy ounce of 99.5% (".995") pure gold
- a **standard ounce** is a troy ounce of 22 carat gold, 91.66% pure (11 "fine ounces" plus one ounce of alloy material)
- in modern day, an **ounce of gold** (1 troy ounce) is referred as a 99.99% pure gold piece or gold grains (gold shot)

Apothecaries' ounce

The obsolete apothecaries' ounce (abbreviated ℥) equivalent to the troy ounce, was formerly used by apothecaries (now called pharmacists or chemists).

Maria Theresa ounce

"Maria Theresa ounce" was once introduced in Ethiopia and some European countries, which was equal to the weight of one Maria Theresa thaler, or 28.0668 g. Both the weight and the value are the definition of one "Birr", still in use in present-day Ethiopia and formerly in Eritrea.

Spanish ounce

The Spanish pound (Spanish *libra*) was 460 g. The Spanish ounce (Spanish *onza*) was $\frac{1}{16}$ of a pound, i.e. 28.75 g.

Metric ounces

Some countries have redefined their ounces in the metric system.

In 1820, the Dutch have redefined their ounce (in Dutch, *ons*) as 100 grams. Dutch amendments to the metric system, such as an *ons* of 100 grams, has been inherited, adopted, and taught in Indonesia beginning in elementary school. It is also listed as standard usage in Indonesia's national dictionary, the *Kamus Besar Bahasa Indonesia*, and the government's official elementary‐school curriculum.

East Asia has a traditional ounce, known as a tael, of varying value. In China, it has been given a metric value of 50 grams.

Ounce-force

An ounce force is 1/16 of a pound-force, or 0.2780139 newton. It is not necessary to identify it as an avoirdupois ounce; there is no troy ounce-force.

Fluid Ounce

A fluid ounce (abbreviated fl oz, fl. oz. or oz. fl.) is a unit of volume equal to about 28 ml in the imperial system or 30 ml in the US system. The fluid ounce is sometimes referred to simply as an "ounce" in applications where its use is implicit. The imperial fluid ounce is also equivalent to the volume occupied by 1 imperial ounce of water weighed in air at 62°F.

Other uses

Fabric weight

Ounces are also used to express the "weight", or more accurately density, of a textile fabric in North America, Asia or the UK, as in "*16 oz denim*". The number refers to the

weight in ounces of a given amount of fabric, either a yard of a given width, or a square yard.

Grain

The small golden disk close to the 5cm marker is a piece of pure gold weighing one troy grain. Shown for comparison are a tape measure and coins of major world currencies.

A **grain** is a unit of measurement of mass that is based upon the mass of a single seed of a cereal. In medieval times the average masses of wheat and barley grain were used to define units of mass, with the troy grain based on barley. The grain is the only unit of mass measure common to the three traditional English mass and weight systems (avoirdupois, Apothecaries', troy); the obsolete Tower grain was lighter than the troy grain.

Since 1958, the **grain** or **troy grain** (Symbol: **gr**) measure has been defined in terms of units of mass in the International System of Units as precisely 64.79891 milligrams. However, the measure for pearls and diamonds - the **pearl grain** and the **metric grain** - are equal to $\frac{1}{4}$ of a (metric) carat, i.e. 50 mg (0.77 gr).

There are precisely 7,000 grains per avoirdupois pound in the Imperial and U.S. customary units, and 5,760 grains in the Troy pound.

Usage in North America

A box of .38 Special cartridges that have 148-grain bullets

The grain is used to measure the mass of bullets, gunpowder, smokeless powder, and preformed gold foil; it is the measure used by the balances used in handloading; bullets are measured in increments of one grain, gunpowder in increments of 0.1 grains. Moreover, the grain is used to weigh fencing equipment, including the foil. In archery, the grain is used to weigh arrows and arrow parts.

The grain is the most common unit used to measure the hardness of water. In particular it is used to quantitively describe the abundance of calcium Ca^{2+} and magnesium Mg^{2+} minerals in water. Typically, the measure is noted in Grains per Gallon (GPG). Water, untreated, typically can measure up to 100 gpg. This measure is critical to setting accurately the resin cation bead regeneration cycle periodicity of both sodium chloride brine and potassium chloride brine flushed water softeners.

The 5-grain aspirin. The back of a bottle of aspirin indicates that the dosage is "325 mg (5 gr)".

Grains are still used occasionally in medicine in the United States, especially in medical prescriptions, usually via the abbreviation "gr." For example, a regular tablet of aspirin is sometimes referred to as "five grain aspirin," or 325 mg. Grains are commonly used for medications that have been included in the United States Pharmacopeia for many decades, such as codeine, opium and phenobarbital combinations. For example, a prescription for tablets containing 325 mg of aspirin and 30 mg of codeine (brand name is Empirin with codeine), is written thus: "ASA gr. v c cod. gr. ss tablets," where "ASA" is short for aspirin (**A**cetyl**S**alicylic **A**cid), "v" is the roman numeral for five, "c" is the abbreviation for "with" and "ss" stands for one-half. Likewise, a prescription for B&O Supprettes #15A, which is a compound medication containing belladonna alkaloids and opium, may be written: "Belladonna gr. 1/4 c opium gr ss", as B&O Supprettes #15A contain 16.2 mg (1/4 grain) of powdered belladonna and 30 mg (1/2 grain) of opium. Similarly, a prescription for 60 mg (1 grain) of phenobarbital is often written: "Phenobarb. gr. i". Formulations of these older medications (e.g., Donnatal, Phenobarbital, etc.), often use grains on the product label along with the metric equivalent. For example, Extended-Release Donnatal tablets contain $\frac{3}{4}$ grain (approximately 48.6 mg) of phenobarbital. Given the potential error in mistaking the abbreviations for "grains" and "grams" (gr and g, respectively), and for consistency with other medical orders, metric units are preferred to avoirdupois or apothecary units; hence, the use of grains in the medical profession is rapidly becoming outmoded.
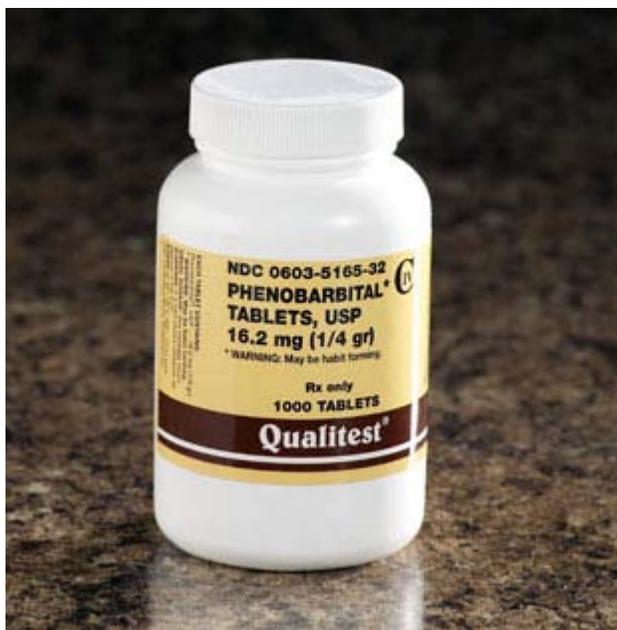
Bottle of 1/4 grain phenobarbital tablets

Grains are also used in environmental permitting to quantify particulate emissions. Grains are used to measure the amount of moisture per cubic foot of air, a measure of absolute humidity.

History

carob seed ~200 mg

barley grain ~65 mg

wheat grain ~50 mg

At least since antiquity, grains of wheat or barley were used by Mediterranean traders to define units of mass; along with other seeds, especially those of the carob tree. According to a longstanding tradition, 1 carat (the mass of a carob seed) was equivalent to the weight of 4 wheat grains or 3 barleycorns. But since the weights of these seeds are highly variable, especially that of the cereals as a function of moisture, this is a convention more than an absolute law.

The history of the modern troy grain can be traced back to a royal decree in 13th century England:

By consent of the whole Realm the King's Measure was made, so that an English Penny, which is called the Sterling, round without clipping, shall weigh Thirty-two Grains of Wheat dry in the midst of the Ear; Twenty-pence make an Ounce; and Twelve Ounces make a Pound.
—Henry III of England

The traditional reading of this text is that it refers to the troy pound, and that the reference to sterling pennies is purely symbolic. According to a more recent reading, however, the pound in question is the Tower pound, and it talks about the actual mass of real sterling pennies. The Tower pound, abolished in 1527, consisted of 12 ounces like the troy pound, but was $\frac{1}{16}$ lighter. In any case, with both readings one needs to substitute 24 barley grains for the 32 wheat grains of the text, according to the general convention of a 4:3 equivalence, for it to make sense. The weight of the original sterling pennies was 22½ troy grains, or 24 "Tower grains" if the Tower pound was divided in the same way as the troy pound. Regardless of which pound this text originally referred to, a (troy) ounce still equals 20×24 = 480(troy) grains, and a pound consists of 12×20×24 = 5760 grains.

Originally the troy pound was only "the pound of Pence, Spices, Confections, as of Electuaries", and the merchants used different standards, which had to be compatible with those used abroad. One such standard, the avoirdupois pound, was later fixed officially at exactly 7000 troy grains. It consists of 16 avoirdupois ounces of 437½ troy grains each.

Chapter-11

Pound

The **pound** or **pound-mass** (abbreviations:**lb**, **lb$_m$**, **lbm**) is a unit of mass used in the imperial, United States customary and other systems of measurement. A number of different definitions have been used, the most common today being the international avoirdupois pound which is legally defined as exactly 0.45359237 kilograms.

The unit is descended from the Roman *libra* (hence the abbreviation "lb"); the name *pound* is a Germanic adaptation of the Latin phrase *libra pondo*, 'a pound weight'.

Usage of the unqualified term *pound* reflects the historical conflation of mass and weight resulting from the near uniformity of gravity on Earth. This accounts for the modern distinguishing terms *pound-mass* and *pound-force*.

Definitions

Historically, in different parts of the world, at different points in time, and for different applications, the pound (or its translation) has referred to broadly similar but not identical standards of mass or force.

British pounds

A number of different definitions of the pound have been used in Britain. Amongst these are the avoirdupois pound and the obsolete tower, merchant's and London pounds. The weight of precious metals when given in pounds and/or ounces usually assumes Troy pounds and ounces; these units are not otherwise used today.

Historically the pound sterling was a tower pound of silver. In 1528 the standard was changed to the Troy pound.

English pounds

Unit	Pounds						Ounces			Grains	Metric	
	avdp.	troy	tower	merc.	lond.	metric	avdp.	troy	tower		g	kg
Avoirdupois	1	$^{175}/_{144}$	$^{35}/_{27}$	$^{28}/_{27}$	$^{35}/_{36}$	$^{10}/_{11}$	**16**	$14\,^{7}/_{12}$	$15\,^{5}/_{9}$	7000	454	$^{9}/_{20}$
Troy	$^{144}/_{175}$	1	$^{16}/_{15}$	$^{64}/_{75}$	$^{4}/_{5}$	$^{3}/_{4}$	$13\,^{29}/_{175}$	**12**	$12\,^{4}/_{5}$	5760	373	$^{3}/_{8}$
Tower	$^{27}/_{35}$	$^{15}/_{16}$	1	$^{4}/_{5}$	$^{3}/_{4}$	$^{7}/_{10}$	$12\,^{12}/_{35}$	$11\,^{1}/_{4}$	**12**	5400	350	$^{7}/_{20}$
Merchant	$^{27}/_{28}$	$^{75}/_{64}$	$^{5}/_{4}$	1	$^{15}/_{16}$	$^{7}/_{8}$	$15\,^{3}/_{7}$	$14\,^{1}/_{16}$	15	6750	437	$^{7}/_{16}$
London	$^{36}/_{35}$	$^{5}/_{4}$	$^{4}/_{3}$	$^{16}/_{15}$	1	$^{14}/_{15}$	$16\,^{16}/_{35}$	15	16	7200	467	$^{7}/_{15}$
Metric	$^{11}/_{10}$	$^{4}/_{3}$	$^{10}/_{7}$	$^{8}/_{7}$	$^{15}/_{14}$	1	$17\,^{3}/_{5}$	16	$17\,^{1}/_{7}$	7716	500	$^{1}/_{2}$

1. ^ English-metric ratios (in grey) are approximate.

Avoirdupois pound

The avoirdupois pound was invented by London merchants in 1303. Originally it was based on independent standards. During the reign of Henry VIII of England, the avoirdupois pound was redefined as 7,000 troy grains. Since then, the grain has often been considered as a part of the avoirdupois system. By 1758, two standard weights for the avoirdupois pound existed, and when measured in troy grains they were found to be of 7,002 grains and 6,999 grains.

Imperial Standard Pound

In the United Kingdom, weights and measures have been defined by a long series of Acts of Parliament, the intention of which has been to regulate the sale of commodities. Materials traded in the marketplace must be quantified according to accepted units and standards in order to avoid fraud; the standards themselves must be legally defined so as to facilitate the resolution of disputes brought to the courts; only legally defined measures will be recognised by the courts. Quantifying devices used by traders (weights, weighing machines, containers of volumes, measures of length) are subject to official inspection, and penalties apply if they are fraudulent. The Weights and Measures Act of 1878 marked a major overhaul of the British system, and the definition of the Pound given there remained in force until modern times. The Pound was defined thus (Paragraph 4) 'The … platinum weight … deposited in the Standards department of the Board of Trade … shall continue to be the imperial standard of ..weight… and the said platinum weight shall continue to be the imperial standard for determining the imperial standard pound for the United Kingdom'. Para 13 states that the weight 'in vacuo' of this standard shall be called the imperial standard pound, and that all other weights mentioned in the act and permissible for commerce shall be ascertained from it alone. The First Schedule of the Act gives more details of the standard pound:- It is a platinum cylinder nearly 1.35 inches high, and 1.15 inches diameter, and the edges are carefully rounded off. It has a groove about 0.34 inches from the top, to allow the cylinder to be lifted using an ivory fork. It was constructed following the destruction of the Houses of Parliament by fire in 1834,

and is stamped P.S. 1844, 1 lb (P.S. stands for 'Parliamentary Standard'). This definition of the imperial pound remains unchanged.

Relationship to the kilogram

The 1878 Act says that contracts worded in terms of metric units will be deemed by the courts to be made according to the imperial units defined in the Act, and a table of metric equivalents is supplied whereby, in such cases, the imperial equivalents may be legally calculated. This effectively defines, for the UK courts and for commerce, the metric units in terms of imperial ones. The equivalence for the pound is given as 1 lb = 453.59265 g or 0.45359 kg, which would make the kilogram weigh approximately 2.2046213 lb. In 1883, it was determined jointly by the Standards Department of the Board of Trade and the Bureau International that 0.4535924277 kg was a better approximation, and this figure, rounded to 0.45359243 kg was given legal status by an Order in Council in May 1898. The Weights and Measures Acts (WMAs) of 1939 and 1958 defined the pound by reference to the WMA of 1878, so as late as 1963 the legal definition of the pound was the same as that given in 1878 (*i.e.* the platinum standard of 1844).

However, in the WMA of 1963 the pound was redefined for the first time as a mass (not a weight) equal to 0.45359237 kg (to match the definition of the International pound agreed in 1959), and 'For the purposes of any measurement of weight, ... the weight of any thing may be expressed... in the same terms as its mass'. The definition of the Pound mass in terms of the imperial standard pound of 1844 was also ratified. This is its present status in the United Kingdom, the same dimension and value having been ratified in the Weights and Measures Act 1985.

United States usage

In the United States, the (avoirdupois) pound as a unit of mass has been officially defined in terms of the kilogram since the Mendenhall Order of 1893. In 1893, the relationship was specified to be 2.20462 pounds per kilogram. In 1894, the relationship was specified to be 2.20462234 pounds per kilogram. This change followed a determination of the British pound.

According to a 1959 NIST publication, the international pound differed from the United States 1894 pound by approximately one part in 10 million. The difference is so insignificant that it can be ignored for almost all practical purposes.

International pound

The United States and countries of the Commonwealth of Nations agreed upon common definitions for the pound and the yard. Since 1 July 1959, the international avoirdupois pound has been defined as exactly 0.45359237 kg.

In the United Kingdom, the use of the international pound was implemented in the Weights and Measures Act 1963.

The yard or the metre shall be the unit of measurement of length and the pound or the kilogram shall be the unit of measurement of mass by reference to which any measurement involving a measurement of length or mass shall be made in the United Kingdom; and- (a) the yard shall be 0.9144 metre exactly; (b) the pound shall be 0.45359237 kilogram exactly.
—*Weights and Measures Act*, 1963, Section 1(1)

An avoirdupois pound is equal to 16 avoirdupois ounces and to exactly 7,000 grains. The conversion factor between the kilogram and the international pound was therefore chosen to be divisible by 7, and an (international) grain is thus equal to exactly 64.79891 milligrams.

Troy pound

The troy pound takes its name from the French market town of Troyes in France where English merchants traded at least as early as the time of Charlemagne (early 9th century). The system of Troy weights was used in England by apothecaries and jewellers.

A troy pound is equal to 12 troy ounces and to 5,760 grains. Today, the grain is common to the avoirdupois and troy systems of units of mass making an international troy pound equal to 373.2417216 grams.

The troy pound is no longer in general use. In Canada, Australia, the United Kingdom, and other places the troy pound is no longer a legal unit for trade (WMA 1878). In the United Kingdom, the use of the troy pound was abolished on 6 January 1879 in accordance with the WMA of 1878, though the troy ounce was retained. The troy ounce is still used for measurements of precious metals such as gold, silver, and platinum, and sometimes gems such as opals.

Most measurements of the mass of precious metals using pounds refer to troy pounds, even though it is not always explicitly stated that this is the case. Some notable exceptions are:

- Encyclopædia Britannica which uses either avoirdupois pounds or troy ounces, likely never both in the same article, and
- the mass of Tutankhamun's sarcophagus lid. This is 110 kilograms. It is often stated to have been 242 or 243 (avoirdupois) pounds but sometimes, much less commonly, it is stated as 296 (troy) pounds.

Tower pound

The system called tower weight was the more general name for King Offa's pound. This dates to 757 AD and was based on the silver penny. This in turn was struck over Arabic dirhams (2d). The pound was based on the weight of 120 Arabic silver dirhams, which have been found in Offa's Dyke. The same coin weight was used throughout the Hanseatic League.

The mercantile pound (1304) of 6750 troy grains, or 9600 tower grains, derives from this pound, as 25 shilling-weights or 15 tower ounces, for general commercial use. Multiple pounds based on the same ounce were quite common. In much of Europe, the apothecaries' and commercial pounds were different numbers of the same ounce.

The tower system was referenced to a standard prototype found in the Tower of London and ran concurrently with the avoirdupois and troy systems, until it fell out of use and was abolished in 1527.

The tower pound is equivalent to about 350 grams.

1 mercantile pound (15 oz)	=	9,600 tower grains	=	6,750 troy grains
1 tower pound (12 oz)	=	7,680 tower grains	=	5,400 troy grains
1 tower ounce (20 dwt)	=	640 tower grains	=	450 troy grains
1 tower pennyweight (dwt)	=	32 tower grains	=	22½ troy grains

Merchants' pound

The merchants' pound (*mercantile pound*, *libra mercantoria* or *commercial pound*) was equal to 9,600 wheat grains (15 tower ounces or 6,750 grains). It was used in England until the 14th century for most goods (other than money, spices and electuaries).

London pound

The London pound is that of the Hansa, as used in their various trading places. This is based on 16 of tower ounces, each ounce divided as the tower ounce. It never became a legal standard in England; the use of this pound waxed and waned with the influence of the Hansa itself.

A London pound was equal to 7,200 troy grains (16 tower ounces or, equivalently, 15 troy ounces).

1 London pound	=	1⅓ tower pounds	=	7,200 troy grains
1 London ounce	=	1 tower ounce	=	450 troy grains
1 London pennyweight	=	1 tower pennyweight	=	22½ troy grains

Wool pound

The wool pound was equal to 6,992 grains. It was a unit of mass used to measure the weight of wool.

Roman libra

V. Gewicht.

Das Wiener Pfund Handelsgewicht, worauf hier Rücksicht genommen wird, hat 0,560012 Kilogramm.

Nahmen der Örter und ihrer Handelsgewichte	Gewicht in Wien. Handels-pfunden	Gewicht in franz. Kilo-gramm
Ägypten, Rotolo	0,757	0,424
Cantaro = 100 Rotoli		
Amsterdam, Pfund à 16 Unzen à 2 Loth	0,822	0,460
Zentner = 100 ℔		
Athen, Ofa à 400 Drachmen	2,730	1,529
Cantaro = 44 Ofe		
Baden, Pfund	0,893	0,500
Zentner = 100 ℔		
Baiern, Pfund von 32 Loth	1,000	0,560
Zentner = 100 ℔		
Belgien, Livre (Kilogramm)	1,786	1,000
Bremen, Pfund	0,890	0,498
Zentner = 116 ℔		
Dänemark, Pfund von 32 Loth	0,892	0,499
Zentner = 100 ℔		
England, Handelspfund à 16 Unzen à 16 Drachmen	0,810	0,454
Zentner = 112 ℔		
Troy Pfund von 12 Unzen	0,666	0,373
Frankfurt a. M., Pfund à 32 Loth	0,865	0,484
Zentner = 112 ℔		
Frankreich, Kilogramm von 1000 Gramm	1,786	1,000
altes Pfund Markgewicht	0,875	0,490
Genua, Libbra peso grosso	0,623	0,349
Libra peso sottile	0,566	0,317
Cantaro = 150 Libbre		
Hamburg, Pfund à 32 Loth à 4 Quentchen	0,865	0,484
Zentner = 112 ℔		
Hannover, Pfund à 32 Loth à 4 Quentchen	0,835	0,468
Zentner = 100 ℔		
Holland, Pond (Kilogramm)	1,786	1,000
Köln, Pfund à 2 Mark à 16 Loth	0,835	0,468
Zentner = 106 ℔		
Konstantinopel, Rotolo	1,007	0,564
Ofa	2,291	1,283
Cantaro = 100 Rotoli = 44 Ofe		
Lemberg, Pfund à 32 Loth à 4 Quentchen	0,750	0,420
Lissabon, Libra	0,820	0,459
Quintal = 4 Arobas à 32 Libras		
Lübeck, Pfund à 32 Loth	0,863	0,483
Zentner = 112 ℔		
Mailand, Libbra peso grosso à 12 once	1,362	0,763
Libbra peso sottile	0,584	0,327
Libbra metrica (Kilogramm)	1,786	1,000
Neapel, Libbra à 12 once	0,573	0,321
Rotolo à 33⅓ once	1,591	0,891
cantaro = 100 Rotoli		
Nordamerik. Freystaaten, Londner Handelspfund	0,810	0,451
Polen, Pfund	0,724	0,406
Prag, böhmisches Pfund von 32 Loth	0,918	0,514
Preußen, Berliner Pfund à 32 Loth à 4 Quentchen	0,835	0,468
Zentner = 110 ℔		
Rom, Libra à 12 Once	0,606	0,339
Cantaro grosso = 10 Cantari sottili à 100 Libre		
Rußland, Pfund von 32 Loth à 3 Solotnik	0,731	0,410
Pud von 40 ℔	29,251	16,381
Sachsen, Pfund von 32 Loth	0,834	0,467
Zentner = 110 ℔		
Sardinien, Libbra (Kilogramm) à 10 Once	1,786	1,000
Schweden, Victualien- oder Schal-pfund	0,760	0,425
Zentner = 120 ℔		
Schweiz, in den meisten Kantonen Pfund à 32 Loth	0,893	0,500
Smyrna, Ofa à 400 Drachmen	2,172	1,216
Cantaro = 45 Ofe		
Spanien, Pfund oder Libra	0,822	0,460
Quintal = 4 Arobas à 25 Libras		
Toscana, Libbra von 12 Once	0,606	0,340
Triest, wie Wien; beym Einkaufe fremder Waaren braucht man auch das venetianische Gewicht		
Venedig, Libbra grossa	0,852	0,477
Libbra sottile	0,538	0,301
Würtemberg, leichtes Pfund à 32 Loth	0,835	0,468
Zentner = 104 ℔		
Zollvereit, Zollpfund	0,893	0,500
Zollzentner = 100 ℔		

Various historic pounds from a German textbook dated 1848

The libra (Latin for "scales / balance") is an ancient Roman unit of mass that was equivalent to approximately 327 grams. It was divided into 12 *uncia*, or ounces. The libra is the origin of the abbreviation for pound, lb. The commonly used abbreviation *lbs* to indicate the plural unit of measurement does not reflect Latin usage, in which *lb* is both the singular and plural abbreviation.

French livre

Since the Middle Ages, various pounds (*livre*) have been used in France. Since the 19th century, a *livre* has referred to the *metric pound*, 500g.

The *livre esterlin* was equivalent to about 367.1 grams (5,665 gr) and was used between the late 9th century and the mid-14th century.

The *livre poids de marc* or *livre de Paris* was equivalent to about 489.5 grams (7,555 gr) and was used between the 1350s and the late 18th century. It was introduced by the government of John II.

The *livre métrique* was set equal to the kilogram by the decree of *13 Brumaire an IX* between 1800 and 1812. This was a form of official metric pound.

The *livre usuelle* was defined as 500 grams, by the decree of 28 March 1812. It was abolished as a unit of mass effective 1 January 1840 by a decree of 4 July 1837, but is still used informally.

German and Austrian Pfund

Originally derived from the Roman libra, the definition varied throughout Germany in the Middle Ages and onward. The measures and weights of the Habsburg monarchy were reformed in 1761 by Empress Maria Theresia of Austria. The unusually heavy Habsburg (civil) pound of 16 ounces was later (after the kilogram was defined) found to be 560.012 g. Bavarian reforms in 1809 and 1811 adopted essentially the same standard pound. In Prussia, a reform in 1816 defined a uniform civil pound in terms of the Prussian foot and distilled water, resulting in a Prussian pound of 467.711 g.

Between 1803 and 1815 all German regions west of the River Rhine were French, organised in the *départements* Roer, Sarre, Rhin-et-Moselle, and Mont-Tonnerre. As a result of the Congress of Vienna these became part of various German states. However, many of these regions retained the metric system and the French *système usuel* with the metric pound of precisely 500 g. In 1854 the pound of 500 g also became the official mass standard of the German Customs Union, but states differed in the way they subdivided it (decimally, in 30 parts or in 32 parts), and local pounds continued to co-exist with the Zollverein pound for some time in some German states. Nowadays, the term *Pfund* is still in common use and universally refers to a pound of 500 g.

Russian funt

The Russian pound (Фунт, funt) is an obsolete Russian unit of measurement of mass. It is equal to 409.51718 grams.

Skålpund

The Skålpund was a Scandinavian measurement that varied in weight between regions. From the 17th century onward, it was equal to 425.076 grams in Sweden. It was abandoned in 1889 when Sweden switched to the metric system.

In Norway the same name was used for a weight of 498.1 grams, and in Denmark it equalled 471 grams.

In the 19th century Denmark followed Germany's lead and redefined the pound as 500 grams.

20 skålpund = 1 lispund

Jersey pound

A Jersey pound is an obsolete unit of mass used on the island of Jersey from the 14th century to the 19th century. It was equivalent to about 7,561 grains (490 grams). It may have been derived from the French livre poids de marc.

Trone pound

The trone pound is one of a number of obsolete Scottish units of measurement. It was equivalent to between 21 and 28 avoirdupois ounces (about 600-800 grams).

Metric pounds

In many countries upon the introduction of a metric system, the pound (or its translation) became an informal term for 500 grams,

The Dutch *pond* is an exception. It was officially redefined as 1 kilogram, with an ounce of 100 grams, but people seldom use it this way. In daily life *pond* is exclusively used for amounts of 500 grams, and to a lesser extent, *ons* for 100 grams.

In German the term is *Pfund*, in French *livre*, in Dutch *pond*, in Spanish and Portuguese *libra*, in Italian *libbra*, and in Danish and Swedish *pund*.

Though not from the same linguistic origin, the Chinese *jin* (also known a "catty") has a modern definition of exactly 500 grams, divided into ten *cun*. Traditionally about 605 grams, the *jin* has been in use for more than two thousand years, serving the same purpose as "pound" for the common-use measure of weight.

Hundreds of older pounds were replaced in this way. Examples of the older pounds are one of around 459 to 460 grams in Spain, Portugal, and Latin America; one of 498.1 grams in Norway; and several different ones in what is now Germany.

Although the use of the pound as an informal term persists in these countries to a varying degree, scales and measuring devices are denominated only in grams and kilograms. A pound of product must be determined by weighing the product in grams as the use of the *pound* is not sanctioned for trade within the European Union.

Use in commerce

In the United States of America the United States Department of Commerce, the Technology Administration, and the National Institute of Standards and Technology (NIST) have defined the use of mass and weight in the exchange of goods under the Uniform Laws and Regulations in the areas of legal metrology and engine fuel quality in NIST Handbook 130.

NIST Handbook 130 states:

V. "Mass" and "Weight."
The mass of an object is a measure of the object's inertial property, or the amount of matter it contains. The weight of an object is a measure of the force exerted on the object by gravity, or the force needed to support it. The pull of gravity on the earth gives an object a downward acceleration of about 9.8 m/s^2. In trade and commerce and everyday use, the term "weight" is often used as a synonym for "mass." The "net mass" or "net weight" declared on a label indicates that the package contains a specific amount of commodity exclusive of wrapping materials. The use of the term "mass" is predominant throughout the world, and is becoming increasingly common in the United States. (Added 1993)
W. Use of the Terms "Mass" and "Weight."
When used in this handbook, the term "weight" means "mass". The term "weight" appears when inch-pound units are cited, or when both inch-pound and SI units are included in a requirement. The terms "mass" or "masses" are used when only SI units are cited in a requirement. The following note appears where the term "weight" is first used in a law or regulation.
NOTE 1: When used in this law (or regulation), the term "weight" means "mass."

U.S. federal law, which supersedes this handbook, also defines weight, particularly Net Weight, in terms of the avoirdupois pound or mass pound. From 21CFR101 Part 101.105 – Declaration of net quantity of contents when exempt:

(a) The principal display panel of a food in package form shall bear a declaration of the net quantity of contents. This shall be expressed in the terms of weight, measure, numerical count, or a combination of numerical count and weight or measure. The statement shall be in terms of fluid measure if the food is liquid, or in terms of weight if the food is solid, semisolid, or viscous, or a mixture of solid and liquid; except that such

statement may be in terms of dry measure if the food is a fresh fruit, fresh vegetable, or other dry commodity that is customarily sold by dry measure. If there is a firmly established general consumer usage and trade custom of declaring the contents of a liquid by weight, or a solid, semisolid, or viscous product by fluid measure, it may be used. Whenever the Commissioner determines that an existing practice of declaring net quantity of contents by weight, measure, numerical count, or a combination in the case of a specific packaged food does not facilitate value comparisons by consumers and offers opportunity for consumer confusion, he will by regulation designate the appropriate term or terms to be used for such commodity.

(b)(1) Statements of weight shall be in terms of avoirdupois pound and ounce.

From paragraph "a" above, although the avoirdupois pound is a measure of mass, in commerce it is used with the term "Net Weight", because "there is a firmly established general consumer usage and trade custom of declaring the contents of a liquid by weight, or a solid..."

Use in weaponry

Smoothbore cannon and carronades are designated by the weight in imperial pounds of round solid iron shot of diameter to fit the barrel. A cannon that fires a six-pound ball, for example, is called a *six-pounder*. Standard sizes are 6, 12, 18, 24, 32 and 42 pounds; 68-pounders also exist, and other nonstandard weapons use the same scheme.

Chapter-12

Maund and Candy

Maund

The vast extent of the Bengal Presidency (shown here in 1858) facilitated the adoption of the standard of 100 Troy pounds for the maund throughout British India.

The **maund** is the anglicized name for a traditional unit of mass used in British India, and also in Afghanistan, Persia and Arabia: the same unit in the Moghul Empire was sometimes written as *mun* in English, while the equivalent unit in the Ottoman Empire

and Central Asia was called the *batman*. At different times, and in different South Asian localities, the mass of the maund has varied, from as low as 25 pounds (11 kg) to as high as 160 pounds (72½ kg): even greater variation is seen in Persia and Arabia.

In British India, the maund was first standardized in the Bengal Presidency in 1833, where it was set equal to 100 Troy pounds (82.28 lbs. av.). This standard spread throughout the British Raj. After the independence of India and Pakistan, the definition formed the basis for metrication, one maund becoming exactly 37.3242 kilograms. A similar metric definition is used in Nepal.

Origins

Anglicized as "maund", the *man* as a unit of weight is thought to be of at least Chaldean origin, with Sir Henry Yule attributing Akkadian origins to the word. The Hebrew *maneh* (הנמ) and the Ancient Greek *mina* (μνᾶ) are thought to be cognate. It was originally equal to one-ninth of the weight of an *artaba* of water, or approximately four to seven kilograms in modern units.

The modification of the vowel in the anglicized name is thought to be an indication that the word came into English via Portuguese.

South Asia

British Indian units of mass

Mughal Empire

1 **maund**	= 40 seers
1 seer	= 30 dams
1 dam	= 5 tanks
1 tank	= 3 mashas
1 masha	= 8 ruttees

Bengal Presidency

1 **maund**	=	8 passerees
1 passeree	=	5 seers
1 seer	=	16 chitaks
1 chitak	=	5 tolas
1 tola	=	12 mashas
1 masha	=	8 rattis
1 ratti	=	4 dhans

Regulation VII 1833 fixed the mass of one tola as 180 troy grains (11.663 8038 grams)

Bombay Presidency

1 candy	=	20 **maunds**
1 **maund**	=	40 seers
1 seer	=	72 tanks

The maund was fixed at 28 pounds avoirdupois (¼ hundredweight)
(12.700 586 36 kilograms)

Madras Presidency		
1 candy	=	20 **maunds**
1 **maund**	=	8 vis
1 vis	=	5 seers
1 seer	=	8 pollums
1 pollum	=	10 pagodas

The maund was fixed at 25 pounds avoirdupois
(11.339 809 25 kilograms)

Mughal Empire

Prinsep (1840) summarizes the evidence as to the weight of the *mun* (later "maund")
during the reign (1556–1605) of Akbar the Great, which comes from the *Ain-i-Akbari*
written by the vizier Abu'l-Fazl ibn Mubarak (anglicized as "Abul Fuzl"). The principal
definition is that the *mun* is forty *seers*; and that each *seer* is thirty *dams*.

1 *mun* = 40 *seers* = 1200 *dams*

The problem arises in assigning the values of the smaller units.

The section of the *Ain-i-Akbari* that defines the *mun* also defines the *dam* as five *tanks*. A
separate section defines the *tank* as twenty-four *ruttees*. However, by the 19th century,
the *tank* was no longer a uniform unit across the former Mughal territories: Prinsep
quotes values of 50 grains (3.24 g) in Darwar, 72 grains (4.67 g) in Bombay and
268 grains (17.37 g) in Ahmednugur.

The *jilály*, a square silver rupee coin issued by Akbar, was said by the *Ain-i-Akbari* to be
11¼ *mashas* in weight: surviving *jilály* and other Mughal rupee coins weigh 170–
175 Troy grains (11.02–11.34 g), so the *masha*, defined as eight *ruttees*, would be about
15½ grains (1 g). *Masha* weights sent back to London in 1819 agree with this value. This
basis gives a *mun* of 34¾ lb. av. (15¾ kg).

However, in yet another section of the *Ain-i-Akbari*, the *dam* is said to be "twenty *mashas*
seven *ruttees*": using this definition would imply an Imperial mass of about 47 lb. av.
(21⅓ kg) for the *mun*. Between these two values, the maund in Central India was often
found to be around 40 lb. av. (18 kg) in the East India Company survey of 1821.

A Maund was 55.5 British pounds under Akbar.

Nineteenth century
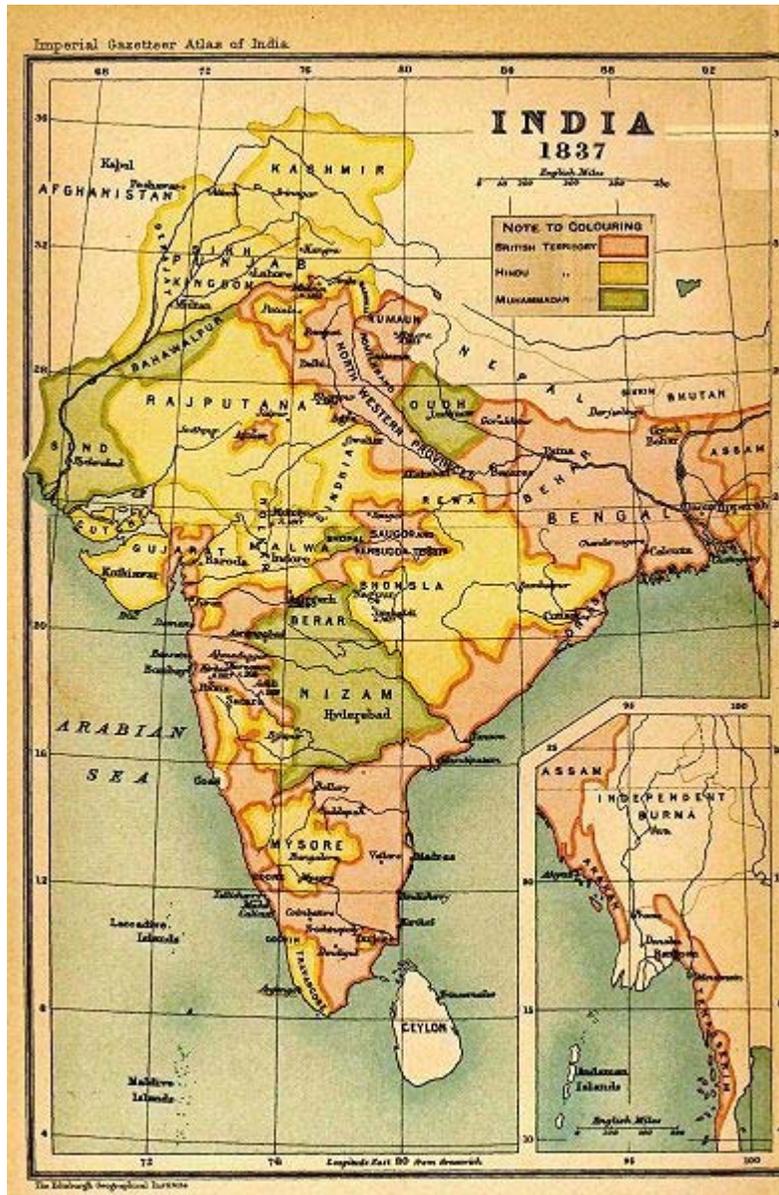
British India is shown in pink on this 1837 map. The Madras Presidency is in the southeast, the Bombay Presidency is in the west and the Bengal Presidency is in the northeast.

The maund of India may as a *genus* be divided into four different *species*:

1. That of Bengal, containing 40 seers, and averaging about 80 lbs. avoir.
2. That of Central India (Malwa, Ajmeer, &c.) generally equal to 40 lbs. avoir. and containing 20 seers (so that the seer of this large portion of the continent assimilates to that of Bengal.)
3. The maund of Guzerat and Bombay, equal to ¼ cwt. or 28 pounds and divided into 40 seers of smaller grade.

4. The maund of Southern India, fixed by the Madras government at 25 lbs. avoir.

There are, however many other varieties of maund, from 15 to 64 seers in weight; which it is unnecessary to particularize.

– Prinsep (1840), p. 77

Prinsep's values for the maund come from a survey organized by the East India Company in 1821. The Company's agents were asked to send back examples of the standard weights and measures used in the places they were stationed, and these were compared with the English standards in London by Patrick Kelly, the leading British metrologist of the time. The results were published as an appendix to the second edition of Kelly's *Universal Cambist* (1831), and later as a separate book entitled *Oriental Metrology* (1832).

It will be seen from Kelly's results below that Prinsep's generalizations are only partially correct. The Gujarat maund is more closely related to the Central Indian maund than to the standardized Bombay maund, except in the town of Anjar, except that it is divided into 40 seers instead of 20 as was found in Malwa.

Central India and Gujarat

Place	Sub-division	Imperial lb. oz. dr.			Metric kg
Ahmadābād, in Gujarat	40 seers	42	4	13	19.817
Amod, in Broach	40 seers	40	8	12	
Anjar, in Cutch	40 seers	27	3	8	
Bairseah, in Malwa	40 seers	77	1	12	
Bārdoli, in Surat	39¾ seers, 2 pice	37	4	4¾	
Broach, in Gujarat	40 seers	40	8	12	
Baroda, in Gujarat	42 seers	44	9	10	
Cambay, in Gujarat	40 seers	37	8	0	
Chanadore, Central Provinces	64 seers	149	12	0	
Dewas, in Malwa	64 seers	137	8	2	
Doongurpoor, in Rajputana	40 seers	50	1	14	
Hānsot, in Broach	40 seers, "market"	38	9	9	
	42 seers, for oil	40	8	6	
	40 *pergunna* seers	39	3	10	
Indore, in Malwa	20 seers, for grain	40	8	6	
	40 seers, for opium	81	0	12	
Jambusar, in Broach	40 seers, "market"	40	6	4	
	42 seers, for cotton	42	6	9	

		Imperial lb. oz. dr.	
Kota, in Rajputana	40 seers	30 0 0	
Kumbharia, in Surat	40 seers 8 pice	37 13 10	
Kurod, in Surat	40 seers 15 pice	37 15 8½	
Malwa	20 seers	40 7 8	
Mundissor, in Malwa	15 seers	34 4 4½	
Okalesur, in Broach	40 seers	38 8 13	
	40 seers, "*pergunna*"	40 6 13	
Omutwara, in Malwa	28 seers	54 10 8	
Oujein, in Malwa	16⅞ seers	33 5 13	
Pertabgurh, in Ajmer	20 seers	38 8 14	
Rutlam, in Malwa	20 seers	40 7 8	
Surat, in Gujarat	40 seers	37 8 0	

Bombay Presidency

Place	Sub-division	Imperial lb. oz. dr.	Metric kg
Ahmadnagar	40 seers	78 15 12	
Aurangabad	40 seers	74 10 10	
Belgaum	44 seers	26 3 15	
Bombay	40 seers	28 0 0	
Carwar, in Kanara	42 seers	26 0 0	
Dindoor	64 seers	157 10 10	
	12½ seers, for ghee, etc.	24 10 4⅓	
Dukhun Poona	14 seers, for metals	27 9 9⅔	
	48 seers, for grain	94 9 8	
Goa (Portuguese)	—	24 12 0	
Jamkhair, in Ahmednagar	64 seers	147 10 0	
Jaulnah, in Hyderabad	40 seers	80 2 8	
Onore, in Kanara	40–44 seers	25 0 0	
	12½ seers, for ghee, etc.	24 10 4⅓	
Poona	14 seers, for metals	27 9 9⅔	
	48 seers, for grain	94 9 8	
Roombharee, in Ahmednagar	64 seers	160 13 8	

Madras Presidency

Place	Sub-division	Imperial			Metric
		lb.	oz.	dr.	kg
Anjengo, in Travancore	—	28	0	0	
Bangalore, in Mysore	40 seers	25	0	0	
Bellary, in Madras	48 seers	25	6	0	
Calicut, in Malabar	68 seers	34	11	11	
Cochin, in Malabar	42½ seers	27	2	11	
Coimbatoor, in Mysore	40 seers	24	1	0	
Colachy, in Travancore	125 pollums	18	12	13	
Hyderabad, in Madras	12 seers, "*kucha*"	23	13	0	
	40 seers, "*pucka*"	79	6	0	
Madras	40 seers, or 8 vis	25	0	0	
Madura, in Carnatic	39.244 seers	25	0	0	
Mangalore	46 seers, "market"	28	2	4	
	46 seers, "Company's"	28	8	13	
	40 seers, for sugar	24	7	8	
Masulipatam, in Madras	"*kucha*"	35	10	0	
	"*pucka*"	80	0	0	
Negapatam, in Carnatic	41.558 seers	25	0	0	
Pondicherry	8 vis	25	14	5½	
Quilon, in Travancore	25 old Dutch pounds	27	5	8	
Sankeridroog, in Carnatic	41.256 seers	25	0	0	
Seringapatam	40 seers, "*kucha*"	24	4	8	
Tellicherry, in Malabar	64 seers	32	11	0	
Tranquebar, in Coromandel	68 Danish pounds	74	12	9.6	
Travancore, in Madras	—	25	0	6½	
Trichinopoly, in Carnatic	13.114 seers	25	0	0	
Vizagapatam, in Madras	"*kucha*"	35	10	0	
	"*pucka*"	80	0	0	
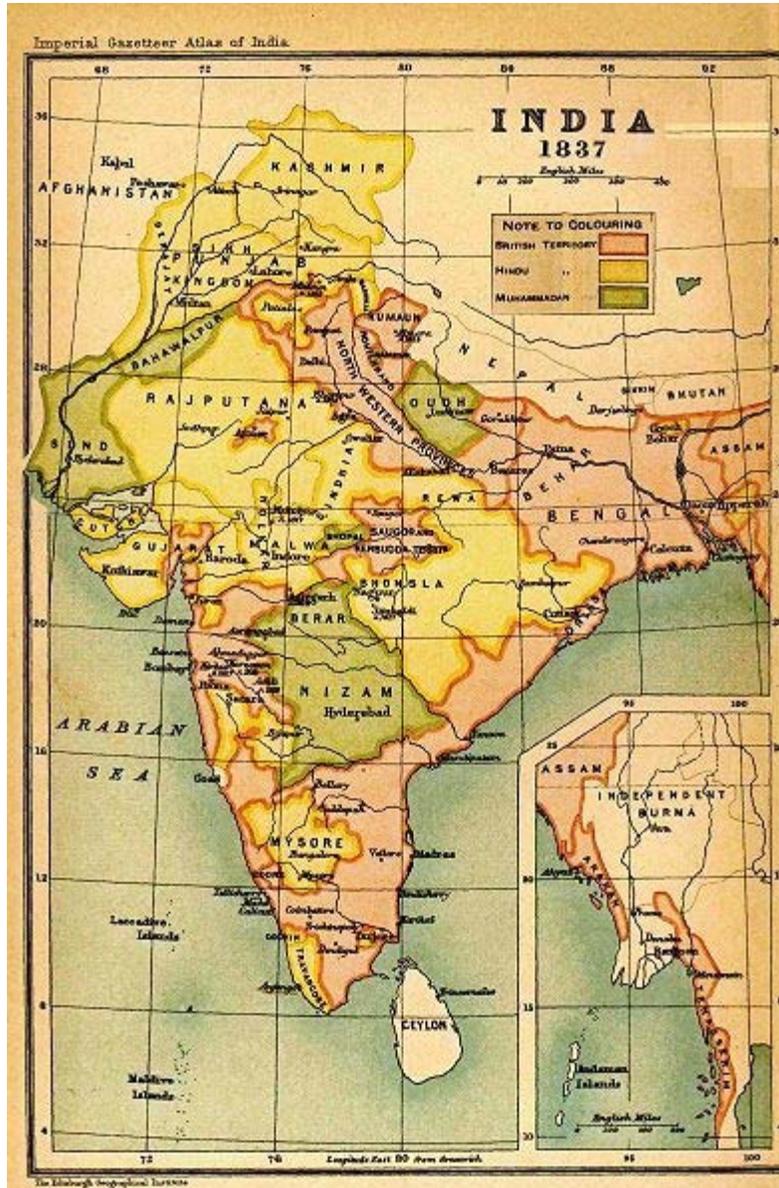
Candy

British India is shown in pink on this 1837 map. The Madras Presidency is in the southeast, the Bombay Presidency is in the west and the Bengal Presidency is in the northeast.

The **candy** or **candee** , also known as the **maunee**, was a traditional South Asian unit of mass, equal to 20 maunds and roughly equivalent to 500 pounds avoirdupois (227 kilograms). It was most used in southern India, to the south of Akbar's empire, but has been recorded elsewhere in South Asia. In Marathi, the same word was also used for

a unit of area of 120 bighas (25 hectares, very approximately), and it is also recorded as a unit of dry volume.

The candy was generally one of the largest (if not *the* largest) unit in a given system of measurement. The word was adopted into several South Asian languages before the compilation of dictionaries, presumably through trade as several Dravidian languages have local synonyms.

Unit of mass

The candy was equal to twenty maunds, but the value of the maund was not standardised across South Asia. There were at least three different approximate values for maund in early nineteenth century India, ranging from 11.34 kg to 37.32 kg, and values from outside India varied even wider. Much of our knowledge of the values of South Asian mass units comes from an 1821 study ordered by the British East India Company and subsequently published as *Kelly's Oriental Metrology*, although the approximate value of 500 pounds for the candy is attested as early as 1618. The earliest European reference to the candy (1563) puts its mass at 522 arráteis (239.6 kg, 528.2 lbs.).

The three Presidencies of British India had already undertaken a fair degree of standardisation of weights and measures by the time of Kelly's study. In the Madras Presidency, the maund was fixed at 25 lbs. av. (11.340 kg), making the candy equal to 500 lbs. av. (226.796 kg). In the Bombay Presidency, the maund was fixed at 28 lbs. av. (12.701 kg), making the candy exactly equal to 5 hundredweight (560 lbs. av., 254.012 kg). In Bombay itself (present-day Mumbai), a separate value of the candy was recorded for "grain", equal to 8 parahs or 358 lbs. 6 oz. 4 dr. (162.563 kg). In the Bengal Presidency, where the candy was not traditionally used, the maund (or *mun*) was a much larger unit, 100 troy pounds (37.324 kg, equivalent to a candy of 746.5 kg).

The effects of this standardisation can also be seen in other territories under direct British control. In Ceylon, the candy (also known as the bahar) was 500 lbs (226.796 kg) as on the Continent. Use of the candy is also recorded in British Burma, where it was the equivalent of 150 vis: its equivalent in Imperial units was measured as 500 lbs. (226.796 kg) in Pegu and 550 lbs. (249.476 kg) in Rangoon.

Perhaps the most striking example is from the princely state of Travancore in southwest India. At the British East India Company trading station of Anjengo, (near modern-day Kadakkavoor), the candy was equal to 35 telong and fixed at 560 lbs. (254.012 kg), as in Bombay. At Colachy (modern-day Kolachal) however, less than 50 miles (80 km) to the south, the candy was measured at only 376 lbs. 1 oz. 2 dr. (170.583 kg).
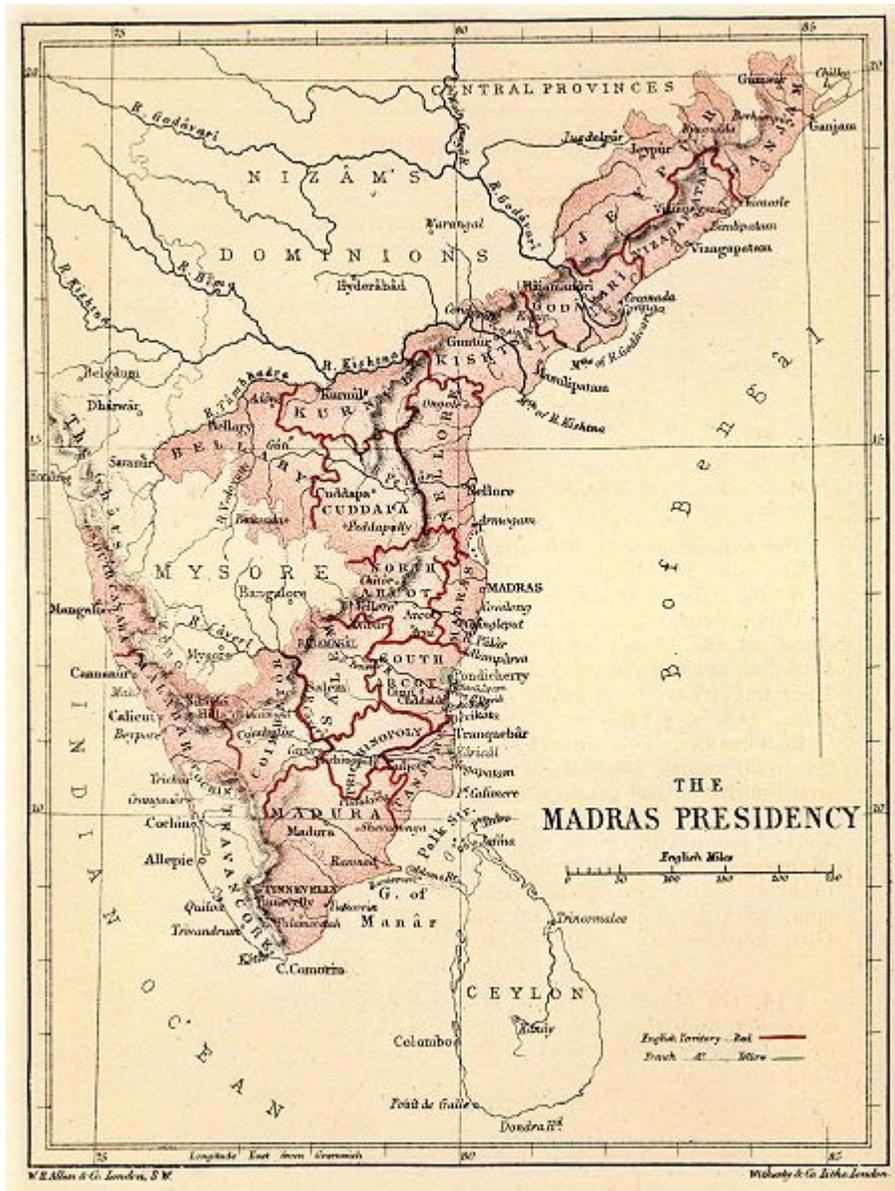
Madras Presidency shown in an 1880 map.
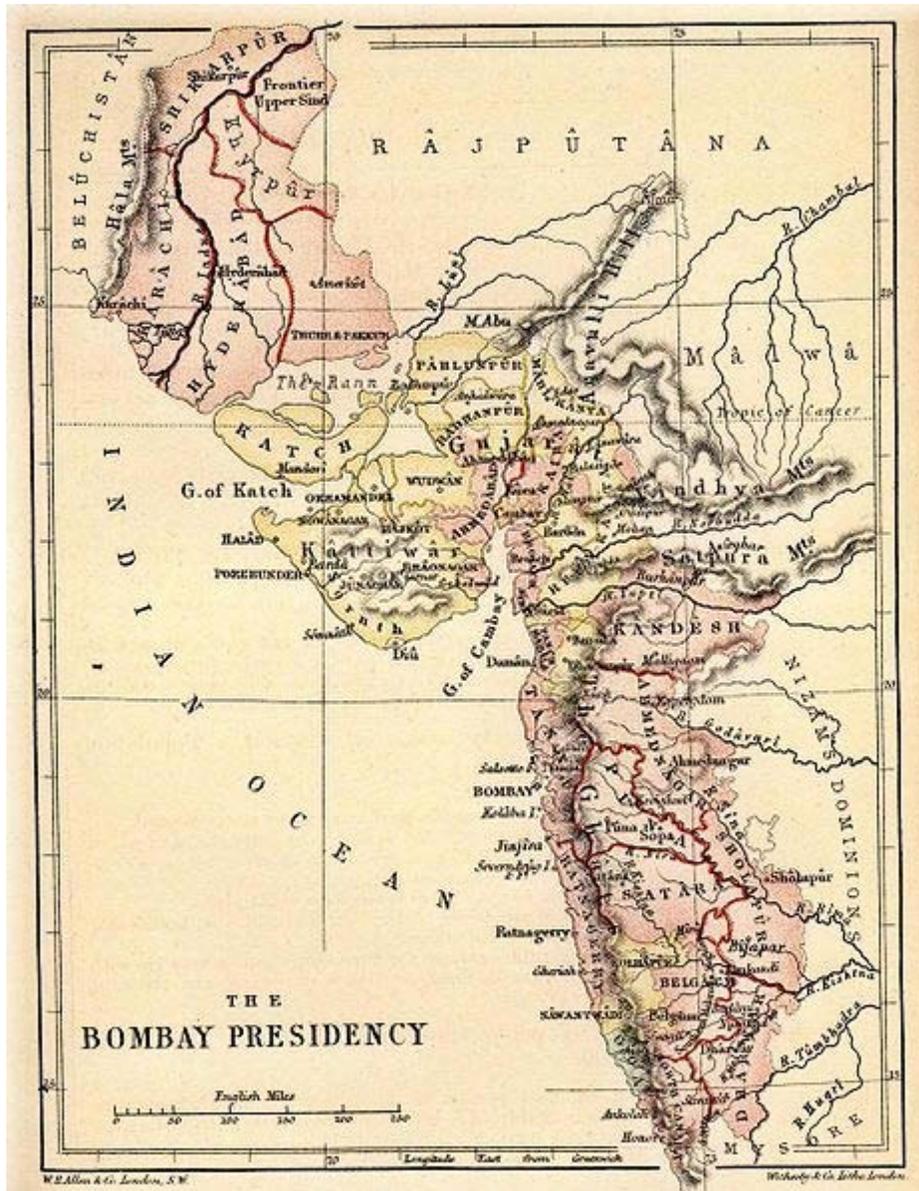
Bombay Presidency in an 1880 map.
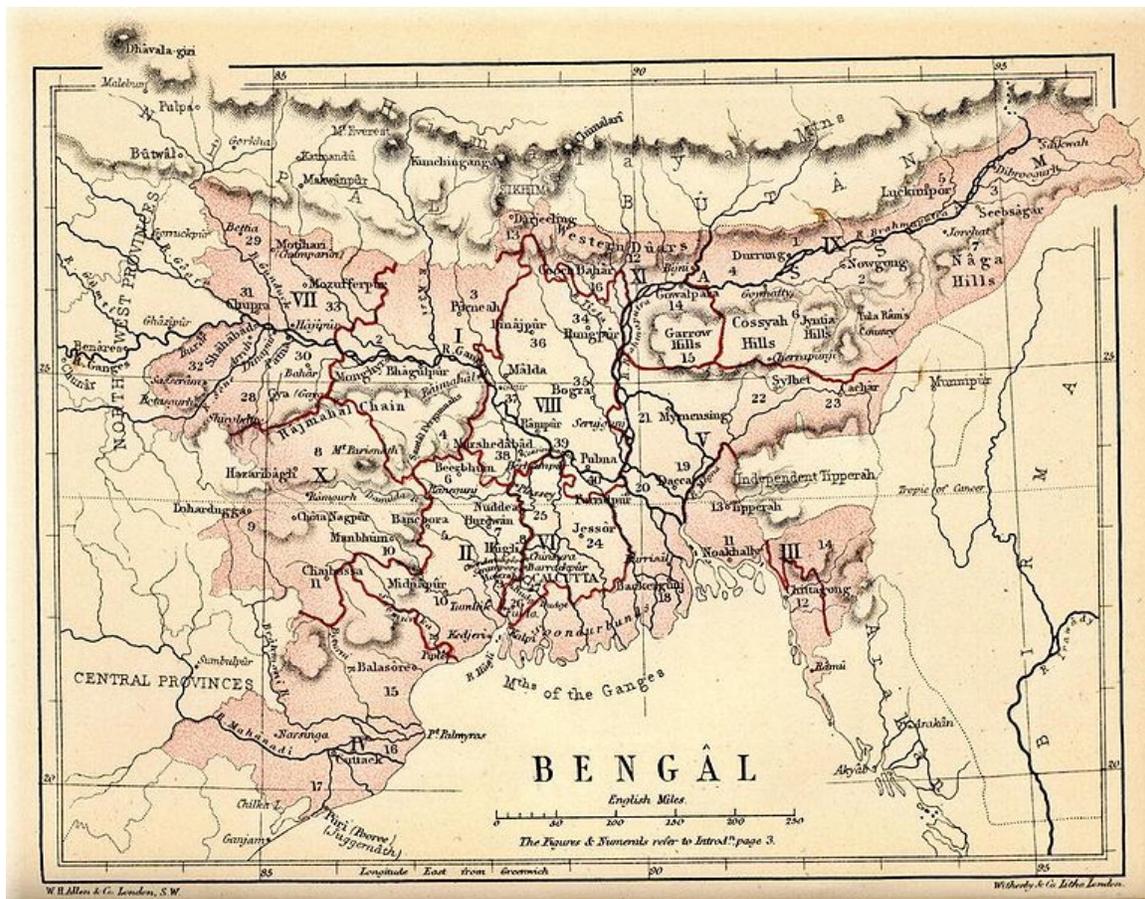
Bengal Presidency in 1880.

In the region of the Central Provinces, the maund was roughly 40 lbs., which is probably about the value it had under the Mughal Empire. The candy was not recorded as being in use as a unit of measurement in this region in 1821. Although not a part of the Central Provinces region, the unusually high value recorded for the candy in Baroda, Gujarat (modern-day Vadodara) – 892 lbs. 1 oz. 4 dr. (404.640 kg) – can be explained by this higher value of the Mughal maund. The candy in Surat, the main port of Gujerat, is also consistently quoted as being much larger than the same unit further south.

Unit of area

The candy is also recorded as a unit of area in Marathi, equal to 120 bighas. It is impossible to accurately convert this to modern units given the huge variability in the different values of the bigha in different locations. In particular, Kelly's 1821 study of South Asian metrology is completely silent on land measures in the Bombay Presidency. Molesworth defines the Marathi bigha as equal to twenty pandas or to 400 square kathys but also notes that it varies in different districts. The same author defines the kathy as "a land measure,—five cubits and five handbreadths […] also the measuring rod": other authors are silent on the unit. A cubit is roughly equal to five handbreadths, so the kathy

can be taken to be roughly 25 square cubits: that is, 8100 square inches or 6.25 square yards. This would make the bigha roughly 2500 square yards, or half an acre, in agreement with measurements in other areas of India. The candy, therefore, can be taken to be approximately 60 acres or 25 hectares.

The celebrated Scottish orientalist Sir Henry Yule gives a slightly larger value for the candy as a unit of area ("approximately 75 acres"), and describes it as the area of land which will produce one candy of grain. The Telegu unit of the putty is also used in the same way: one putty of land is that area which will produce one putty of rice.

Unit of dry volume

Several sources also describe the candy as a unit of dry measure. Again, it is difficult to give an accurate conversion to modern units, as most sources quote conversions to mass units for specific goods, and the few specific conversion factors that exist range from 8 to 25 bushels. More plausible is that one candy of dry measure was the volume that would have been occupied by one candy (in mass) of water, that is about 254 litres (7 bushels) in Bombay (present-day Mumbai).

- One candy of "grain" (unspecified) in Bombay was recorded by Kelly as 8 parahs or 358 lbs. 6 oz. 4 dr. (162.563 kg), compared to a standard Bombay candy of 560 lbs. (254.012 kg), a factor of 0.640. This factor is lower than the relative density of modern hulled rice (0.753) but higher than the that of rough rice (0.577).
- One parah for salt measure for Bombay was reported as 1607.6 cubic inches (26.344 litres), implying a candy for dry measure of salt as 210.8 litres: the factor (1.20, based on 254 litres for one candy of water) is identical to the relative density of caked salt.
- The Ceylonese standard parah was a cube of sides 11.57 inches, that is 25.41 litres.
- Molesworth defines the Marathi palah as 120 seers, implying a candy of 960 seers and a maund of 48 seers. The Bombay seer is given by Kelly as 11 oz. 3 dr. (317.2 g) for both grain and other commercial goods.

Not all grain measures in candies should be taken as dry measures. The United Nations Statistical Office reported that the candy was in use in the 20th century:

- in east India for measuring rice, with a value of approximately 210.636 kg compared to the old Madras standard candy of 226.796 kg;
- in Ceylon (later Sri Lanka) for measuring copra, with a value of 560 lbs.

Both of these are obviously related to the candy as a unit of mass.

Carat, Tael, Batman (unit) and Kendrick Mass

Carat (mass)

The **carat** is a unit of mass equal to 200 mg (0.007055 *oz*), and it is used for measuring gemstones and pearls.

The current definition, sometimes known as the **metric carat**, was adopted in 1907 at the Fourth General Conference on Weights and Measures, and soon afterwards in many countries around the world. The carat is divisible into one hundred *points* of two milligrams each. Other subdivisions, and slightly different mass values, have been used in the past in different locations.

In terms of diamonds, a *paragon* is a flawless stone of at least 100 carats (20 g).

The ANSI X.12 EDI standard abbreviation for the carat is **CD**.

Etymology

First attested in English in the middle 15th century, the word *carat* came to English from Middle French *carat*, in turn from Italian *carato*, which came from Arabic *qīrāṭ* (طاريق), a term for a very small unit of weight defined by reference to a small seed, which in turn comes from Greek κεράτιον (*kerátion*), literally meaning "small horn" (diminutive of κέρας - *keras*, "horn") but also "carob seed" which was used as a unit of weight. The Latin word for carat is *siliqua*. The carob tree is Ceratonia siliqua.

In past centuries, different countries each had their own carat unit, all roughly equivalent to the mass of a carob seed, though the carob seed itself was not used as the standard reference point for the weight. These units were often used for weighing gold.

Historical definitions in the United Kingdom

Board of Trade carat

In the United Kingdom, before 1888, the **Board of Trade carat** was exactly $3\frac{1647}{9691}(\approx 3.170)$ grains; after 1887, the Board of Trade carat was exactly $3\frac{17}{101}(\approx 3.168)$ grains. Despite it being a non-metric unit, a number of metric countries used this unit for its limited range of application.

The Board of Trade carat was divisible into four *diamond grains*, but measurements were typically made in multiples of $\frac{1}{64}$ carat.

Pound carat and ounce carat

There were also two varieties of *refiners' carats* once used in the United Kingdom — the **pound carat** and the **ounce carat**. The pound troy was divisible into 24 *pound carats* of 240 grains troy each; the pound carat was divisible into four *pound grains* of 60 grains troy each; and the pound grain was divisible into four *pound quarters* of 15 grains troy each. Similarly, the ounce troy was divisible into 24 *ounce carats* of 20 grains troy each; the ounce carat was divisible into four *ounce grains* of 5 grains troy each; and the ounce grain was divisible into four *ounce quarters* of 1¼ grains troy each.

The carat of the Romans and Greeks

The *solidus* was also a Roman weight unit. There is literary evidence that the weight of 72 coins of the type called *solidus* was exactly a Roman pound, and that the weight of a *solidus* was 24 *siliquae*. The weight of a Roman pound is generally believed to have been 327.45 *g* or possibly up to 5 *g* less. Therefore the metric equivalent of 1 *siliqua* was approximately 189 *mg*. The Greeks had a similar unit of the same value.

Gold fineness in carats, comes from carats and grains of gold in a solidus of coin. One solidus = 24 carats, 1 carat = 4 grains, is preserved right up to this day. A book gives gold fineness in carats of 4 grains, and silver in (pound) of 12 ounces each 20 dwt.

The carat in Byzantine Egypt

A carob based weight unit was also used in Egypt in the Byzantine and early Arab periods. In this region, glass weights were used for weighing coins. From these the weight of the Egypt carat has been reconstructed as 196 *mg*. This is consistent with the average weights of carob seeds in the region.

The Syrian and Arabic carat in the First Millennium CE

According to literary sources, the Arabic carat was only 2% less than the Syrian carat. Based on coins and glass weights their weight was reconstructed as approximately

212 *mg*. This is consistent with literary information that a solidus weighed slightly less than 22 carats.

Tael

Tael can refer to any one of several weight measures of the Far East. Most commonly, it refers to the Chinese tael, a part of the Chinese system of weights and currency.

In Taiwan, Hong Kong, and Southeast Asia it is equivalent to 10 mace (*qián* 錢) or $\frac{1}{16}$ catty, albeit with slightly different equivalents in metric in these two places. These Chinese units of measurement are usually used in the Chinese herbal medicine stores as well as gold and silver exchange.

Names and etymology

The English word *tael* comes through Portuguese from the Malay word *tahil*, meaning "weight". Early English forms of the name such as "tay" or "taes" derive from the Portuguese plural of tael, *taeis*.

Tahil in Singaporean English) is used in Malay *and* English today when referring to the weight in Malaysia, Singapore, and Brunei where it is still used in some contexts especially related to the significant Overseas Chinese population.

In Chinese, tael is written 兩 (simplified Chinese: 两) and pronounced *liǎng* in Mandarin Chinese. In Chinese and Vietnamese, the phrase "half a catty, eight taels" (半斤八兩 and *kẻ tám lạng người nửa cân*, respectively), meaning two different presentations of the same thing (similar to the English phrase "Six of one and half-a-dozen of the other"), is still often used today.

In Thai, the tael is called *tamlueng*. The Thai expression roughly equivalent to "speech is silver; silence is golden", *Phūt pai sǭng phai bīa, ning sīa tamlưng thǭng* is literally, "if you talk, (you'll get) 2 *phai* [i.e., a small sum] of money; if you remain silent, (you'll get) a *tamlueng* [i.e., a lot] of gold".

Historical usage

Japanese Edo era tael sycees. In descending size, 30, 20, 10, 5, 4, 3, and 2 tael sycees.

In China, there were many different weighting standards of tael depending on the region or type of trade. In general the silver tael weighed around 40 grams. The most common government measure was the *Kùpíng* (庫平 "treasury standard") tael, weighing 1.2 Troy ounces (37.3 g). A common commercial weight, the *Cáopíng* (漕平 "canal shipping standard") tael weighed 1.18 Troy ounces (36.7 g) of marginally less pure silver.

As in China, Japan used the tael (両 *ryō*) as both a unit of weight and, by extension, a currency.

The Siamese (Thai) tael or *tamlueng* was a unit of weight and was equal to four ticals.

Tael currency

Traditional Chinese silver sycees and other currencies of fine metals were not denominated or made by a central mint and their value was determined by their weight in taels. They were made by individual silversmiths for local exchange, and as such the shape and amount of extra detail on each ingot were highly variable; square and oval shapes were common but "boat", flower, tortoise and others are known. The local tael

also took precedence over any central measure, so the Canton tael weighed 37.5g, the Convention or Shanghai tael was 33.9 g (1.09 oz troy), and the Customs or *Hǎiguān* (海關) tael 37.8 g (defined as $1\frac{1}{3}$ oz avoirdupois, about 1.22 oz troy). The conversion rates between various common taels were well known. The tael was still the basis of the silver currency and sycee remained in use until the end of the Qing Dynasty in 1911. Common weights were 50 tael, 10 tael, and 5 down to 1.

Modern studies suggest that, on purchasing power parity basis, one tael of silver was worth about 4130 modern Chinese yuan in the early Tang Dynasty, 2065 in the late Tang Dynasty, and 660.8 in the mid Ming Dynasty.

In Siam (now Thailand), the tael or *tamlueng* was a currency subdivision equal to $\frac{1}{32}$ of a tical, the base currency which became the Thai baht.

Contemporary usage

The tael is still in use as a weight measurement in a number of countries though usually only in limited contexts.

China

The Republic of China's standardised **market tael** (市兩 *shìliǎng*) of 31.25 g was modified by the People's Republic of China in 1959. The new market tael was 50 g or $\frac{1}{10}$ catty (500 g) to make it compatible with metric measures. In Shanghai, silver is still traded in taels.

Some foodstuffs in China are sold in units also called "taels", but which do not necessarily weigh one tael. For cooked rice, the weight of the tael is approximated using special tael-sized ladels. Other items sold in taels include the shengjian mantou and the xiaolongbao, both small buns commonly found in Shanghai. In these cases, one tael is traditionally four and eight buns respectively.

Hong Kong

The tael is a legal weight measure in Hong Kong, and is still in active use. In Hong Kong, one tael is 37.79936375 g, and in ordinance 22 of 1884 is $1\frac{1}{3}$ oz. avoir. Similar to Hong Kong, in Singapore, one tael is defined as $1\frac{1}{3}$ ounce and is approximated as 37.7994 g

Taiwan

The Taiwan tael is 37.5 g and is still used in some contexts. Taiwan never adopted the Republic of China's market tael of 31.25 g; its tael is derived from the tael or *ryō* of the Japanese system (equal to 10 *momme*) which was 37.5 g. Although the catty is still frequently used in Taiwan, the tael is only used for precious metals and medicines.

Vietnam

In French Indochina, the colonial administration standardised the tael *(lạng)* as 100 g but this unit is no longer used in Vietnam. However, a different tael (called *cây*, *lạng*, or *lượng*) unit of 37.5 g is used for domestic transactions in gold. Real estate prices are often quoted in taels of gold rather than the local currency over concerns over monetary inflation.

Batman (unit)

The **batman** was a unit of mass used in the Ottoman Empire and among Turkic peoples of the Russian Empire. It has also been recorded as a unit of area in Uyghur-speaking regions of Central Asia. The name is Turkic (Ottoman Turkish *baṭmān*; Chagatai *bātmān*), but was also sometimes used for the equivalent unit in Persia (من , *man*). The equivalent unit in British India was anglicized as the maund. The value of the batman (or maund) varied considerably from place to place.

Origins

The *man* as a unit of weight is thought to be of at least Chaldean origin, with Sir Henry Yule attributing Akkadian origins to the word. The Hebrew *maneh* (מנה) and the Ancient Greek *mina* (μνᾶ) are thought to be cognate. It was originally equal to one-ninth of the weight of an *artaba* of water, or approximately four kilograms in modern units. İnalcık believes the ancient Persian *patimāna* may have come from the late Assyrian word for "mana of the king". The *man* or *batman* spread throughout Arabia and Persia: it was adopted by the Ottoman Empire, and brought to India by the Mughal Empire. The first attestation which gives a comparison to European weights was by Pegolotti in his *Pratica della mercatura*, written about 1340. He reported the *batman* as the main unit of mass in Ayasluğ ("Altoluogo di Turchia" to Pegolotti; modern Selçuk, in western Turkey), equivalent to 32 Genoese pounds (*libbre*).

Ottoman Empire

The batman (or bateman) was first recorded in English in 1599, in Babylon (probably modern Baghdad), where it was said to be equal to "7 pound and 5 ounces English weight". In the central Ottoman system of weights, the batman was equal to six okas, as is attested in 1811 in Aleppo, 1821 in Baghdad and in 1850 in Constantinople. At this point, the batman was equal to 16 lb. 8 oz. avoirdupois (7.484 kg).

Arabia

Place	Local	Imperial lb.	oz.	dr.	Metric kg
Bayt al-Faqih	¹⁄₁₀ frazil	2	0	10	0.9249
Jeddah	30 uqiyyas	2	3	9⅗	1.0092
Mocha	40 uqiyyas	3	5	0	1.5025

Source: Kelly's *Oriental Metrology* (1832)

The *mann* (مَنّ) had doubtless formed a part of the Arabian system of weights before the arrival of the Ottomans. It was divided into *uqiyyas* (the number varying with the location), while ten *mann* made one *frazil*. A still larger unit of mass was the *bahar*, of ten to forty *frazils*. The Arabic *mann* was smaller than the Ottoman *batman* at about 2–3 lb. av. (1–1½ kg), except in Basra where there were two maunds in use, both much larger than either the Arabic *mann* or the Ottoman *batman*.

Turkey

The Turkish system of weights and measures was metrified in 1931. The *oka* was redefined as exactly one kilogram, while the *batman* became ten *okas* (10 kg).

Central Asia

The batman was used in Central Asia up until at least the 18th century. In Khiva in 1740, there were said to be two batmans (as in Persia): the "great batman" of 18 Russian pounds (фунт, *funt*; approx. 7.4 kg) and the "lesser batman" of 9¼ Russian pounds (approx. 3.8 kg).

In Uyghur, the batman was also a measure of land area, the area that could be sown with one batman (in mass) of seed.

Idel-Ural

The Tatar batman is an equivalent to 1000 pood or 16.4 tonnes.

Persia

Place	Local	Imperial lb.	oz.	dr.	Metric kg
Bandar-Abbas ("Gamron")	*tabrézy*	6	12	0	3.0617
	sháhy	13	8	0	6.1235
Bushehr	720 mithqals	7	10	15	3.4852
Shiraz	600 mithqals	12	10	14.4	5.7521
Tabriz	300 mithqals	6	5	7.2	2.8761

The two main commercial weights in Persia were the *tabrézy man* (نم زیربت), literally the *man* of Tabriz, and the *sháhy man* (نم ءاش), literally the Shah's *man*, which was twice as large. The *sháhy man* was particularly used in Shiraz and Isfahan. Kelly also distinguishes a *man* used for copra and "provisions" at Gamron (modern Bandar-Abbas) of 7 lb. 12 oz. av. (3.5153 kg).

The United Nations Statistical Office found a wide range of values for the *man* in Iran in 1966, from 3 kg to 53 kg. The *man* was divided into *mithqals* (the number depending on the locality): larger subdivisions included the *abbassi* and the *ratl*. The term *batman* appears to be reserved for the *tabrézy man*, approximately 2.969 kg in 1966.

Afghanistan

The *mann* (Pashto: نم) was also used as a unit of mass in Afghanistan, but varied widely between different localities. In Kandahar is was about 8 lb. av. (3½ kg), while in Peshawar it was 80 lb. av. (35 kg).

Kendrick mass

The **Kendrick mass** is a mass obtained by multiplying the measured mass by a numeric factor. The Kendrick mass is used to aid in the identification of molecules of similar chemical structure from peaks in mass spectra. The method of stating mass was suggested in 1963 by the chemist Edward Kendrick.

Definition

According to the procedure outlined by Kendrick, the mass of CH_2 is defined as 14.000 Da, instead of the IUPAC mass of 14.01565 Da.

To convert an IUPAC mass to the Kendrick mass, the equation

$$Kendrick\ mass = IUPAC\ mass \times \frac{14.00000}{14.01565}$$

is used. The mass in dalton units (*Da*) can be converted to the Kendrick scale by dividing by 1.0011178.

Other groups of atoms in addition to CH_2 can be used to obtain the Kendrick mass, for example COO, H_2, H_2O, and O. In this case, the Kendrick mass for a family of compounds F is given by

$$Kendrick\ mass\ (F) = (observed\ mass) \times \frac{nominal\ mass\ F}{exact\ mass\ F}.$$

For hydrocarbon analysis, F=CH$_2$.

A recent publication has suggested that Kendrick mass be expressed in Kendrick units with symbol *Ke*.

Kendrick mass defect

The Kendrick mass defect is defined as the exact Kendrick mass subtracted from the nominal (integer) Kendrick mass:

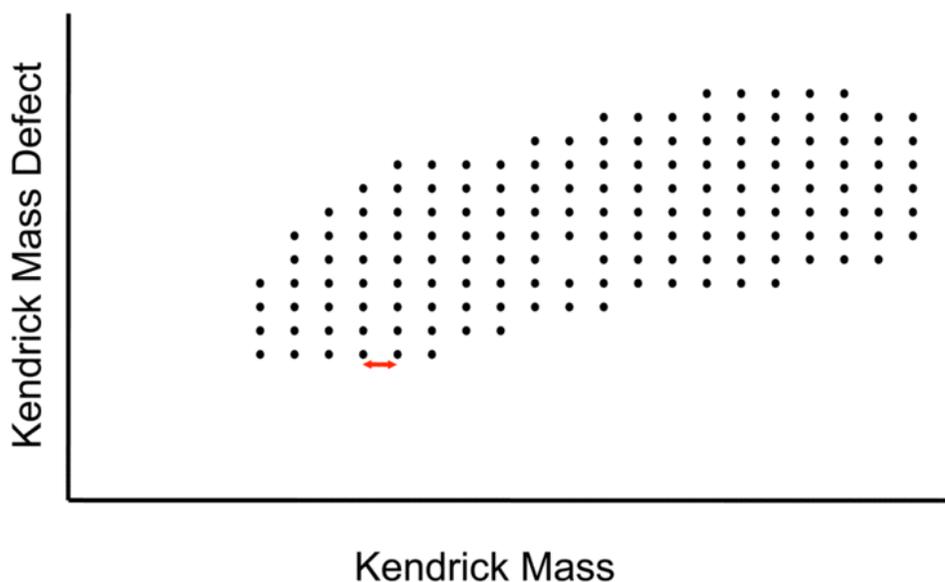$$Kendrick\ mass\ defect = nominal\ Kendrick\ mass - Kendrick\ mass$$

An alkylation series have the same degree of saturation and number of heteroatoms (nitrogen, oxygen and sulfur) but differ by the number of CH$_2$ units. Members of an alkylation series have the same Kendrick mass defect.

The Kendrick mass defect has also been defined as

$$Kendrick\ mass\ defect = nominal\ Kendrick\ mass - Kendrick\ mass \times 1,000$$

The abbreviations *KM* and *KMD* have been used for Kendrick mass and Kendrick mass defect, respectively. In some definitions, the KMD

Kendrick mass analysis

Plot of Kendrick mass defect as function of Kendrick mass; horizontal lines indicate common repeat units. Each dot in the plot corresponds to a peak measured in a mass spectrum.

In a Kendrick mass analysis, the Kendrick mass defect is plotted as function of nominal Kendrick mass for ions observed in a mass spectrum. Ions of the same family, for example the members of an alkylation series, have the same Kendrick mass defect but different nominal Kendrick mass and are positioned along a horizontal line on the plot. If the composition of one ion in the family can be determined, the composition of the other ions can be inferred. Horizontal lines of different Kendrick mass defect correspond to ions of different composition, for example degree of saturation or heteroatom content.

A Kendrick mass analysis is often used in conjunction with a Van Krevelen diagram, a two- or three- dimensional graphical analysis in which the elemental composition of the compounds are plotted according to the atomic ratios H/C, O/C, or N/C.