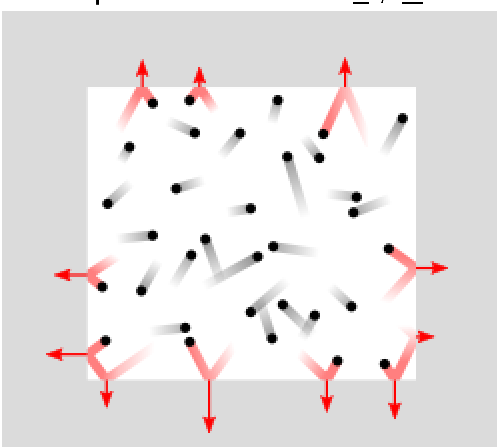
Quantum Mechanics_*Pressure*

Pressure

Common symbols	*P*
SI unit	Pascal (Pa)
In SI base units	1 kg/(m·s^2)
Derivations from other quantities	$P = F / A$



Pressure as exerted by particle collisions inside a closed container.

Pressure (symbol: *P* or *p*) is the ratio of force to the area over which that force is distributed.

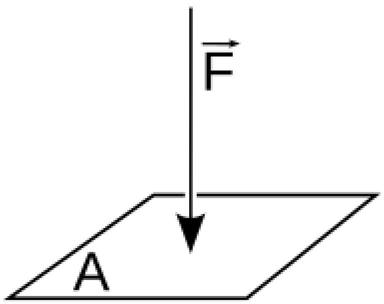
Pressure is force per unit area applied in a direction perpendicular to the surface of an object. Gauge pressure (also spelled *gage*pressure)[a] is the pressure relative to the local atmospheric or ambient pressure. Pressure is measured in any unit of force divided by any unit of area. The SI unit of pressure is thenewton per square metre, which is called the*Pascal* (Pa) after the seventeenth-century philosopher and scientist Blaise Pascal. A pressure of 1 Pa is small; it approximately equals the pressure exerted by a dollar bill resting flat on a table. Everyday pressures are often stated in kilopascals (1 kPa = 1000 Pa).

Definition

Pressure is the amount of force acting per unit area. The symbol of pressure is *p*.[b][1]

Formula

Conjugate variables of thermodynamics	
Pressure	Volume
(Stress)	(Strain)
Temperature	Entropy
Chemical potential	Particle number



Mathematically:

$$p = \frac{F}{A} \text{ or } p = \frac{dF_n}{dA}$$

where:

p is the pressure,

F is the normal force,

A is the area of the surface on contact.

Pressure is a scalar quantity. It relates the vector surface element (a vector normal to the surface) with the normal force acting on it. The pressure is the scalarproportionality constant that relates the two normal vectors:

$$d\mathbf{F}_n = -p\,d\mathbf{A} = -p\,\mathbf{n}\,dA$$

The minus sign comes from the fact that the force is considered towards the surface element, while the normal vector points outward.

It is incorrect (although rather usual) to say "the pressure is directed in such or such direction". The pressure, as a scalar, has no direction. The force given by the previous relationship to the quantity has a direction, but the pressure does not. If we change the

orientation of the surface element, the direction of the normal force changes accordingly, but the pressure remains the same.
Pressure is transmitted to solid boundaries or across arbitrary sections of fluid *normal to* these boundaries or sections at every point. It is a fundamental parameter in Thermodynamics, and it is conjugate to Volume.

Units

Mercury column
The SI unit for pressure is the Pascal (Pa), equal to one newton per square metre(N/m^2 or $kg \cdot m^{-1} \cdot s^{-2}$). This special name for the unit was added in 1971;[2] before that, pressure in SI was expressed simply as N/m^2.
Non-SI measures such as pounds per square inch and *bars* are used in some parts of the world, primarily in the United States of America. The cgs unit of pressure is the barye (ba), equal to 1 $dyn \cdot cm^{-2}$ or 0.1 Pa. Pressure is sometimes expressed in grams-force/cm^2, or as kg/cm^2 and the like without properly identifying the force

units. But using the names kilogram, gram, kilogram-force, or gram-force (or their symbols) as units of force is expressly forbidden in SI. The technical atmosphere (symbol: at) is 1 kgf/cm^2 (98.0665 kPa or 14.223 psi).

Since a system under pressure has potential to perform work on its surroundings, pressure is a measure of potential energy stored per unit volume measured in J·m^{-3}, related to energy density.

Some meteorologists prefer the hectopascal (hPa) for atmospheric air pressure, which is equivalent to the older unit millibar (mbar). Similar pressures are given in kilopascals (kPa) in most other fields, where the hecto- prefix is rarely used. Theinch of mercury is still used in the United States. Oceanographers usually measure underwater pressure in decibars (dbar) because an increase in pressure of 1 dbar is approximately equal to an increase in depth of 1 meter.

The standard atmosphere (atm) is an established constant. It is approximately equal to typical air pressure at earth mean sea level and is defined as follows:

standard atmosphere = 101,325 Pa = 101.325 kPa = 1,013.25 hPa.

Because pressure is commonly measured by its ability to displace a column of liquid in a manometer, pressures are often expressed as a depth of a particular fluid (e.g., centimeters of water, mm or inches of mercury). The most common choices are mercury (Hg) and water; water is nontoxic and readily available, while mercury's high density allows a shorter column (and so a smaller manometer) to be used to measure a given pressure. The pressure exerted by a column of liquid of height h and density ρ is given by the hydrostatic pressure equation $p = \rho g h$. Fluid density and local gravity can vary from one reading to another depending on local factors, so the height of a fluid column does not define pressure precisely. When millimeters of mercury or inches of mercury are quoted today, these units are not based on a physical column of mercury; rather, they have been given precise definitions that can be expressed in terms of SI units.[*citation needed*] One mmHg (millimeter of mercury) is equal to one torr. The water-based units still depend on the density of water, a measured, rather than defined, quantity. These*manometric units* are still encountered in many fields. Blood pressure is measured in millimeters of mercury in most of the world, and lung pressures in centimeters of water are still common.

Underwater divers use the metre sea water (msw or MSW) and foot sea water (fsw or FSW) units of pressure, and these are the standard units for pressure gauges used to measure pressure exposure in diving chambers and personal decompression computers. A msw is defined as 0.1 bar, and is not the same as a linear metre of depth, and 33.066 fsw = 1 atm.[3] Note that the pressure conversion from msw to fsw is different from the length conversion: 10 msw = 32.6336 fsw, while 10 m = 32.8083 ft

Gauge pressure is often given in units with 'g' appended, e.g. 'kPag' or 'psig', and units for measurements of absolute pressure are sometimes given a suffix of 'a', to avoid confusion, for example 'kPaa', 'psia'. 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[4] For example, "P_g = 100 psi" rather than "P = 100 psig".

Differential pressure is expressed in units with 'd' appended; this type of measurement is useful when considering sealing performance or whether a valve will open or close.

Presently or formerly popular pressure units include the following:

- atmosphere (atm)
- manometric units:
  - centimeter, inch, and millimeter of mercury (torr)
  - Height of equivalent column of water, including millimeter (mm H_2O), centimeter(cm H_2O), meter, inch, and foot of water
- customary units:
  - kip, short ton-force, long ton-force, pound-force, ounce-force, and poundal per square inch
  - short ton-force and long ton-force per square inch
  - fsw (feet sea water) used in underwater diving, particularly in connection with diving pressure exposure and decompression
- non-SI metric units:
  - bar, decibar, millibar
    - msw (metres sea water), used in underwater diving, particularly in connection with diving pressure exposure anddecompression
  - kilogram-force, or kilopond, per square centimeter (technical atmosphere)
  - gram-force and tonne-force (metric ton-force) per square centimeter

- barye (dyne per square centimeter)
- kilogram-force and tonne-force per square meter
- sthene per square meter (pieze)

v t e	Pascal (Pa)	bar (bar)	technical atmosphere (at)	standard atmosphere (atm)	torr (Torr)	Pounds per square inch (psi)
1 Pa	≡ 1 N/m^2	10^{-5}	1.0197×10^{-5}	9.8692×10^{-6}	7.5006×10^{-3}	1.450377×10^{-4}
1 bar	10^5	≡ 10^6 dyn/cm^2	1.0197	0.98692	750.06	14.50377
1 at	0.980665×10^5	0.980665	≡ 1 kp/cm^2	0.9678411	735.5592	14.22334
1 atm	1.01325×10^5	1.01325	1.0332	≡ p_0	≡ 760	14.69595
1 Torr	133.3224	1.333224×10^{-3}	1.359551×10^{-3}	1.315789×10^{-3}	≈ 1 mm_{Hg}	1.933678×10^{-2}
1 psi	6.8948×10^3	6.8948×10^{-2}	7.03069×10^{-2}	6.8046×10^{-2}	51.71493	≡ 1 lb_F/in^2

Pressure units

Examples

As an example of varying pressures, a finger can be pressed against a wall without making any lasting impression; however, the same finger pushing a thumbtackcan easily damage the wall. Although the force applied to the surface is the same, the thumbtack applies more pressure because the point concentrates that force into a smaller area. Pressure is transmitted to solid boundaries or across arbitrary sections of fluid *normal to* these boundaries or sections at every point. Unlikestress, pressure is defined as a scalar quantity. The negative gradient of pressure is called the force density.

Another example is of a common knife. If we try to cut a fruit with the flat side it obviously will not cut. But if we take the thin side, it will cut smoothly. The reason is that the flat side has a greater surface area (less pressure) and so it does not cut the fruit. When we take the thin side, the surface area is reduced and so it cuts the fruit easily and quickly. This is one example of a practical application of pressure.

For gases, pressure is sometimes measured not as an *absolute pressure*, but relative to atmospheric pressure; such measurements are called *gauge pressure*. An example of this is the air pressure in an automobile tire, which might be said to be "220 kPa (32 psi)", but is actually 220 kPa (32 psi) above atmospheric pressure. Since atmospheric pressure at sea level is about 100 kPa (14.7 psi), the absolute pressure in the tire is therefore about 320 kPa (46.7 psi). In technical work, this is written "a gauge pressure of 220 kPa (32 psi)". Where space is limited, such as on pressure gauges, name plates, graph labels, and table headings, the use of a modifier in parentheses, such as "kPa (gauge)" or "kPa (absolute)", is permitted. In non-SI technical work, a gauge pressure of 32 psi is sometimes written as "32 psig" and an absolute pressure as "32 psia", though the other methods explained above that avoid attaching characters to the unit of pressure are preferred.[5]

Gauge pressure is the relevant measure of pressure wherever one is interested in the stress on storage vessels and the plumbing components of fluidics systems. However, whenever equation-of-state properties, such as densities or changes in densities, must be calculated, pressures must be expressed in terms of their absolute values. For instance, if the atmospheric pressure is 100 kPa, a gas (such as helium) at 200 kPa (gauge) (300 kPa [absolute]) is 50% denser than the same gas at 100 kPa (gauge) (200 kPa [absolute]). Focusing on gauge values, one might erroneously conclude the first sample had twice the density of the second one.

Scalar nature

In a static gas, the gas as a whole does not appear to move. The individual molecules of the gas, however, are in constant random motion. Because we are dealing with an extremely large number of molecules and because the motion of the individual molecules is random in every direction, we do not detect any motion. If we enclose the gas within a container, we detect a pressure in the gas from the molecules colliding with the walls of our container. We can put the walls of our container anywhere inside the gas, and the force per unit area (the pressure) is the same. We can shrink the size of our "container" down to a very small point (becoming less true as we approach the atomic scale), and the pressure will still have a single value at that point. Therefore, pressure is a scalar quantity, not a vector quantity. It has magnitude but no direction sense associated with it. Pressure acts in all directions at a point inside a gas. At the surface of a gas, the pressure force acts perpendicular (at right angle) to the surface.

A closely related quantity is the stress tensor σ, which relates the vector force $\vec{F}$ to the vector area $\vec{A}$ via

$$\vec{F} = \sigma \vec{A}$$

This tensor may be expressed as the sum of the viscous stress tensor minus the hydrostatic pressure. The negative of the stress tensor is sometimes called the pressure tensor, but in the following, the term "pressure" will refer only to the scalar pressure.

According to the theory of general relativity, pressure increases the strength of a gravitational field (see stress-energy tensor) and so adds to the mass-energy cause of gravity. This effect is unnoticeable at everyday pressures but is significant inneutron stars, although it has not been experimentally tested.[6]

Types

Fluid pressure

Fluid pressure is the pressure at some point within a fluid, such as water or air (for more information specifically about liquid pressure, see section below).

Fluid pressure occurs in one of two situations:

1. an open condition, called "open channel flow"
    a. the ocean, or
    b. swimming pool, or
    c. the atmosphere.
2. a closed condition, called closed conduits
    a. water line, or
    b. gas line.

Pressure in open conditions usually can be approximated as the pressure in "static" or non-moving conditions (even in the ocean where there are waves and currents), because the motions create only negligible changes in the pressure. Such conditions conform with principles of fluid statics. The pressure at any given point of a non-moving (static) fluid is called the **hydrostatic pressure**.

Closed bodies of fluid are either "static", when the fluid is not moving, or "dynamic", when the fluid can move as in either a pipe or by compressing an air gap in a closed container. The pressure in closed conditions conforms with the principles of fluid dynamics.

The concepts of fluid pressure are predominantly attributed to the discoveries ofBlaise Pascal and Daniel Bernoulli. Bernoulli's equation can be used in almost any situation to determine the pressure at any point in a fluid. The equation makes some assumptions about the fluid, such as the fluid being ideal[7] and incompressible.[7] An ideal fluid is a fluid in which there is no friction, it isinviscid,[7] zero viscosity.[7] The equation is written between any two points *a* and *b* in a system that contain the same fluid.

$$\frac{p_a}{\gamma} + \frac{v_a^2}{2g} + z_a = \frac{p_b}{\gamma} + \frac{v_b^2}{2g} + z_b$$ [8]

where:

p = pressure of the fluid

$\gamma = \rho g$ = density · acceleration of gravity = specific weight of the fluid.[7]

v = velocity of the fluid

g = acceleration of gravity

z = elevation

$\frac{p}{\gamma}$ = pressure head

$\frac{v^2}{2g}$ = velocity head

Applications

- Hydraulics brakes
- Artesian well
- Blood pressure
- Hydraulic head
- Plant cell turgidity
- Pythagorean cup

Explosion or deflagration pressures

Explosion or deflagration pressures are the result of the ignition of explosivegases, mists, dust/air suspensions, in unconfined and confined spaces.

Negative pressures

low pressure chamber inBundesleistungszentrum Kienbaum, Germany

While **pressures** are, in general, positive, there are several situations in which negative pressures may be encountered:

- When dealing in relative (gauge) pressures. For instance, an absolute pressure of 80 kPa may be described as a gauge pressure of −21 kPa (i.e., 21 kPa below an atmospheric pressure of 101 kPa).
- When attractive forces (e.g., van der Waals forces) between the particles of a fluid exceeds repulsive forces due to thermal motion. These forces explain ascent of sap in tall plants. Negative pressure must exist at the top of any tree taller than 10 m, which is the pressure head of water that balances the atmospheric pressure. Van der Waals forces maintain cohesion of columns of sap that run continuously in xylem from the roots to the top leaves.
- The Casimir effect can create a small attractive force due to interactions withvacuum energy; this force is sometimes termed "vacuum pressure" (not to be confused with the negative *gauge pressure* of a vacuum).
- Depending on how the orientation of a surface is chosen, the same distribution of forces may be described either as a positive pressure along one surface normal, or as a negative pressure acting along the opposite surface normal.
- In the cosmological constant.

Stagnation pressure

Stagnation pressure is the pressure a fluid exerts when it is forced to stop moving. Consequently, although a fluid moving at higher speed will have a lower static pressure, it may have a higher stagnation pressure when forced to a standstill. Static pressure and stagnation pressure are related by:

$$p_0 = \frac{1}{2}\rho v^2 + p$$

where

p_0 is the Stagnation pressure

v is the flow velocity

p is the static pressure.

The pressure of a moving fluid can be measured using a Pitot tube, or one of its variations such as a Kiel probe or Cobra probe, connected to a manometer. Depending on where the inlet holes are located on the probe, it can measure static pressures or stagnation pressures.

Surface pressure

There is a two-dimensional analog of pressure - the lateral force per unit length applied on a line perpendicular to the force.

Surface pressure is denoted by π and shares many similar properties with three-dimensional pressure. Properties of surface chemicals can be investigated by measuring pressure/area isotherms, as the two-dimensional analog of Boyle's law, $\pi A = k$, at constant temperature.

$$\pi = \frac{F}{l}$$

Pressure of an ideal gas

Main article: Ideal gas law

In an Ideal gas, molecules have no volume and do not interact. Pressure varies linearly with temperature, volume, and quantity according to the Ideal gas law,

$$P = \frac{nRT}{V}$$

where:

P is the absolute pressure of the gas

n is the amount of substance

T is the absolute temperature

V is the volume

R is the ideal gas constant.

Real gases exhibit a more complex dependence on the variables of state.[9]

Vapor pressure

Vapor pressure is the pressure of a vapor in thermodynamic equilibrium with its condensed phases in a closed system. All liquids and solids have a tendency toevaporate into a gaseous form, and all gases have a tendency to condense back to their liquid or solid form.

The atmospheric pressure boiling point of a liquid (also known as the normal boiling point) is the temperature at which the vapor pressure equals the ambient atmospheric pressure. With any incremental increase in that temperature, the vapor pressure becomes sufficient to overcome atmospheric pressure and lift the liquid to form vapor bubbles inside the bulk of the substance. Bubble formation deeper in the liquid requires a higher pressure, and therefore higher temperature, because the fluid pressure increases above the atmospheric pressure as the depth increases.

The vapor pressure that a single component in a mixture contributes to the total pressure in the system is called partial vapor pressure.

Liquid pressure

When a person swims under the water, water pressure is felt acting on the person's eardrums. The deeper that person swims, the greater the pressure. The pressure felt is due to the weight of the water above the person. As someone swims deeper, there is more water above the person and therefore greater pressure. The pressure a liquid exerts depends on its depth.

Liquid pressure also depends on the density of the liquid. If someone was submerged in a liquid more dense than water, the pressure would be correspondingly greater. The pressure due to a liquid in liquid columns of constant density or at a depth within a substance is represented by the following formula:

$$P = \rho g h$$

where:

- *P* is liquid pressure
- *g* is gravity at the surface of overlaying material
- ρ is density of liquid
- *h* is height of liquid column or depth within a substance

Another way of saying this sameformula is the following:

$$P = \text{weight density} \times \text{depth}$$

Derivation of this equation

This is derived from the definitions of pressure and weight density. Consider an area at the bottom of a vessel of liquid. The weight of the column of liquid directly above this area produces pressure. From the definition:

$$\text{Weight density} = \frac{\text{weight}}{\text{volume}}$$

we can express this weight of liquid as

$$\text{Weight} = \text{weight density} \times \text{volume}$$

where the volume of the column is simply the area multiplied by the depth. Then we have

$$\text{Pressure} = \frac{\text{force}}{\text{area}} = \frac{\text{weight}}{\text{area}} = \frac{\text{weight density} \times \text{volume}}{\text{area}}$$

$$\text{Pressure} = \frac{\text{weight density} \times (\text{area} \times \text{depth})}{\text{area}}$$

With the "area" in the numerator and the "area" in the denominator canceling each other out, we are left with:

$$\text{Pressure} = \text{weight density} \times \text{depth}$$

Written with symbols, this is our original equation:

$$P = \rho g h$$

The pressure a liquid exerts against the sides and bottom of a container depends on the density and the depth of the liquid. If atmospheric pressure is neglected, liquid pressure against the bottom is twice as great at twice the depth; at three times the depth, the liquid pressure is threefold; etc. Or, if the liquid is two or three times as dense, the liquid pressure is correspondingly two or three times as great for any given depth. Liquids are practically incompressible – that is, their volume can hardly be changed by pressure (water volume decreases by only 50 millionths of its original volume for each atmospheric increase in pressure). Thus, except for small changes produced by temperature, the density of a particular liquid is practically the same at all depths.

Atmospheric pressure pressing on the surface of a liquid must be taken into account when trying to discover the *total* pressure acting on a liquid. The total pressure of a liquid, then, is $\rho gh +$ the pressure of the atmosphere. When this distinction is important, the term *total pressure* is used. Otherwise, discussions of liquid pressure refer to pressure without regard to the normally ever-present atmospheric pressure.

It is important to recognize that the pressure does not depend on the *amount* of liquid present. Volume is not the important factor – depth is. The average water pressure acting against a dam depends on the average depth of the water and not on the volume of water held back. For example, a large, shallow lake with a height of 3 m exerts only half the average pressure that the 6 m-tall small, deep pond does. A person will feel the same pressure whether his/her head is dunked a meter beneath the surface of the water in a small pool or to the same depth in the middle of a large lake. If four vases contain different amounts of water but are all filled to equal depths, then a fish with its head dunked a few centimeters under the surface will be acted on by water pressure that is the same in any of the vases. If the fish swims a few centimeters deeper, the pressure on the fish will increase with depth and be the same no matter which vase the fish is in. If the fish swims to the bottom, the pressure will be greater, but it makes no difference what vase it is in. All vases are filled to equal depths, so the water pressure is the same at the bottom of each vase, regardless of its shape or volume. If water pressure at the bottom of a vase were greater than water pressure at the bottom of a neighboring vase, the greater pressure would force water sideways and then up the narrower vase to a higher level until the pressures at the bottom were equalized. Pressure is depth dependent, not volume dependent, so there is a reason that water seeks its own level.

Direction of liquid pressure

An experimentally determined fact about liquid pressure is that it is exerted equally in all directions.[10] If someone is submerged in water, no matter which way that person tilts his/her head, the person will feel the same amount of water pressure on his/her ears. Because a liquid can flow, this pressure isn't only downward. Pressure is seen acting sideways when water spurts sideways from a leak in the side of an upright can. Pressure also acts upward, as demonstrated when someone tries to push a beach ball beneath the surface of the water. The bottom of a boat is pushed upward by water pressure (Buoyancy).

When a liquid presses against a surface, there is a net force that is perpendicular to the surface. Although pressure doesn't have a specific direction, force does. A submerged triangular block has water forced against each point from many directions, but components of the force that are not perpendicular to the surface cancel each other out, leaving only a net perpendicular point.[10] This is why water spurting from a hole in a bucket initially exits the bucket in a direction at right angles to the surface of the bucket in which the hole is located.Then it curves downward due to gravity. If there are three holes in a bucket (top, bottom, and middle), then the force vectors perpendicular to the inner container surface will increase with increasing depth – that is, a greater pressure at the bottom makes it so that the bottom hole will shoot water out the farthest. The force exerted by a fluid on a smooth surface is always at right angles to the surface. The speed of liquid out of the hole is $\sqrt{2gh}$, where *h* is the depth below the free surface.[10] Interestingly, this is the same speed the water (or anything else) would have if freely falling the same vertical distance *h*.

Kinematic pressure

$$P = p/\rho_0$$

is the kinematic pressure, where p is the pressure and ρ_0 constant mass density. The SI unit of P is m^2/s^2. Kinematic pressure is used in the same manner askinematic viscosity ν in order to compute Navier-Stokes equation without explicitly showing the density ρ_0.

Navier-Stokes equation with kinematic quantities

$$\frac{\partial u}{\partial t} + (u\nabla)u = -\nabla P + \nu\nabla^2 u$$

Notes

1. ^ The preferred spelling varies by country and even by industry. Further, both spellings are often used *within* a particular industry or country. Industries in British English-speaking countries typically use the "gauge" spelling. Many of the largest US manufacturers of pressure transducers and instrumentation use the spelling "gage pressure" in their most formal documentation sensotec.comHoneywell-Sensotec's FAQ page and fluke.com, Fluke Corporation's product search page.
2. ^ The usage of P vs p is context-driven. It depends on the field in which one is working, on the nearby presence of other symbols for quantities such as powerand momentum, and on writing style.

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