Pressure

Definition:
Pressure is the force (F) per unit area (A) applied on a surface in a direction perpendicular to the surface:

\[ P = \frac{F}{A} \]

The SI units of pressure is Pascal (Pa), where 1Pa = 1N/m²

For an object sitting on a surface the force pressing on the surface equals to the weight of that object (remember weight is a force (F=mass*acceleration; weight= Mg), not to be confused with mass).

Whether you think about it or not, the concept of pressure comes handy in many of your daily activities. The most obvious one is the use of a knife. If you use a blunt knife, the contact area with the object you are trying to cut is large and you have to apply more force to cut through. Sharpening the knife reduces the contact area and hence the force you need to apply.

What is vacuum? There is no difference between pressure and vacuum (both are force per unit area). Vacuum simply refers to part of the pressure scale; most commonly it means pressure below atmospheric pressure.

Pressure and fluids (air and water):
Air pressure is the force exerted on a surface by the weight of an air column above it. Earth’s atmosphere is pressing against you with a force of 1 kg per each cm² of your body (or 14.7 pounds per square inch). The total weight that the atmosphere exerts on your body will be similar to that of two elephants pressing on you equally in all directions (assuming total area of the human to be 17,000–18,000cm² that will translate to 17-18 tons). Atmospheric pressure decreases with increasing altitude. At any level in the atmosphere the pressure is regarded as the weight of air above a unit area at that elevation. At higher elevations, there are fewer air molecules (and hence smaller weight) compare to the same unit area at a lower elevation. The discomfort you feel in your middle ear when an airplane takes off is a testimony for the change in pressure with changing altitude.

Similarly when you dive the pressure on you is the weight exerting on your body by the atmosphere and water column above you. As you dive deeper and deeper the pressure increases (remember, water density is approximately 1000 larger than air density) at a rate of 1 atmosphere (=1.03kg/cm²) per 10 meter. This pressure is felt at air cavities which are compressible but not over much of the body which is fluid and thus mostly incompressible.
These pressures are termed “static pressures” or “hydrostatic pressures” and are found in fluids at rest (as opposed to additional, dynamics pressures, that are due to flow, see below). The pressure is exerted equally in all directions (even upward!). When a body is submerged in water (or air) the hydrostatic pressure outside it must offset by the hydrostatic pressure inside it, otherwise it will collapse (or expand). 

It is expressed as: \( P = \rho gh \) where \( \rho \) is the density of the fluid, \( g \) is gravitational acceleration and \( h \) is the height of the fluid. 

(Recall: \( P=F/A \) and \( F = \text{Weight} = M \times g \) the mass of a fluid is given by \( M = \rho \times V \) and the volume of the fluid is \( V = A \times H \) → \( P = (\rho Ah) \times g/A = \rho gh \).)

When fluids are moving, pressure becomes a more complicated concept to deal with. When work is done some energy can be gained or lost (but recall that the energy of the whole system is conserved). 

Like in solid mechanics, fluid mechanics involves several forms of energy:

1. \( e \)-internal energy per unit volume, comprised of kinetic and potential \textit{molecular} energy. This is stored energy that can be released.
2. \( PV \)-pressure-volume energy (\( P \)-pressure, \( V \)-volume).
3. \( Mgz \)-mechanical potential energy associated with the fluid’s mass (\( M \)-mass, \( g \)-gravitational constant, \( z \)-height). This is also stored energy that can be released
4. \( Mv^2/2 \)-mechanical kinetic energy that is proportional to the velocity (\( v \)) of the flow.

Consider a flow in a pipe. When no work is preformed and the a flow of an incompressible fluid is steady and frictionless (i.e., “ideal” fluid), the energy is conserved along the pipe and therefore the energy at point 1 along the pipe will be the same as the energy at point 2 along the pipe \( E_1 = E_2 \)

The total energy at each point is the sum of all forms of energy and hence

\[
M_1 \frac{v_1^2}{2} + M_1gz + P_1V_1 = M_2 \frac{v_2^2}{2} + M_2gz + P_2V_2
\]

Dividing by the mass

\[
\frac{v_1^2}{2} + gz + P_1\rho = \frac{v_2^2}{2} + gz + P_2\rho
\]

This is known as Bernoulli’s principle.

The applications of this low is that when flow is approaching a constriction and accelerates (as in a case of a pipe that its diameter suddenly decreases, see cartoon below), the pressure at the constriction must drop (to keep the energy equation balanced; Figure 1). Similarly, flow above a topography changes its velocity. This change in momentum is done by the pressure force. Fluid accelerates down a pressure gradient and decelerates when the pressure gradient reverses (Fig. 2).
Figure 1. Fluid above a hill (clam, boulder, etc') is accelerated (from High to low pressure) and decelerated (from low to high pressure) with lines representing...
streamlines. The pressure field supplies the force to accommodate that adjustment.

References:
Faber, T. E., 1995, Fluid dynamics for physicists, Chapter 1.