➢ Hardness

Hardness is a measure of how resistant solid matter is to various kinds of permanent shape change when a compressive force is applied. Some materials (e.g. metals) are harder than others (e.g. plastics). Macroscopic hardness is generally characterized by strong intermolecular bonds, but the behavior of solid materials under force is complex; therefore, there are different measurements of hardness: *scratch hardness*, *indentation hardness*, and *rebound hardness*.

Hardness is dependent on

: ductility, elastic stiffness, plasticity, strain, strength, toughness, viscoelasticity, and viscosity.

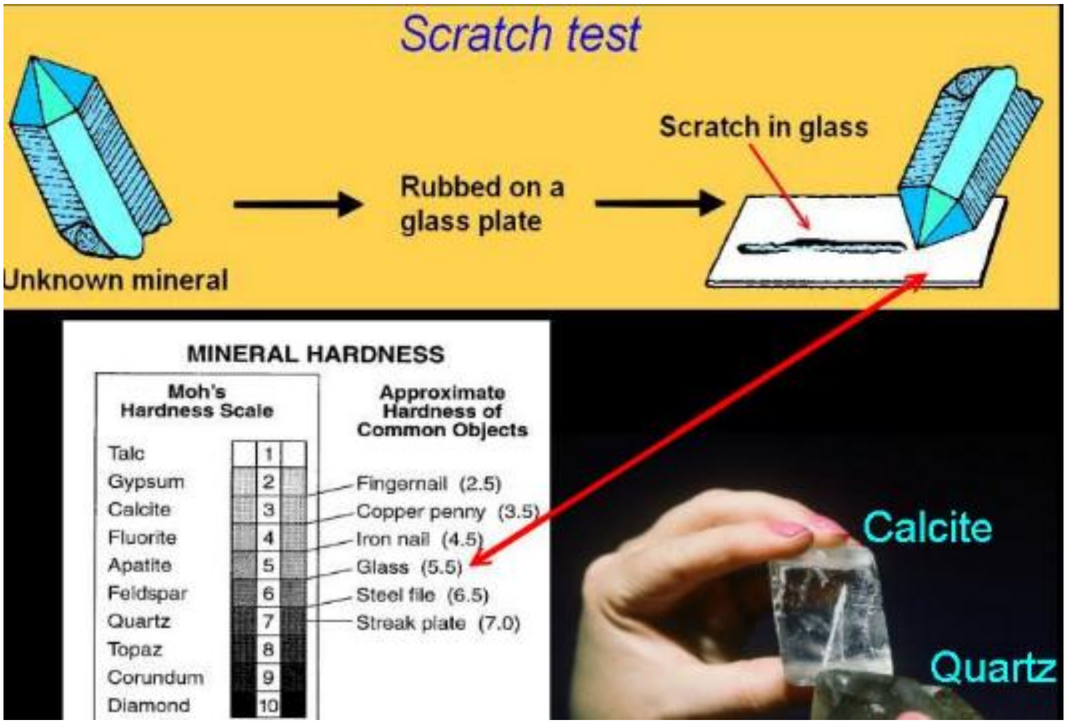
➢ Measuring hardness

There are three main types of hardness measurements: *scratch*, *indentation*, and *rebound*. Within each of these classes of measurement there are individual measurement scales. For practical reasons conversion tables are used to convert between one scale and another.

Scratch hardness

Scratch hardness is the measure of how resistant a sample is to fracture or permanent plastic deformation due to friction from a sharp object. The principle is that an object made of a harder material will scratch an object made of a softer material. When testing coatings, scratch hardness refers to the force necessary to cut through the film to the substrate.

In order to use it a weight of known mass is added to the scale arm at one of the graduated markings, the tool is then drawn across the test surface. The use of the weight and markings allows a known pressure to be applied without the need for complicated machinery.



The **Mohs scale of mineral hardness** is a qualitative ordinal scale characterizing scratch resistance of various minerals through the ability of harder material to scratch softer material. Created in 1812 by German geologist and mineralogist Friedrich Mohs, it is one of several definitions of hardnessin materials science

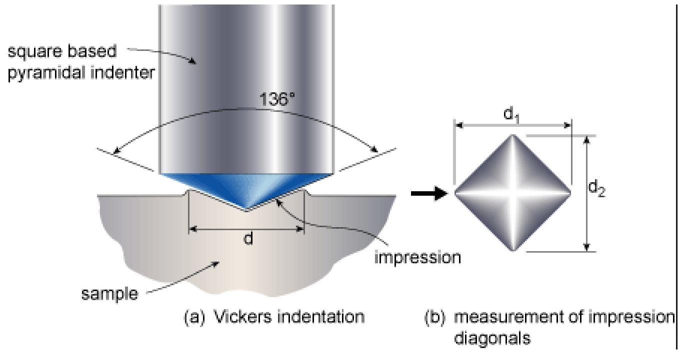
Indentation hardness

Indentation hardness measures the resistance of a sample to material deformation due to a constant compression load from a sharp object; they are primarily used in engineering and metallurgy fields. The tests work on the basic premise of measuring the critical dimensions of an indentation left by a specifically dimensioned and loaded indenter.

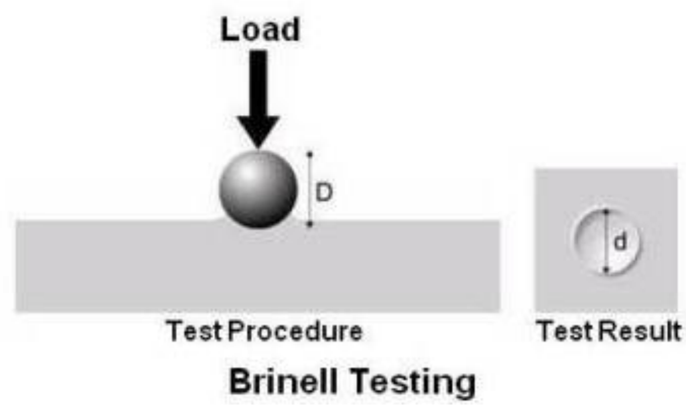
❖ Macro indentation tests

The term "macro indentation" is applied to tests with a larger test load, such as 1 kgf or more. There are various macro indentation tests, including:

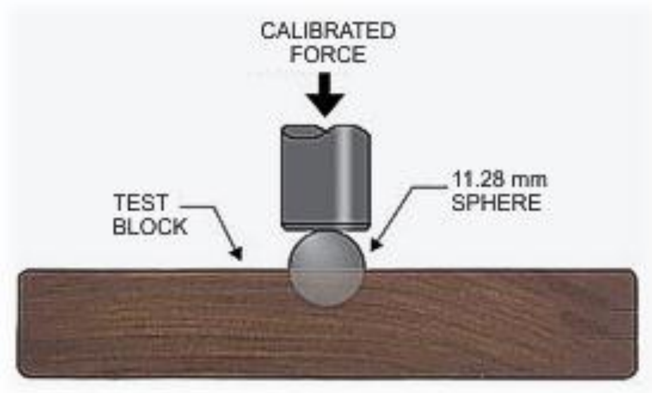
- Vickers hardness test (HV), which has one of the widest scales



- Brinell hardness test (HB)

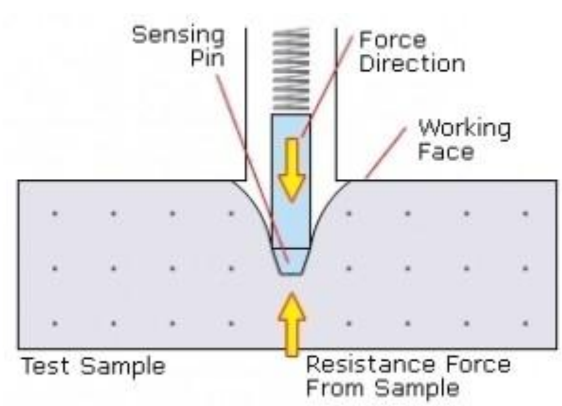


- Knoop hardness test (HK), for measurement over small areas
- Janka hardness test, for wood The Janka Side Hardness test measures the force required to press an 11.28mm (0.444 inch) steel ball to half its diameter cross-grain into a block of wood. This force is recorded in both pounds-force (lbf) and kilo-Newtons (kN).



- Meyer hardness test
- Rockwell hardness test (HR), principally used in the USA

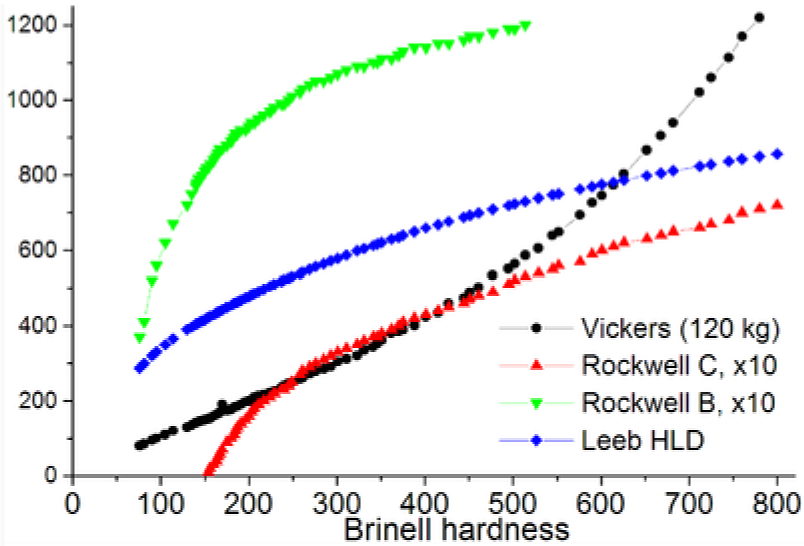
Shore hardness test, for polymers , rubbers and elastomers : **Durometer** is one of several measures of the hardness of a material.Higher numbers indicate harder materials; lower numbers indicate softer materials. Durometer is typically used as a measure hardness in polymers, elastomers, and rubbers , The A scale is for softer ones, while the D scale is for harder ones.



- Barcol hardness test, for composite materials.

The **Barcol hardness test** characterizes the indentation hardness of materials through the depth of penetration of an indentor, loaded on a material sample and compared to the penetration in a reference material. The method is most often used for composite materials such as reinforced thermosetting resins or to determine how much a resin or plastic has cured.

Hardness comparison table



❖ Microindentation tests

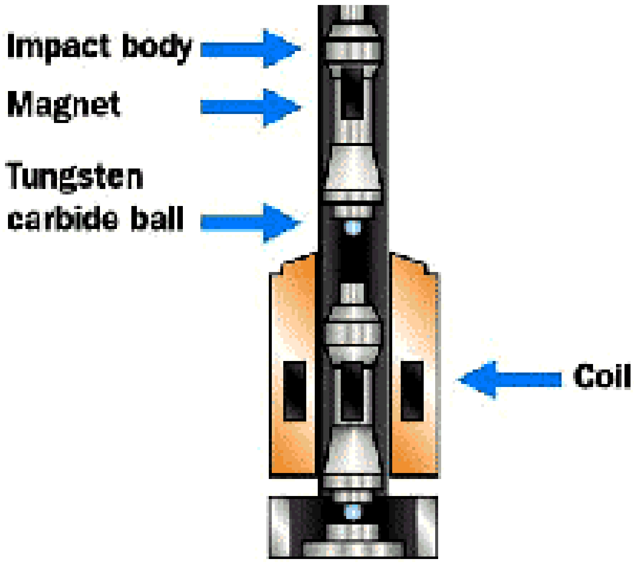
The term "microhardness" has been widely employed in the literature to describe the hardness testing of materials with low applied loads. A more precise term is "microindentation hardness testing." In microindentation hardness testing, a diamond indenter of specific geometry is impressed into the surface of the test specimen using a known applied force (commonly called a "load" or "test load") of 1 to 1000 gf. Microindentation tests typically have forces of 2 N (roughly 200 gf) and produce indentations of about 50 µm. Due to their specificity, microhardness testing can be used to observe changes in hardness on the microscopic scale. Unfortunately, it is difficult to standardize microhardness measurements; it has been found that the microhardness of almost any material is higher than its macrohardness.

Additionally, microhardness values vary with load and work-hardening effects of materials.[2] The two most commonly used microhardness tests are tests that also can be applied with heavier loads as macroindentation tests:

- Vickers hardness test (HV)
- Knoop hardness test (HK)

Rebound hardness

Rebound hardness, also known as *dynamic hardness*, measures the height of the "bounce" of a diamond-tipped hammer dropped from a fixed height onto a material. This type of hardness is related to elasticity. The device used to take this measurement is known as a scleroscope ,Two scales that measures rebound hardness are the Leeb rebound hardness test and Bennett hardness scale.



Materials and hardness :

A comparison of hardness of some typical materials:

Material	Brinell Hardness
Pure Aluminum	15
Pure Copper	35
Mild Steel	120
304 Stainless Steel	250
Hardened Tool Steel	650/700
Hard Chromium Plate	1000
Chromium Carbide	1200
Tungsten Carbide	1400
Titanium Carbide	2400
Diamond	8000
Sand	1000

Relation between hardness and strength

For many materials , relationship between ultimate strength and Brinell hardness number is roughly linear :

For steel :

$\sigma_{ult} = 3.4$ **HB (MPa)**

For Cast Iron

$\sigma_{ult} = 1.58$ **HB (MPa)**

Vibration

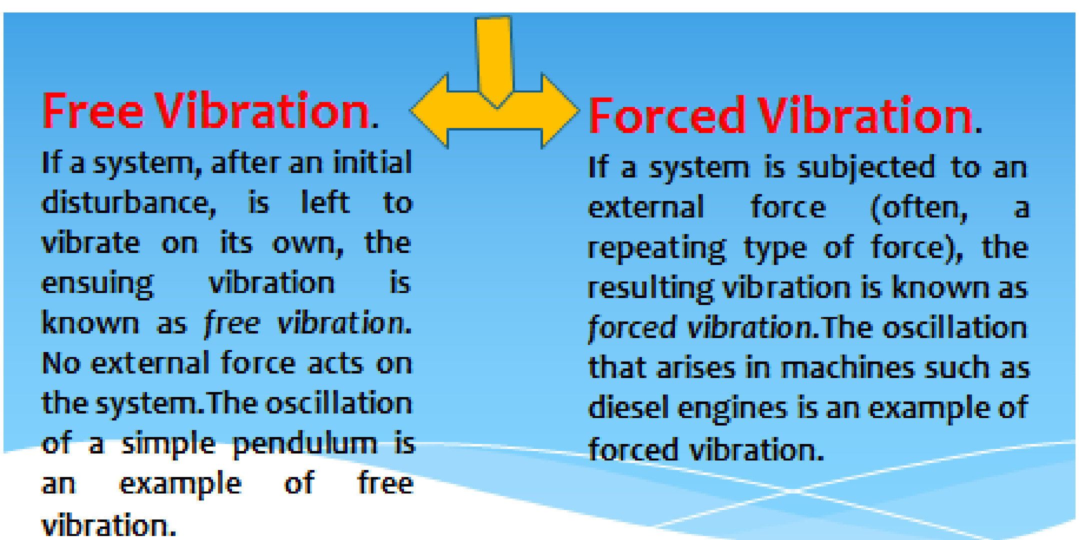
Any motion that repeats itself after an interval of time is called *vibration* or *oscillation*. The swinging of a pendulum and the motion of a plucked string are typical examples of vibration. The theory of vibration deals with the study of oscillatory motions of bodies and the forces associated with them.

A vibratory system, in general, includes a means for storing potential energy (spring or elasticity), a means for storing kinetic energy (mass or inertia), and a means by which energy is gradually lost (damper).

The vibration of a system involves the transfer of its potential energy to kinetic energy and of kinetic energy to potential energy, alternately. If the system is damped, some energy is dissipated in each cycle of vibration and must be replaced by an external source if a state of steady vibration is to be maintained.

Classification of Vibration

Vibration can be classified in several ways. Some of the important classifications are as follow:



Failures by Vibration

If the frequency of the external force coincides with one of the natural frequencies of the system, a condition known as *resonance* occurs, and the system undergoes dangerously large oscillations. Failures of such structures as buildings, bridges, turbines, and airplane wings have been associated with the occurrence of resonance.

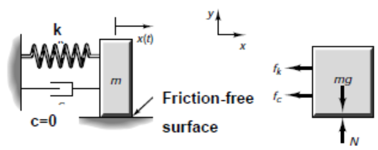
Case study

In April 1831, a brigade of soldiers marched in step across England's Broughton Suspension Bridge. According to accounts of the time, the bridge broke apart beneath the soldiers, throwing dozens of men into the water.

After this happened, the British Army reportedly sent new orders: Soldiers crossing a long bridge must "break stride," or not march in unison, to stop such a situation from occurring again.

Structures like bridges and buildings, although they appear to be solid and immovable, have a natural frequency of vibration within them. A force that's applied to an object at the same frequency as the object's natural frequency will amplify the vibration of the object in an occurrence called mechanical resonance.

Free-body diagram and equations of motion



- Newton's Law:

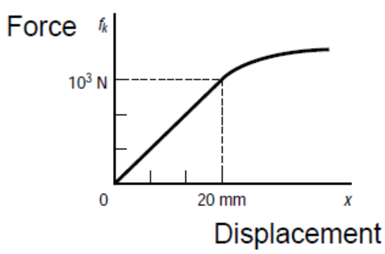
$$m\ddot{x}(t) = -kx(t)$$

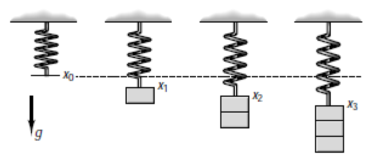
$$m\ddot{x}(t) + kx(t) = 0$$

$$x(0) = x_0, \dot{x}(0) = v_0$$

Stiffness

- From strength of materials (Solid Mech) recall:





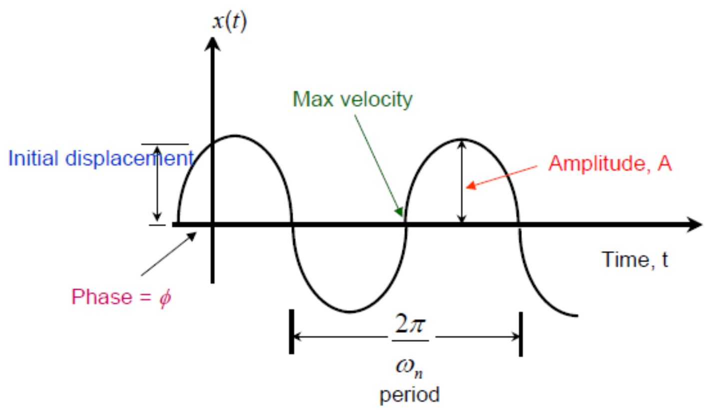
2nd Order Ordinary Differential Equation with Constant Coefficients

$$\text{Divide by } m : \ddot{x}(t) + \omega_n^2 x(t) = 0$$

$$\omega_n = \sqrt{\frac{k}{m}} \ : \ \text{natural frequency in rad/s}$$

$$x(t) = A\sin(\omega_n t + \phi)$$

Periodic Motion



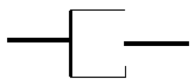
Example For m= 300 kg and ω_n =10 rad/s compute the stiffness:

$$\omega_n = \sqrt{\frac{k}{m}} \Rightarrow k = m\,\omega_n^2$$

$$= (300)10^2 \text{ kg/s}^2$$

$$= 3 \times 10^4 \text{ N/m}$$

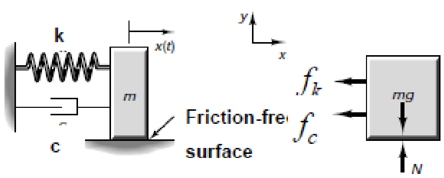
Linear Viscous Damping



$$f_c = c\dot{x}(t)$$

- A mathematical form
- Called a dashpot or viscous damper
- Somewhat like a shock absorber
- The constant c has units: Ns/m or kg/s

Spring-mass-damper systems



- From Newton's law:

$$m\ddot{x}(t) = -f_c - f_k$$
$$= -c\dot{x}(t) - kx(t)$$
$$m\ddot{x}(t) + c\dot{x}(t) + kx(t) = 0$$
$$x(0) = x_0,\ \dot{x}(0) = v_0$$

Divide equation of motion by m

$$\ddot{x}(t) + 2\zeta\omega_n\dot{x}(t) + \omega_n^2 x(t) = 0$$

where $\omega_n = \sqrt{k/m}$ and

$$\zeta = \frac{c}{2\sqrt{km}} = \text{damping ratio (dimensionless)}$$

$$\zeta = \frac{c}{c_{cr}} :$$