**Rotational dynamics**:

The equivalent of force for rotation is the moment of force.

The equivalent of mass for rotation is the moment of inertia.

The equivalent of linear velocity for rotation is the angular velocity.

The Second Law of Newton for rotation then can be written with these substitutions.

M = Jε, here M the is moment of force, J is the moment of inertia (or tensor of inertia for the most general case of rotation of a rigid body) and ε is angular acceleration (this is the Law of Newton for rotation).

F =ma (Law of Newton for translation)

**Static** equilibrium means that all forces and moments are zero.

**Chain**, which is very light and holds very heavy uniform bridge, takes the form of a **parabola**.

**Chain line** of a heavy chain attached to nothing is expressed though the **cosh**.

**Internal forces** are visible in a free-body diagram, where constraints are substituted with forces.

An internal force cannot change the location of the center of mass of a mechanical system: I cannot pull myself out of the mud.

Only **external force** can change the location of the center of mass of a mechanical system.

The main **theorems** of theoretical mechanics are as follows:

Linear momentum change theorem says that change in linear momentum is equal to the external force.

$$\frac{d(mv)}{dt}=F\_{e}$$

Angular momentum change theorem says that change in angular momentum is equal to the moment of the external force.

$$\frac{d(Jω)}{dt}=M\_{e}$$

Kinetic energy change theorem says that change in kinetic energy is equal to the sum of works of external and internal forces.

$$∆\left(KE\right)=W\_{e}+W\_{i}$$

This is the most general theorem of theoretical mechanics, which allows solving any problems.

The **implications** of theoretical mechanics are in applying a moment to the most loaded wheels of a vehicle because the rolling friction helps the motion whereas the sliding friction opposes the motion casing lots of waste of energy. Thus, the 4-wheel drive is more effective and efficient than if the moment is not applied to all wheels of a vehicle.

**Hook’s Law** links the force and displacement of a structure: F = -kx. Here k is the **modulus of Hook**, k is often called E. This is the **elastic** case. The function is **linear**. Here the **deformation** is **reversible**: when force is removed, the system is return to its original state before the deformation.

For **plasticity** and **creep** the deformations are irreversible and the functions are always non-linear.

The equations of elasticity, plasticity, creep and **fracture** theories are often expressed in a tensor form, linking the stress tensor with the strain tensor through the tensor of physical constants:

$$σ\_{ij}=C\_{ijmn}ε\_{mn}$$

Here $σ\_{ij}$ is a stress tensor, $C\_{ijmn}$ is a tensor of physical constants of the material linking stresses with strains, and $ε\_{mn}$ is the stain tensor.

A tensor is a generalization of a vector for the cases when directions matter.

If the **ultimate strength** is exceeded then the structure **fails**.

**Fluids**:

 = m/V

P = F/A

P = gh

**Bernoulli’s law**

**Oscillations**:

The solution for the harmonic oscillator problem is y = Asin(ω0t+p). Here y is the oscillating physical quantity with the amplitude A, natural frequency ω0 or resonant frequency, the initial phase p, and t is time.

This equation is mathematically identical for the oscillation of a pendulum, mass on a spring in classical mechanics and an LC-circuit in electrodynamics.

For the mass on a spring $ω\_{0}=\sqrt{\frac{k}{m}}$ and the period $T=2π\sqrt{\frac{m}{k}}$.

For the pendulum $ω\_{0}=\sqrt{\frac{g}{L}}$ and the period $T=2π\sqrt{\frac{L}{g}}$.

For the LC-circuit $ω\_{0}=\sqrt{\frac{1}{LC}}$ and the period $T=2π\sqrt{LC}$.

**Resonance** (infinite increase of the amplitude) occurs when the frequency of the external force is equal to the natural frequency.

**Waves** are spread of oscillations in space.

**Transverse** waves

**Longitudinal** waves

The oscillation can be **damped**

The **intensity** of a wave is inversely proportional to the inverse square of the distance to the source

**Wave front**

**Reflection: angle of incidence = angle of reflection** (same as for light)

**Interference, refraction** and **diffraction**

The **wave equations** are as follows:

v = fλ. Here v is the velocity of the wave, f is its frequency and λ is its length.

The period of the wave T = 1/f.

For waves in a **string** the **wave equation** and its solution are as follows:

Equation: $\frac{∂^{2}y}{∂t^{2}}=v^{2}\frac{∂^{2}y}{∂x^{2}}$, solution: y = sin(x-vt), here v is the velocity of the wave across the string, x is the space coordinate and t is time coordinate. Here the waves are **standing**. These frequencies are called **fundamental**.

These equation and solution are mathematically identical to electromagnetic case, to the solution of the simplified Maxwell’s equations, only v is substituted with c, which is the speed of light.

The most common wave equation in physics is the Schrödinger’s equation but it is an equation of quantum physics and not the classical mechanics, which is mainly considered here.

**Pitch** is the frequency of a **sound**.

The **speed of sound** is approximately 343 m/s in the air at 20 degrees Centigrade.

For **sound** waves the effect of **Doppler** holds just like for electromagnetic waves. This is the result of the constancy of the velocity of the wave.

A moving towards an observer object radiates the wave of the higher frequency, when reaching the observer the frequency is natural, and away from the observer – lower frequency.

The **intensity** of the sound or **loudness** is measured on the decimal logarithmic scale.

The **audible range** of sound for humans is from 20 Hz to 20 kHz = 20000 Hz.

Infrasound has lower frequency than 20 Hz.

Ultrasound has higher frequency than 20 kHz.

**Harmonics** or **overtones**

**Open tube**

**Closed tube**