More about force

See also : Force-basics

1. Inertia force

[*Note:* This is the approach used by engineers. Physicists tend to treat inertia force as being fictitious - see Section 4]

When a mass *m* is being accelerated at a rate *a* m/sec^2, it provides a resisting force i.e. a force in the opposite direction to that of the motion. This force is a basic property of matter.

The value of this resisting force, $F_{in.}$ is:

$$F_{in} = ma \qquad (1)$$

If a mass *m* is decelerated at a rate -*a,* it provides a motive force i.e. a force in the direction of motion.

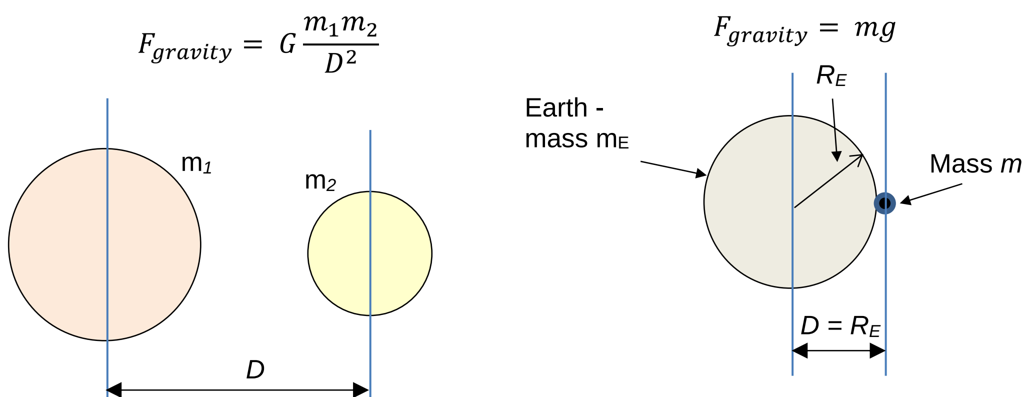
The inertia force is a special case of the momentum force -see Newton's Laws.

Gravity force

Newton's Universal Law of gravity states that two masses, m_1 and m_2, are drawn towards each other by a force that is proportional to the product of the masses divided by D^2, where *D* is the distance apart of the centres of gravity of the masses. This law is expressed as

$$F_{gravity} = G\frac{m_1 m_2}{D^2} \qquad (2)$$

where G is the Universal Gravity constant



(a) Gravity force between 2 masses

(b) Gravity force between a mass and the Earth

Figure 1 Gravity force

The gravity force that we normally identify is due to a the attraction of a mass *m* at the surface of the Earth and the mass of the Earth itself - m_E . If in equation (4) the following substitutions are made:

$m_1 = m$

$m_2 = m_E = 5.9736 \times 10^{24}$ kg

G = 6.67428×10^{-11} m^3/kg/sec^2

$D = R_E =$ 6371 km (mean radius of the Earth)

then Equation (2) becomes :

$F_{gravity}$ = m*6.67428^{-11}*5.9736^{24}/6371000^2 = m*9.82 Newtons

i.e. $F_{gravity} = mg$ (3)

where g is the local gravity constant = 9.82 m/sec^2

g has the same dimensions as acceleration but it is a gravity constant. It is often described as the 'acceleration due to gravity' but this is only true in the special case of a mass falling in a vacuum near the surface of the earth.

Weightlessness

The condition of being weightless has two meanings:

- When the effect of gravity on a body is negligible, e.g. a body in space where the effect of gravity from celestial bodies is negligible.
- When the effect of gravity is not perceptible due to it being balanced by other forces, e.g. for a mass falling towards the Earth in a vacuum where only gravity and inertia forces are present or for a situation where the gravity and centrifugal forces are in balance

2. Types of Force

Gravity force

Universal gravity: $F = Gm_1m_2/D^{2,}$

Local gravity: $F = mg$

Spring force: $F = Ku$ for a linear spring

Forces due to change in momentum:

Inertia force: $F = md^2u/dx^2 = ma$ (change in velocity, no change in mass)

'Rocket' force: $F = v_e dm/dt$ (no change in velocity, change in mass)

Momentum force: $F = d(mv)/dt$ (both velocity and mass change)

Centrifugal force: $F = m\omega^2 r$

Friction forces:

Static friction: Force that prevents the body from moving relative to the surface

Sliding Friction: $F = \mu N$

Rolling Friction: $F = C_{rr} N$

Surface friction (drag): $F = \rho C_d v^2 A^2$

Gas/liquid pressure force: $F = qA$

Damping force: e.g. force proportional to velocity: $F = Cdu/dt$

Hydrostatic force: due to force of gravity on the liquid: $F = \rho ghA$

Magnetic forces

Nuclear forces

3. Conceptual Frameworks for Force

This section discusses differences in how physicists and engineers work with force relationships when acceleration is involved. The diagram shows a basic model of a dynamic system. A mass m is restrained by a spring of stiffness K m/N and an applied (i.e. motive) force - $F(t)$ - that changes with time, is applied to it. Only movement in the

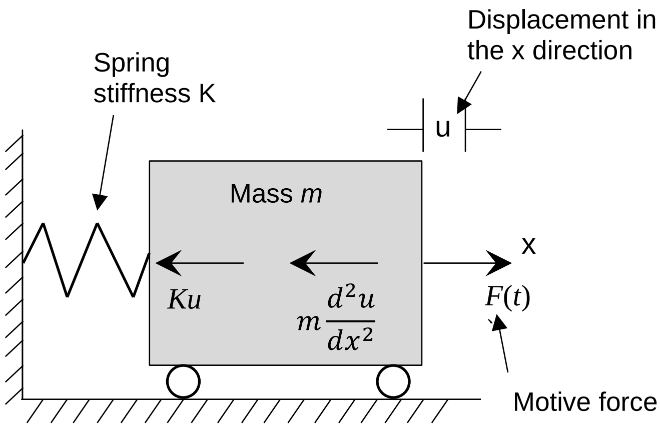


Figure 2 Mass and spring model

x direction is considered. Friction and damping are neglected. The spring force is a resisting force with the value Ku.

Physicists' approach

For this situation, a physicist is likely to base the relationship for the forces on Newton's Second Law of Motion as:

$$m\frac{d^2u}{dx^2} = F(t) - Ku \qquad (4)$$

i.e. mass x acceleration = net motive force

= sum of the motive forces minus the sum of the resisting forces

The $m\frac{d^2u}{dx^2}$ (mass x acceleration) term is not considered to be a real force. It is a 'fictitious force'. Hence the motion would be considered to be 'out of balance' by an amount $F(t) - Ku$.

If the applied force does not vary with time, then the $m\frac{d^2u}{dx^2}$ term is zero, the system is in a *static* state and the expression would be:

$$F(t) - Ku = 0.0 \qquad (5)$$

The concept of *equilibrium* applies only to static situations. Therefore Equation (5) is an equation of equilibrium. Equation (4) is not considered to be an equation of equilibrium.

For physicists, the *equations of motion* are those that relate displacement, velocity and acceleration e.g. *u = v + at*

Engineers' approach

An engineer is likely to base the relationship for the forces in Figure 1 on the *equilibrium condition* as:

$$F(t) = m\frac{d^2u}{dx^2} + Ku \qquad (6)$$

i.e. Sum of applied forces = sum of resisting forces.

The $m\frac{d^2u}{dx^2}$ term is an *inertia force.* It acts in the opposite direction to that of the acceleration i.e. it is a resisting force for acceleration and a motive force for deceleration. Equation (6) is identical to (4) but is defined as an equilibrium equation. This can be justified by the *d'Alembert principle of inertia forces* that an accelerating body at a point in time can be treated as an equivalent static system; the resulting equations represent *dynamic equilibrium*.

Equation (6) is valid for a body as a whole, for a part of a body and for the interaction between bodies. In this form it can be viewed as a general statement of Newton's Third Law (that refers only to forces between bodies).

Engineers tend to describe Equation (6) as an *equation of motion.*

Summary

Whether or not 'equilibrium' refers only to static situations and what is meant by 'equation of motion' are semantic issues but whether the mass x acceleration term should or should not be treated as a force is a philosophical issue.

Since both approaches lead to the same outcome, either is valid but it may be important to know about them.

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