I. General Physics

1. Newton's First Law of Motion Equuilibrium

Newton's first law of motion states that a body will be at rest or moving with constant velocity along a straight line when either it is free from all external forces or the resultant of all external forces acting on it is zero.

Strictly speaking, no body in the universe is ever completely free from external forces. Newton's first law, therefore, finds its practical applications in bodies under zero resultant forces.

A body is to be in equilibrium (or, more strictly, translational equilibrium) when it is at rest or moving with constant velocity along a straight line.

Therefore it is inferred from Newton's first law that for a body to be in qquilibrum the resultant of all external for forces on it must be zero. But the resultant force can be on only when both its x-component and y-component are zero, hence, for a body to be in equilibrium we must have

$$R_x = \quad F_x = 0 ,$$

$$R_y \equiv \quad F_y = 0 ,$$

These equations are called the condition for equilibrium and are extensively used for solving problems of statics

From the following example the reader will see for himself how a systematic procedure is followed in solving problems of statics by method of equilibrium.

Example 1-2 **Find** the tesions in the strings 1,2,and 3 in fig.10.

Solution It is found usdful, in solving a problem of statics, to isolate a body under consideration from its surroundings and sketch a diagram of the body with all the forces acting on it. This is called the free-body diagram no forces exerted by the body should be included.

First, draw the free-body diagram of the hanging body. See, fig.1-11(a). It is acted on by the upward pull T1 and the downward gravity W. Equilibrium condition in the y-direction gives

$$F_y - T_1 - W = 0 ,$$

or $$T_1 = W \qquad (a)$$

Second, regard string 1 as a body under consideration (part b of the figure). As its weight is negligible, it is also acted on by two forces in the y-direction, viz, the upward pull T_1'' of the knot o and the downward pull T_1' of the body, which is the reaction to T_1. Equilibrium condition gives

$$F_y = T_1'' - T_1' = 0 ,$$

$$T_1'' = T_1' \qquad (b)$$

Third, consider the knot O. As shown in the free-body diagram (part c of the figure), it is acted on by the pull of three strings, T_1''', T_2 and T_3, of which T_1''' is the reaction to T_2''. Resolving T_2 and T_3 into their respective x- and y-components and applying the condition for equilibrium, we obtain

$$F_x = T_3 \cos\theta_3 - T_2 \cos\theta_2 = 0,$$

$$F_y = T_2 \sin\theta_2 + T_3 \sin\theta_3 - T''' = 0 ,$$

From the first equation we get $T_3 = T_2 \cos\theta_2 / \cos\theta_3$, and then substitute it in the second to obtain

$$T_2(\sin\theta_2 + \sin\theta_3 \frac{\cos\theta}{\cos O}) = T_1'''$$

or $$T_2 = \frac{T_1'''}{\sin\theta_2 + \sin\theta_3 \dfrac{\cos\theta_2}{\cos\theta_3}}$$

$$= \frac{T_1''' \cos\theta_3}{\sin\theta_2 \cos\theta_3 + \sin\theta_3 \cos\theta_2} \qquad (c)$$

We notice that to obtain the final solution, eqations(a), (b) and (c) resulting from Newton's first law should be combined with the following action-and-reaction relations obtained from Newton's third law:

$$T_1 = T_1'$$

and $$T_1'' = T_1'''$$

The final expressions for T_2 and T_3, after employing a familiar trigonometric identity, are

$$T_2 = \frac{W \cos\theta_3}{\sin(\theta_2+\theta_3)}$$

and $$T_3 = \frac{W \cos\theta_2}{\sin(\theta_2+\theta_3)}$$

From this example we have seen that a weightless strin can transmit a pull without changing its magnitude, as a conclusion of the application of Newton's first and third laws.

2. Inertia Mass

1. Inertia

That a body, in the absence of applied forces, remains at rest or in uniform motion along a straight line is attributed to a property of the body called inertia. It is because of this that Newton's first law is sometimes called the law of inertia.

the law of inertia.

When a force acts on a body, the body no more continues in its state of rest or of uniform motion, but undergoes a change in its state of motion. Does the body in accelera-tion still have its inertia? In other words, does the tendency to remain in its orignal state of motion still exist The answer is "yes". Imagine a force, acting on body A (a cart, say), produces an acceleration of 1 m/s^2, while the same force acting on body B (a wheelb arrow, say), produces an acceleration of 2 m/s^2. Why is the acceleration of body A equal to 1 m/s^2 and not 2 m/s^2, and why is the accelera-tion of body B equal to 2 m/s^2 and not more(say 4 m/s^2)? It is obvious that body A is more "reluctant" to change its velocity than body B, and body B may still be more reluctant to change its velocity than a third body which, under the same force, will have an acceleration of 4 m/s^2. Reasoning this way, we may say that, ever body shows more or less "reluctance" with which it changes its velocity under the action of a given force, unless its acceleration is infinity, which is, of course, impossible. This reluctance maifests the body's inertia.

Every material body has its inertia, no matter whether it is at rest, in unform motion, or in accelerated motion. Inertia is an intrinsic property of matter.

2. Mass

Mass is measured on an equal-arm balance. When a body of known mass is in balance with a body of unknown mass, their masses are said to be equal. The unit of mass is the kilogram.

When two bodies of masses m_1 and m_2, are acted on by equal forces (as indicated by the equal readings of the spring balances or by the equal weights shown in fig.), It is found that the rstio of their accelerations equals the reciprocal of the ratio of their masses, or

$$\frac{a_1}{a_2} = \frac{m_2}{m_1}$$

In other words, under the action of a given force the acceleration is inversely proportional to the mass, or

$$a \quad \frac{1}{m}$$

If $m_1 \quad m_2$, then $a_2 \quad a_1$. The body of greater mass has the smaller acceleration. This means that this body is more difficult to accerate than the body of smaller mass.

Mass is a quantitative measure of inertia.*

3. Newton's Second Law

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Experiments using similar set-up as that shown in fig. can be done with a definite mass and different forces(fig

It is found that for agiven mass, the acceleration is directly proportional to the applied force, or

$$a \quad F$$

Combining eqs.(3-2) and (3-3) we obtain

$$za \quad \frac{F}{M},$$

or

$$a = k\frac{F}{m},$$

where k is a proportionality constant. whose value depends on the unit systm.

The SI unit of force is the newton(N). A newton is the force that will impart to a body of mass 1 kg an acceleration 1 m/s^2.

In this system the value of k reduces to unity. Hence we have

$$F = ma$$

This is the mathematical expression for Newton's second law

Force and acceleration are both vector quantities, It is found by exeriment that the acceleration is always in the direction of the force, regardless of the direction of the velocity. Thus, if the applied force has the same direction of the force(fig.3-3a).If the applied is opposite in direction to the velocity, the motion of the body is retarded,it moves more and more slowly until it stops and then reverses its direction of motion and begins to move faster and faste (fig.3-3b), provided that the force continues to act. If the applied force makes an angle with the velocity, the velocity will change, in general, both in magnitude and in direction (fig.3-3c). Thus Newton's second law can be written in the vector form:

$$\bar{F} = m\bar{a} \qquad (3-5)$$

As long as a constant force acts on a body, the motion is that of uniform acceleration. As soon as the force chang (in magnitude or in direction or both), the acceleration changes instantly. At the moment the force ceases to act, the motion becdmes uniform, that is, the acceleration stops at the same moment. Thus the relation between the force and the acceleration as defined by eq.(3-5) is one of instantaneous nature.

In the above we have assumed that the body is acted on by a single force. But this is hardly ever the actual case. When several force act on a body, each produces its own acceleration according to Newton'ssecond law independently of other forces. The resulting acceleration is the vector sum oof the several independnt accelerations. This is called the principle of indepedence. By virtue of this principle and the vector nature of force and acceleration, the resultant force and the resultant acceleration bear the same relation as an individual force and the acceleration it produces (fig.3-4). Thus if the acceleration in Newton's second law is understood to mean the resultant one, the force should also mean a resultant force.

If the body is a composite one, different parts of the body may interact with each other. The force with which one part of a body acts on another is called an internal force. Internal forces, existing in action-and reaction pairs, act on different parts of the same body. When the body is considered as a whole, these interal forces counteract each other and produce no acceleration of the body. The force in Newton's second law, therefore, refers to external forces only.

In summary, we may state Newton's second law as follows: When the resultant external force on a body is not zero, it produces an acceleration of the body. The acceleration of the body at any instant has the same direction as the resultant externalforce at that instant, and the magnitude of the acceleration is in direct proportion to the magnitude of the resultant external force at that instant, and is ininverse proportion to the mass of the body.

It is sometimes convenient to resolve forces and accelerations into orthogonal components and write Newton's law in the component form

$$F_x = ma_x,$$

$$F_y = ma, \qquad (3\text{-}6)$$

where F_x and F_y are the algebraic sums of the x- and y-components of forces respctively.

Whenaa body is acted on by its weight alone, its acceleration is that duo to gravity g. The weight of abody, according to Newton'ssecond law, can thus be written as

$$W = mg. \qquad (3\text{-}6)$$

This equation is valid whether the body is falling freely with acceleration g, or stays at rest, or in any other motion. As the value of g is a constant independent of the mass of the body, we see from this equation that weight of abody is in direct proportion to its mass. This is what distinguishes the gravitational attrction from other types of forces.

4. Newton's Third Law

Actions And Reactions

When body A exerts a force on body B, body B exerts at the same time on body A another force which is equal in magnitude but opposite in direction and has the same line of action. This is a statement of Newton's third law of motion Either force between the two bodies can be called the action, and the other the reaction.

Newton's third law is sometimes simply worded as:

Action and reaction are equal, opposite and colinear.

According to this law, forces always occur in pairs. A sinfle isolated force does not exst.

A few points regar ding Newton's third law should be metioned here.

(1) Action and reaction act on different bodies. Equal and opposite as they are, they cannot balance each other. Instead, they produce different results on the respective bodies.

(2) Action and reaction start, vary, and cease simultaneneously.

(3) Action and reaction are forces of the same nature. Consider ablock resting on atabletop, as shown in fig.1-4 (a). There are two action-reaction pairs(part b): (1)the weight of the block W which is the attraction the earth exerts on the block, and its reaction------the attraction the block exerts on the earth(not shown in the figure because it should be drawn at the center of the earth). Both are gravitational attractions (2) The normal supporting for force N the tabletop exerts on the block and the pressure N' the block exerts on the tabletop. Both arise from deformations and are of elastic origin. Further, if we push the block in the horizontal direction(part c), two more pairs of action and reaction come into play(part d):(3)The push F, and its reaction-----the force F' the block exerts

on the figure; both are e;astic forces. (4) The friction exerted on the block by the tabletop, and the fri.tion F' exerted on the tabletop by the block. Both are frictional forces.

N = N' and f = f' by Newton's third lar. What is the relation between W and N? Between F and f? Are they necessarily equal all conditions? The answer will be found in chapter 2.

In order to find the reaction to a known force, you have only to read backward the description of the force, e.g., for "earth on block", you read "block on earth", and then see if they are of the same nature. If they are, you havve got the reaction right,

Example 1-1 What is the force that pushes a mansforward when he walks?

Reasoning While his left leg is stepping forward, his right foot "kicks" backward. If the ground were perfectly smooth the right foot would slip back on the ground. Actually, the backward slipping of the foot is prevented by the static friction. It is therefore the static friction that "pushes" the man forward.

Example 1-2 In a tug-fo war, does the team that wins pull with a greater force?

Reasoning No. The action and reaction between team A (winner) and the rope, namely, F_1 and F_1' in fig. 1-6, and those between hhe rope and team B, namely, F_{11} and F_2', are respectively equal by Newton's third law. Neglecting the mass of the rope, we can say that the forces on its ends are equal and opposite (by virtue of Newton's second law), i.e., $F_1 = F_2$. It follows that $F_1' = F_2'$. This suggests that we treat the rope as a medium for transmitting the force between the teams. F_2' and F_1' can thus be considered as action an and reaction between the teams through the rope. They are always equal. Team A cannot increase its pull without at the same tame increasing the pull of team B by the same amount.

The winner will be the team that gets a firmer grip on the ground, i.e., the team that presses harder on the ground and gets a greater frictional reaction from it. As we have assumed team A to be the winner, the friction force f_1 it gets frome the ground is greater than f_2 ---- the friction on team B. Thus, we have, for the forces on the two teams respectively,

$$f_1 \quad F_1' \qquad\qquad F_2' \quad f_2$$

It is obvious now that the whole system will move in the direction of team A.

5. Conservation of Energy

Let us rewrite the work-energy theorem with the potential energy taken into account

$$W = Em_2 - Em \qquad (5\text{-}1)$$

Here we have us d the subscript m to denote mechanical ene ergy. In this equation, W is the work done by forces other than the gravitational force and the elastic force. The work done by such forces has always been found to associa- ted with a change in some form of energy. The work of fric- tional forces is associated with the increase of heat, or internal energy of a body. A temperature rise is usually observed after an inelastic collision or after a block has been pulled along a rough floor. The work done during the explosion of a bomb is associated with the release of the chemical energy from the dynamite. Thus we can associate the work of non-gravitional, non-elastic forces with a change in the relevant energy by

$$W = -(E_{11}' * E_1') \qquad (4\text{-}2)$$

where E' denotes the sum of all other forms of energy. The minus sign can be checked against the facts: When friction does negative work, the internal energy increases. When explosive forces do positive work, chemical energy decreases Substituting eq. (4-2) into eq. (4-1), we obtain

$$Em1 + E1' = Em2 + E''. \qquad (4\text{-}3)$$

This equation has taken all kinds of energy into account, and is called the conservation of energy which may be stated as:

Energy can neither be created nor destroyed, it can only be transformed from one kind to another, total energy being conserved.

This is one of the fundamental laws of nature. It provides a unified description of all types of motions taking plce in the material word.

Questions

1. A steel bolt is resting on a table while a magnet is dropped from above(fig.4-1). Under the attraction of the magnet, the bolt jumps up to meet it in the air, get stuck to it, and then they fall together. Let it be suppoed that at the instant the bolt leaves the tabletop from rest, the falling magnet has a velocity v, directed downward, and that the bolt remains in the air for a time t before falling to the table. What is the velocity with which they hit the tabletop? The masses of the magnet and the bolt are known to be m1 and m2 respectivrly.

2. While a car is driving at 36km/hr (10m/s) on a level road, the driver steps hard on the gas so as to double the power output of the engine(originally 10kW). What is the acceleration of the car at this instant? Describe the subseqent motion of the car if the power output is then kept constant, Will it eveturally attain a steady speed? If so,

what is it?

3. Which of the following quantities

(a) momentum

(b) the magnitude of momentum

(c) kinetic energy

(d) mechanical energy

of a system consisting of two balls remains unchanged:

(1) at the beginning and the end of an elastic collision,

(2) throughout the elastic collision?

4. Show that in addition to eqs.(4-) and (4-), $v1' = v1$ and $v2'$ are also roots of the simultaneous equations of energy conservation and momentum conservation. (Theoretically quadratic simultaneous equations should have two pais of roots). Discuss the possible physical meaning of roots. Does they represent the result of a collision?

5. A horseshoe magnet of mass m stand on end on a frictionless table. A steel ball of mass m is rolled toward the magnt from far away with velocity v and goes through the magnet and far beyond(fig.4-). Assume that there is no mechanical energy loss of the system during the whole process.

(a) What is the final velocity of the ball?

(b) What is the final velocity of the magnet?

6. A bullet is fired horizonally into the boboof a ballistic pendulum and remains embedded in it. After that the bob swings up until itreaches a certain height h (fig. 4-)

(a) Does the initial kinetic energy of the bullet equal the potntial energy of the bullet-pendulum system at the height h?

(b) Why is momentum conserved and mechanical energy not, as the bullet makes its way into the bob?

(c) Why is mechanical energy conserved and momentum not, after that?

7. A bullet hits a ballistic pedulum in the horizontal direction. In which case will the pendulum swing the height? why?

6. The First Law of Thermodynamics

1. Internal Energy of a Body

In contrast to the mechanical energy of a body which is determiined by the state of motion of the body as a whole, the internal energy is defined as the sum of the energies determined by the state of the particles that make up the body. A body resting on the ground may have zero mechanical energy, but its internal energy is never zero. A body consist of molecules, atoms, nuclei, and subnuclear prarticles, charged or uncharged. In its broad sense the internal energy contains the <u>kinetic</u> and potential energy of the molecules, the chemical, electrical, nuclear, and all other forms of energy possessed by all the particles. Of these energies, however, none but the kinetic and potential energies of the mole