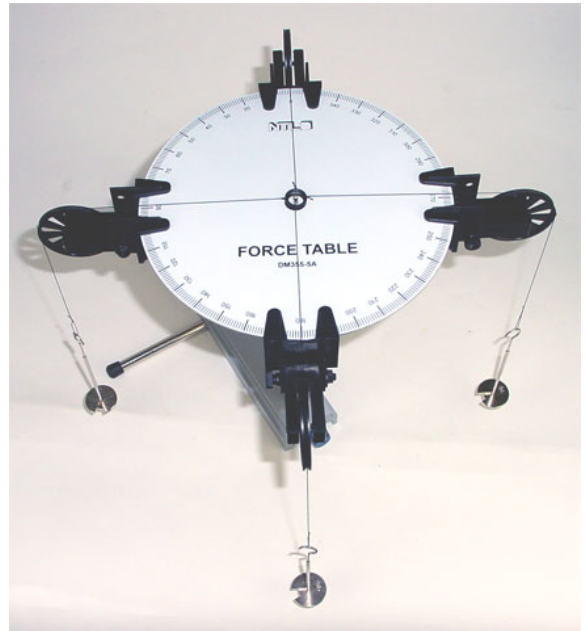


2.6) Combination of Several Forces

Material:

- 1 stand rail 30 cm
- 2 support rods, 25 cm
- 2 plastic caps for support rods
- 1 force table with accessories
- 4 pulley for force table
- 4 mass hangers for slotted weights, 10 g
- Slotted weights

(cord)
Set square
Paper
Pencil



In physics, a fundamental distinction is made between scalar quantities and vector quantities. Scalars are characterised by their size and their magnitude alone. These are, for example, mass or energy. In the case of vectors, apart from their magnitude, their direction is also decisive. Thus, it is not just important how fast something moves, but also in what direction. The velocity is thus a vector, as is the acceleration. In the case of forces, too, it is not just their strength, i.e. their magnitude that is important, but also the direction in which they act. Thus, forces are also vectors.

Scalars are thus represented by just a number. In the case of vectors, how many values are needed to define a vector unambiguously depends on the dimension. In our following experiments, we will work on the force table. Everything will happen in two dimensions and we will need two values to completely and unambiguously define a vector. These are either the magnitude and the angle to a reference axis (polar coordinates) or its Cartesian coordinates.

When several forces act on a body, to get the total force, we must add its vectors. This can be done graphically simply by drawing the first vector, then appending the second at the end of the first, followed by the third at the end of the second etc. The resultant vector is then the line joining the start of the first vector to the end of the last. In case of only two forces acting, a so-called force parallelogram can also be drawn. The four sides are the vectors of the acting forces and one of the diagonals is the vector of the resultant force.

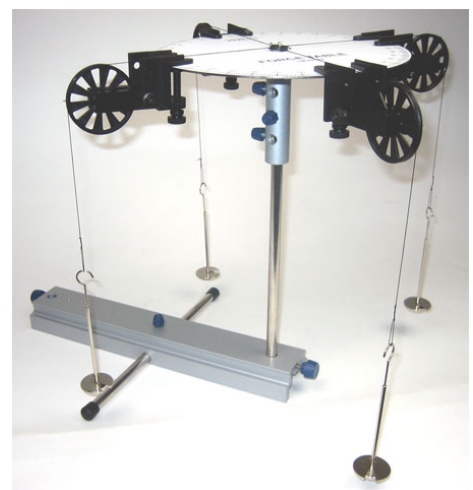
Note:

The preparation of the experiments is done here by means of graphical addition. If more exact calculation results are desired, of course, the calculations for the experiments can also be done in polar coordinates with the help of the sine and cosine laws.

Preparation:

Construction according to the diagram:

One of the 25 cm support rods is pushed through the lateral bore of the stand rail and fixed by means of the knurled screw. Plastic caps are put on at both ends of the support rod. The second 25 cm support rod is joined to the force table by means of the round bosshead. The other end of the support rod is fixed vertically in the stand rail. At the edge of the force table, 3 pulleys are first installed in any desired position. These are flipped right down.



The retaining pin is screwed in the middle of the force table and the retaining ring with the four loops is placed on it. Three of the four loops are taken over the rollers. In each of these loops, one mass hanger for slotted weights is hung.

What is involved in the following experiments is always to obtain an equilibrium between the three or four forces that are acting. These forces act in the form of weights over the pulleys on the retaining ring. Equilibrium means that the forces nullify each other, so that the resultant force is the null vector. If they are in equilibrium the retaining ring floats over the force table, since a body on which no forces act does not change its state of motion. If the forces do not nullify each other, the retaining ring would be accelerated in the direction of the resultant force. This is prevented by the retaining pin.

Experiment 1:

In the table, two of the forces to be set on the force table are specified. The third force should then be adjusted in such a way that the forces nullify each other. It must therefore act in the opposite direction from the resultant of the first two forces, and must be of equal magnitude. We determine this force first graphically, then set it on the force table and check whether the retaining ring is at rest.

Note:

The forces are so adjusted that the pulley (notch on the retaining ring of the pulley is used as a marking) is pushed to the specified angle φ and on the mass hanger for slotted weights, the given weights F are hung.

The length of the force vectors corresponds to the magnitude of the force. In the graphical calculation, therefore, a meaningful scale must be selected, so that the drawings do not become too small (e.g. first setting: 1 cm corresponds to 0.1 N). The weight of the mass hanger for slotted weights is 0.1 N. (When setting the equilibrium, the retaining ring must be additionally fastened so that it does not slide over the pin).

F_1 [N] F_2 [N] F_3 [N] φ_1 [°] φ_2 [°] φ_3 [°] F_4 [N] φ_4 [°]

φ_1 [°]	F_1 [N]	φ_2 [°]	F_2 [N]	φ_3 [°]	F_3 [N]
0	1	120	1	240	1
0	1	120	0.3	197	0.9
0	0.8	90	0.6	217	1
0	0.8	60	0.8	210	1.4
0	1	30	1	195	1.9

Experiment 2:

Essentially, we repeat the first experiment, but now, however, we use all four pulleys. This means that three forces are specified with their angles and magnitudes, and the fourth force has to be determined such that the body is in equilibrium. The fourth force is again determined graphically. To do so, the three forces are added graphically (meaningful scale). The fourth force must then be exactly opposite the resultant and have the same magnitude. The results are tested on the force table.

φ_1 [°]	F_1 [N]	φ_2 [°]	F_2 [N]	φ_3 [°]	F_3 [N]	φ_4 [°]	F_4 [N]
0	100	90	100	180	100	270	100
0	100	45	80	180	100	225	80
0	80	60	60	197	90	225	35
0	100	80	60	110	60	238	145
0	120	130	60	185	60	240	45

Conclusion:

In the case of vectorial physical quantities, it is not just their magnitude, but also the direction that is decisive.

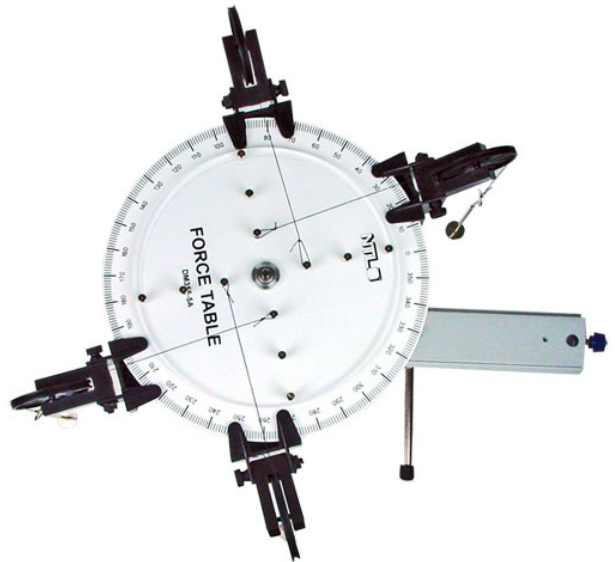
If the forces acting on a body are in equilibrium, the body behaves as if there were no force acting on it. The body does not change its state of motion because the resultant force is the null vector.

2.7) Point of Application of a Force - Torque

Material:

- 1 stand rail 30 cm
- 2 support rods, 25 cm
- 2 plastic caps for support rods
- 1 force table
- 1 torque crown with 4 cords
- 4 pulleys for force table
- 4 mass hangers for slotted weights
- Slotted weights

(cord)
Set square
Paper
Pencil



Apart from the direction and the magnitude of a force, it is also important where a force acts on a body. When a force acts on the centre of gravity of a body, it can push it in only one direction. However, if the same force acts at another point, for example, on the outer part of a wheel, then it depends on the direction of the force, whether the body is only moved or whether it is rotated. In general, the body will always start to rotate when the applied force is not parallel to the joining vector.

The further away from the centre of a doorknob you press, the easier it is to turn it. Using a lever, the farther away from the fulcrum you push it, the easier it is to lift it. From this, it can be seen that not only are the magnitude and direction of a force decisive, but also the point where the force acts. A force can thus set a body in rotation. Whether and how the body rotates is decided by the torque related to the force. The torque \vec{N} is a vector and is obtained 3-dimensionally.

$$\vec{N} = \vec{F} \times \vec{r}$$

F is the acting force and r is the joining vector between the fulcrum and the point of action of the force. In the 3-dimensional case, N is vertical on F and r and its magnitude. It is the biggest when F and r are normal to one another.

In our 2-dimensional tests, there are only two possible directions for the torque. Either it acts clockwise or counterclockwise. The convention is that torques that act clockwise should have a minus sign. The magnitude of the torque is obtained as:

$$|\vec{N}| = |\vec{F}| * |\vec{r}| * \sin \theta$$

θ is then the angle between the vectors F and r .

The torque is the same for rotation as the force is for translation (rectilinear movement). This means that there is a principle of inertia for the rotation as well. It is:

A body on which no torque is acting remains at rest or if it is already rotating, it remains in constant rotation.

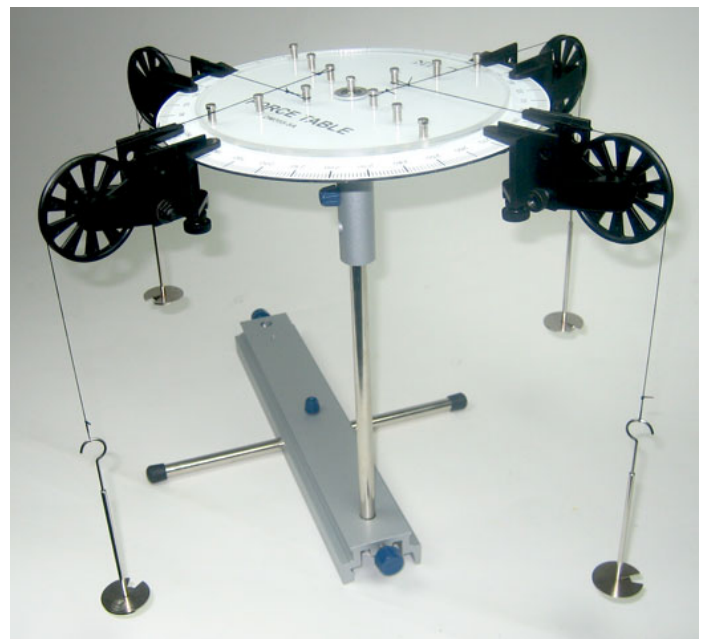
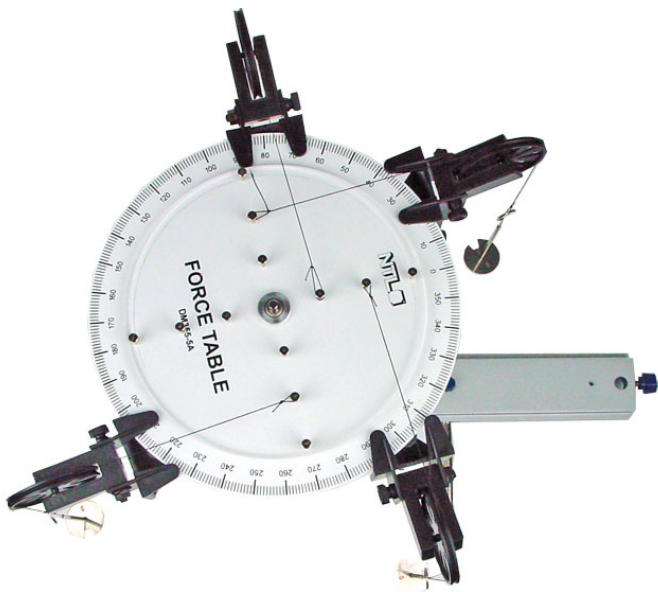
(Naturally, this also applies when there are torques acting on a body that nullify each other).

The next experiment also relates to such bodies in which the torques are in equilibrium.

Preparation:

Construction according to the diagram:

One of the 25 cm support rods is pushed through the lateral bore of the stand rail and fixed by means of the knurled screw. Plastic caps are put on at both ends of the support rod. The second 25 cm support rod is joined to the force table by means of the round bosshead. The other end of the support rod is fixed vertically in the stand rail. The torque crown is screwed to the force table. The four threads are hung from the four innermost pins of the torque crown (distance to the centre 2.5 cm; distance between the pins 2.5 cm each). On every cord, at the other end, a mass hanger for slotted weights is hung. The four pulleys are placed in such a way that the power arm (joining line between the centre and the point of action) and the relevant force include an angle of 90° . The cords should be mounted in such a way that the torques nullify each other. Therefore, two equally large torques must act in both directions (see the diagram).



The torques nullify each other in this “Home position”.

Experiment 1:

We now make one of the mass hangers for slotted weights heavier by another 20 g. What do we observe?

The rotary table starts to rotate according to the acting torque.

On which mass hanger must we put a total of 20 g mass to nullify the torques?

The 20 g can be distributed at will across the two counteracting mass hangers.

Which torques act in the same direction?

The two respective opposite ones.

We remove the masses and leave only the mass hangers for slotted weights on the cords.

Experiment 2:

We increase the mass in three mass hangers for slotted weights by 50 g. On one of the hangers, we increase the mass to a total of 120 g (mass hanger 10 g + masses 110 g). Now, the equilibrium is disturbed again. At which retaining pin would one of the two counteracting cords have to be put to restore the equilibrium again? (Before rearranging the suspended weights, the pulley must always be placed in such a way that the cord goes straight over the roller. Even the angle between the power arm of the lever and the force must be 90° once again, since the sine of this angle also plays an important role for the magnitude).

One of the two counteracting cords must be fastened to the retaining pin that is located 2.5 cm further outwards.

How could the torque be balanced if two forces that are acting in one direction are doubled, without the counter-forces having to be doubled?

Both the oppositely acting cords, which are located 5 cm from the centre could be fastened on the corresponding retaining pin..

Experiment 3:

We now allow three of the four torques to act in one direction. Three cords are fastened to the retaining pin located 5 cm from the centre. The relevant pulleys must be placed correctly (see diagram).

Only the mass hangers for slotted weights and additionally 5 g slotted weights are hanging from all three cords. The fourth force must act on one of the four innermost retaining pins. This fourth torque must balance out the other three. How much mass must now be hung from the cord?

A total of 90 g must hang from the fourth cord to balance out the torque.

Experiment 4:

We will now remove one of the pulleys. Three of the four cords are placed around three of the innermost retaining pins (the fourth cord is not required). On one of these three cords, a weight of 0.6 N is hung over a pulley at an angle of 90° . 0.6 N each is to act on the other two cords also. What is the angle that the power arm and the force must include between them, so that the torques nullify each other (both angles should be of equal magnitude, else there is an infinite number of solutions)? The solutions should be calculated and then using the set square, set on the force table. The equilibrium can thus be checked.

The angles must be 30° or 150° or 210° or 330° in magnitude. The sine of the first two angles is 0.5; the sine of the last two is -0.5.

Conclusion:

The torque caused by a force depends on the distance of the point of action of the force from the fulcrum. The longer the power arm (joining vector between point of action and fulcrum), the larger is the torque, given the same force. In addition, the torque depends to a great deal on the angle between the power arm and the force vector.

The principle of the moment of inertia states that a body on which no torque is acting, remains in the same state of uniform rotation (constant angular speed) or at rest.

