611-0255 (40-242) Force Table

Warranty:

We replace all defective or missing parts free of charge. All products warranted to be free from defect for 90 days. Does not apply to accident, misuse, or normal wear and tear.

Assembly:

Fasten support rod to tripod base by screwing in rod.

Level table before use.

Screw 8-32 bolt with attached knob into hole in the "center pin". The center pin is used to hold the top onto the support shaft.

Description:

The Force Table demonstrates one of the fundamental laws of physics, the **First Condition of Equilibrium**, which is defined as: *A body is in equilibrium - will undergo no change in motion - if the vector sum of the total of all external forces acting upon it is zero.*

The apparatus uses a small ring, four masses with known weights, and four pulley clamps to position the weights to known angles to demonstrate equilibrium visually. It proves that the body remains in a state of rest and undergoes no motion when the weights are balanced.

It is well suited for the demonstration of the First Condition for Equilibrium since the magnitude and direction of all forces acting upon the body in the state of equilibriums can be quantified easily.

The object to be studied is a small metal ring held in place by a plastic mounting pin in the center of the disc. Attached to the ring is a weight pan harness consisting of 4 fasteners with cords. Place previously measured weights into each pan and hang freely over the disc edge, using the force of gravity to hold in place. The cords connecting the weights to the center ring pass over 4 pulleys which clamp, like vises, onto the disc edge. The precise location of each pulley can be determined by reading the position on the scale crossed by the cord.

The ring is held in place by the mounting pin until all 4 weights are balanced. When the weights are balanced and the pin removed, the ring will remain positioned over the central mounting hole and will not move. The weights have known values and the angle at which each is held is read on the degree scale. These values are a visual representation of the state of equilibrium and illustrate a concept that can also be worked out analytically and graphically.

Other Materials Needed:

- Set of 4 slotted weights
  100 to 500 grams recommended
- Protractor
- Ruler
- Graph Paper
- Level Tester
- Trigonometry table
  Or calculator with trigonometry functions.

Caution:

Do not exceed 1 kg. Damage to Force Table could result.

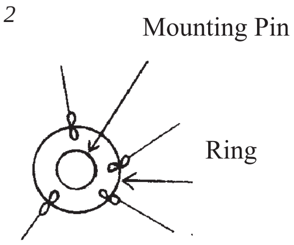
How To Use:

1. Assemble table according to assembly instructions. Level table.
- If weight harness is not already assembled, the fasteners can be attached to the ring by squeezing ring and slipping large loop of each fastener over the open end of the ring as you would keys on a key ring.
2. Slip mounting pin into hole in center of disc. Place ring, with fasteners and cords attached, over mounting pin. (Ring, fasteners, and cords will be termed *weight harness* in these instructions.)
3. Weigh each weight hanger and record its weight in grams.
4. Position four pulley clamps onto edge of table. Pulley wheel has a notch cut into its circumference. Use thumbscrew on pulley to fasten to edge of disc. Turn screw until clamp is held securely.
5. Slip free end of cord over wire hanger. Thread length of cord through notch in pulley wheel. Weight hanger will now hang freely over edge of table.
6. Repeat for other 3 weight hangers. Cord to each should pass over each pulley wheel and attach to central ring.
7. Measure each of 4 slotted weights and record values in grams. We recommend using weights ranging from 100 to 500 grams in each hanger. No more weight is needed since pulleys are sensitive.
8. To each weight, add the weight of the hanger. This will be the final weight in grams. Although all 4 hangers weigh about the same their

weight cannot be ignored because the weight of each hanger will act at a different angle and will have a different impact on the central ring.

9. Place one previously measured weight on hanger . The weights will pull the metal ring askew so that only the mounting pin holds it in its central place.
10. Experiment with moving the four weights into different positions relative to each other until no portion of the metal ring touches the mounting pin. See *Diagram 2,* with ring, fasteners and pin.

Diagram 2



- Be sure the cords are positioned relative to the ring so that their lines of action intersect at the mounting open. (An example of this position is illustrated in *Diagram 2.*) This can be checked by pulling the ring aside and releasing it. Check to make sure it returns to position in the center. If not, adjust weights by moving the pulleys to different locations until the ring relocates evenly around the mounting pin every time it is disturbed. At this point, the 4 fasteners will be pointing toward the middle of the pin.

11. Remove the mounting pin. The ring will now remain in position at the exact center. This is because *all forces acting upon the ring are balanced* and produce no change in the motion of the ring. The ring is in a state of *equilibrium.*
12. Read angles of all 4 forces using location where cord crosses the scale to indicate the exact number of degrees.

Theory:

Part 1: Graphical Method of Adding Vectors

The First Condition for Equilibrium demonstrated visually - holding the central ring motionless by means of four balanced weights - can also be illustrated graphically.

A vector or vector quantity can be drawn as a straight line segment with a certain length and direction. Its length represents the magnitude of the vector quantity and its direction, indicated by an arrow at one end, represents the direction of the vector quantity.

When more than one vector is to be represented graphically, the polygon method can be used to determine if the joint action of all vectors results in the condition of equilibrium. If the graphical representation of four separate forces results in the construction of a four-sided closed figure, then the First Condition for Equilibrium has been met.

The Polygon Method is illustrated in *Diagram 3,* which includes *Table 1* listing 4 forces with known masses and directions. Table 1 contains actual data gathered during the working of a sample problem, which is used to illustrate the graphical and (in the sections below) analytical methods of duplicating the results of the Force Table. Any other 4 masses and angles could have been chosen, as long as the four forces are in balance and in a state of equilibrium.

The four forces listed in Table 1 are represented graphically as vectors A, B, C, and D. A scale and direction are selected. In this case, the direction is determined by the angles of the forces in the Sample Problem and the scale is one quarter-inch for every 20 grams, chosen for ease of illustration using standard quarter-inch graph paper. The angle of each force has been read on the circular scale of the Force Table, suing the position where the cord crosses the scale to indicate the precise angle. For convenience sake, one of the forces is chosen to lie at 0°. This force, represented as Vector A, becomes the *x-axis.*

Vector A is drawn first and serves as a frame of reference. To make it easier to construct the polygon, A has been preselected to correspond with the x-axis and has a direction of 0°. Since Vector A has a mass of 290 grams, its length is drawn as 29 quarter-inch units on graph paper. An arrow indicates the direction of Vector A from a point of origin 0. *(Diagram 3,* although drawn to scale, has been reduced to conform to the margins of these instructions.)

Next Vector B is drawn, using the head of Vector A - its arrow - as B's point of origin. B's length is determined by its mass in grams. The angle of Vector B must be drawn on a line parallel to the X-axis, which is represented by the dotted lines extending past the X-axis in *Diagram 3.* The angle is measured counterclockwise (by definition.) Therefore the data of the sample problem can be translated graphically as follows: Vector B has a length of 17 units and an angle of 126.2°.

Vector C is drawn from the head of Vector B using dotted lines parallel to the X-axis. The angle of Vector C reflects an opposite change of direction since it exceeds 180°. Vector D completes the polygon with its angle of 251.2° causing Vector D to meet Vector A at A's point of origin.

Vector D represents the **equilibriant,** the single force that must be applied to keep a body in equilibrium when under the action of other forces. In a vector polygon, the equilibriant is represented by the vector that closes the polygon.

Thus a four-sided polygon is completed. Since it exactly meets at the point of origin, 0, it proves graphically that the 4 forces represented as Vectors A, B, C, and D with values ascribed to them in Table 1 are in a state of equilibrium.

When the vector polygon representing all the external forces acting upon a body is a closed figure, the First Condition for Equilibrium has been satisfied.

Part 2: Analytical Method of Adding Vectors

Another way to determine if several forces, acting together, meet the First Condition for Equilibrium is to resolve each force into its rectangular or resultant forces and add them up separately. Where each set of rectangular (X and Y) components of the forces separately adds to zero, the First Condition for Equilibrium has been satisfied. If the total of all the resultants of all forces acting along the X-axis equals zero, and the total of all the resultant of all forces acting along the Y-axis equals zero, the body is in a state of equilibrium.

A resultant is another term for vector sum, and can be defined as: *the single vector quantity that would produce the same result as two vector quantities added, or acting together.* Any single force may be replaced by two or more forces whose joint action will product the same effect as the single force. These forces are called the components of the single force.

The following examples refer to *Diag. 4.* Force B is the resultant of Forces Bx and By. Conditions are unchanged if Force B replaces Bx and By, the X and Y components for Force B.

Using the trigonometric laws of sines and cosines, the relationship between B, Bx and By is defined as:

$B_x = B \cos \theta$

$B_y = B \sin \theta$

The data used graphically in the sample problem can now be applied analytically. Refer to Table 2. F represents the force, in grams. θ is the angle at which the force is acting. X and Y are the X and Y components of the force in question and are determined by using the trigonometric laws of sines and cosines. Trigonometric reference tables of a calculator with trigonometric functions can be used to locate the applicable sines and cosines. A calculator is recommended.

The resulting values are either positive or negative depending upon the size of the angle q. *Table 3,* below, indicates the positive and negative values

Diagram 3

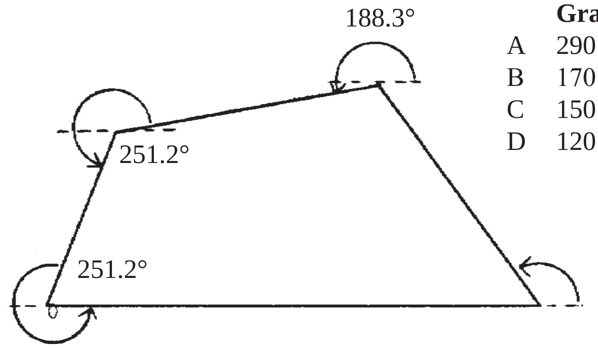
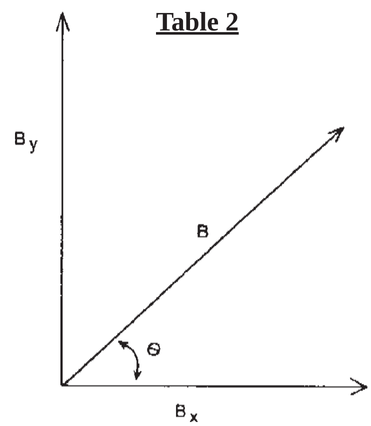


Table 1

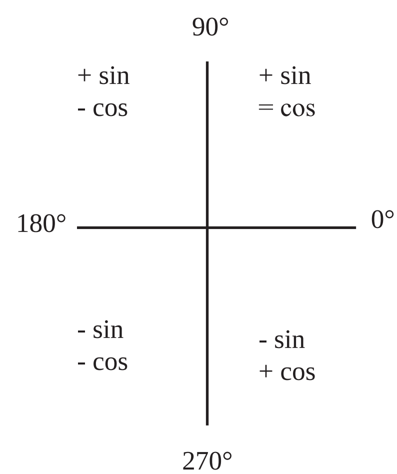
	Grams	Angle
A	290	0°
B	170	126.2°
C	150	188.3°
D	120	251.2°

Table 2



F (grams)	θ (angle)	x	y
290	0	290	0
170	126.2	-100.4	137.2
150	188.3	-148.4	-21.7
120	251.2	-38.7	-113.6
		2.5	1.9
		ΣFx	ΣFy

Table 3



of sines and cosines in each of the four quadrants. These positive and negative values are determined by definition. They will be computed automatically with a calculator.

Using Table 2 and data from the sample problem, each force (with its weight in grams) and each angle (determined by reading the degrees off the Force Table scale) has been resolved into X and Y components. This is done by applying the trigonometric laws defined above. For example,

Where $F = 290$,

$F_x = 290 (\cos 0°)$
$= 290 (1)$
$= 290$ and

$F_y = 290 (\sin 0°)$
$= 290 (0)$
$= 0$

The same procedure is repeated for the other 3 angles and forces, yielding the numbers listed in Table 2.

The total of all the X components if determined. All four X values are added together to yield 2.5. The total of the Y values is taken separately, resulting in 1.9. These figures are close enough to the value zero to be statistically negligible.

Where R represents the resultants of the various forces, ΣFx represents the sum of all the X components and ΣFy represents the sum of all Y components, the First Condition for Equilibrium is satisfied when these statements are met:

$R_x = \Sigma F_x = 0$

Problems:

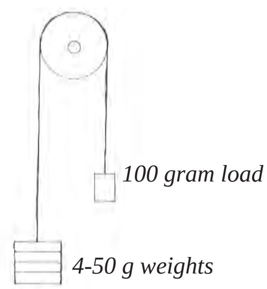
The 6 problems below require the Force Table for solution.

1. Three forces, termed A, B and C, and the respective angles at which they are acting are listed.
   2. Find the weight (in grams) and angle (degrees) of the fourth, or resultant, force. Any other weights and angles can be chosen as long as the weights do not exceed 1000 grams in any one pan.
3. Answers can be checked mathematically using trigonometry as explained in the section describing the analytical method.

Force	Weight (grams)	Angle (degrees)
A	150	0
B	110	70
C	250	150
A	200	0
B	100	50
C	200	180
A	200	0
B	100	35
C	50	148
A	200	0
B	200	95
C	150	120
A	150	0
B	200	65
C	150	145
A	100	0
B	200	80
C	160	125

Correction for Friction Errors:

The **Science First** Clamp Pulley has a Coefficient of Friction around 0.04. For example, a pulley with a 200 gram load on each side, as shown, is in equilibrium. If a small amount of mass is added or subtracted, no movement occurs until approx. 8 grams is added or removed. Potential error exists for up to +/- 8 grams. To determine the exact value of the load, add additional weight until the load moves up without acceleration and record this value. Next, subtract weight until the load falls. Halfway in between is the correct value. *Confucius says: "Current is halfway between too much and too little."*



Replacement Parts:

611-0265 Clamp Pulley - For force tables or table tops. Adjusts with thumbscrew, fits surfaces to 19 mm thick.

Definitions:

Components - 2 or more forces whose joint action will produce the same effect as a single force

Equilibrium - A condition in which the motion of a body remains unchanged despite the fact that several forces are acting on the body.

Equilibriant - That single force that must be applied to keep a body in equilibrium when it is under the action of other forces.

Concurrent Forces - Forces that act on the same point.

Vector or vector quantity - A quantity that has both magnitude and direction. It is represented by a line segment whose length represents the magnitude of the vector quantity and whose direction is that of the vector quantity.

Vector sum resultant - The single vector quantity that would produce the same result as two vector quantities added, or acting together.

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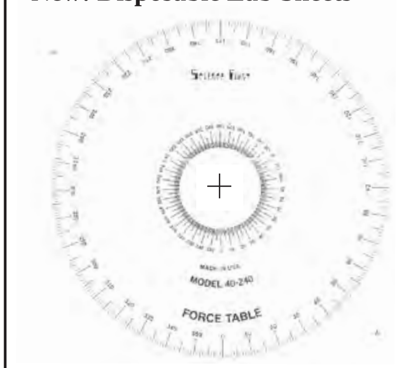

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