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SHORT COMMUNICATION

A Simple Static Equilibrium Demonstration Kit for Teaching and Learning Vector Addition Concept in Physics

Alat Bantu Mengajar Keseimbangan Statik untuk Pengajaran dan Pembelajaran Konsep Penambahan Vektor dalam Fizik

Rosly J.[1], Wan Zul Adli W. M., M. Roszairi H., Shaharudin A. & M. Mustamam A. K.
Physics Kits and Instrumentation Research Group
Physics Department, Universiti Pendidikan Sultan Idris, 35900 Tanjong Malim, Perak, Malaysia
[1]e-mail: rosly@fsmt.upsi.edu.my

Abstract

We present a simple demonstration kit capable of helping students to apply the algebra of vectors addition to a simple static equilibrium problem.

Keywords physics demontration kits, teaching and learning, vector addition concept, static equilibrium

Abstrak

Kami tunjukkan satu alat bantu mengajar untuk membantu pelajar memahami konsep penambahan vekor bagi masalah keseimbangan statik.

Kata kunci alat bantu mengajar fizik, pengajaran dan pembelajaran, konsep penambahan vektor, keseimbangan statik

Introduction

There are a great number of physical quantities that cannot be specified by just a number but required an additional information, that is, their direction. Such quantities are called vectors, e.g. velocity, forces, and angular momentum. The algebra of vectors is, to some extent, different from that of ordinary numbers. The understanding of vectors and their algebra is of fundamental importance as it is relevant to all branches of physics. For students who are new to the concept, it might be very difficult for them to grasp this relatively simple concept.

Here we present a simple demonstration kit utilizing the static equilibrium problem that may help students to understand the algebra of vectors to a real problem.

In vector addition, given two vectors **A** and **B**, we would like to add them together to form a resultant vector **C**

$$\mathbf{C} = \mathbf{A}+\mathbf{B} \tag{1}$$

Graphically, this is shown in Figure 1. A more convenient and accurate method to perform such vector operation is to first resolve the vectors into their components along

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coordinate axes. Suppose we are working in two dimensions (*xy*-plane). Having specified the coordinate system, as shown in Figure 2, we can resolve every vector into its components as shown in Table 1.

Table 1 The *x* and *y* components of vector **A**, **B** and **C**

Vector	*x*-component	*y*-component
A	$A_x = A \sin\beta$	$A_y = A\cos\beta$
B	$B_x = B\sin\alpha$	$B_y = B\cos\alpha$
C	$C_x = A_x + B_x$	$C_y = A_y + B_y$

The components of the resultant vector, C_x and C_y are obtained by arithmetically adding the corresponding components

$$C_x = A_x + B_x = A\sin\beta + B\sin\alpha \tag{2}$$

$$C_y = A_y + B_y = A\cos\beta + B\cos\alpha \tag{3}$$

The resultant vector **C** is therefore

$$\mathbf{C} = C_x\mathbf{i} + C_y\mathbf{j} \tag{4}$$

where **i** and **j** are unit vectors pointing in the *x* and *y* directions, respectively.

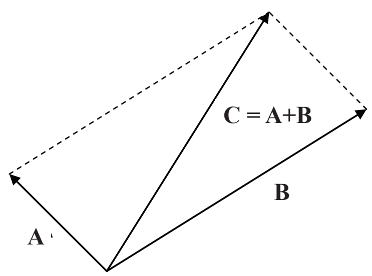

Figure 1 A graphical representation of vector addition. Vector **C** is the vector sum of vectors **A** and **B**

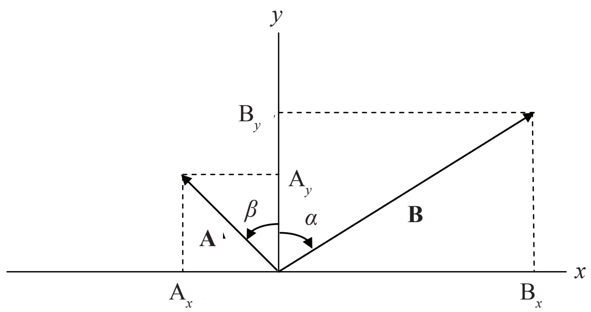

Figure 2 Decomposition of vector **A** and **B** into their respective components along coordinate axes

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Experimental setup and procedure

The experimental setup is shown in Photo 1. The vectors we want to deal with are the forces exerted on the knot point. They are the tensions of the strings, $\mathbf{T}_1$, $\mathbf{T}_2$ and $\mathbf{T}_3$. $\mathbf{T}_1$ and $\mathbf{T}_2$ are measured using spring balances, while $\mathbf{T}_3$ is equal to the gravitational force mg acting on the load of mass, m. Non-permanently attached to a magnetic board; the position and the angle of the spring balances can be freely adjusted, thus allowing several sets of experimental data to be observed. The angles are measured using a 360° protractor marked in degrees, which is also non-permanently attached to the magnetic board.

Figure 3 shows the free-body diagram of the knot point. Since the knot is in static equilibrium (acceleration is zero), by Newton's Second Law

$$\Sigma \mathbf{F} = 0 \tag{5}$$

So that,

$$\mathbf{T}_1 + \mathbf{T}_2 + \mathbf{T}_3 = 0 \tag{6}$$

Applying the rule of vector addition, we rewrite the above equation in component form

$$\mathbf{T}_{1x} + \mathbf{T}_{2x} + \mathbf{T}_{3x} = 0 \tag{7}$$

$$\mathbf{T}_{1y} + \mathbf{T}_{2y} + \mathbf{T}_{3y} = 0 \tag{8}$$

We need to show that equations (6), (7) and (8) are experimentally verified.

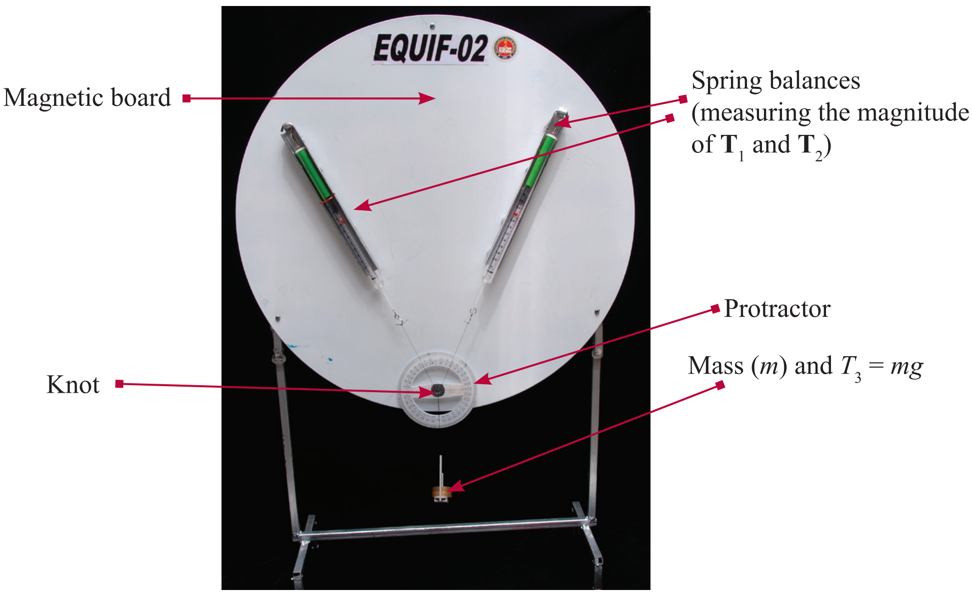

Photo 1 Experimental setup of forces in equilibrium

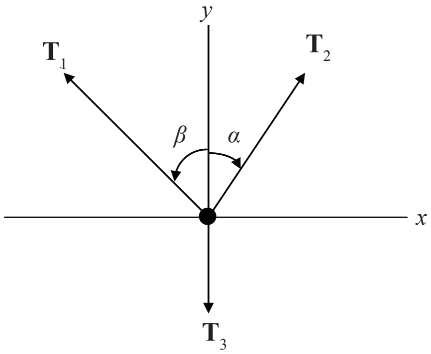

Figure 3 A free body diagram showing the forces acting on the knot of the strings

Results

Here we show an exemplary result to verify the reliability of the demonstration kit. The tension in the upper strings $\mathbf{T}_1$ and $\mathbf{T}_2$ makes angles $\beta = 8^\circ$ and $\alpha = 54^\circ$ with the vertical respectively. The magnitudes of the tensions of these upper two strings can be read from the two spring balances. Thus, $T_1 = 1.32$ N and $T_2 = 0.24$ N. On the other hand, the magnitude of the tension $T_3$of the lower string is equal to the gravitational force acting on mass *m*. Therefore, $T_3 = mg = 1.47$ N.

From Table 2, it can be seen that, within the experimental errors, the total force in *x* and *y* components is equal to zero. Thus, we have shown that Equation (6) holds true.

Table 2 Results

Force	*x*-component	*y*-component
$\mathbf{T}_1$	$T_{1x} = -1.32 \sin 8^\circ = -0.18$ N	$T_{1y} = 1.32 \cos 8^\circ = 1.31$ N
$\mathbf{T}_2$	$T_{2x} = 0.24 \sin 54^\circ = 0.19$ N	$T_{2y} = 0.24 \cos 54^\circ = 0.14$ N
$\mathbf{T}_3$	$T_{3x} = 0$ N	$T_{3y} = -1.47$ N
$\mathbf{T}_1+\mathbf{T}_2+\mathbf{T}_3 = 0$	$T_{1x} + T_{2x} + T_{3x} = 0$ (theory) $= 0.01$ N (experiment)	$T_{1y} + T_{2y} + T_{3y} = 0$ (theory) $= -0.02$ N (experiment)

The result obtained was found to be in good agreement with the theory.

Conclusion

This simple and low-cost experiment or demonstration set is intended for high school students who are new to the concept of vectors. We believe that this illustrative experiment can improve students' understanding to the fundamentally important concept of vectors.