

Mechanics of Machinery

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2 Introduction

2.1 Hook's law

When a force exerts on a spring and lengthen it, its length elongated is proportional to the magnitude of force under the elastic limit, which is called Hook's law. According to Hook's law:

$$F = -kX$$

(k is the coefficient of the spring, F is restored force and X is the length elongated) The minus sign in the formula represents the direction of spring force is opposite to the way it deforms. Suppose an object with mass M is hung under a spring, according to Newton's

second law $F=Mg$ and to the relation between external force and elongated length, we can measure X and derive coefficient k .

2.2 Static equilibrium

2.2.1 Resultant of concurrent forces

The basic definition of static equilibrium is: When an object is at static equilibrium, every particle of it is in static state. This is a more rigid definition, it regulates that the object must be still. On the other hand, the loose definition is called mechanical equilibrium. Mechanical equilibrium requires:

1. No resultant force acts on the particle.
2. No resultant torque acts on the particle.

If a system is a rigid body, the definition of mechanical equilibrium is:

1. No resultant force acts on each particle.
2. No resultant torque acts on each particle.

When the rigid body is under mechanical equilibrium, its linear acceleration is zero, so is the angular acceleration. Therefore, it will move in constant velocity or constant angular velocity.

2.2.2 Decomposition of force

The principle is the same as 2.2.1. Force is a vector which has magnitude and direction, so we can use parallelogram method to do addition. In statics, we often face two problems: one is that we know two components of force, calculating their resultant force; the other is that we know a force, calculating its two components of force. Problems stated above all can be solved by parallelogram method. If we use parallelogram method, we need geometry and trigonometry to get the magnitude and direction of resultant force. However, this kind of problem can be easily solved by Cartesian coordinate method.

2.3 Torque equilibrium

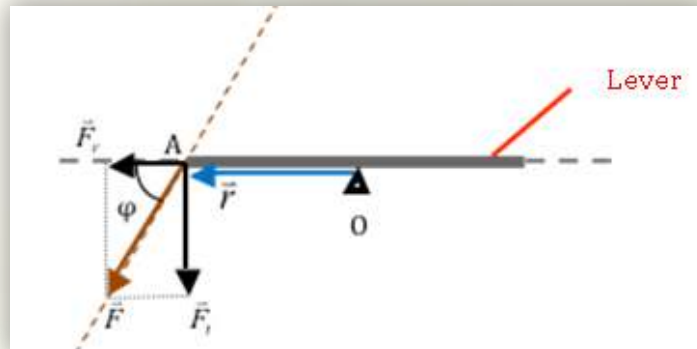
2.3.1 Parallel force of plummet

In mechanics, physical quantity describing a force makes an object rotate by an axis or fulcrum is called torque τ .

The below picture will illustrate precisely. A force $\vec{F}$ acts on point A relative to the fulcrum O shown by the triangle mark. The position of A relative to O is defined by vector $\vec{r}$, where the angle between $\vec{F}$ and $\vec{r}$ is φ .

To decide how $\vec{F}$ make the lever rotate by the axis, we decompose $\vec{F}$ into two forces: $\vec{F}_r$ parallel with $\vec{r}$ passing through the center of axis and $\vec{F}_t$ vertical with $\vec{r}$.

with magnitude $F \sin \phi$ which rotates the lever. Same as the composition of force, torque also has resultant torque. If resultant torque is zero, the object won't rotate; otherwise, it will rotate.

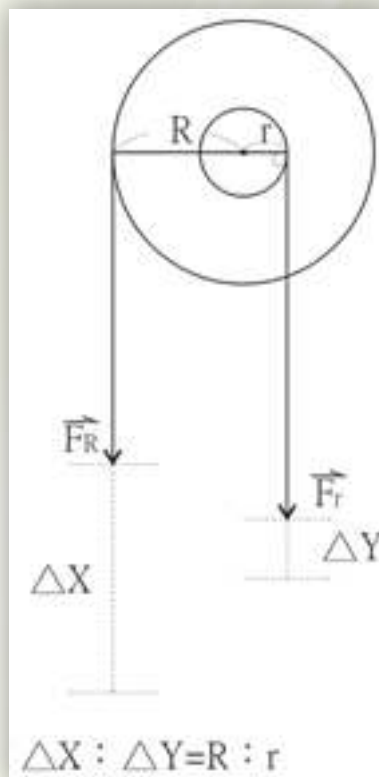


2.3.2 Lever experiment on the different side Principle is the same as 2.3.1.

2.3.3 Lever experiment on the same side Principle is the same as 2.3.1.

2.3.4 Wheel and axle

Principle is the same as 2.3.1. As the below figure shows, two wheels with different radius and same center are fixed on the same point of the axis. When the big wheel rotates one revolution, so does the small one. Thus, the ratio of displacement of big wheel ΔX to that of small wheel ΔY is equal to the ratio of circumference of the big to the small, that is, the ratio of R to r .

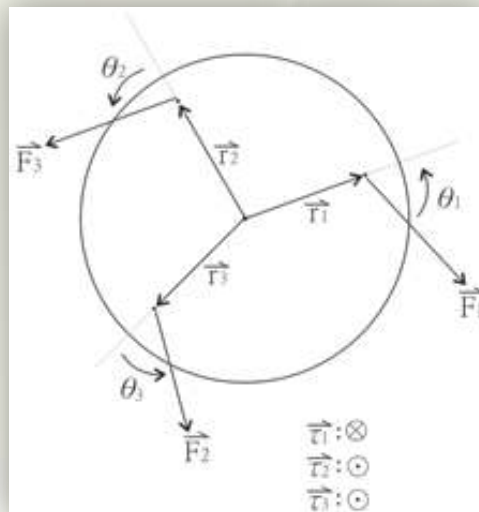


Let's take a look at the torque. Let the center of circle be the fulcrum, according to the principle of torque, torque produced by $\vec{F}_R$ is outward to the paper while $\vec{F}_r$ is inward to the paper. Two forces counteract. In addition, since the property of wheel, no matter what the angle of force is, the force will naturally be perpendicular to the position vector. Hence, $\vec{\tau}_R = \vec{R} \times \vec{F}_R = R F_R \sin 90^\circ$ and $\vec{\tau}_r = \vec{r} \times \vec{F}_r = r F_r \sin 90^\circ$

In equilibrium, $F_R : F_r = r : R$

2.3.5 Multiple torque

Principle is the same as 2.3.1. There are $\vec{F}_1$, $\vec{F}_2$ and $\vec{F}_3$ three forces whose angles are separately θ_1 , θ_2 and θ_3 relative to $\vec{r}_1$, $\vec{r}_2$ and $\vec{r}_3$.



Then torques are

$$\vec{\tau}_1 = \vec{r}_1 \times \vec{F}_1 \quad \vec{\tau}_2 = \vec{r}_2 \times \vec{F}_2 \quad \vec{\tau}_3 = \vec{r}_3 \times \vec{F}_3$$

When their resultant torque is zero, that is,

$$\vec{\tau}_1 + \vec{\tau}_2 + \vec{\tau}_3 = 0$$

From cross product, we know $\vec{\tau}_2$ and $\vec{\tau}_3$ are outward to the paper while $\vec{\tau}_1$ is inward to the paper. Let $\vec{\tau}_2$ and $\vec{\tau}_3$ be positive, then $\vec{\tau}_1$ is negative. That is, $\vec{\tau}_2 = \tau_2$, $\vec{\tau}_3 = \tau_3$, $\vec{\tau}_1 = -\tau_1$

Therefore, $F_2 r_2 \sin \theta_2 + F_3 r_3 \sin \theta_3 = F_1 r_1 \sin \theta_1$

2.4 Center of mass and gravity

Center of mass:

The motion of one point which can represent the whole body, as if total mass of the body centers on this special point, is called center of mass.

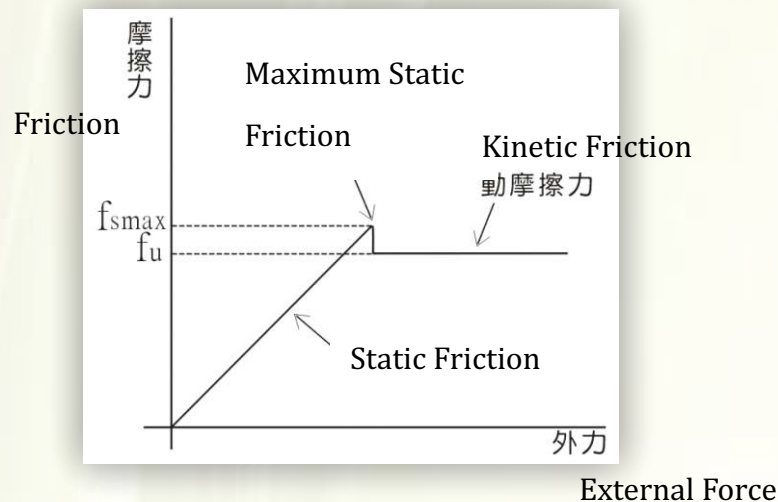
Center of gravity:

According to law of universal gravitation, we know that any object which has mass will be attracted to the earth, therefore, it has weight. We can see an object composed of infinite tiny particles which are all attracted by gravitational force. Since the volume of the object is much smaller than the earth, gravitational force on every particle can be viewed as parallel force. Resultant parallel force is the weight of the object, and it acts on the center of gravity. In other words, that gravitational force acts on the object is equivalent to that it acts on a point, and this point is called center of gravity.

2.5 Inclined plane

2.5.1 Maximum static friction

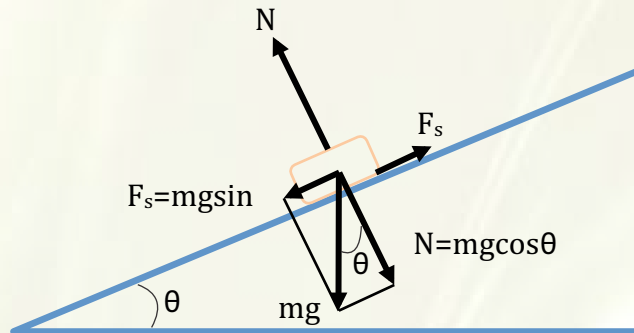
When a spring scale pull a block horizontally before it moves, there exists a resistance force although it is still. From experiment, we can find the resistance force comes from the block and the contact surface. In this moment, the resistance force has equal magnitude and opposite direction of pulling force. Before the block moves, when pulling force gets bigger, the static friction also becomes bigger. See the figure below.



In this experiment, we use inclined plane to let an object slide down due to gravitational force. When an object with mass m is placed on the inclined plane with angle θ , gravitational force can be decomposed to force parallel and perpendicular to inclined plane $mg\sin\theta$ and $mg\cos\theta$. When the angle θ increases gradually and the moment

object starts to move, force parallel to inclined plane is equal to maximum static friction F_{smax} .

$$F_{smax} = mgsin\theta$$



2.5.2 Coefficient of static friction

See principle in 2.10. From the result of experiment, we can conclude that under the same material condition, static friction f_s is proportional to normal force N .

$$f_s = u_s N$$

Therefore,

$$u_s = f_s / N = mgsin\theta_c / mgcos\theta_c = tan\theta_c$$

2.5.3 Coefficient of kinetic friction

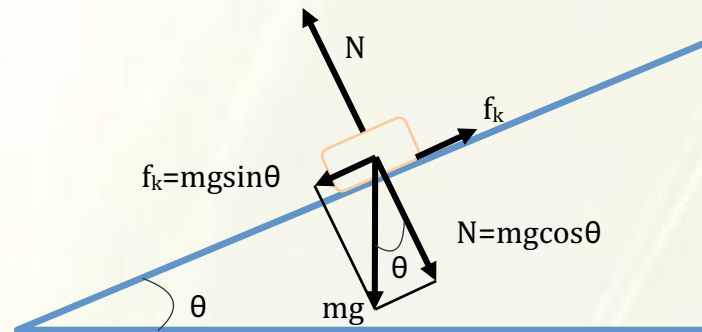
See principle in 2.10. When an object with mass m is placed on the inclined plane with angle θ , gravitational force can be decomposed to force parallel and perpendicular to inclined plane $mgsin\theta$ and $mgcos\theta$. Then when it moves, force parallel to inclined plane is equal to kinetic friction f_k .

$$f_k = mgsin\theta$$

On the other hand, force perpendicular to inclined plane is normal force N , $N = mgcos\theta$. Analyzing the whole system, we get $mgsin\theta - f_k = ma$; furthermore,

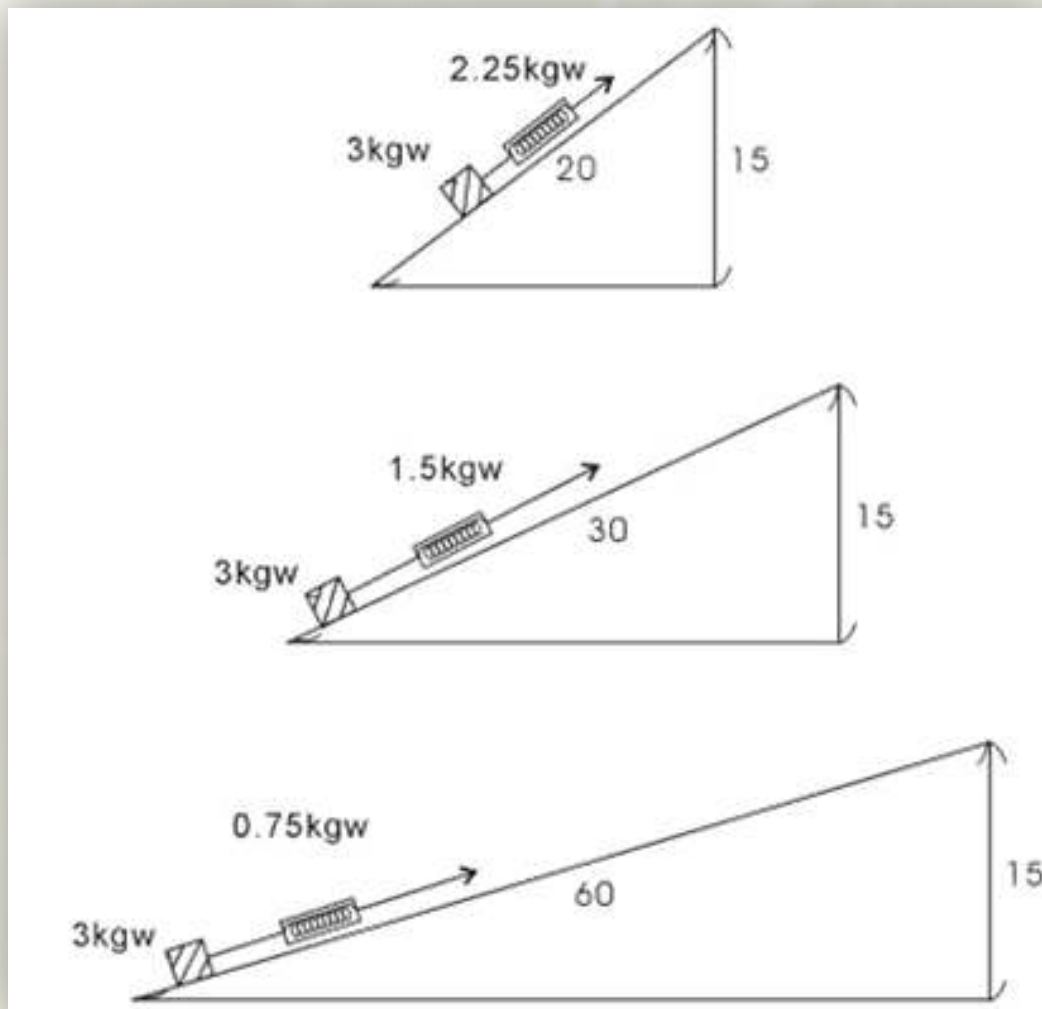
$$\mu_k = \frac{f_k}{N} = \frac{g sin\theta - a}{g cos\theta} \quad a = \frac{2S}{t^2}$$

Where a is acceleration of the object, g is acceleration of gravity, S is the displacement from origin to terminal point, and t is the time needed to move from origin to terminal point.



2.5.4 Pulley blocks

Besides using lever, pulley and axle, using inclined plane can be labor-saving to move heavy stuffs to higher place; however, it will take too much time. There are many designs related to inclined plane in our daily lives, such as stairs and disabled access ramp. Under the condition that terminal points are at the same height, the longer the plane is, the more labor-saving it will be. That is, the smaller the angle is, the more labor-saving it will be. See the figure below.



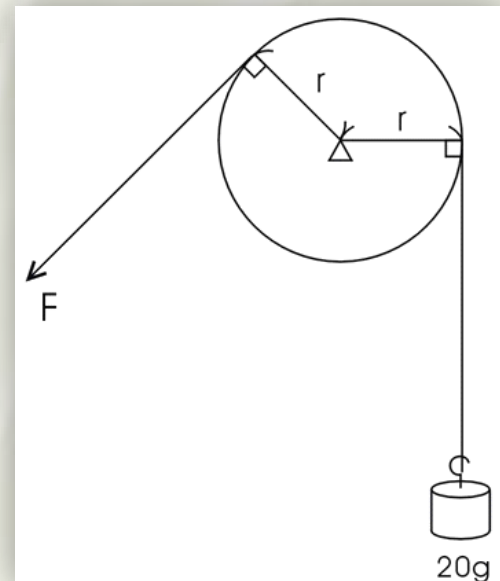
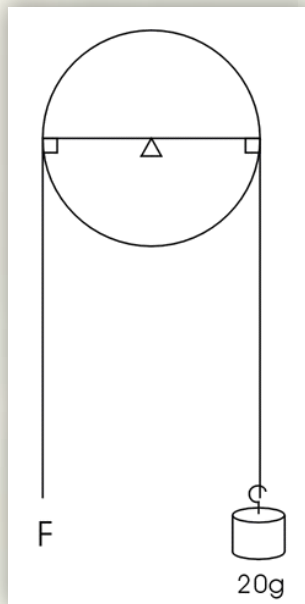
2.6 Pulley system

2.6.1 Single pulley: fixed pulley and movable pulley

A pulley is a wheel on an axle or shaft that is designed to support movement and change of direction of a taut cable, rope or belt along its circumference. It can be categorized to fixed pulley and movable pulley. Actually, the mechanical function of pulley is the same as lever.

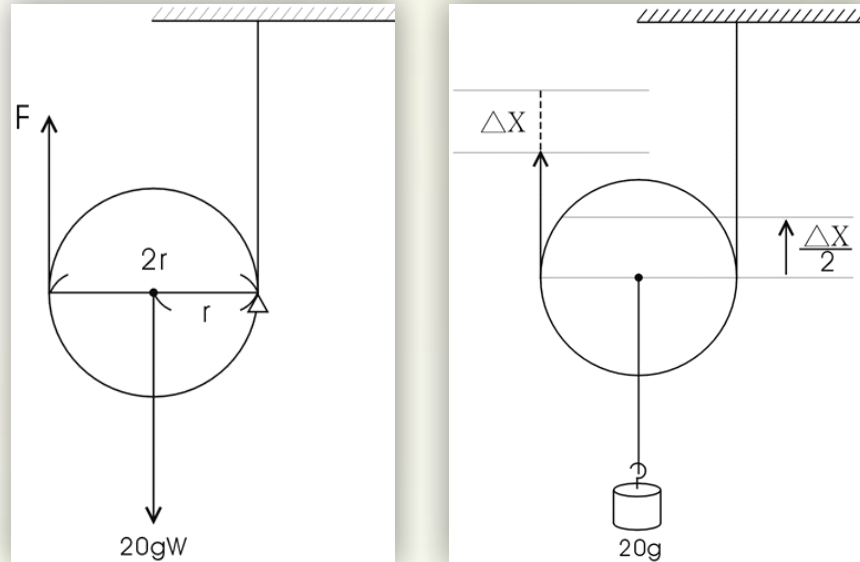
Fixed pulley:

Point of effort force and load force are at two edges of wheel when we let the axle be the fulcrum Δ . No matter what angle the force acts, arm of effort force is always perpendicular to effort force, so is the load force. Hence, if we keep the length of arm of effort force and load force the same, although the fixed pulley is not labor-saving, it can change the direction of force no matter the angle is.



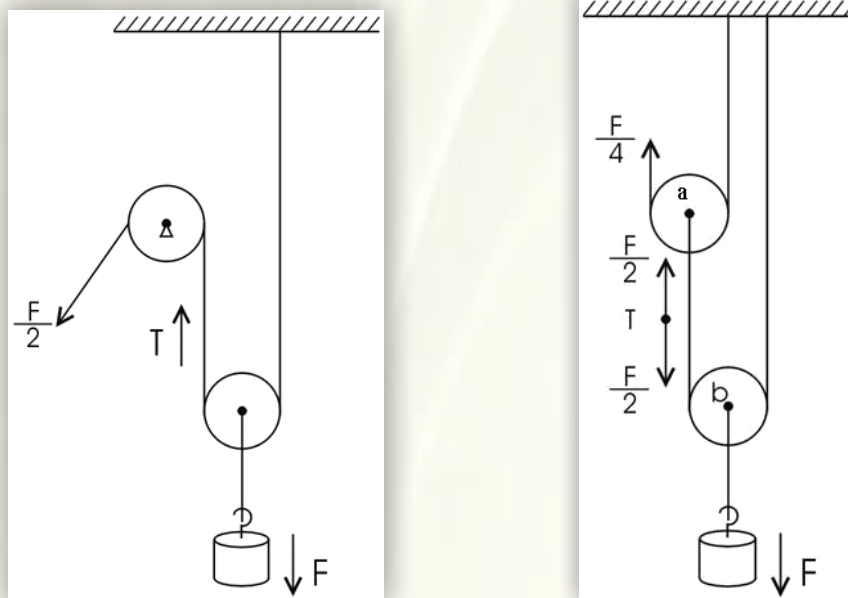
Movable pulley:

Point of effort force is on the edge of wheel and point of load force is at the center of the wheel when we pull upwardly by force F and let the edge of the other side be the fulcrum Δ . Arm of effort force is diameter $2r$ and arm of load force is radius r . The former is twice longer than the latter. It only needs effort force to behalf of load force to reach torque equilibrium. Consequently, if we pull a $20g$ weight without considering pulley's mass, we at least exert $10g$ to it. See the figure below.



2.6.2 Double pulleys: movable pulleys

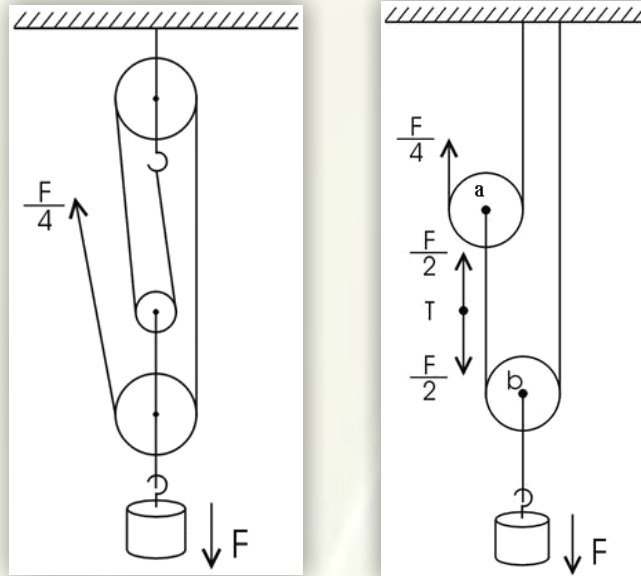
From 2.6.1, we know the kind and principle of pulley. Two movable pulleys compose a system. If a heavy stuff has a downward gravitational force F , according to the property of the movable pulley, we know at least our pulling force $T = F/2$ so that we can pull the pulley. This effect is as if the movable pulley a is hung by a heavy matter having gravitational force $F/2$. Therefore, if not considering the weight of pulley a , we can pull it up unless the magnitude of force is $F/4$.



2.6.3 Comprehensive experiment of pulley

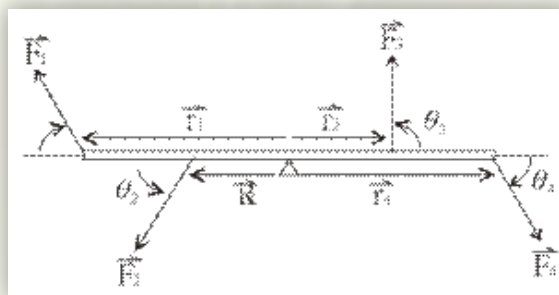
From 2.6.1, we know the kind and principle of pulley. Shown as the figure below, single pulley fixed on the wall becomes a fixed pulley. The rope passes through two

movable pulleys, from the property of them, the effort force of this pulley system is a quarter of load force. Through the design of pulley system, effort force can lift the heavy stuff to the highest point. The right figure tells us that when pulley *a* reaches to the highest point, pulley *b* only can reach half of it.



2.7 Multiple force equilibrium

Besides the fulcrum, There are $\vec{F}_1, \vec{F}_2, \vec{F}_3$, and $\vec{F}_4$ three forces whose angles are separately $\theta_1, \theta_2, \theta_3$ and θ_4 relative to $\vec{r}_1, \vec{r}_2, \vec{r}_3$ and $\vec{r}_4$.



Then, torques become

$$\vec{\tau}_1 = \vec{r}_1 \times \vec{F}_1 \quad \vec{\tau}_2 = \vec{r}_2 \times \vec{F}_2 \quad \vec{\tau}_3 = \vec{r}_3 \times \vec{F}_3 \quad \vec{\tau}_4 = \vec{r}_4 \times \vec{F}_4$$

When their resultant torque is zero, that is,

$$\vec{\tau}_1 + \vec{\tau}_2 + \vec{\tau}_3 + \vec{\tau}_4 = 0,$$

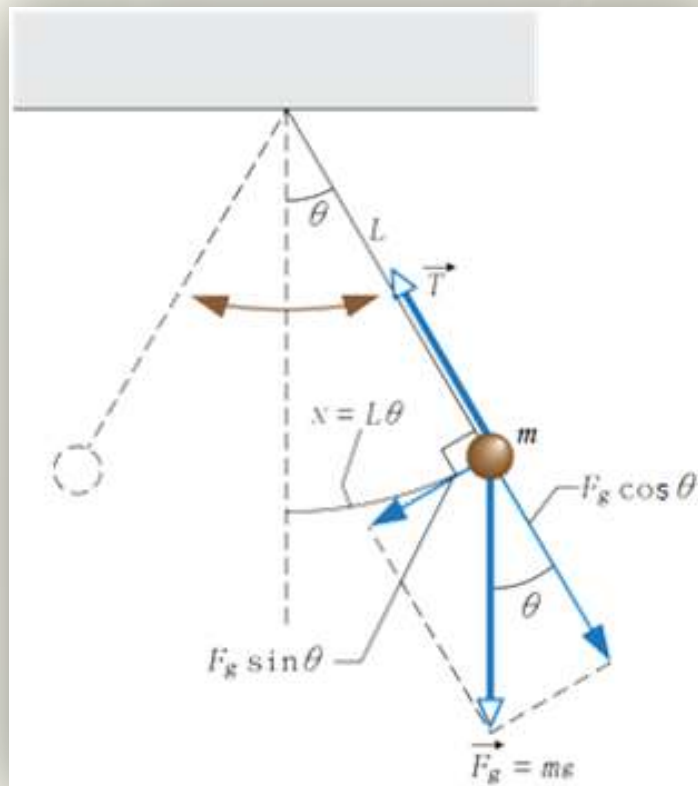
From cross product, we know $\vec{\tau}_2$ and $\vec{\tau}_3$ are outward to the paper while $\vec{\tau}_1$ and $\vec{\tau}_4$ are inward to the paper. Let $\vec{\tau}_2$ and $\vec{\tau}_3$ be positive, then $\vec{\tau}_1$ and $\vec{\tau}_4$ are negative.

That is, $\vec{\tau}_2 = \tau_2$, $\vec{\tau}_3 = \tau_3$, $\vec{\tau}_1 = -\tau_1$, $\vec{\tau}_4 = -\tau_4$

Therefore, $F_2 r_2 \sin \theta_2 + F_3 r_3 \sin \theta_3 = F_1 r_1 \sin \theta_1 + F_4 r_4 \sin \theta_4$

2.8 Simple pendulum

A simple pendulum is one which can be considered a point mass suspended from a string of negligible mass. Due to gravitational force, we can take a tiny angle to swing it. If the angle θ is smaller than 5 degree or $\sin\theta$ is approximate to θ , the motion of pendulum can be regarded as simple harmonic motion.



3 Equipment



- 3.1 Magnetic whiteboard 40cm x 53 cm x1
- 3.2 Aluminum legs for fix whiteboard x2
- 3.3 Weight group 20g x10
- 3.4 Metal mass hanger x3
- 3.5 Magnetic mounting set with durable plastic structure and fixed 6 NdFeB magnets
- 3.6 Aluminum lever L=40 cm with small hole every 2cm for pendant use x1
- 3.7 Friction wooden block x1
- 3.8 Plastic stabilizer plate with angle indicator x1
- 3.9 Five-sided metal plate x1
- 3.10 Single pulley x1
- 3.11 Double pulley x1
- 3.12 Removable block 153g x1
- 3.13 Fishing thread x1
- 3.14 Ring x1
- 3.15 Metal pin x4
- 3.16 Metal hook x3

4 Installation, Procedure and Result

4.1 Hook's Law

4.1.1 Installation

4.1.1.1 Stick the spring scale on the whiteboard first. Use the knob on top of it and let initial value be zero.

4.1.2 Procedure

4.1.2.1 Hang the weights on the hook of the spring scale and increase 20g each time. Record the result and derive the coefficient of spring. See figure (1).

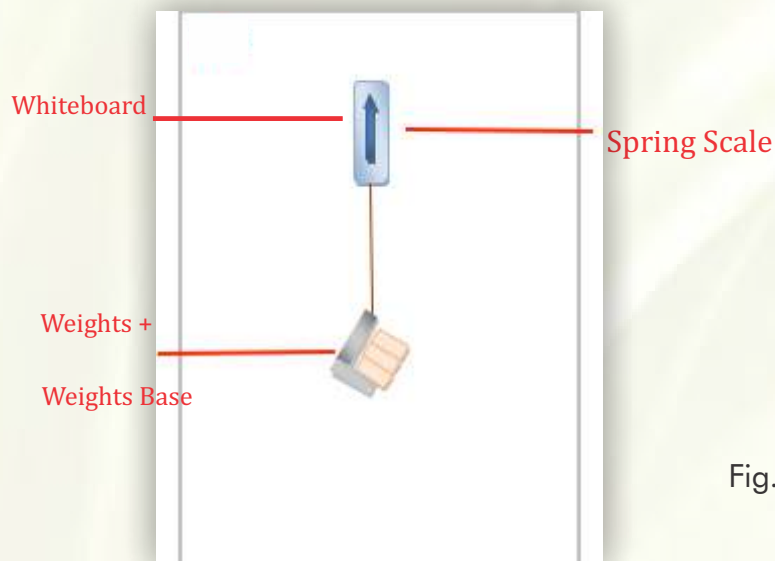


Fig.(1)

4.1.2.2 Try to plot the diagram between force and elongated length.

4.2 Static equilibrium

4.2.1 Resultant of concurrent forces

4.2.1.1 Installation

4.2.1.1.1 Stick the spring scale on the whiteboard first. Use the knob on top of it and let initial value be zero.

4.2.1.2 Procedure

4.2.1.2.1 Connect one side of two strings with S hook and then with O ring. Make them pass over two pulleys and hung with spring scale and weights. See figure (2).

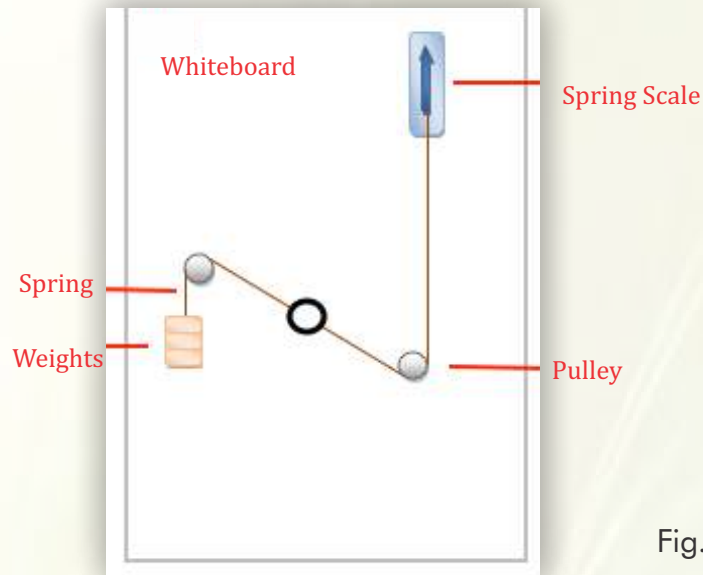


Fig.(2)

- 4.2.1.2.2 Record the magnitude and direction of force F_e acting on the spring scale.
- 4.2.1.2.3 Connect one side of the third string with S hook and O ring. Make the other side pass through the pulley and hang weights on it. Let O ring be the concurrent point of resultant force. These three forces: F_e from spring scale and F_1, F_2 from weights reach static equilibrium. See figure (3).

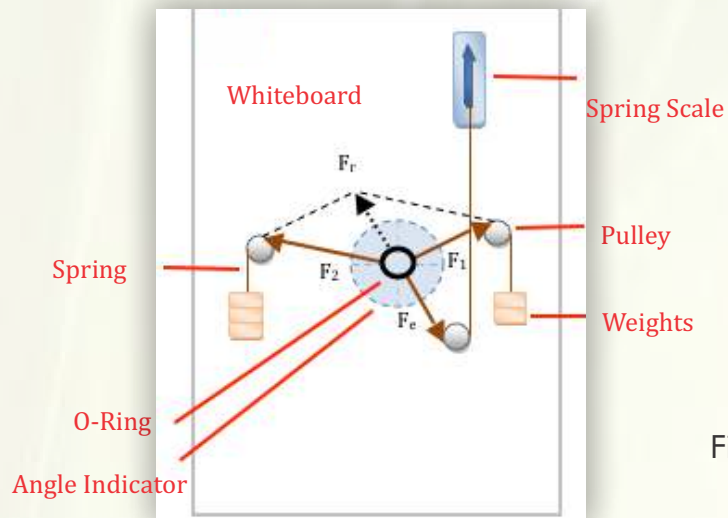


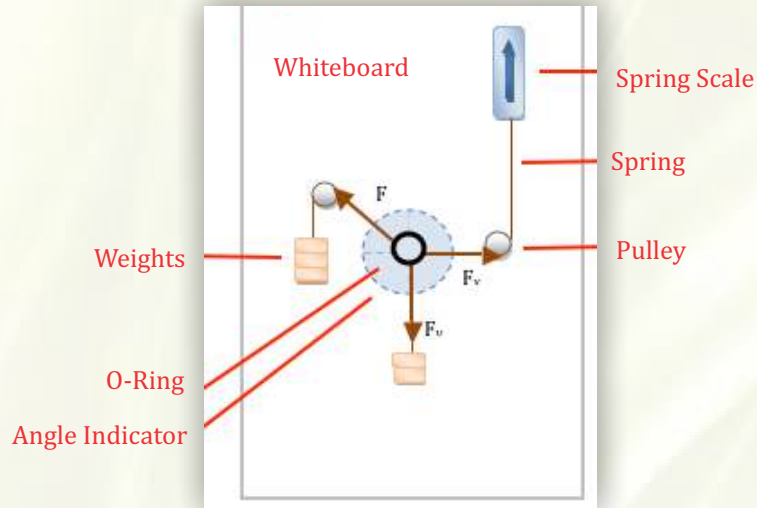
Fig.(3)

- 4.2.1.2.4 Add weights sufficiently, adjust F_1 and F_2 , and make F_e reach equilibrium, where the magnitude of F_e equal to that of 4.2.1.2.2.
- 4.2.1.2.5 Plot force and angle from the data by vector, and the selection of ratio is 50mm/N. Use parallelogram theorem to plot resultant force F_r of F_1 and F_2 and compare it with F_e .
- 4.2.1.2.6 Change the magnitude and direction of F_1 with same F_e . Adjust the magnitude and direction of F_2 and repeat procedure from 4.2.1.2.3 to 4.2.1.2.5.

4.2.2 Static equilibrium: Decomposition of force

4.2.2.1 Installation

4.2.2.1.1 Assemble equipment like figure (4). The direction of F_x and F_y are X axis and Y axis of Cartesian coordinate. F is the resultant force of F_x and F_y , that is, F_x and F_y are decomposition forces of F .



4.2.2.2 Procedure

4.2.2.2.1 Add weights and set the magnitude of F and F_y . Read the readings of F_x on the spring scale.

4.2.2.2.2 Plot the analyzing diagram on Cartesian coordinate by ratio 50mm/N. Compare error of measured value with theoretical value.

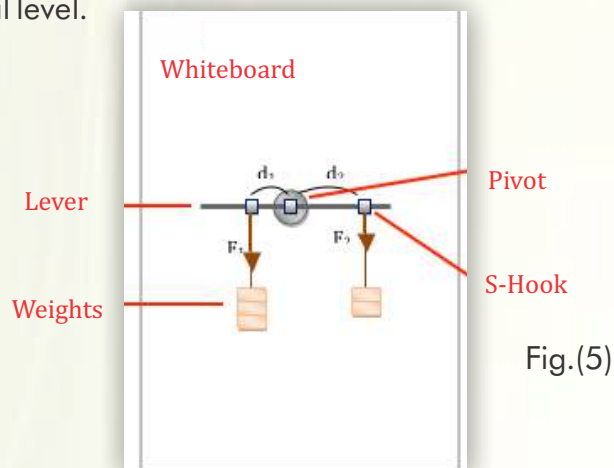
4.2.2.2.3 Change the weight of weights and repeat procedure from 4.2.2.2.1 to 4.2.2.2.2.

4.3 Torque equilibrium

4.3.1 Parallel force of plummet

4.3.1.1 Installation

4.3.1.1.1 Assemble equipment like figure (5). Insert lever into the pivot and adjust it to horizontal level.



4.3.1.1.2 Use two strings, connect one side of them with S hook and hang it on arm of force and the other side with weight base.

4.3.1.2 Procedure

4.3.1.2.1 Adjust F_1 and F_2 to equilibrium, at this time, force and distance of both side are equal.

4.3.1.2.2 Keep distance d_1 from pivot to F_1 remain the same. Add weights gradually. When the number of weights of both side aren't equal, adjust the distance properly and make them reach equilibrium. Record F_2 down.

4.3.1.2.3 Keep F_1 remain the same and change distance d_1 . When distances of both side are different, adjust them to reach equilibrium and record F_2 down.

4.3.2 Lever experiment on the different side

4.3.2.1 Installation

4.3.2.1.1 Assemble equipment like figure (6). Insert lever into the pivot and adjust it to horizontal level.

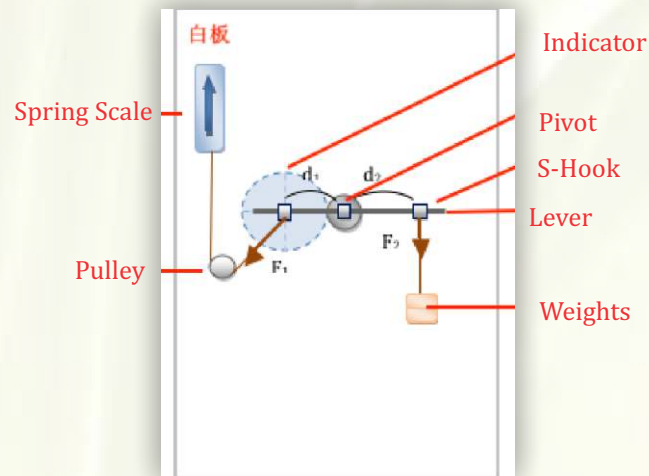


Fig.(6)

4.3.2.1.2 Use two strings, connect one side of them with S hook and hang it on arm of force and the other side with weight base or hook on spring scale.

4.3.2.2 Procedure

4.3.2.2.1 Hang weight base and weights on the right side, adjust F_1 to make lever reach horizontal balance and measure the angle of F_1 .

4.3.2.2.2 Keep distance d_2 from pivot to F_2 remain the same. Add weights gradually. Adjust F_1 properly and make the lever reach equilibrium. Record F_1 down.

4.3.2.2.3 Keep F_2 remain the same and change d_2 . Change F_1 to reach equilibrium and record it down. (Note: You must notice whether the spring scale and each equipment are at the same level; if not, adjust them by screws behind the spring scale.)

4.3.3 Lever experiment on the same side

4.3.3.1 Installation

4.3.3.1.1 Assemble equipment like figure (7). Insert lever into the pivot.

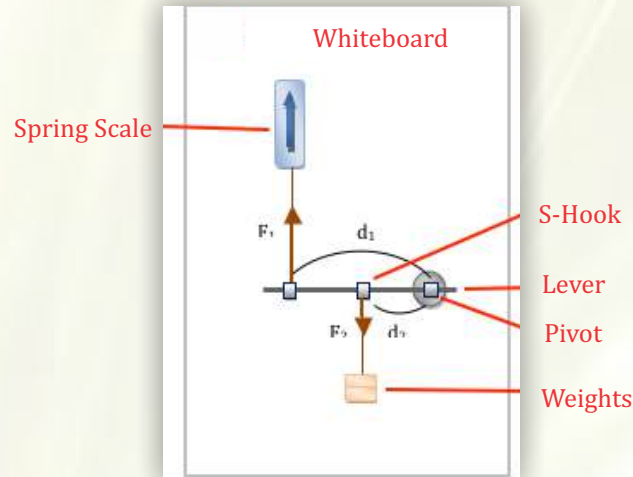


Fig.(7)

4.3.3.1.2 Use two strings, connect one side of them with S hook and hang it on arm of force and the other side with weight base or hook on spring scale.

4.3.3.2 Procedure

4.3.3.2.1 Hang weight base and weights at F_2 , adjust F_1 to make lever reach horizontal balance.

4.3.3.2.2 Keep distance d_2 from pivot to F_2 remain the same. Add weights gradually. Adjust F_1 properly and make the lever reach equilibrium. Record F_1 down.

4.3.3.2.3 Keep F_2 remain the same and change d_2 . Change F_1 to reach equilibrium and record it down. (Note: You must notice whether the spring scale and each equipment are at the same level; if not, adjust them by screws behind the spring scale.)

4.3.4 Wheel and axle

4.3.4.1 Installation

4.3.4.1.1 Assemble the equipment up. See figure (8).

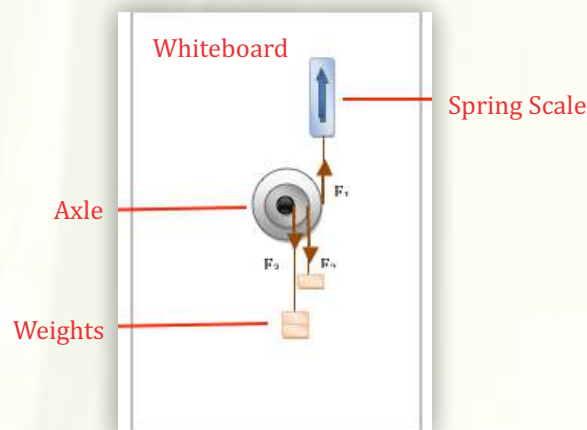


Fig.(8)

4.3.4.2 Procedure

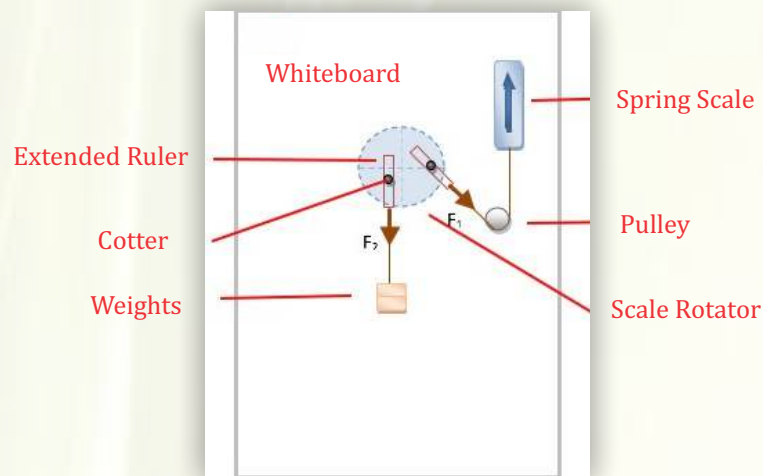
- 4.3.4.2.1 Pass the string with the largest radius through the axle a full circle and connect it to the spring scale. Pass the string with middle radius a full circle and connect it to the weight base.
- 4.3.4.2.2 Record the result when it reach equilibrium.
- 4.3.4.2.3 Add the magnitude of F_2 and record it down.
- 4.3.4.2.4 Change the radius of axle of F_2 and repeat procedure from 4.3.4.2.2 to 4.3.4.2.3.
- 4.3.4.2.5 Change the radius of axle of F_2 and repeat procedure from 4.3.4.2.2 to 4.3.4.2.3.
- 4.3.4.2.3. Analyze the result. (Note: You must notice whether the string from spring scale is parallel to the wall; if not, adjust it by screws behind the spring scale.

4.3.5 Multiple torque

4.3.5.1 Two forces

4.3.5.1.1 Installation

- 4.3.5.1.1.1 Insert the cotter into the scale rotator.
- 4.3.5.1.1.2 Use two strings, connect one side of them with S hook and hang it on arm of force and the other side with weight base or hook on spring scale.
- 4.3.5.1.1.3 Finish the installation like figure (9).



4.3.5.1.2 Procedure

- 4.3.5.1.2.1 Hang weights on F_2 , record the result of F_1 and F_2 separately and plot the analyzing diagram of force in order to verify whether the torque of the system is at equilibrium.
- 4.3.5.1.2.2 Change the weight of F_2 and observe the data of F_1 .

4.3.5.2 Triple forces

4.3.5.2.1 Installation

4.3.5.2.1.1 Insert the cotter into the scale rotator.

4.3.5.2.1.2 Use two strings, connect one side of them with S hook and hang it on arm of force and the other side with weight base or hook on spring scale.

4.3.5.2.1.3 Finish the installation like figure (10).

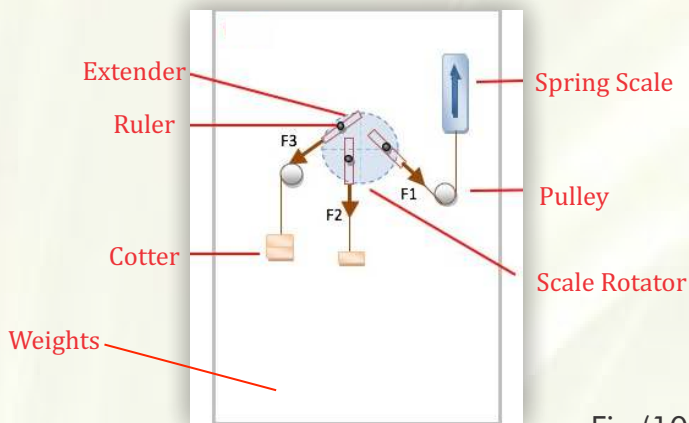


Fig.(10)

4.3.5.2.2 Procedure

4.3.5.2.2.1 Hang weights on F_2 and F_3 , observe and plot the analyzing diagram of em is at force in order to verify whether the torque of the system equilibrium.

4.3.5.2.2.2 Change the weight of F_2 and F_3 or the position of the hole inserted. Repeat procedure 4.3.5.2.2.1 and record the result.

4.4 Center of mass and gravity

4.4.1 Method 1

4.4.1.1 Installation

4.4.1.1.1 Insert cotter into the pulleys with holes and cover the metal pentagon and one side of the string on the cotter. See figure (11).

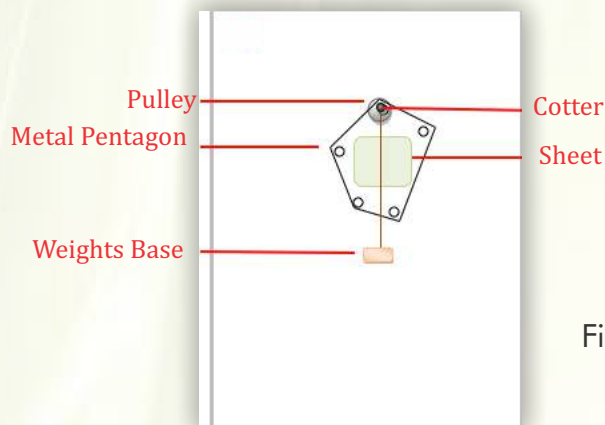


Fig.(11)

4.4.1.2 Procedure

4.4.1.2.1 Take a sheet for plotting and adhere it to the metal plate. Wait until it reaches equilibrium, then plot the string on the sheet.

4.4.1.2.2 Change and hang another metal hole and plot the string on the sheet successively. Find the center of gravity at the cross point of two lines.

4.4.2 Method 2

4.4.2.1 Installation

4.4.2.1.1 Assemble the equipment like figure (12).

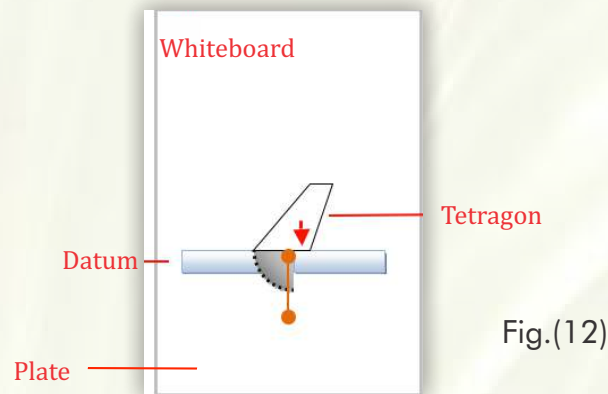


Fig.(12)

4.4.2.2 Procedure

4.4.2.2.1 Take tetragon plate and make it stand on the datum plate, afterwards, loosen your hands slowly.

4.4.2.2.2 Observe the direction of the indicator is outside or inside and the state of tilt.

4.4.2.2.3 Change the base of tetragon and record the result.

4.5 Inclined plane

4.5.1 Maximum static friction

4.5.1.1 Installation

4.5.1.1.1 Assemble the equipment like figure (13).

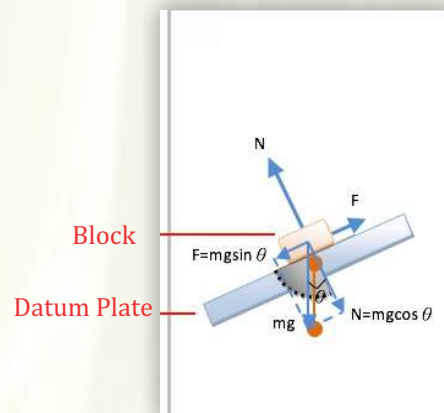


Fig.(13)

4.5.1.2 Procedure

4.5.1.2.1

4.5.1.2.2 Place the block on the datum plate with the bigger area side. Adjust the degree of tilt until the moment the block slide down slowly. Record the tilted angle θ .

4.5.1.2.2 Repeat procedure 4.5.2.2.1 five times, calculate the average tilted angle θ and get maximum static friction F_{smax} .

4.5.1.2.3 Add 100g weights each time and repeat procedure from 4.5.1.2.1 to 4.5.1.2.2.

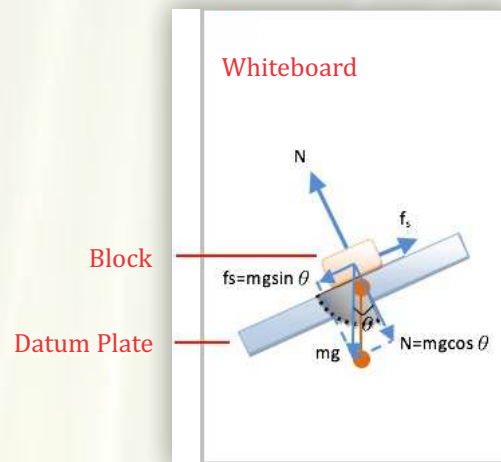
4.5.1.2.4 Change the smaller frictional area and repeat procedure from 4.5.1.2.1 to 4.5.1.2.3.

4.5.1.2.5 Change different materials of frictional surface and repeat procedure from 4.5.1.2.1 to 4.5.1.2.3.

4.5.2 Coefficient of static friction

4.5.2.1 Installation

4.5.2.1.1 Assemble the equipment like figure (14).



4.5.2.2 Procedure

4.5.2.2.1 Place the block on the datum plate with the bigger area side. Adjust the degree of tilt until the moment the block slide down slowly. Record the tilted angle θ .

4.5.2.2.2 Repeat procedure 4.5.2.2.1 five times, calculate the average tilted angle θ , get frictional force f_s and normal force N and derive coefficient of static friction μ_s .

4.5.2.2.3 Add 100g weights each time and repeat procedure from 4.5.2.2.1 to 4.5.2.2.2.

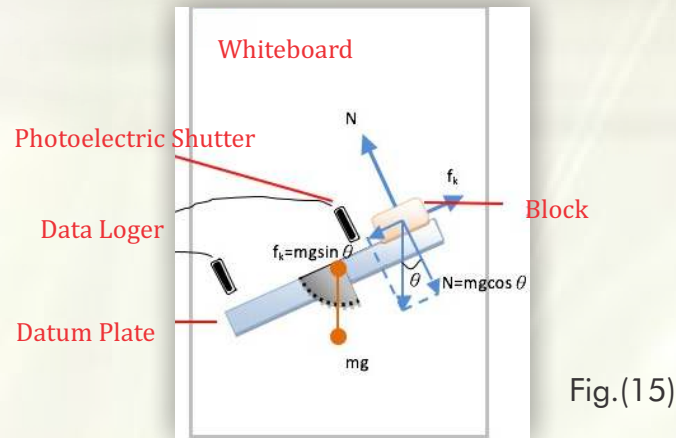
4.5.2.2.4 Change the smaller frictional area and repeat procedure from 4.5.2.2.1 to 4.5.2.2.3.

4.5.2.2.5 Change different materials of frictional surface and repeat procedure from 4.5.2.2.1 to 4.5.2.2.3.

4.5.3 Coefficient of kinetic friction

4.5.3.1 Installation

4.5.3.1.1 Assemble the equipment like figure (13).



4.5.3.2 Procedure

4.5.3.2.1 Place the block on the datum plate with the bigger area side. Adjust the degree of tilt until the moment the block slide down slowly. Record the time and position of initial point and final point.

4.5.3.2.2 Fix the tilted angle and repeat procedure 4.5.3.2.1 five times. Derive its average acceleration a and calculate the coefficient of kinetic friction μ_k .

4.5.3.2.3 Add 100g weights each time and repeat procedure from 4.5.3.2.1 to 4.5.3.2.2.

4.5.3.2.4 Change the smaller frictional area and repeat procedure from 4.5.3.2.1 to 4.5.3.2.3.

4.5.3.2.5 Change different materials of frictional surface and repeat procedure from 4.5.3.2.1 to 4.5.3.2.3.

4.5.4 Pulley blocks

4.5.4.1 Decomposition force of pulley block of parallel datum plate

4.5.4.1.1 Installation

4.5.4.1.1.1 Connect one side of the string with the spring scale and the other side with the pulley block. Place it on the datum plate. The equipment is shown as figure (16).

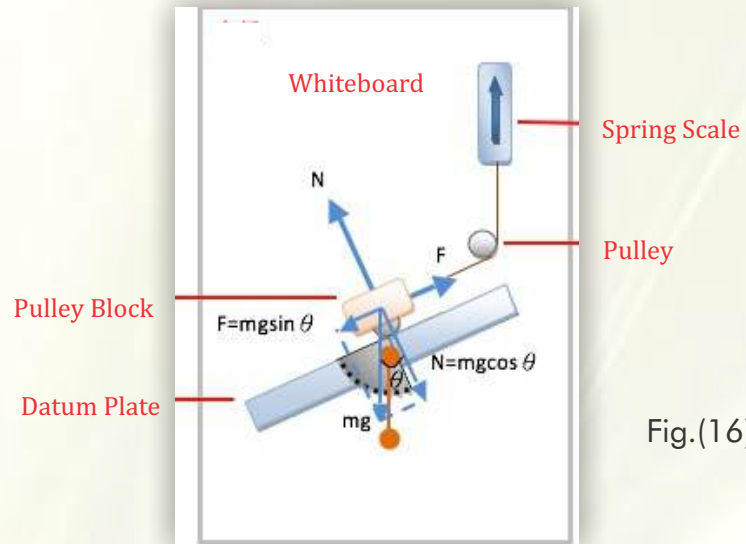


Fig.(16)

4.5.4.1.2 Procedure

4.5.4.1.2.1 Use and protractor adjust template at 10 degrees. The string connected with pulley block must be parallel with datum plate.

4.5.4.1.2.1 Observe and record the result. Analyze the force on the inclined plane to derive decomposition of gravitational force of pulley block parallel to datum plate.

4.5.4.1.2.2 Change the tilted angle and the result in sequence. Calculate the force of pulley cart and compare its error with the spring scale readings.

4.5.4.2 Relation between weights and tilted angle

4.5.4.2.1 Installation

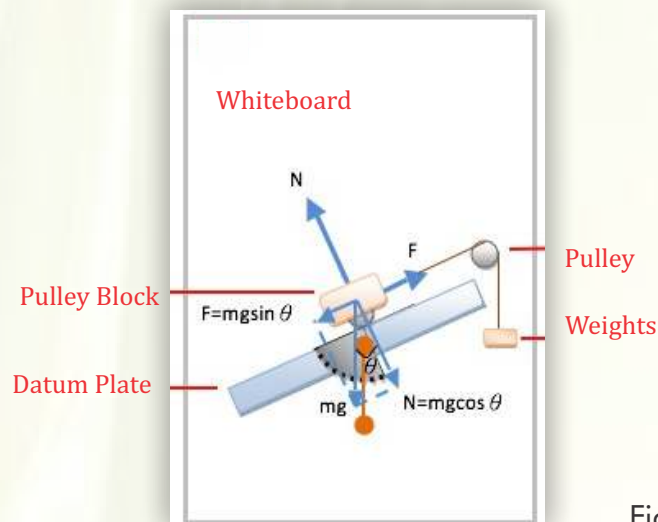


Fig.(17)

4.5.4.2.1.1 Assemble the equipment like

4.5.4.2.2 Procedure

4.5.4.2.2.1 Change the spring scale with weight base 20g. Adjust the tilted angle and make pulley block reach equilibrium. See figure (18)



Fig.(18)

4.5.4.2.2.2 Add weights in sequence, adjust angle, observe and record the result.

4.5.4.2.2.3 Calculate the decomposition force parallel to datum plate and the error with force of weights.

4.5.4.3 Relation between normal force and tilted angle

4.5.4.3.1 Installation

4.5.4.3.1.1 Succeed with prior experiment, change weights with 20g. When pulley block on the inclined plane reaches equilibrium, connect the string with spring scale and movable hook of the block. Adjust the string with the pulley, which makes the force acting on pulley car from spring scale perpendicular to datum plate and force of weights parallel to datum plate. See figure (19).

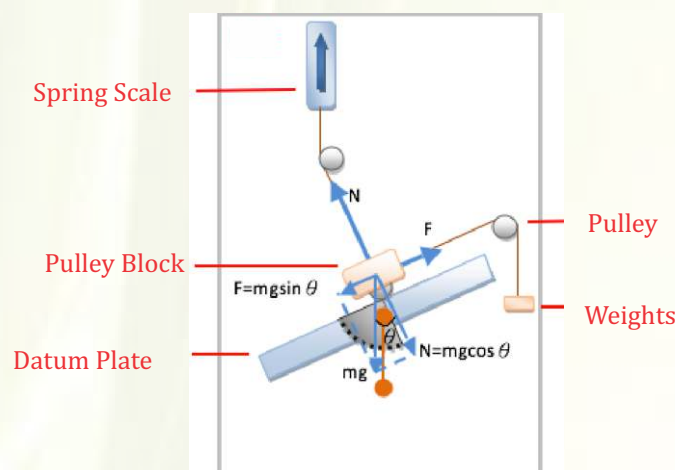


Fig.(19)

4.5.4.3.2 Procedure

4.5.4.3.2.1 Add weights in sequence and adjust the tilted angle to make pulley block reach equilibrium. Afterwards, adjust the spring scale to make pulley block exactly leave datum plate. Observe and record the result.

4.5.4.3.2.2 Calculate the decomposition force of pulley block perpendicular to datum plate and derive the error with normal force.

4.5.5 Pulley system

4.5.5.1 Single pulley: fixed pulley and movable pulley

4.5.5.1.1 Fixed pulley 4.5.5.1.1.1 Installation

4.5.5.1.1.1.1 Connect one side of the string with spring scale and the other side with weight base, which passes through two fixed pulleys. See figure (20).

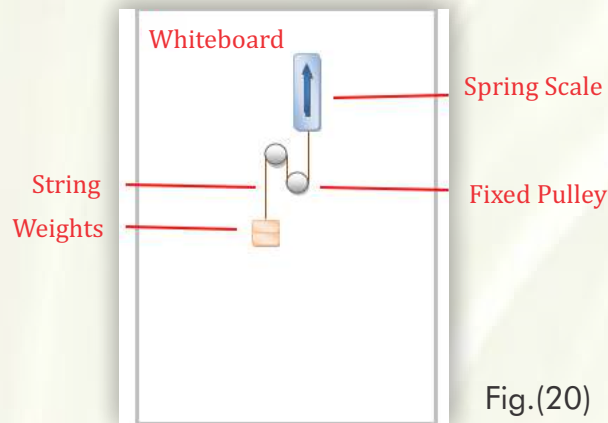


Fig.(20)

4.5.5.1.1.2 Procedure

4.5.5.1.1.2.1 Add weights in sequence and record the result. Compare them with original weights.

4.5.5.1.2 Movable pulley 4.5.5.1.2.1 Installation

4.5.5.1.2.1.1 Connect one side of the string with spring scale passing through movable single pulley and the other side with S hook hooking the axle beside the fixed pulley. See figure (21).

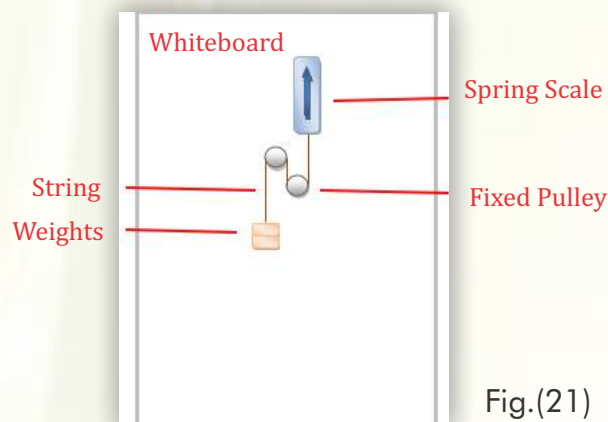


Fig.(21)

4.5.5.1.2.2 Procedure

4.5.5.1.2.2.1 Hook the weight base with S hook and use S hook to hook the hole on the single pulley.

4.5.5.1.2.2.2 Add weights in sequence and record the result. Verify whether it is labor-saving.

4.5.5.1.3 Displacement of movable pulley 4.5.5.1.3.1 Installation

4.5.5.1.3.1.1 Same as 4.5.5.1.2.1.1.

4.5.5.1.3.2 Procedure

4.5.5.1.3.2.1 Fix the effort force. Use hands to hold the string originally fixed in fixed pulley. Consider the string passes through the movable pulley vertically, so we pull it vertically with hands.

4.5.5.1.3.2.2 Record the result. Observe whether the pulling displacement is twice longer than displacement of movable pulley.

4.5.5.1.3.2.3 Change the direction of force. With same weight, record the readings of spring scale from 0 to 180 degrees of movable pulley. Record the result.

4.5.5.2 Double pulleys: movable pulley

4.5.5.2.1 Fixed pulley and movable pulley

4.5.5.2.1.1 Installation

4.5.5.2.1.1.1 Connect the string with spring scale passing through movable single pulley and fixed pulley. Fix it on the axle behind fixed pulley with S hook. See figure (22).

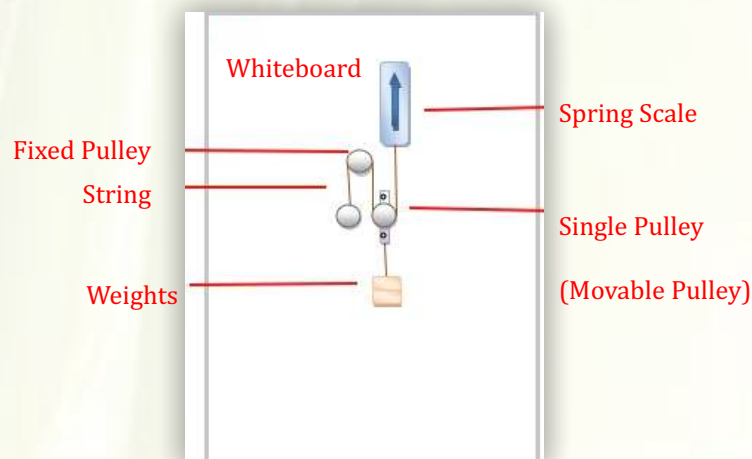


Fig.(22)

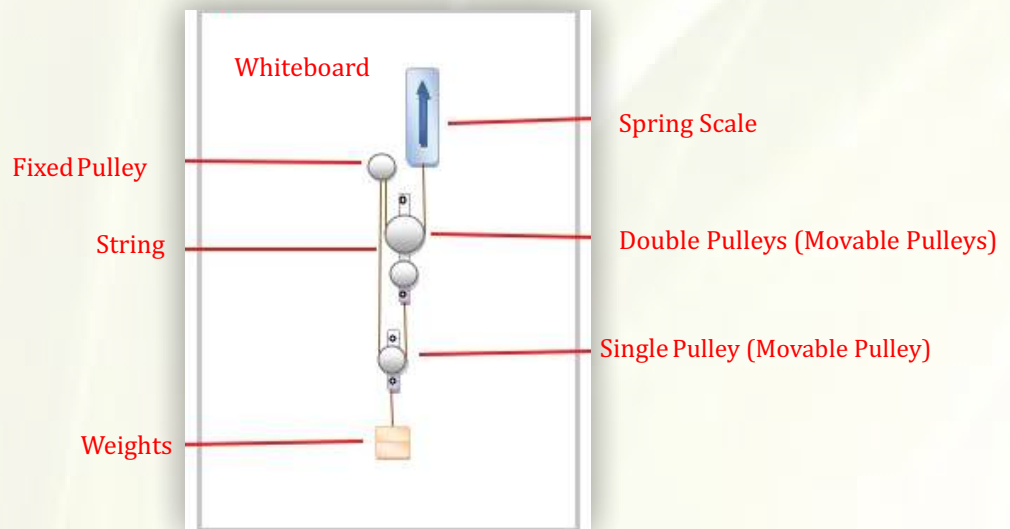
4.5.5.2.1.2 Procedure

4.5.5.2.1.2.1 Hook the weight base with S hook and use S hook to hook the hole on the single pulley.

4.5.5.2.1.2.2 Add 20g weights in sequence, observe and record the result. Verify whether it is labor-saving and calculate the error.

4.5.5.2.2 Movable pulleys 4.5.5.2.2.1 Installation

4.5.5.2.2.1.1 Connect the first string with spring scale passing through the first movable pulley to the axle behind the fixed pulley. Afterwards, connect one side of the second string with S hook and the other side with downward hole of the first movable pulley, and then pass through the second movable pulley to the axle behind the fixed pulley; lastly, use S hook to connect weight base with hole below the second movable pulley. See figure (23)



4.5.5.2.2.2 Procedure

4.5.5.2.2.2.1 Add 20g weights in sequence, observe and record the result. Verify whether it is labor-saving and calculate the error.

4.5.5.2.3 Displacement of movable pulleys

4.5.5.2.3.1 Installation

4.5.5.2.3.1.1 Same as procedure 4.5.5.2.2.1.1.

4.5.5.2.3.2 Procedure

4.5.5.2.3.2.1 Fix the effort force. Use hands to hold the string originally fixed in fixed pulley. Consider the string passes through the movable pulley vertically, so we pull it vertically with hands. Record the result. Observe whether the pulling displacement is four times longer than displacement of movable pulley.

4.5.5.3 Comprehensive experiment of pulley

4.5.5.3.1 Single and double pulley

4.5.5.3.1.1 Installation

4.5.5.3.1.1.1 See a big and a small pulley as a double fixed pulleys. Connect the string with spring scale passing through a fixed pulley to the big pulley on top of the double fixed pulleys and to the big pulley below the double movable pulleys, and then make it pass through the small pulley on top of the double fixed pulleys. Lastly, hook the axle behind the small pulley below the double fixed pulleys with S hook. Use S hook to connect weight base with hole below the double movable pulleys. See figure (24).

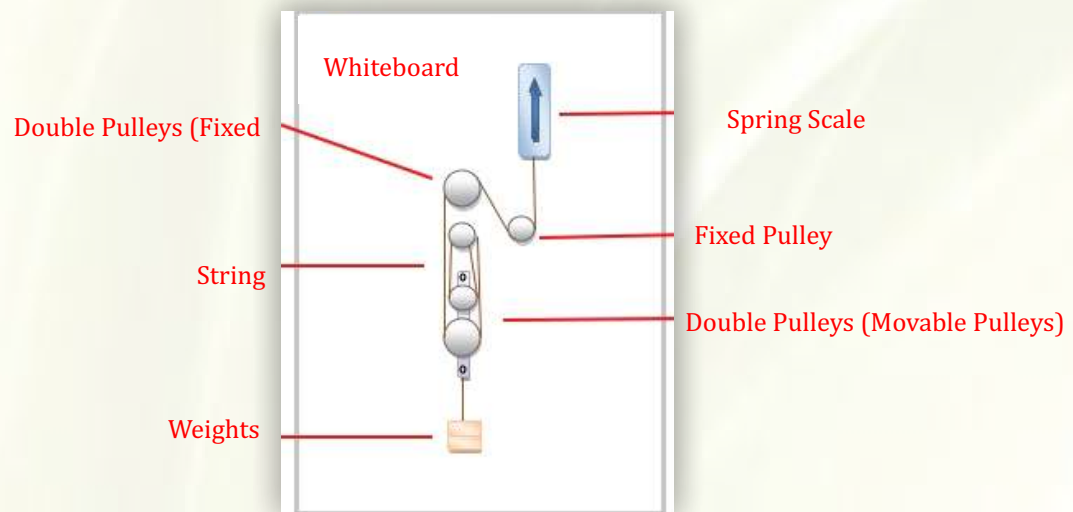


Fig.(24)

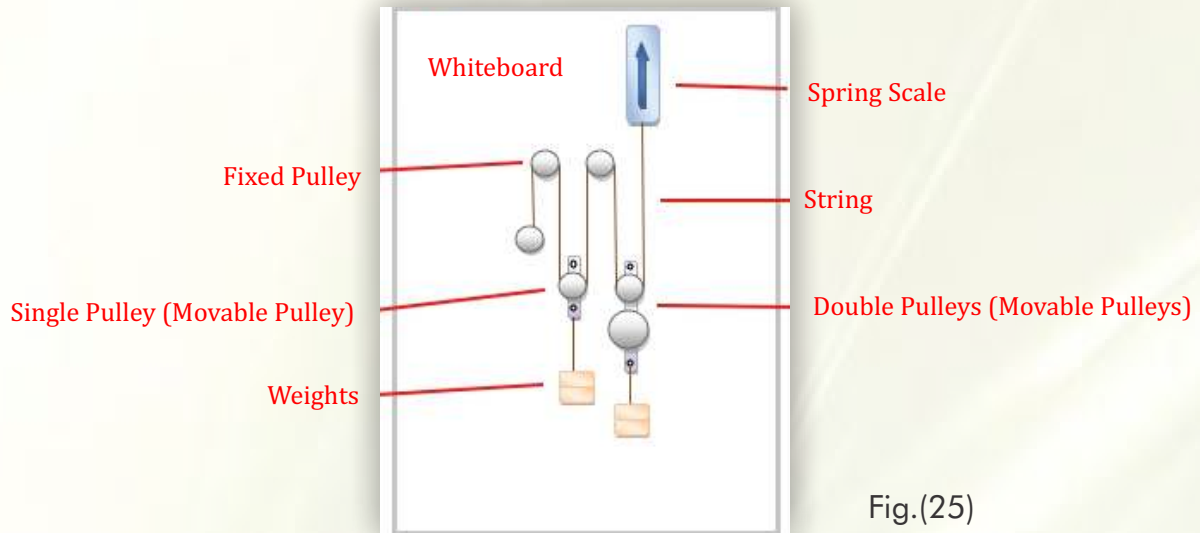
4.5.5.3.1.2 Procedure

4.5.5.3.1.2.1 Add 20g weights in sequence, observe and record the result. Verify the effort force is one-fourth of the load force in this pulley system.

4.5.5.3.2 Two double pulleys (double fixed pulleys and double movable pulleys)

4.5.5.3.2.1 Installation

4.5.5.3.2.1.1 See figure (25).



4.5.5.3.2.2 Procedure

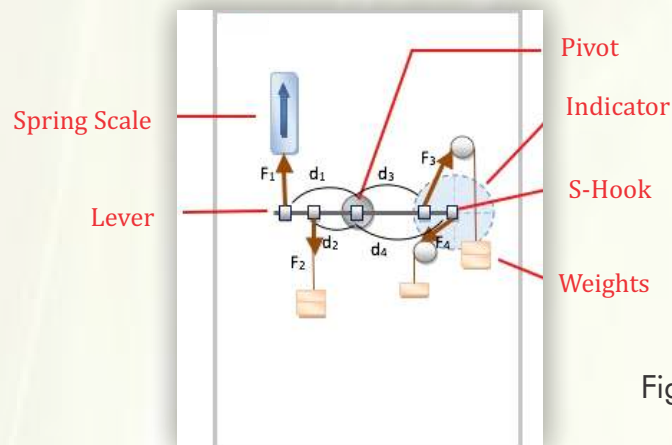
4.5.5.3.2.2.1 Add 20g weights in sequence, observe and record the result. Verify the effort force is one-fourth of the load force in this pulley system.

4.5.6 Multiple force equilibrium

4.5.6.1 Method 1

4.5.6.1.1 Installation

4.5.6.1.1.1 Install the lever into the pivot to stay horizontal balance. (Use overlap of vertical line and vertical indicator on the pivot to adjust.) See figure (26).



4.5.6.1.2 Procedure

4.5.6.1.2.1 Exert four forces with different magnitude and direction. Observe and analyze the result recorded.

4.5.6.1.2.2 Plot the diagram of static equilibrium. Observe whether it has the torque equilibrium condition.

4.5.6.2 Method 2

4.5.6.2.1 Installation

4.5.6.2.1.1 Connect the string with spring scale and S hook to adjust to the horizontal balance. See figure (27).

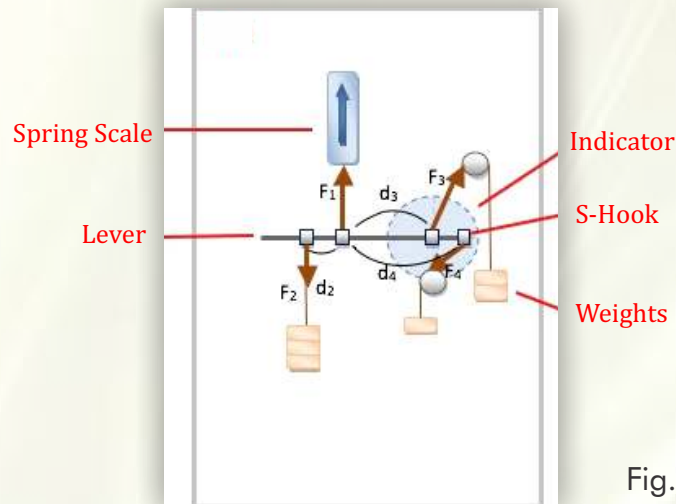


Fig.(27)

4.5.6.2.2 Procedure

4.5.6.2.2.1 Exert three forces with different magnitude and direction. Observe and analyze the result recorded.

4.5.6.2.2.2 Plot the diagram of static equilibrium. Observe whether it has the torque equilibrium condition.

4.5.7 Single pendulum

4.5.7.1 Installation

4.5.7.1.1 Connect one side of the string with O ring and fixed pulley and the other side with weight base. See figure (28).

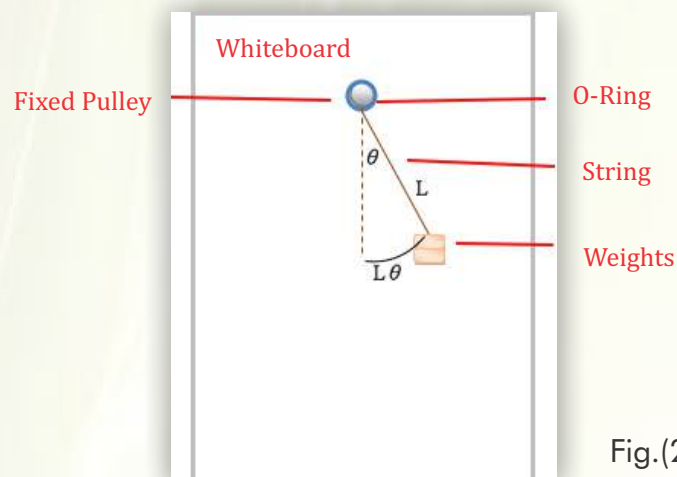


Fig.(28)

4.5.7.2 Procedure

4.5.7.2.1 Measure the length of pendulum (about 40cm). Take angle θ less than 5 degrees. Use counter to record the time interval t during the period it swings 20 times, so the period $T = t(s) / n(\text{times})$. Record the result.

4.5.7.2.2 Repeat the time t four times to get the average value. Compare it with the theoretical value.

4.5.7.2.3 Change the length to 20cm and 10cm. Repeat procedure from 4.5.7.2.1. to 4.5.7.2.2. and record the result.

4.5.7.2.4 Change the weight of counterpoise. Repeat procedure from 4.5.7.2.1. to 4.5.7.2.3. and record the result.



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