The Physics of Pulleys

Respective blueprint	The Pulleys
Description	In this pedagogical sequence students will learn the properties of pulleys, and Forces using the system of pulleys.
Learning Objectives	Students will: - Learn how to create a Pulley system - Understand Forces and gravity - Be able to calculate the Tension and acceleration in a pulley system - Be able to use Newton's second Law

Related curricular subject(s)	Physics, History
Prerequisites / preparatory actions for teachers	Teachers should gather the materials for the blueprint
Prerequisites / preparatory actions for students	Understand the basics of physics, know how to use and create a pulley. Have basic knowledge on Forces.
Age of students	12-15
Duration	2-3 hours
Level of difficulty	Hard

Step by step description of the tasks

Step 1: What is a Pulley?

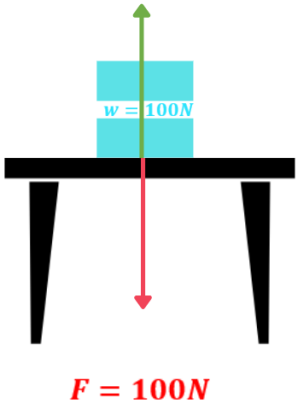
The teacher introduces the concept of Pulley to the class.

First evidence of the existence of pulleys dates back to Ancient Egypt (1991-1802 A.C.N) and Mesopotamia in the early 2nd millennium A.C.N. Pulleys are identified as being one of six simple machines used to lift weights by Hero of Alexandria (c. 10-70 CE), in Roman Egypt. They are form by a block and tackle in order to provide a mechanical advantage to apply large forces. Pulleys can also be assembled as belt and chain drives in order to transmit power from one rotating shaft to another. Plutarch's Parallel Lives makes the account of a scene in which Archimedes uses compound pulleys and the block-and-tackle system to pull a fully laden ship towards him as if it was gliding through water, hereby proving its effectiveness[1]. Pulleys were also commonly used in farming, building works and wells.

Step 2: Small reminder of the concept of Force and Newtons

Force: “A **force** is a push or pull upon an object resulting from the object's **interaction** with another object. Whenever there is

an **interaction** between two objects, there is a force upon each of the objects. When the **interaction** ceases, the two objects no longer experience the force. Forces only exist as a result of an interaction."[2]



Resistance of the Table pushes upward by 100N

Gravity pulls the weight down by 100N

Pulley systems are used in mechanics problems in physics. The best way to solve pulley problems in mechanics is by utilizing Newton's second law of motion and understanding Newton's third and first laws of motion.

Newton's second law states:

$$F = m.a$$

Where, F is for the net force, which is the vector sum of all the forces acting on the object. m is the mass of the object, which is a scalar quantity meaning mass only has magnitude. Acceleration gives Newton's second law its vector property.

[1] *Pulley*. (2001, September 5). Wikipedia, the free encyclopedia. Retrieved April 4, 2022, from https://en.wikipedia.org/wiki/Pulley#:~:text=The%20earliest%20evidence%20of%20pulleys,machines%20used

[2] *The meaning of force*. (n.d.). The Physics Classroom. https://www.physicsclassroom.com/class/newtlaws/Lesson-2/The-Meaning-of-Force

The Newton: "Force is a quantity that is measured using the standard metric unit known as the **Newton**. A Newton is abbreviated by an "N." To say "10.0 N" means 10.0 Newton of force. One Newton is the amount of force required to give a 1-kg mass an acceleration of 1 m/s/s. Thus, the following unit equivalency can be stated:

1 Newton = 1 kg • m/s2 "[3]

Step 3: Make the students brainstorm ideas on how the pulleys may work and be used in everyday life.

So what is it used for? First, make a brainstorming session with the students to try and understand how and what the pulley may be used for. If possible, make a demonstration to them of real-life pulleys working (a nearby well, a curtain, etc). If not possible to have a real-life pulley in class, show the students some videos of a pulleys working in different contexts (nautical, building work, well, etc). After hearing their thoughts, you may ask them how useful do they think the pulleys are? And can they think of anything they could apply them to ease their everyday life?

Step 4: Explain and/or build the Pulley system – The Atwood Machine[4]

The teacher explains the Atwood Machine as an illustration of Newton's Second Law. At the same time, he may build the pulley system with the students to illustrate each step with one pulley, 2 pulleys, 3 pulleys, etc. Instead of using kg, you may use small change (same coins). You will be

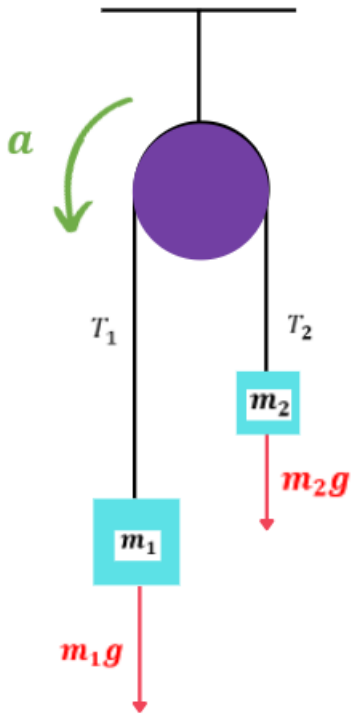
[3] *Ibid.*
[4] Michel van Biezen. (2013, January 20). *Physics - Mechanics: The Pulley (1 of 2)*. YouTube. https://www.youtube.com/watch?v=kvCnjVSpuv0

able to see the ratios of weight needed to lift an initial weight with different pulley systems. We would advise letting the students try their hand with the pulley system on their own before exploring the theory.

With one pulley, the Atwood Machine:

A string is placed avec a massless and frictionless pulley (to simplify the exercise, we consider the mass and friction of the pulley to be negligible).

A mass of 8kg is suspended at one end while a mass of 5 kg is suspended at the other end of the rope. What is the acceleration of the system?



$$m_1 = 8kg \quad m_2 = 5kg$$

$$F = m.a$$

$$a = \frac{F_{net}}{m_T}$$

$$a = \frac{m_1 g - m_2 g}{m_1 + m_2}$$

$$a = \frac{(m_1 - m_2).g}{m_1 + m_2}$$

$$a = \frac{(8kg - 5kg).(9.8m/sec^2)}{8kg + 5kg}$$

$$a = \frac{(3kg).(9.8m/sec^2)}{13kg}$$

$$a = \frac{(3\cancel{kg}).(9.8\ m/sec^2)}{13\cancel{kg}}$$

$$a = 2.26\frac{m}{sec^2} = 2m/sec^2$$

Now, how can we calculate the tension of the ropes?

$$T_1 = m_1 g - m_1 a$$

$$T_2 = m_2 g + m_2 a$$

$$T_1 = (8kg).\left(9.\frac{8m}{sec^2}\right) - (5kg).(2.26m/sec^2)$$

$$T_1 = (8kg).\left(9.\frac{8m}{sec^2}\right) - (8kg).(2.26m/sec^2)$$

$$T_1 = 60.32\ N$$

$$T_2 = (5kg).\left(9.\frac{8m}{sec^2}\right) + (5kg).(2.26m/sec^2)$$

$$T_2 = 60.3\ N$$

$$T_1 = T_2$$

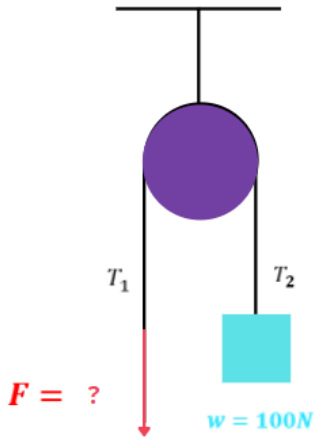
So the tension of two ropes holding weights on either sides of a pulley is always equal.

You may direct the students to search for more information online. If the teacher wants, they can use the pulley system we created to illustrate the principle of the Atwood Machine with the students.

Now that we know how to calculate Tension and Acceleration, let us spice things up a little bit.

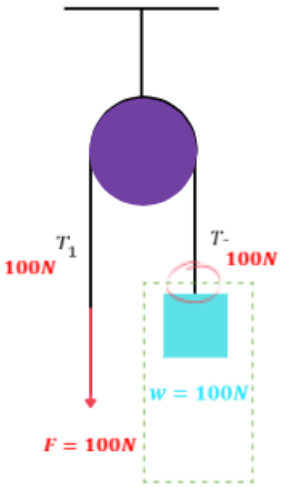
Step 5: Presenting the science behind the experiment of the pulley system[5]

The teacher should explain the principles of pulleys mechanics and mechanical advantage. For each step, do it physically with the students first and let them draw conclusion, then go over the theory and explain again using the pulley system as an example.



[5] Michel van Biezen. (2015, June 23). *Mechanical Engineering: Particle Equilibrium (11 of 19) Why are Pulleys a Mechanical Advantage?* YouTube. https://www.youtube.com/watch?v=6GuldysCVjI

We saw with the Atwood Machine, that with a single pulley, Tension 1 and Tension 2 are always equal. So, with a weight of 100N, which Force is needed to lift it up with 1, 2, 3 or 4 pulleys?



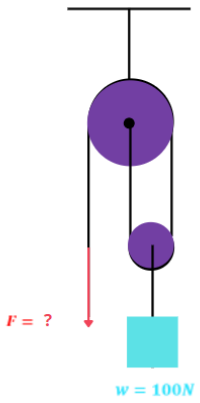
With one pulley, it is the same as with the Atwood Machine.

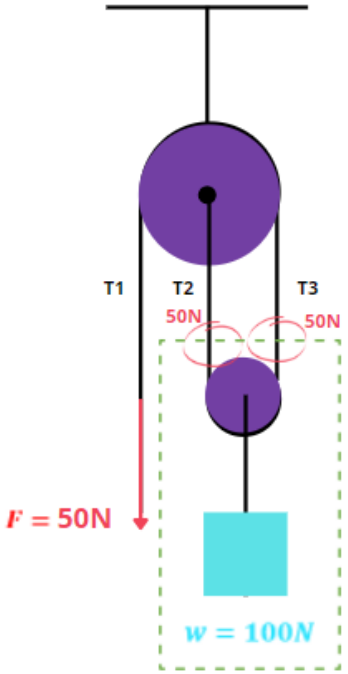
When you look at the ropes holding the weight, there is only one, and the other rope of the pulley is the one you pull. The tension T1 = T2. Thus, you need 100 Newton Force to uplift a 100N weight. The distance lifted and the distance pulled is also the same.

$$\boldsymbol{F = 100N}$$

Now, let's observe with two pulleys:

Let us observe the number of ropes and the tension in all of them.





The weight is help up with two ropes. (T2 and T3) Around the second pulley T2 = T3. And on the first pulley, T1 = T3. Which means that T1 = T2 = T3. Therefore, to lift a weight of 100 Newtons, we need a Force of 50 Newtons, since it is divided into two upholding ropes. The price for this reduced Force however, is that to lift the 100 N of 1m above ground, you will need to pull the rope by 2m.

Now the same with 3 pulleys.

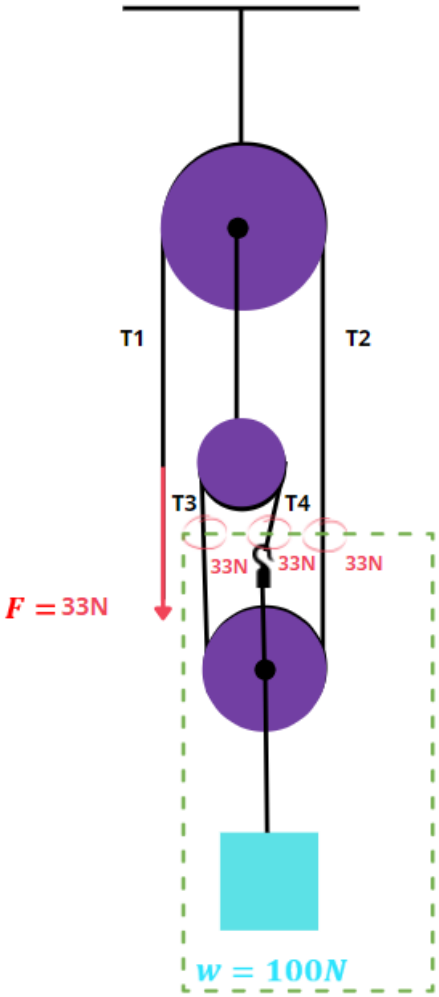
We can see that the weight is held up by 3 different ropes.

Given that T1 = T2, and that T2 = T3, and T3 = T4, then T1 = T2 = T3 = T4.

So, as the weight is spread over 3 rope lengths : T2, T3, T4. The Force needed is of 100N/3 = 33N.

However, to lift the weight of 1m, you will need to pull on the rope by 3m.

The distance lifted = the distance pulled/the number of ropes holding the weight.



Conclusion

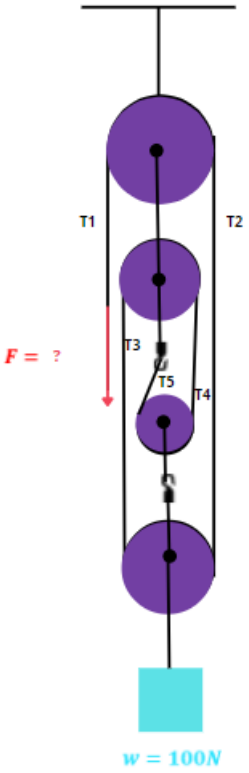
In this lesson the students learn about the use of pulleys and Newton's theorem. They learn how they were used in ancient Egypt, and they can use them to do some of our everyday tasks. They learn how to calculate the Force necessary to lift weights using several pulleys, as well as the Tension in each rope and the acceleration in a system.

Assessment activities

Activity 1. Find information about the pulley and its components and present them to the class.

Activity 2. Search for information on how Newton's Second Law can be used.

Activity 3. With your pupils, draw and complete the diagram of a 4-pulley system.



[6]

What is the Force needed to lift 100N up?

..... N

To lift a weight of 100N up by 1m, how many meters of rope will you need to pull?

.....m

[6] All pulley graphics were created by Logopsycom, using Canva

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- *Pulley*. (n.d.). Energy Education. https://energyeducation.ca/encyclopedia/Pulley