FireFighterPrep Comprehensive Guide to Canadian Fire Service Exams

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Teaching Mechanical Aptitude

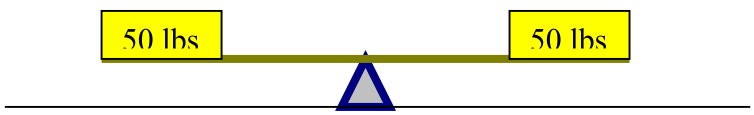
Below is a list of simple machines which firefighters often use to perform their duties.

- Lever
- Wheel and Axle
- Inclined Plane
- Belt Drive
- Pulley
- Screw
- Gears

Complex machines basically employ one or a combination of the above machines. The purpose of all these tools is to make given tasks easier. Mechanical movements and forces govern these tools.

Levers

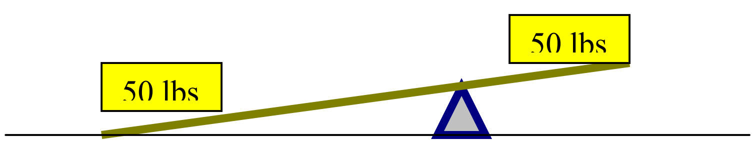
Levers are devices we are familiar with as many of us grew up using them as toys such as teeter-totters. These tools allow lighter weights to lift heavier weights through the use of leverage. What you have to understand about levers is how the position of the fulcrum (pivot point) will affect different weights.



fulcrum

With two equal weights situated equidistant from the fulcrum, neither side should fall. The two weights will balance each other and neither side will go up or down.

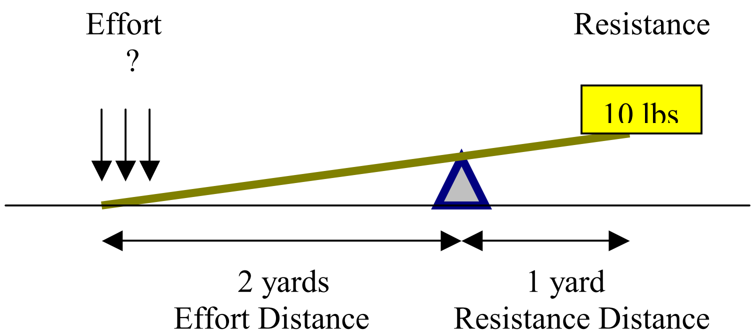
If the same weights are not positioned equidistant from the fulcrum, the weight closer to the fulcrum will be lifted into the air by the weight further away.



As stated above, this is the principle of leverage. In order to lift the 50 lbs on the right, there wouldn't even need to be 50 lbs on the left. A lighter weight (amount of force) could lift the 50 lbs.

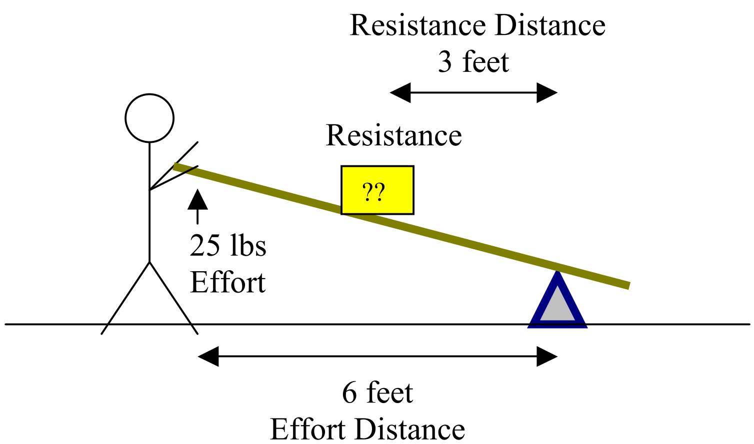
There is a mathematical equation which allows you to determine how much force is required to lift a weight depending on how far each weight is from the fulcrum.

$$\boxed{\text{Effort x Effort Distance = Resistance x Resistance Distance}}$$



Effort x 2 = 10 x 1
Effort = 10 / 2
Effort = 5 lbs

You should be aware of a second class of lever. Have you ever seen a situation such as this?



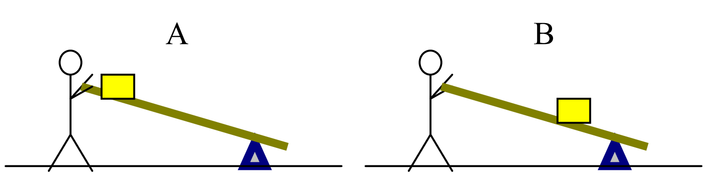
Effort x Distance Effort = Resistance x Resistance Distance

25 x 6 = Resistance x 3
Resistance = 150 / 3
Resistance = 50 lbs

In this configuration, you can lift 50 lbs by using 25 lbs of effort.

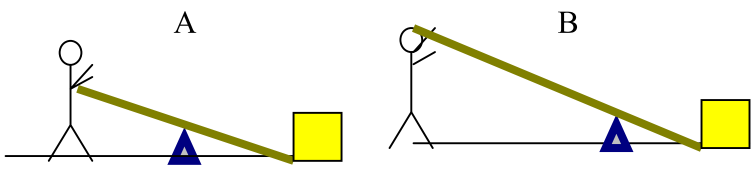
General Rules of Levers

1) The closer the resistance is to the fulcrum the less effort is required to lift the object.



Lifting the box in example A requires more effort than lifting the box in example B. You should also notice that in example B the person loses potential height.

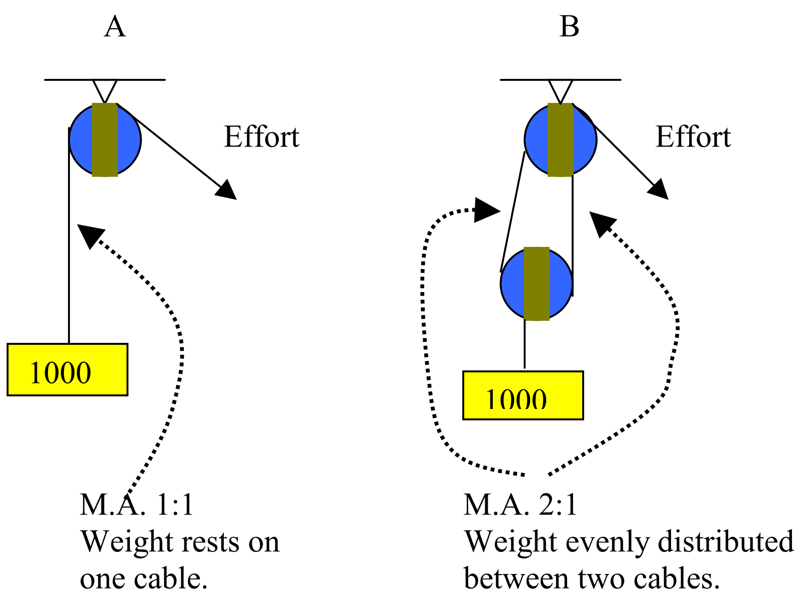
2) The further the effort is from the fulcrum the less effort is required to lift the object.



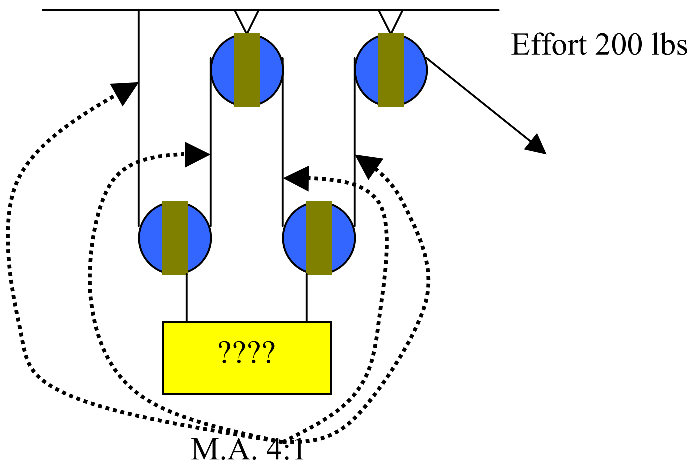
Lifting the box in example A requires more effort than lifting the box in example B. You should also notice that in example B the person is required to move the lever a greater distance to gain the mechanical advantage.

Pulleys

Firefighters often use pulleys in order to lift or pull heavy objects. They can be either fixed (motionless) or moveable. In order to work with pulleys, you need to understand the mechanical advantage (M.A.) they provide. To determine this, count the number of cables that are supporting the weight, excluding the cable which is acting as the Effort. Consider the examples below.



C



M.A. 4:1
Weight evenly distributed
between 4 cables.

The mathematical formula to calculate the Effort requirements is as follows:

$$\boxed{\text{Effort} = \frac{\text{Weight (resistance)}}{\text{Mechanical Advantage}}}$$

In Example A, the weight is 1000 lbs and the M.A. is 1. With this system, it would take 1000 lbs of effort to lift the 1000 lb weight.

Effort = 1000 / 1 = 1000 lbs

In example B, the weight is 1000 lbs and the M.A. is 2. With this system, it would take 500 lbs of effort to lift the 1000 lb weight.

Effort = 1000 / 2 = 500 lbs

In example C, the effort is 200 lbs and the M.A. is 4. With 200 lbs of effort you would be able to lift up to 800 lbs.

200 = Weight / 4

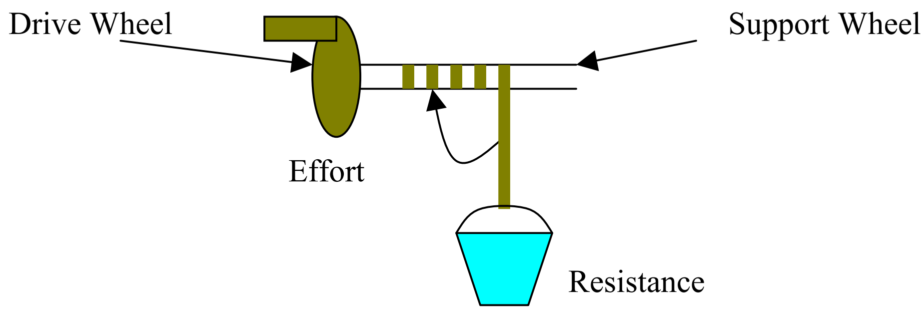
Weight = 200 x 4 = 800 lbs

As with levers, the Mechanical Advantage comes with a price. As Effort decreases with Mechanical Advantage, so does potential height. In other words, the more pulleys you use, the less high you can raise the object without pulling more rope through the system. There is a formula to determine the length of cable that is hauled through a pulley system and the height the object is actually raised.

$$\boxed{\text{Length of Pull} = \text{Height (lift)} \times \text{Mechanical Advantage}}$$

Wheel and Axle

One of the most recognized wheel and axle systems is a water well. This system involves a large wheel attached to a rod or axle or smaller wheel that performs work. When someone turns the large wheel handle at a well, this turns the smaller rod, which winds the rope to raise the bucket.

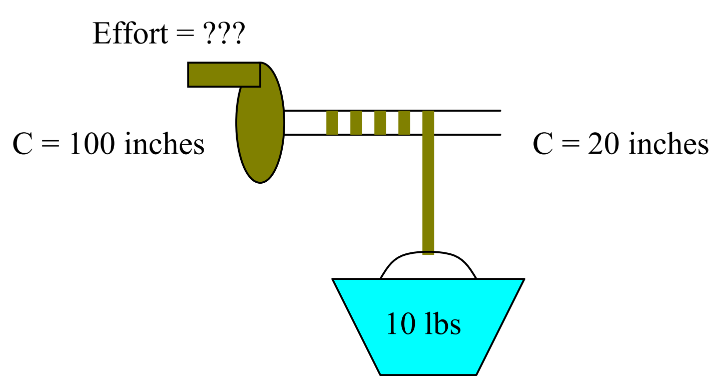


As with most mechanical devices, the wheel and axle makes the job of raising the water, or the resistance, easier. The larger the drive wheel is in relation to the support wheel, the less effort is required to lift the same resistance weight. You must know how to calculate the circumference in order to work with these problems. This is taught in the math teaching section, but here is a quick reminder of the formula:

C = 2 (л) (r)
C = circumference
Л = 3.14
r = radius

The formula for calculating the Mechanical Advantage of a wheel and axle is the following.

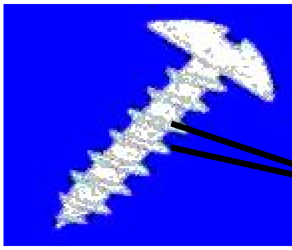
(Effort) x (C. Drive Wheel) = (Resistance) x (C. Support Wheel)



Effort x (C drive) = Resistance x (C support)
Effort x 100 = 10 x 20
Effort = 200 / 100
Effort = 2 lbs of effort would be required to lift the bucket

Screw

Screws are used for a variety of purposes, such as wedging into wood to hold material together, and also for lifting heavy objects such as motor vehicles through the use of a jackscrew. The composition of a screw is a rod with spiral threading on it.

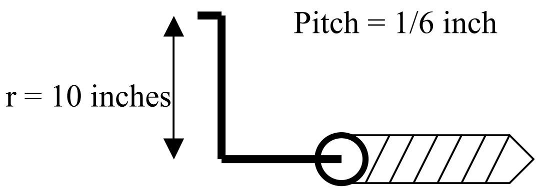


Pitch is an important concept for understanding the mechanical advantage of screws. Pitch is defined as the distance between two winds of the screw.

The pitch determines the amount of work that a screw performs during one complete revolution. The larger the pitch, the more work is done. However, larger pitches require more effort. Smaller pitches require more revolutions to complete the same job, but less effort is required to complete these revolutions.

As with the Wheel and Axle, you should be comfortable calculating circumference before attempting to solve problems with screws.

The mechanical advantage of a screw is calculated by dividing the circumference of the turning handle by the screw pitch.



$$C = 2 \pi r$$
$$= 2\,(3.14)\,(10)$$
$$= 62.8 \text{ inches}$$

$$\boxed{\text{M.A.} = \text{Circumference of the handle} \div \text{Pitch of the Screw}}$$

M.A. = 62.8 ÷ 1/6

M.A. = 62.8 x 6

M.A. = 376.8 : 1

If you have difficulty remembering how to divide fractions, review the teaching material in the math section.

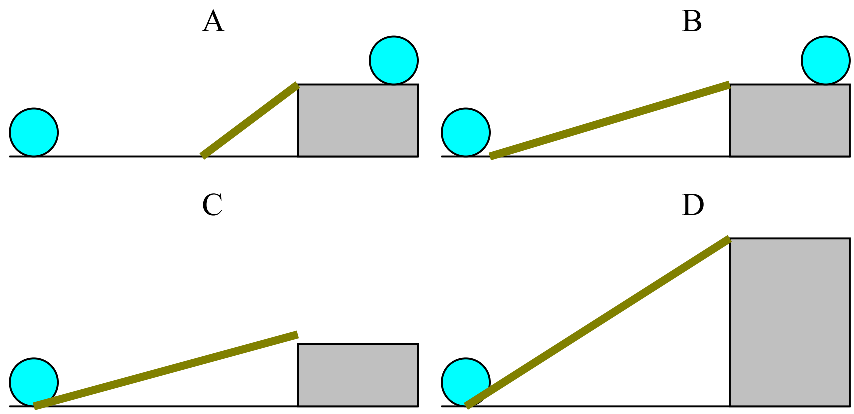
You have to multiply the number by the fraction's reciprocal.

The next step is to apply the mechanical advantage to a weight problem. Suppose you are required to lift a 3,000 lb motor vehicle. In using the jackscrew above, which has a M.A. of 377:1, how much effort would be required?

Effort = Resistance / Mechanical Advantage
Effort = 3,000 / 377
Effort = 8 lbs of effort would be required

Inclined Plane

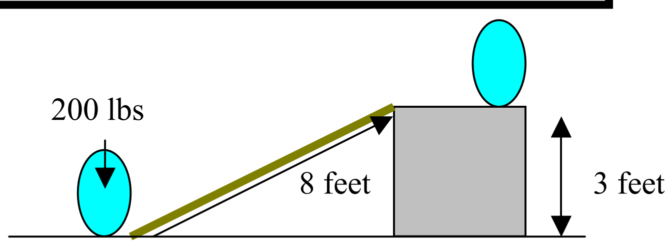
An inclined plane is simply a ramp that is used to make lifting objects easier. They are used in a variety of situations, such as loading trucks to creating roads for trucks to drive out of open-pit mines. For an inclined plane, the effort required to lift an object decreases the longer the inclined plane is, and the shorter its height.



In order to move the drums above, option A would require more effort than option B, while option D would require more effort than option C.

There is a mathematical formula to calculate the amount of effort required to lift an object. The necessary variables are the height of the object, the weight of the object, and the length of the inclined plane.

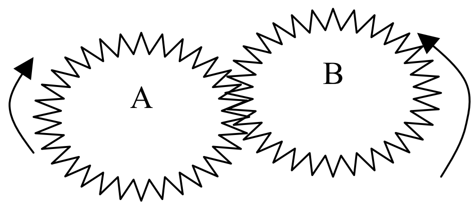
$$\boxed{\text{Effort} \times \text{Length of Plane} = \text{Resistance} \times \text{Height}}$$



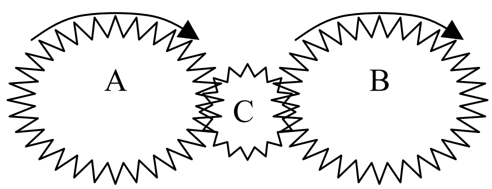
Effort x 8 = 200 x 3
Effort = 600 / 8
Effort = 75 lbs of effort is required to elevate the drum.

Gears and Belt Drives

Gears can be thought of as wheels with teeth which work together to change the direction of force. These wheels also increase or decrease the amount of torque (twisting force) that is applied from the drive gear (the gear that initiates the movement).

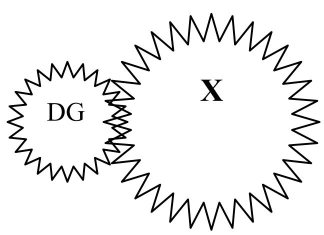


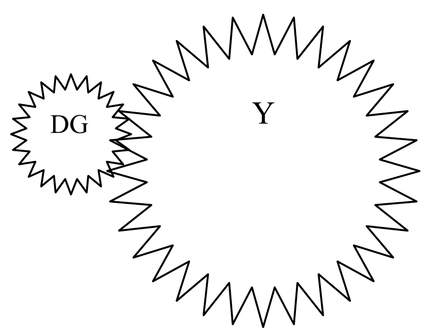
It is extremely important that you understand the dynamics of gears. When two gears intermesh teeth, Gear A (the drive gear) will spin the Gear B in the opposite direction regardless of whether this is clockwise or counterclockwise. If you want two gears to spin in the same direction, you need to have an intermediary gear between them.



Gear C causes gear A and gear B to turn in the same direction.

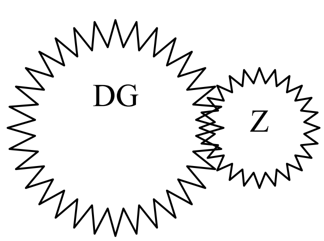
In addition to changing the direction of force, gears can influence speed and torque if different sized gears are used with each other. Gear DG represents the drive gear, or the gear that is hooked up to a motor or another source of power.





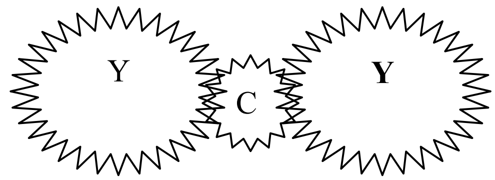
Gear X is twice as large as gear DG. Gear X will have twice as much torque, but will spin at ½ the speed.

Gear Y is three times the size of gear DG. Gear Y will have three times as much torque, but will spin at 1/3 the speed.



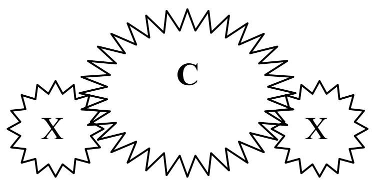
Gear Z is ½ the size of gear DG. Gear Z will have ½ as much torque, but will spin twice as fast as gear DG.

You should also be aware of other principles regarding different sized gears. If two gears of the exact same size are linked by a smaller (or larger) gear, there will be no difference in the speed or torque of the two gears being linked.



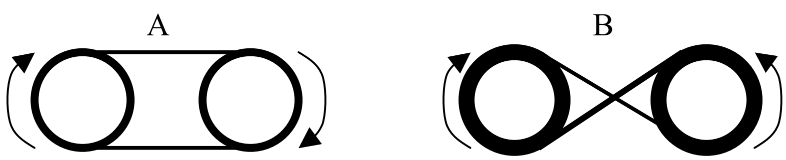
Both gear Y's will have the same speed and torque.

Both gear X's will have the same speed and torque.



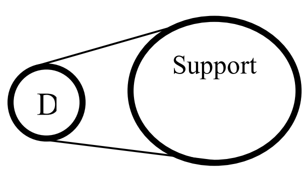
Belt Drives

Belt drives operate similarly to gears but are interconnected with a belt as opposed to intermeshing teeth. This configuration is frequently used in motor vehicles. One of the main differences in the operation of belt drives in comparison to the operation of gears is the fact that joined belt drives spin in the same direction unless the belt between the two wheels is twisted.



In example A, both wheels will spin in the same direction. In example B, the twist in the belt causes the wheels to spin in opposite directions.

Belt drives follow the same principles as gears in regards to torque and speed for differing wheel sizes.



Wheel A is the drive gear and is ½ the size of the support wheel. The support wheel will therefore have twice as much torque, but will only spin at ½ the speed.