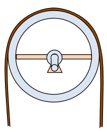
Lever

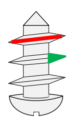
Machine used to move a load with less effort, or more distance & speed, or in a new direction.
From the French *lever* [luh-vee]: to raise or lift (think *levitate*).

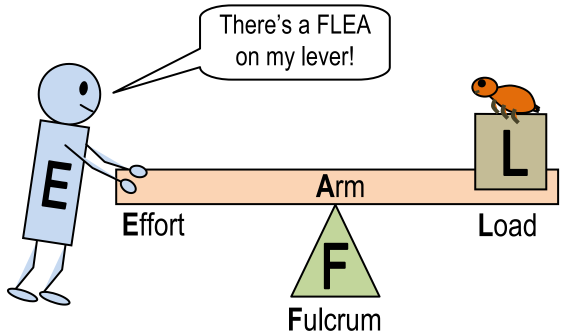
The Six Simple Machines

Lever
Pulley
Wheel & Axle



Inclined Plane
Wedge
Screw





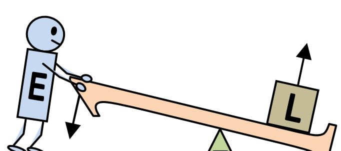
- **Fulcrum** : Pivot point or hinge
- **Load** : Object or force that resists movement
- **Effort** : Force applied to move Load
- **Arm** : Structure that transfers force

Lever Classes

F	L	E
1	2	3

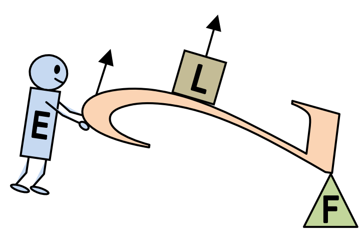
What's in the middle?

1st Class
Fulcrum in Middle



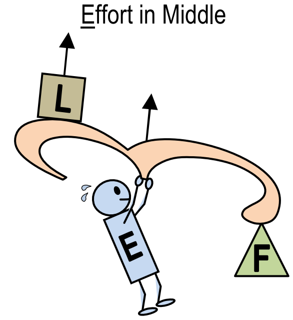
- *Less* Effort needed to move Load.
- Load moves *slower/less* than Effort.
- Load moves in *different* direction to Effort.

2nd Class
Load in Middle



- *Less* Effort needed to move Load.
- Load moves *slower/less* than Effort.
- Load moves in *same* direction as Effort.

3rd Class
Effort in Middle



- *More* Effort needed to move Load.
- Load moves *faster/more* than Effort.
- Load moves in *same* direction as Effort.

Tip

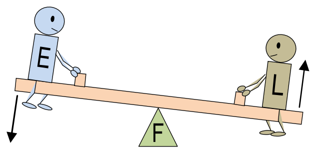
When analyzing a lever, first find the Fulcrum, then imagine lines drawn from it to the Load and Effort.

Lever Examples

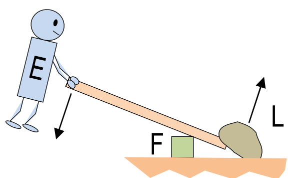
Arrows = Direction of Movement ↑↓

L & E can be above or below Arms

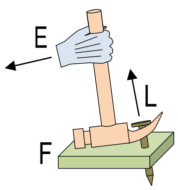
1st Class



Seesaw

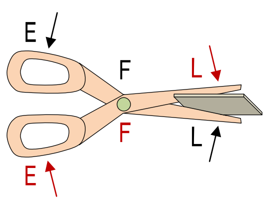


Pry Bar



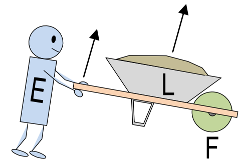
Claw Hammer

Double 1st Class

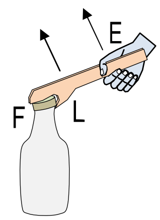


Scissors

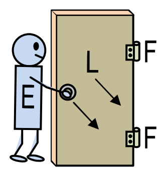
2nd Class



Wheelbarrow

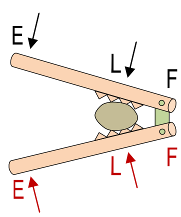


Bottle Opener



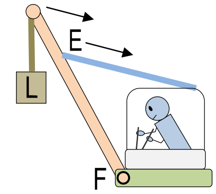
Door

Double 2nd Class

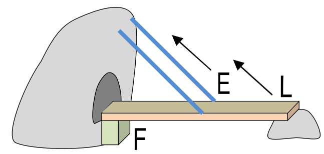


Nutcracker

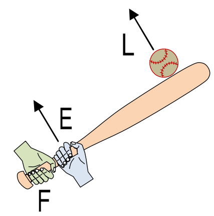
3rd Class



Crane

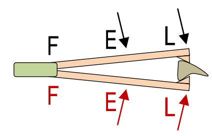


Cantilever Bridge



Sports Bat

Double 3rd Class



Tweezers

Add to these lists as you discover more lever examples. (The same item may fit in more than one class.)

1st Class
Balance Scale
Spatula (if push handle down)
Catapult (if launcher at end)

2nd Class
Wrench
Spatula (if lift handle up)
Stapler / Paper Cutter

3rd Class
Broom / Rake / Hoe
Striking Hammer / Hatchet
Catapult (if launcher in middle)

Double 1st Class
Pliers / Wire Cutters
Tin Snips / Garden Shears

Double 2nd Class
Wrist Squeezer
Fireplace Bellows

Double 3rd Class
BBQ Tongs
Human Limbs / Jaw

Hybrid: Nail clippers: 2nd (top) + Dbl 3rd (bottoms)

Law of the Lever

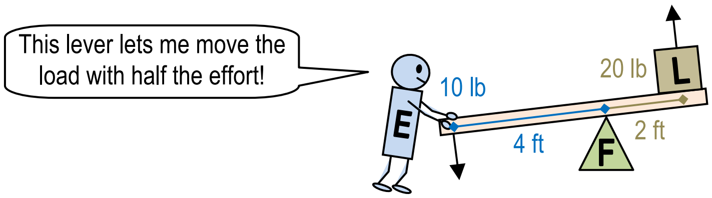
The Work *input* to a lever equals the Work *output* by the lever.

Work = Force × Distance

$$\underbrace{F_E D_E}_{Work_{IN}} = \underbrace{F_L D_L}_{Work_{OUT}}$$

Force of Effort [Input] — Distance to Effort (from Fulcrum) — Force of Load [Output] — Distance to Load (from Fulcrum)

$F_E D_E = F_L D_L$
"whistle *feedee fiddle* while you work"



In a real lever, a portion of Work is lost to friction.

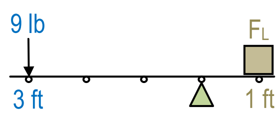
$$F_E D_E = F_L D_L$$
$$(10lb)(4ft) = (20lb)(2ft)$$
$$40\ ft\text{-}lb = 40\ ft\text{-}lb$$

Rule of Thumb
The longer the Effort arm, the easier it is to move the Load.

Archimedes (Greece, ~200 BCE)

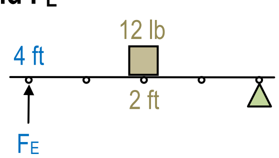
Lever Problems

Find F_L



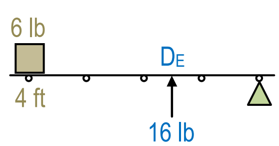
$$F_E D_E = F_L D_L$$
$$(9\ lb)(3\ ft) = F_L(1\ ft)$$
$$\frac{(9\ lb)(3\ ft)}{(1\ ft)} = \frac{F_L(1\ ft)}{(1\ ft)}$$
$$\boxed{27\ lb = F_L}$$

Find F_E



$$F_E D_E = F_L D_L$$
$$F_E(4\ ft) = (12\ lb)(2\ ft)$$
$$\frac{F_E(4\ ft)}{(4\ ft)} = \frac{(12\ lb)(2\ ft)}{(4\ ft)}$$
$$\boxed{F_E = 6\ lb}$$

Find D_E



$$F_E D_E = F_L D_L$$
$$(16\ lb)(D_E) = (6\ lb)(4\ ft)$$
$$\frac{(16\ lb)(D_E)}{(16\ lb)} = \frac{(6\ lb)(4\ ft)}{(16\ lb)}$$
$$\boxed{D_E = 1.5\ ft}$$

Tip Mentally multiply respective Effort and Load forces and distances to ensure they yield identical products.

Units of Measure

Force units ×	Distance units =	Work units
1 Pound	1 Foot	1 Foot-Pound
2 lbs	3 ft	6 ft-lbs
1 Newton	1 meter	1 Newton-meter (Joule)
2N	3m	6 Nm (J)

Conversion Factors
1 ft-lb = 1.35 Nm = 1.35 J
1 Nm = 1 J = 0.74 ft-lbs

Since levers rotate in arcs (vs. straight lines), the technically-correct terminology is **Moment = Force × Distance**, where "Moment" is the turning force or torque.

Lever Mechanical Advantage (MA)

MA: Factor by which a lever changes the force, distance & speed, or direction of work.

Tradeoff: Increased output force means less output distance & speed and vice versa.

Deriving MA

$F_E D_E = F_L D_L$

$\frac{F_E D_E}{F_E D_L} = \frac{F_L D_L}{F_E D_L}$

$\frac{D_E}{D_L} = \frac{F_L}{F_E}$

Distance Ratio — *Force* Ratio

A ratio is a relation between numbers

$$MA = \frac{D_E \text{ [Input arm]}}{D_L \text{ [Output arm]}} \quad \text{OR} \quad MA = \frac{\text{Load } [F_L \text{ out}]}{\text{Effort } [F_E \text{ in}]}$$

D_E: Distance to Effort (from Fulcrum)
D_L: Distance to Load (from Fulcrum)

F_L: Force of Load [Output Force]
F_E: Force of Effort [Input Force]

$MA = D_E / D_L$ "made dull by distance"

$MA = L / E$ "male force"

MA = Output / Input "Chairman MAO is In"

The Load is also called the *resistance*, because it resists the Output Force that moves it.

LOAD — OUTPUT — Resistance

Effects of MA

Input Force	*Factor multiplier*	Output Force
F_E ×	MA	= F_L

$F_E \times MA = F_L$ "FEMA fights FLoods" Federal Emergency Management Agency

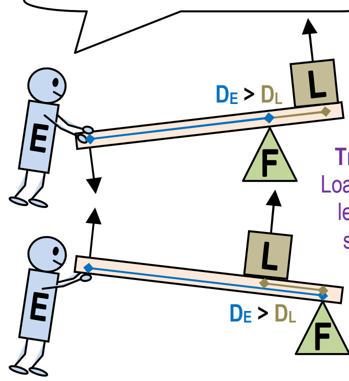
If MA > 1

More Output Force

(Less Output Distance & Speed)

1st or 2nd Class Lever with Fulcrum nearer Load.

Advantage: MA>1 *increases* my force, so I can move the Load with less effort.



Tradeoff Load moves less and slower.

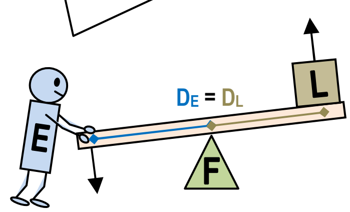
If MA = 1

Equal Output Force

(Change in Direction)

1st Class Lever with Fulcrum centered.

Tradeoff: MA=1 transmits but doesn't increase or decrease my force.



Advantage Load moves in different direction.

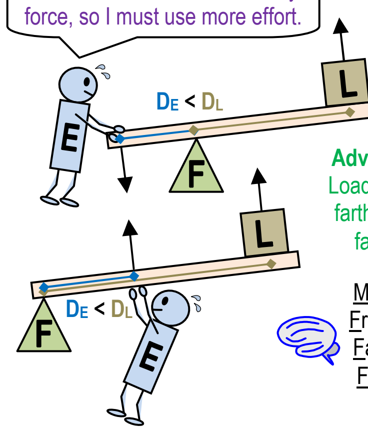
If MA < 1

Less Output Force

(More Output Distance & Speed)

1st or 3rd Class Lever with Fulcrum nearer Effort.

Tradeoff: MA<1 *decreases* my force, so I must use more effort.

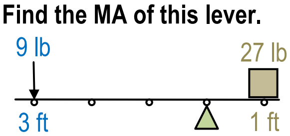


Advantage Load moves farther and faster.

MA < 1 Fraction Farther Faster

MA Problems

Find the MA of this lever.



$MA = D_E / D_L = 3 \text{ ft} / 1 \text{ ft} = 3$

$MA = L / E = 27 \text{ lb} / 9 \text{ lb} = 3$ √

If MA = 5, what Load can be moved with a 10 lb Effort?

$F_E \times MA = F_L$

$10 \text{ lb} \times 5 = F_L$

$50 \text{ lb} = F_L$

If MA = 4, what Effort will move a 20 lb Load?

$F_E \times MA = F_L$

$F_E \times 4 = 20 \text{ lb}$

$F_E = 5 \text{ lb}$

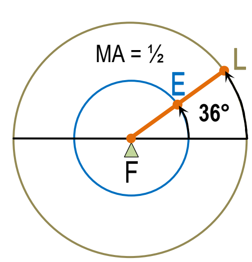
Speed Factor = 1 / MA

If MA = 2, speed factor is ½ (halved)

If MA = ½, speed factor is 2 (doubled)

Circumference Effort Circle
$C_E = 2\pi r_E$
$2\pi(1)$
2π

36° Effort Arc
36/360 (C_E)
1/10 (2π)
0.2π



Circumference Load Circle
$C_L = 2\pi r_C$
$2\pi(2)$
4π

36° Load Arc
36/360 (C_L)
1/10 (4π)
0.4π

Load Arm is twice Effort Arm

0.2π ← Load Arc is twice Effort Arc → 0.4π

Load travels twice as fast!

Your Turn!

Matching

1) ___ Fulcrum a. Transmits force

2) ___ Load b. Input force

3) ___ Effort c. Pivot or hinge

4) ___ Arm d. Force × Distance

5) ___ Work e. Resists movement

True or False

6) ________ A wheelbarrow is a 3rd class lever.

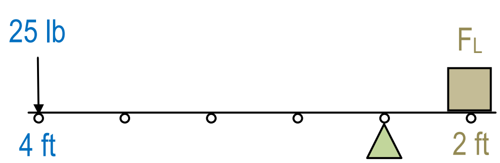
7) ________ A 3rd class lever trades extra effort for more speed.

8) ________ Force *input* must equal Force *output*.

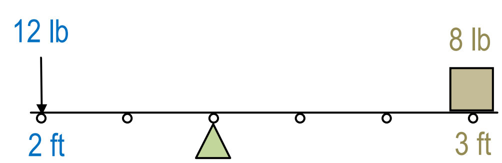
9) ________ A longer Effort Arm requires less effort.

10) _______ A fractional Mechanical Advantage increases speed.

11) Find F_L



12) Find MA using both Distance and Force Ratios.



13) Find MA if 50 lbs of Effort moves a 300 lb Load.

14) Find MA if Effort Arm is half Load Arm.

Answers: 1c, 2e, 3b, 4a, 5d 6F, 7T, 8F (Work, not Force), 9T, 10T 11) 50 lb 12) 8/12 = 2/3 13) 6 14) 1/2