Mechanical Advantage
of Simple Machines

MA of an Inclined Plane

- The mechanical advantage of an inclined plane is equal to the length of the slope divided by the height (rise) of the inclined plane. (This assumes that the effort force is applied parallel to the slope.)

![Diagram of inclined plane](image)

\[
MA = \frac{d_E}{d_R} = \frac{slope}{height}
\]

For example, for the inclined plane illustrated above, assume that the length of the slope (S) is 15 feet and the height (H) is 3 feet. The mechanical advantage would be:

\[
MA = \frac{d_E}{d_R} = \frac{slope}{height} = \frac{15}{3} = 5
\]
• While the inclined plane produces a mechanical advantage, making it feel like it is easier to "lift" the object, it does so by increasing the distance through which the force must move. In the above situation the mechanical advantage of 5 multiplies our effort force five fold, but we have to pay for it by moving five times as far. In other words, if you can lift a 50 kg drum from the ground up onto a one meter tall platform, using the inclined plane above would allow you roll a 250 kg drum up the ramp to a height of one meter, but you would have to roll it for 5 meters.

Practice:
A 6 meter ramp runs from a ground-level sidewalk to a porch. The porch is 2 meters off the ground. What is the mechanical advantage of the ramp?

MA of a Wedge

• The mechanical advantage of a wedge can be found by dividing the length of the slope (S) by the thickness (T) of the big end.

For example, assume that the length of the slope is 20 cm and the thickness is 5 cm. The mechanical advantage is equal to 20/5 = 4. As with the inclined plane, the mechanical advantage gained by using a wedge requires a corresponding increase in effort distance. In this case for every 20 cm you drive the wedge you spread the log 5 cm.
• Which of these wedges has the greatest mechanical advantage?

If you picked A you are correct. Since A is "sharper", it will be easier to drive into the log. However, it may not have enough "pushing" ability to split the log. Wedge B would be much harder to drive into the log, but it clearly has more capability for splitting the log due to its greater thickness at the top.

**MA of a Screw**

The vertical distance between two adjacent screw threads is called the pitch of a screw. One complete revolution of the screw will move it into an object a distance equal to the pitch of the screw. As an example, assume that you place a ruler parallel to a screw and count 10 threads in a distance of one inch. The pitch of the screw would be 1/10. Since there are 10 threads per inch of screw, the distance between two adjacent screw threads is 1/10 of an inch. Also, remember that one complete revolution of a screw will move the screw into an object a distance equal to the pitch of the screw. Therefore, one complete revolution will move a screw with 1/10 pitch a distance of 1/10 of an inch into an object.

In the United States, the convention for describing threads is to give the number of threads per inch. So, for example, in the United States one might ask for a "2-inch quarter-twenty bolt," which would be

• 2 inches long
• have a diameter of a quarter of an inch
• have twenty threads to the inch
• Metric sizes are described in a different way, for example "M3.5 × 1.2". The number following "M" is the diameter in millimeters; the number following "×" is the pitch (also in millimeters), which is the distance from one thread to the corresponding point on the next thread.

• The mechanical advantage of a screw can be found by dividing the circumference of the screw by the pitch of the screw. The gentler the pitch (i.e. finer the thread), the easier it moves, but you have to make a lot of turns.

MA of a Lever

• The mechanical advantage of a lever is the ratio of the length of the effort arm divided by the length of the resistance arm. The arm is measured from the fulcrum to the point of effort or resistance, as the case may be.
MA of a Pulley

• A pulley is said to be a fixed pulley if it does not rise or fall with the load being moved. A fixed pulley changes the direction of a force; however, it does not create a mechanical advantage. It does however, allow one to take advantage of gravity instead of working against it when lifting an object. A fixed pulley is illustrated below.

• A moveable pulley rises and falls with the load that is being moved. A single moveable pulley creates a mechanical advantage; however, it does not change the direction of force.

The mechanical advantage of a moveable pulley is roughly equal to the number of ropes that support the moveable pulley. (When calculating the mechanical advantage of a moveable pulley, count each end of the rope as a separate rope). As shown in the following illustration, two rope ends support the moveable pulley, thus the MA is 2.
• One way to think of this is in terms of carrying an ambulance gurney, a stretcher, or a casket. If the load is 100 kg and one person has to lift it, that person lifts all 100 kg. If two people lift the load each person only needs to lift 50 kg. If four people are lifting each one only has to lift 25 kg, and so on. The load is distributed equally among each person lifting. In a movable pulley system you can think of each supporting rope as a person helping to lift the load.

Practice: What is the mechanical advantage of the pulley system?

MA of a Wheel and Axle

The mechanical advantage of a wheel and axle is the ratio of the radius of the wheel to the radius of the axle

\[ MA_{w&a} = \frac{r_w}{r_a} \]

The MA of 5 in this case means that the in one full rotation the wheel and axle both turn 360 degrees, but the wheel travels 5 times farther than the axle during that one rotation. The pay-out is that the torque on the axle is 5 times greater than the effort applied to the wheel. In the days before power steering it was not uncommon to have a steering wheel with a MA of 20, most modern car steering wheels have an MA of 13.
Practice: