

Experiment 6

Work, Energy, and Mechanical Advantage

Preparation

Prepare for this week's quiz by reviewing last week's experiment, reading this week's experiment and reading the sections in your textbook that cover work, energy, friction, and mechanical advantage.

Principles

When a force acts on an object and causes the object to move, it is doing work. The amount of work done is the product of the force (F) and the distance (x) that the object moves in the direction of the applied force. Work does not have a direction associated with it (it is a scalar quantity) and in the SI system its units are those of force times length, newton-meters (N-m), or Joules (J).

When work is done on an object, its energy will be changed. A change in energy can be used to do work. Work and energy have the same units. One equation for work is:

$$W = F x \cos\theta.$$

If F and x are in the same direction $\cos\theta$ equals 1 and $W = Fx$. Another equation is:

$$W = \Delta E$$

Energy cannot be created or destroyed but its form can be changed. You can put work into a system and use it to change the potential or kinetic energy of an object, or use a change in potential or kinetic energy to get work out of a system. In any real system, some energy will have to be used in overcoming friction. This energy does not disappear but it is changed into a form that is not useful to us. In this case some of the energy is transformed into heat.

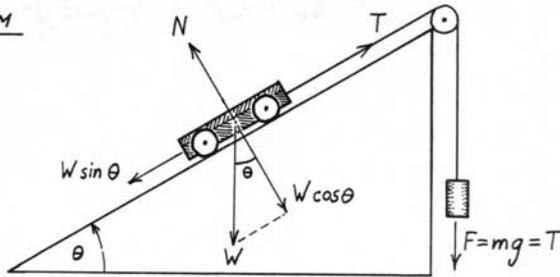
A simple machine is a system for transforming work. When work is put into a system, some is lost to friction and some comes out of the system. Remember, however, that work is the product of force and distance. Therefore, a small force acting over a large distance can produce the same amount of work as a large force acting over a small distance. In this manner, a machine can amplify force, even though it loses energy to friction. The equation for a simple machine can be written like this:

$$Work_{in} - Work_{against\ friction} = Work_{out}$$

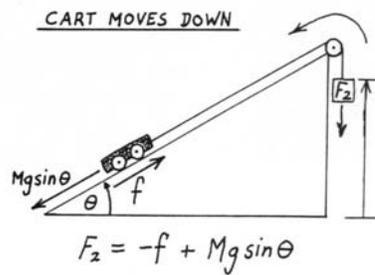
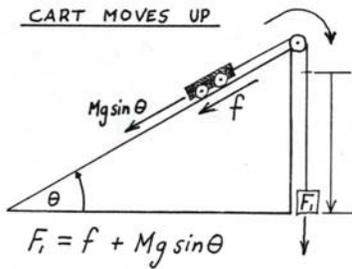
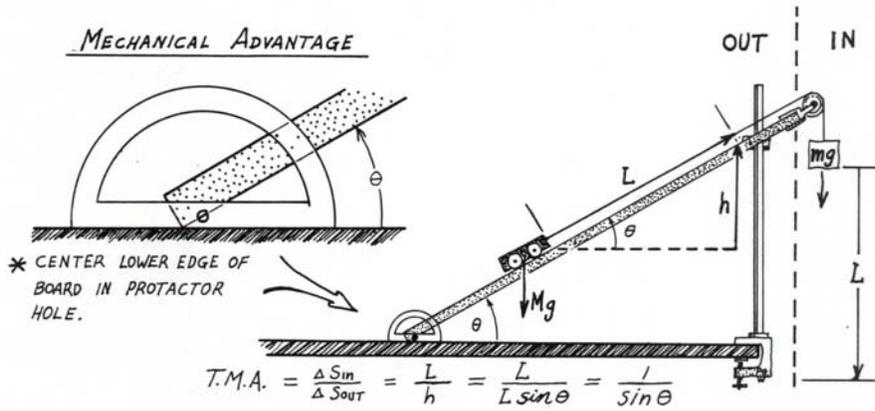
or

$$F_{in} x_{in} - f x_{in} = F_{out} x_{out}$$

FORCE
DIAGRAM



MECHANICAL ADVANTAGE



The **mechanical advantage** of a machine is defined as the ratio of the **output force** to the **input force**:

$$MA = \frac{F_{out}}{F_{in}}$$

If the output force is greater than the input force, the mechanical advantage will be greater than one and this is usually desirable. In an ideal system, where no energy is lost to friction, the work out would equal the work in:

$$F_{in} x_{in} = F_{out} x_{out}$$

or

$$\frac{F_{out}}{F_{in}} = \frac{x_{in}}{x_{out}}$$

The second ratio, x_{in}/x_{out} is called the **theoretical mechanical advantage (TMA)**. The **efficiency** of a machine is defined as the ratio of either the output work to the input work or the mechanical advantage to the theoretical mechanical advantage. It is usually written as a percentage:

$$efficiency = \frac{W_{out}}{W_{in}} * 100\%$$

$$efficiency = \frac{MA}{TMA} * 100\%$$

In a real system, efficiency is always less than 100% because of friction. The friction in this experiment has two sources; one is the static friction between the wheels and the plane and the other is the kinetic friction between the axle and the shaft. Their sum is f .

In this experiment you will investigate these concepts using one simple machine, the inclined plane. A small metal cart with wheels will move up or down the plane, depending on how you arrange your forces. Study the diagrams carefully before you begin.

Equipment

- 1 inclined plane with attached pulley*
- 1 metal cart*
- 1 table clamp*
- 1 threaded rod*
- 1 short rod*
- 1 90° clamp*
- 1 mass hanger*
- 1 set slotted masses*
- 1 pan balance*
- 1 protractor*
- about 1 meter of string*

Procedure

Use only SI units in this experiment. Measure the mass of the cart to the nearest 0.001 kg. Assume that the slotted weights are correct to the nearest 0.001 kg. All forces will be in newtons. Observe the significant digit rules and remember that mass and weight are not the same.

Finding the Mechanical Advantage and Efficiency

In this part of the experiment the cart will move up the plane. The weight hanging on the string will drop through some distance, L , and lose potential energy. The tension on the string will be the input force and L will be the input distance. L is the same as x_{in} . The output force will be the weight to be moved, that is, the weight of the cart, and the vertical distance that it moves will be the output distance h . h is the same as x_{out} . Therefore, for any given input distance, L , the cart will move a vertical distance $h = L \sin \theta$, where θ is the angle between the plane and the horizontal.

1. Find the mass of the cart (M) and compute its weight (w).
2. Adjust the plane until it makes a 17° angle with the table. Compute the TMA for $\theta = 17^\circ$.
3. Tie one end of a string to the hole in the front of the cart chassis. (Do not tie the string to the axle, this will ruin your data!) Tie a 50 g mass hanger to the other end and pass the string over the pulley. Add more masses to the hanger until the cart moves up the plane at constant velocity after you give it a slight push. The tension on the string will be equal to the hanging mass times ($g - a$) where a is the acceleration of the weight. If the weight is not allowed to accelerate, the tension on the string is simply equal to the weight hanging on the string. Record this weight as the input force, F_1 .
4. Compute the MA and the efficiency of the plane.
5. Leave the cart at the top of the plane. Remove weight from the hanger until the cart moves down the plane at constant velocity after you give it a slight push. Record the tension on the string as F_2 .
6. You can now write two equations. In Part I, the input force, acting over the distance L , minus the work against friction over that same distance, L , raised the potential energy of the cart by an amount $w L \sin \theta$. This can be written as:

$$F_1 L - fL = w L \sin \theta$$

The L can be factored out leaving:

$$F_1 - f = w \sin \theta$$

In the second part of the experiment the cart, again moving through some distance L down the plane, lost potential energy equal to $w L \sin \theta$. This input energy minus the work against friction, $f \cdot L$, changed the potential energy of the hanging weight by an amount $F_2 \cdot L$. Again, the L can be factored out and the equation can be written:

$$w \sin \theta - f = F_2$$

Solve the two equations for f and add them. Then solve for f in terms of F_1 and F_2 . Plug in your values and find f .

7. Substitute your value for f into both equations, along with your other known values. Do these equations hold for your experiment? If they don't, you probably measured θ incorrectly. Consult your instructor before you go any further.
8. Put the equipment away.