PHYSICS 534

ANSWERS

EXERCISE-43 **Machines Part-1 /2**

George Thomson was awarded the Nobel prize for physics in 1937 for his work on the diffraction of electrons.

THOMSON

A “simple” machine is a ***single*** mechanical device used to perform work more conveniently by providing a “***mechanical advantage***”. The mechanical advantage of a machine does one of two things:

① Multiplies force (at the expense of distance)
or ② Multiplies speed (at the expense of force)

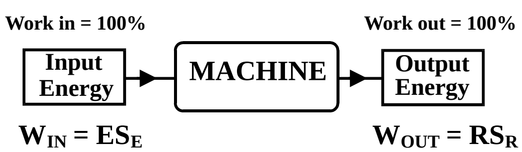
The ***mechanical advantage*** of a machine is the multiplier of the force or speed. It is a number (without units) that tells us the number of times the machine multiplies a force (or speed).

I. M. A. The ideal mechanical advantage is the mechanical advantage of an ideal machine. In effect, it is the ***maximum*** mechanical advantage that a ***frictionless*** machine can deliver.

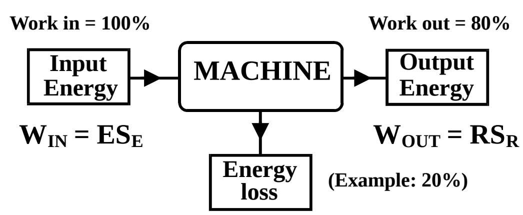
A. M. A. The actual mechanical advantage of a machine is the real mechanical of a machine that has friction and thus loss of energy as heat and sound. The **A.M.A.** is always **less** than the I.M.A.

In order for a machine to operate, it must be supplied with energy. Since energy cannot be created (nor destroyed), it is impossible for any machine to put out more energy than is put into the machine. The diagrams below illustrate an example of the energy flow both in an ideal and in an real (or actual) machine.

IDEAL MACHINE (without friction)



REAL MACHINE (with friction)



Efficiency: The efficiency of a machine tells us what percentage of the input energy is “lost” to friction. Since an ideal machine has no friction (no energy loss), an ideal machine is 100% efficient. However, all real machines have an efficiency of less than 100%. The formula is:

$$\%\ \text{efficiency} = \frac{\text{A.M.A.}}{\text{I.M.A.}} \times 100$$

Two Families of Simple Machines

Note that there are two families of simple machines, the ***lever*** family and the ***inclined-plane*** family. As illustrated below, each family consists of three types of simple machines.

SIMPLE MACHINES

Lever family
- **Lever**
- **Wheel and axle**
- **Pullev**

Inclined-plane family
- **Inclined-plane**
- **Wedge**
- **Jack screw**

TERMINOLOGY

E The effort force is the force that is applied (often simply referred to as the “effort”).

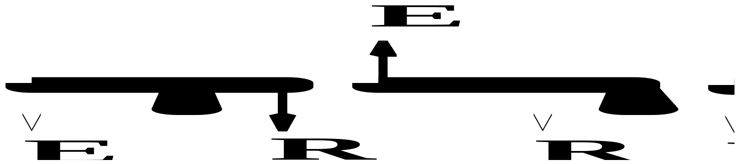
R The resistance force is the output force (often simply referred to as the “resistance”).

s_E The effort distance is the distance through which the effort force acts.

s_R The resistance distance is the distance through which the resistance force acts.

THE LEVER

There are three classes of levers known as the 1st class, the 2nd class, and the 3rd class. As shown below, the difference in each class is the location of the effort force and the resistance force.



$$\frac{\text{Effort distance}}{\text{Resistance distance}} = \frac{\text{Resistance force}}{\text{Effort force}}$$

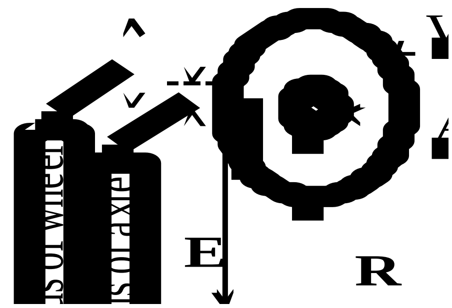
$$\text{A.M.A.} = \frac{\text{Resistance force}}{\text{Effort force}}$$

Note: The 3rd class lever multiplies velocity and not force.

THE WHEEL AND AXLE

The wheel and axle is a member of the lever family consisting of a wheel that is fixed to an axle.

$$\text{I.M.A.} = \frac{\text{Radius of wheel}}{\text{Radius of axle}} \qquad \text{A.M.A.} = \frac{\text{Resistance force}}{\text{Effort force}}$$



THE PULLEY

The third member of the lever family is the pulley. The pulley consists of a wheel that is free to rotate. By itself, a pulley changes the direction of an applied (or effort) force. By combining two or more pulleys (known as a pulley system), the pulley provides a mechanical advantage.

By inspection, we can determine the mechanical advantage of a pulley (or pulley system) simply by counting the number of ***supporting*** ropes. Note that a rope whose tension is upwards (that is, pulls upwards) is a supporting rope. A rope whose tension is downwards is a non-supporting rope. In effect, the mechanical advantage equals the number of supporting (upward pulling) ropes.

☝ ***Remember***: To find the ideal mechanical advantage of a pulley system, count all the ropes except the rope of the effort force ***if it is pulling downward*** (include it if it is pulling upward).

1. What is the purpose of a simple machine?

To provide a mechanical advantage by either multiplying force or speed.

2. Differentiate between an ideal and actual mechanical advantage.

The ideal mechanical advantage is for an ideal machine (without friction).

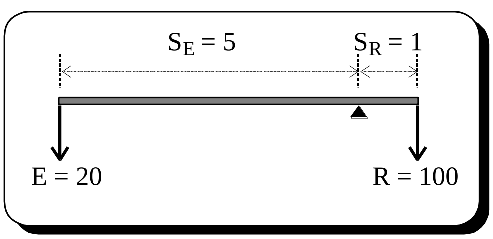
The actual mechanical advantage is for a real machine (with friction).

3. List the two families of simple machines:

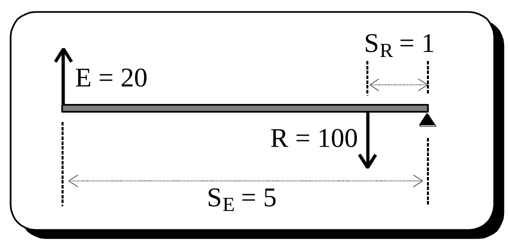
The lever family ***The inclined plane family***

4. Draw a diagram that includes the effort distance and resistance distance of the following simple machines each having an ideal mechanical advantage of 5:

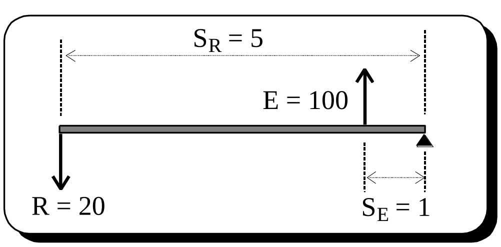
a) The 1st class lever



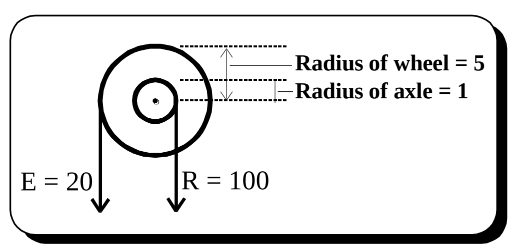
c) The 2nd class lever



b) The 3rd class lever



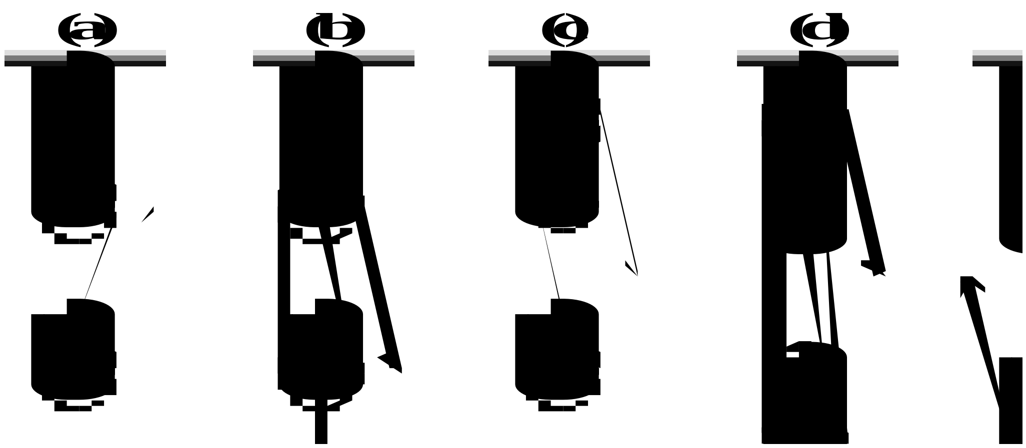
d) The wheel and axle



5. Classify the following simple machines as 1st class lever, 2nd class lever, 3rd class lever or wheel-and-axle:

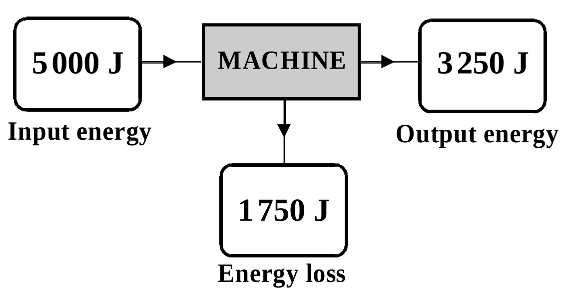
	Machine	Name	Purpose (multiplies what?)
a)	Steering wheel	***Wheel and axle***	***To multiply force***
b)	Wheelbarrow	***2nd class lever***	***To multiply force***
c)	Doorknob	***Wheel and axle***	***To multiply force***
d)	Crowbar	***1st class lever***	***To multiply force***
e)	Broom	***3rd class lever***	***To multiply speed***
f)	Scissors	***1st class lever***	***To multiply force***
g)	Beam balance	***1st class lever***	***To multiply force***
h)	Fishpole	***3rd class lever***	***To multiply speed***
i)	Pliers	***1st class lever***	***To multiply force***
j)	Nutcracker	***2nd class lever***	***To multiply force***

6. State the ideal mechanical advantage for each pulley system below:

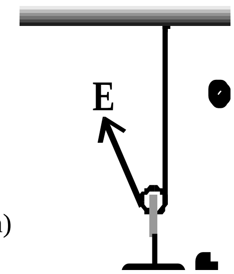


3 ______ ***2*** ______ ***3*** ______ ***4*** ______ ***5*** ______ ***5*** ______

7. Draw the energy flow for a machine which is 65% efficient knowing that the input energy is 5 000 J.



8. A single movable pulley is used to lift a 300 N weight. If the effort force required is 175 N, find:



a) What is the effort force (E)? ***175 N*** (Given)

b) What is the resistance force (R)? ***300 N*** (Given)

c) What is the I.M.A.? [2] ***2*** (By inspection)

d) What is the A.M.A.? [1.7] ***1.7*** (R/E)

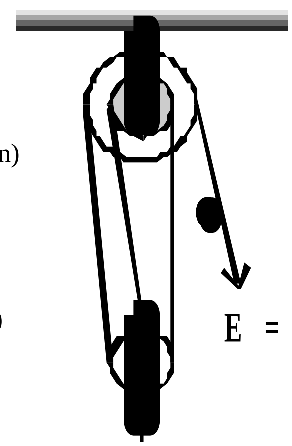
e) What is the percent efficiency? [85%]

$$\% e = \frac{\text{A.M.A.}}{\text{I.M.A.}} \times 100 = \frac{1.7}{2} \times 100 = 85\%$$

f) What percent of the work done is lost? ***15%***

g) What becomes of work lost? ***Wasted as heat and sound.***

9. Using the pulley system illustrated on the right, a woman applies a force of 40 N to lift a mass of 10 kg to a height of 2 m.



a) What is the I.M.A.? ***3*** (By inspection)

b) What is the effort force (E)? ***40 N*** (Given)

c) What is the resistance force (R)? ***100 N*** (Given)

d) What is the resistance distance (S_R)? ***2 m*** (Given)

e) What is the effort distance (S_E)?

$$\text{I.M.A.} = \frac{S_E}{S_R} \quad \therefore \; S_E = (\text{I.M.A.})(S_R) = (3)(2\,\text{m}) = 6\text{ m}$$

f) What is the input work? [240 J]

$$W_{IN} = E\,S_E = (40\,\text{N})(6\,\text{m}) = 240\text{ J}$$

g) What is the output work? [200 J]

$$W_{OUT} = R\,S_R = (100\,\text{N})(2\,\text{m}) = 200\text{ J}$$

h) How much work is lost to friction? [40 J] ***240 – 200 = 40 J***

i) What is the percent efficiency? [83.3%]

$$e\% = \frac{W_{OUT}}{W_{IN}} \times 100 = \frac{200\,\text{J}}{240\,\text{J}} \times 100 = 83.3\%$$

10. A man uses a bar as a lever to lift a 60 kg stone. If the bar is 1.4 m long and the resistance distance is 20 cm, find:

a) The resistance distance (S_R) ***20 cm*** (Given)

b) The resistance force (R) ***600 N*** (Given)

c) The effort distance (S_E) ***120 cm*** (Given)

d) The effort force (E)

$$E\,S_E = R\,S_R$$
$$E = \frac{R\,S_R}{S_E} = \frac{(600\text{ N})(0.20\text{ m})}{(1.20\text{ m})} = 100\text{ N}$$

e) The I.M.A.

$$\text{I.M.A.} = \frac{S_E}{S_R} = \frac{1.20\text{ m}}{0.20\text{ m}} = 6$$

11. In a machine whose efficiency is 80%, an effort force of 50 N acts through a distance of 40 cm. If the resistance distance is 10 cm, find:

a) The effort distance (S_E) ***0.4 m*** (Given)

b) The resistance distance (S_R) ***0.10 m*** (Given)

c) The effort force (E) ***50 N*** (Given)

d) The resistance force (R)

$$e\% = \frac{R\,S_R}{E\,S_E} \times 100 \quad \therefore R = \frac{(E)(S_E)(e\%)}{(S_R)(100)} = \frac{(50\text{ N})(0.40\text{ m})(80)}{(0.10\text{ m})(100)} = 160\text{ N}$$

e) The I.M.A.

$$\text{I.M.A.} = \frac{S_E}{S_R} = \frac{0.40\text{ m}}{0.10\text{ m}} = 4$$

f) The A.M.A.

$$\text{A.M.A.} = \frac{R}{E} = \frac{160\text{ N}}{50\text{ N}} = 3.2$$

g) The work input

$$W_{IN} = E\,S_E = (50\text{ N})(0.40\text{ m}) = 20\text{ J}$$

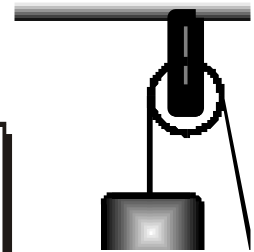
h) The work output

$$W_{OUT} = R\,S_R = (160\text{ N})(0.1\text{ m}) = 16\text{ J}$$

i) The work lost

$$20\text{ J} - 16\text{ J} = 4\text{ J}$$

12. A single fixed pulley is used to lift a 120 N weight a distance of 2 m (see diagram). If a 150 N effort force is required, how much work is lost to overcome friction? [60 J]



By inspection, the I.M.A. is 1.

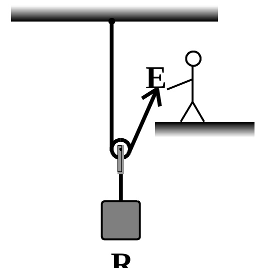
Since the I.M.A. $= \frac{S_E}{S_R}$ $\quad S_E = (\text{I.M.A.})(S_R) = (1)(2\text{ m}) = 2\text{ m}$

$W_{IN} = ES_E = (150\text{ N})(2\text{ m}) = 300\text{ J}$

$W_{OUT} = RS_R = (120\text{ N})(2\text{ m}) = 240\text{ J}$

Work lost to friction = 60 J

13. A mechanic raises a 100 N weight by means of the pulley system as shown on the right. Find:



a) The ideal mechanical advantage ***2***

b) The effort force [50 N]

Since the I.M.A. is 2, the effort force is half

the resistance force: ½(100) = 50 N

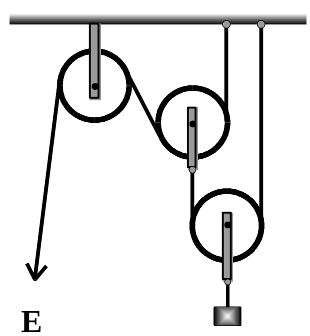
14. A pulley system consists of four pulleys contains four supporting ropes. If the system has an efficiency of 60%, how much weight can be lifted by an effort force of 400 N? [960 N]

I.M.A. = 4 (By inspection)

$$\%e = \frac{\text{A.M.A.}}{\text{I.M.A.}} \times 100 \quad \therefore\ \text{A.M.A.} = \frac{(\%e)(\text{I.M.A.})}{100} = \frac{(60)(4)}{100} = 2.4$$

$$\text{but} \quad \text{A.M.A.} = \frac{R}{E} \quad \therefore\ R = (\text{A.M.A.})(E) = (2.4)(400\text{ N}) = 960\text{ N}$$

15. A 300 N weight hangs on the pulley system shown on the right. Assuming the system is frictionless, what effort force must be applied to hold the mass in equilibrium? [75 N]



By inspection, the I.M.A. is 4.

That is, the effort force is multiplied by 4.

Thus, the effort force is ¼(300) = 75 N

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