PHYSICS 534

ANSWERS

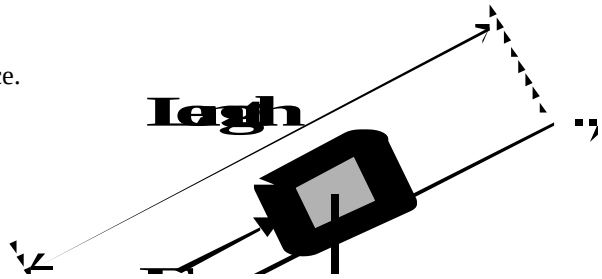
EXERCISE-44 **Machines Part-2 /2**

FERMI

Enrico Fermi was awarded the Nobel prize for physics in 1938 for his work on nuclear reactions.

THE INCLINED-PLANE

The inclined-plane is a simple machine that multiplies the effort force. It consists of a plank (platform or ramp) in which one end is higher than the other end. It has a length and a height. Note that the effort force (E) is applied (or acts) ***parallel*** to the inclined-plane while the resistance force (R) acts ***perpendicularly*** (parallel to the height). In effect, the resistance force is the weight of an object pushed or pulled along the inclined-plane.

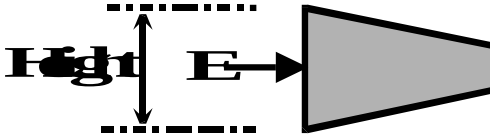


$$\text{I.M.A.} = \frac{\text{Length}}{\text{Height}} = \frac{S_E}{S_R} \qquad \text{A.M.A.} = \frac{\text{Resistance force}}{\text{Effort force}} = \frac{R}{E}$$

THE WEDGE

The wedge is similar to the inclined-plane. However, note that the effort force is applied at the end (height) of the inclined-plane.

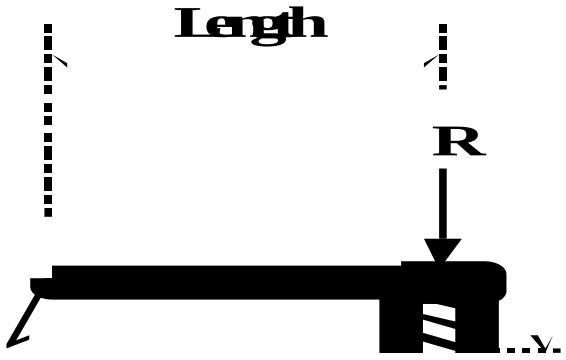
$$\text{I.M.A.} = \frac{\text{Length}}{\text{Height}} = \frac{S_E}{S_R} \qquad \text{A.M.A.} = \frac{\text{Resistance force}}{\text{Effort force}} = \frac{R}{E}$$



THE JACK-SCREW

The jack-screw works on the same principle as the inclined-plane (or wedge). In effect, it consists of an inclined-plane wrapped around a cylinder.

Note that the ***height*** is known as the pitch, "p", and the ***length*** is actually the radius, "r".



$$\text{I.M.A.} = \frac{\text{Circumference}}{\text{Height}} = \frac{2\pi\,\text{Length}}{\text{Height}}$$

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

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

COMPOUND MACHINES

A simple machine consists of a single device. A compound machine is one made up of two or more simple machines. The mechanical advantage of a compound machine is the ***product*** of the mechanical advantage of each simple machine. For example, if a compound machine consists of two simple machines one having a mechanical advantages of 2 and the other a mechanical advantage of 3, then the mechanical advantage of the compound machine is 6 (2 x 3).

➢ *Note*: **To keep the math as simple as possible, use a value of 10 m/s^2 for "g".**

1. List the three simple machines of the inclined-plane family:

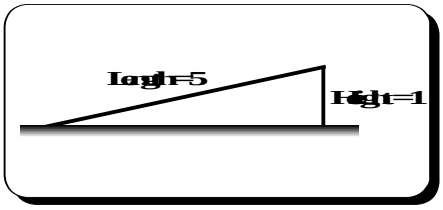
① ***Inclined plane***

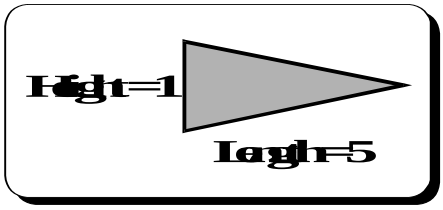
② ***Wedge***

③ ***Jack screw***

2. Draw a diagram of the inclined-plane and the wedge each with an ideal mechanical advantage of five (5).

a) The incline-plane b) The wedge





3. Classify the following simple machines as incline-plane, wedge or jack-screw:

a) Winding staircase	***Inclined plane***	e) Clamp	***Jack screw***
b) Nut and bolt	***Jack screw***	f) Nail	***Wedge***
c) Bench vise	***Jack screw***	g) Ramp	***Inclined plane***
d) Ax	***Wedge***	h) Chisel	***Wedge***

4. Johnny can push with a force of 75 N on a block of ice along an inclined plane. What is the ***shortest*** length plank that he can use as an (ideal) inclined plane to push a 30 kg block of ice from the ground to a height of 1.5 m? [6 m]

$$W_{IN} = W_{OUT}$$
$$E\,S_E = R\,S_R$$
$$S_E = \frac{R\,S_R}{E} = \frac{(300\,\text{N})(1.5\,\text{m})}{75\,\text{N}} = 6\ \text{m}$$

5. A weight of 400 N is lifted by a jack-screw whose pitch (height) is 5 mm. The length of the effort lever is 20 cm. If the effort force was 5 N, what is the efficiency of this simple machine? [32%]

$R = 400\ N \qquad S_R = 5\times10^{-3}\ m \qquad E = 5\ N \qquad S_E = 0.20\ m$

$$A.M.A. = \frac{R}{E} = \frac{400}{5} = 80 \qquad I.M.A. = \frac{2\pi r}{S_R} = \frac{2(3.14)(0.20\,m)}{5\times10^{-3}\,m} = 251.2$$

$$\%e = \frac{A.M.A.}{I.M.A.}\times100 = \frac{80}{251.2}\times100 = 31.8 = 32\%$$

6. A ramp which is 3 m long and 0.5 m high is used to slide a 90 kg mass in order to raise it from one level to a higher level. Assuming it is 75% efficient, determine:

a) The ideal mechanical advantage. [6]

$$I.M.A. = \frac{Length}{Height} = \frac{3\,m}{0.5\,m} = 6$$

b) The actual mechanical advantage. [4.5]

$$\%e = \frac{A.M.A.}{I.M.A.}\times100 \qquad \therefore\ A.M.A. = \frac{(\%\ e)(I.M.A.)}{100} = \frac{(75)(6)}{100} = 4.5$$

c) The force (parallel to the ramp) required to perform the task. [200 N]

$$A.M.A. = \frac{R}{E} \qquad \therefore\ E = \frac{R}{A.M.A.} = \frac{900\,N}{4.5} = 200\ N$$

d) The work done (work-in). [600 J]

$$W_{IN} = E S_E = (200\,N)(3\,m) = 600\ J$$

e) The energy (work) lost to friction. [150 J]

Since efficiency $= 75\%$, energy loss $= 25\%$
Thus, 25% of $600\ J = 150\ J$

7. A ramp is 2.5 m long and 25 cm high. It is used to slide (raise) a box whose mass is 40 kg from the floor to a shelf. The effort force (applied parallel to the ramp) used to accomplish this task is 50 N. Determine:

a) The ideal mechanical advantage. [10]

$$\text{I.M.A.} = \frac{\text{Length}}{\text{Height}} = \frac{2.5\,\text{m}}{0.25\,\text{m}} = 10$$

b) The actual mechanical advantage. [8]

$$\text{A.M.A.} = \frac{\text{R}}{\text{E}} = \frac{400\,\text{N}}{50\,\text{N}} = 8$$

c) The work done (work-in). [125 J]

$$W_{IN} = ES_E = (50\,\text{N})(2.5\,\text{m}) = 125\,\text{J}$$

d) The efficiency of this simple machine. [80%]

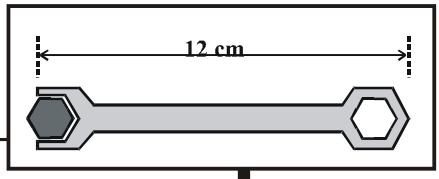
$$\%\,\text{e} = \frac{\text{A.M.A.}}{\text{I.M.A.}} \times 100 = \frac{8}{10} \times 100 = 80\,\%$$

e) The energy (work) lost to friction. [25 J]

Since efficiency $= 80\,\%$, energy loss $= 20\,\%$

$20\,\%$ of $125\,\text{J} = 25\,\text{J}$

8. A mechanic uses a 12 cm long wrench to turn a bolt having a pitch of 5 threads per centimeter. With what fo
us
[3



$$\text{I.M.A.} = \text{A.M.A.} = \frac{\text{Circumference}}{\text{Height}} \quad \text{(Since system is frictionless)}$$

$$\text{Calculation of height : } \frac{5\text{ threads}}{1\text{ thread}} = \frac{0.01\text{m}}{\text{x}} \qquad \text{x} = 0.002\text{ m}$$

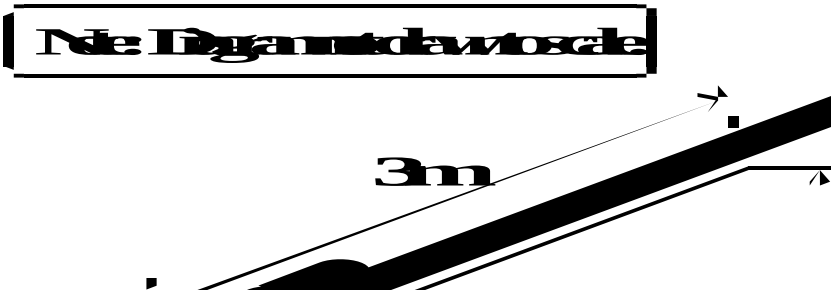
$$\text{Thus, A.M.A.} = \frac{2\pi\text{r}}{\text{Height}} = \frac{2(3.14)(0.12\text{m})}{0.002\text{m}} = 376.8$$

$$\text{But, A.M.A.} = \frac{\text{R}}{\text{E}} \quad \therefore\ \text{R} = (\text{A.M.A.})(\text{E}) = (376.8)(100\text{N}) = 37\,680\text{ N}$$

9. A 200 kg crate is pulled up an inclined plane a distance of 3 m by a winch (wheel and axle). The average frictional force between the crate and the plane is 10% of the crate's weight.

As illustrated in the diagram, the height of the incline is 1.5 m. The handle of the winch (the wheel) has a radius of 40 cm while its cylinder (the axle) has a radius of 10 cm.

What force must be exerted on the handle of the winch to bring the crate up? [300 N]



$$\text{Calculation of frictional force : } 10\%\text{ of weight} = \frac{10}{100}(2000\text{ N}) = 200\text{ N}$$

$$\text{Calculation of work done to raise crate : } \text{E}_\text{P} = \text{mgh} = (200\text{kg})(10\text{m/s}^2)(1.5\text{m}) = 3000\text{ J}$$

$$\text{Calculation of work to overcome friction : } \text{W} = \text{fs} = (200\text{N})(3\text{m}) = 600\text{ J}$$

$$\text{Thus, total work done} = 3000\text{J} + 600\text{J} = 3600\text{ J}$$

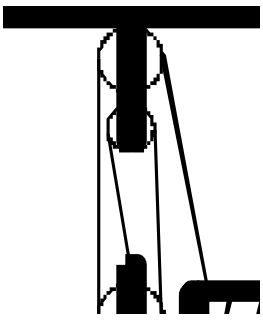
$$\text{Calculation of tension in rope : } \text{W}_\text{T} = \text{F}_\text{T}\text{s}_\text{T} \quad \therefore\ \text{F}_\text{T} = \frac{\text{W}_\text{T}}{\text{s}_\text{T}} = \frac{3600\text{ N}\cdot\text{m}}{3\text{m}} = 1200\text{ N}$$

$$\text{Calculation of winch force : } \text{W}_\text{IN} = \text{W}_\text{OUT}$$

$$\text{Es}_\text{E} = \text{Rs}_\text{R} \quad \text{(R is the tension in rope)}$$

$$\text{E} = \frac{\text{Rs}_\text{R}}{\text{s}_\text{E}} = \frac{(1200\text{N})(0.10\text{m})}{0.40\text{m}} = 300\text{ N}$$

10. A compound machine has an efficiency of 80% and consists of a wheel-and-axle attached to a pulley system. The diameter of the wheel is 60 cm and the diameter of the axle is 20 cm. If the machine is used to raise a 200 kg object, find:



a) The ideal mechanical advantage. [9]

$$\text{I.M.A. of wheel and axle} = \frac{\text{Radius of wheel}}{\text{Radius of axle}} = \frac{0.3\,\text{m}}{0.1\,\text{m}} = 3$$

I.M.A. of pulley system = 3 (By inspection, 3 ropes pulling upward)

Thus, I.M.A. of compound machine = (3)(3) = 9

b) The actual mechanical advantage. [7.2]

Since the machine is 80 % efficient , A.M.A. = 80 % of I.M.A. = (0.80)(9) = 7.2

c) The effort force. [278 N]

$$\text{Since A.M.A.} = \frac{R}{E} \qquad \therefore\ E = \frac{R}{\text{A.M.A.}} = \frac{2000\,\text{N}}{7.2} = 277.7\,\text{N} = 278\,\text{N}$$