AP Physics-B **Work / Power / Simple Machines**

INTRODUCTION: In everyday conversation, the words work and power are used to describe many activities. In physics, the term work has a precise definition – it is not merely an activity where one exerts an effort. Work is a physical quantity. The amount of work done can be calculated. Power is also a physical quantity. It is not merely a measure of one's strength, but the rate at which work is done.

The purpose of this unit is to familiarize you with the physics terms work and power.

WORK is defined as the product of the applied force and the displacement through which an object moves in the direction of the applied force. Work is done only when an object moves some distance due to the net force. An applied force causing no acceleration or motion at a constant velocity means no net work is done on the body.

In vector terms, WORK is defined as the dot product of the applied force and the displacement. WORK is a scalar quantity even though force and displacement are vector quantities. The units for work are NEWTON-METER or JOULE. $W = F \cdot \Delta X$

PERFORMANCE OBJECTIVES: Upon completion of the activities and readings in this unit and when asked to respond either orally or on a written test, you will:

- state the physical definition for work. Solve problems using the equation for work.
- know that the SI unit for work is a JOULE.
- recognize that work is a scalar quantity.
- recognize that the equation for work is not as simple as it first seems. Be able to solve problems where the force is at an angle with the displacement. Be able to solve problems where the applied force is a function of the displacement.
- state the definition for power. Write the equation for power.
- correctly calculate power is watts and in kilowatts
- demonstrate an understanding of the relationship between work and energy transfer. Recognize the usefulness of the term work.
- define a simple machine. Know that simple machines are of two basic types. Be able to calculate the mechanical advantage and efficiency of a machine.

TEXTBOOK REFERENCES: Physics (Sixth Edition) – Chapter 5

"Work is man's great function. He is nothing, he can do nothing, he can achieve nothing, fulfill nothing without working. If you are poor – work. If you are rich, continue working. If you are burdened with seemingly unfair responsibilities, work!

If you are happy, keep right on working! Idleness gives room for doubts and fears. If disappointment comes, work! If your health is threatened – work! When faith falters – work! When dreams are shattered and hope seems dead – work! Work as if your life were in peril, it really is. No matter what ails you – work! Work faithfully – work with faith.

Work is the greatest remedy available for both mental and physical afflictions!"

- *James M. Cohan*

QUESTIONS AND PROBLEMS:

1.) A force of 100.0 N is needed to push a car across an empty parking lot at a constant speed. Two students push the car 40.0 m. How much work is done by the students? *4000 J*

2.) a.) What is the weight of a 49 kg crate? b.) What work is done to lift the crate a distance of 10.0 m? *480.2 N* *4802 J*

3.) A package weighs 35 N. A person carries the package from the ground floor to the fifth floor of an office building, or 15 m upward. a.) How much work does the person do on the package? If the person weighs 750 N, How much total work is done on the package and the person? *525 J* *11,775 J*

4.) A worker carries cement blocks, weighing 150 N each up a ladder onto a scaffold 8.0 m high. The worker carries them at a rate of 2 blocks per minute. How much work is done by the worker in a.) 10 minutes? b.) one hour? *24,000 J* *1.4×10^5 J*

5.) A person carries a bag of groceries weighing 100 N a horizontal distance of 50 m. How much work is done on the groceries?

6.) In the weight-lifting competition of the 1976 Olympics, Vasili Alexeev astounded the world by lifting a record-breaking 562 lb (2500 N) from the floor to over his head (about 2 m). In 1957, Paul Anderson stooped beneath a reinforced wood platform, placed his hands on a short stool to brace himself, and then pushed upward on the platform with his back, lifting the platform and its load about a centimeter. On the platform were auto parts and a safe filled with lead, the composite weight of the load was 6270 lb (27,900 N)! Who – Alexeev or Anderson – did more work?

7.) In driving to the top of a mountain, the amount of work done is about the same whether the road goes straight up of zigzags in gradual slopes. Why then do most mountain roads wind up gradually rather than going straight up?

8.) The design of the road dividers that separate opposing traffic lanes used to consist of metal rails mounted to make contact with the fenders and the doors of the car. The newer design is of concrete with a cross-section very deliberately shaped to make contact with the tires. Why is this new design more effective in slowing down a car that side-swipes it?

9.) Why does it require less work to raise one end of a log than to raise the whole log?

10.) Scissors for cutting paper have long blades and short handles, whereas metal-cutting shears have long handles and short blades. Bolt cutters have very long handles and very short blades. Why is this so?

SIMPLE MACHINES: Machines enable a person to do some work by changing the amount, the direction, or the point of application of the necessary force. Many times, a machine is used to do work on a body using less force but applying the force through a greater displacement. The work output of a machine can never be greater than the work input. Ideally – input and output would be the same, but in real life situations, the output is less than the input. The ratio of work output to work input is called the efficiency of the machine. The ratio of the output force exerted by the machine on a load to the input force exerted by the operator on the machine is defined as the actual mechanical advantage (AMA). The ideal mechanical advantage (IMA) is defined as the ratio of the distance through which the input force acts to the distance through which the output force acts. Efficiency is also equal to the ratio of the AMA to the IMA. Three basic types of simple machines are the lever, the inclined plane, and the pulley.

$\text{Eff} = \text{Work}_{output} / \text{Work}_{input} = \text{AMA} / \text{IMA}$ $\text{IMA} = \Delta X_{input} / \Delta X_{output}$ $\text{AMA} = F_{output} / F_{input}$

11.) A force of 25.0 N is needed to move widgets up a smooth incline 10.0 m long in a widget factory. a.) If the widgets weigh 125 N, what work is done on each? b.) Assume the incline is 100 % efficient. How high above the floor is the top of the incline? c.) Now assume that the incline is 75 % efficient, which is probably more likely. How high above the floor is the top of the inline? *250 J* *2 meters* *1.5 meters*

12.) Workers use a force of 2125 N to push a piano weighing 8800 N up a 20.0 m long ramp. a.) How much work is done on the piano by the workers in pushing it up the ramp? b.) The piano is being moved from street level to the second floor of a building. The second floor is 4.0 m above street level. If the workers decide to lift the piano straight up by using ropes, how much work would they do? c.) What is the efficiency of the ramp? *42,500J* *35,200 J* *83 %*

13.) In order to change a tire, a force of 80.0 N is exerted on the handle of a screw-type bumper jack. The handle to which the steel shaft is attached has a radius of 0.50 m. The handle is turned through 30 revolutions. How much work is done? *7540 J*

14.) Using a pulley system, a worker does 1920 J of work to lift a crate fro one floor to the next in a warehouse. the force is exerted through a distance of 40.0 m on the rope of the pulley system, which is 100% efficient. How much force was used to lift the crate? *48 N*

15.) A force of 3.0 N is required to raise a load of 16 N by means of a pulley system. If the load is raised 1.0 meters while the applied force is exerted through a distance of 8.0 m, find a.) the IMA b.) the AMA, and c.) the efficiency of the pulley system. *8 5.3 67%*

16.) The lever arm of a screw jack is 1.0 m long, and the pitch is 1.50 cm. The efficiency is 13%. Calculate the IMA, the AMA, and the input force necessary to raise a load of 2000 N. *419 54 37N*

WORK AND THE DIRECTION OF THE FORCE: In calculating work, use only the component of the force that acts in the direction of the motion. For example, if you push a lawn mower, the vertical component of the force is balanced by the upward push of the ground. The force that is doing the work is the horizontal component, F_x. The work done by a force acting at some angle with the motion is the product of the force, the displacement, and the cosine of the angle between them. Work = $F(\cos\Theta)\Delta X$

17.) A person applied a force of 600 N to a rope which is tied to a metal box. The rope is held at an angle of 45° with the floor while pulling the box across the floor. The box is moved a distance of 15 m at a constant speed. How much work is done on the box? *6364 J*

18.) A loaded sled weighing 800.0 N is pulled a distance of 200.0 m. To do this, a force of 120 N is exerted on a rope that makes an angle of 60° with the horizontal. How much work is done on the sled? *12000 J*

19.) Because of friction, a force of 400 N is needed to drag a wooden crate across a floor. The rope tied to the crate is held at an angle of 53° with the horizontal. a.) How much tension is needed in the rope to move the crate? b.) What work is done if the crate is dragged 25 m? *665 N 10,000 J*

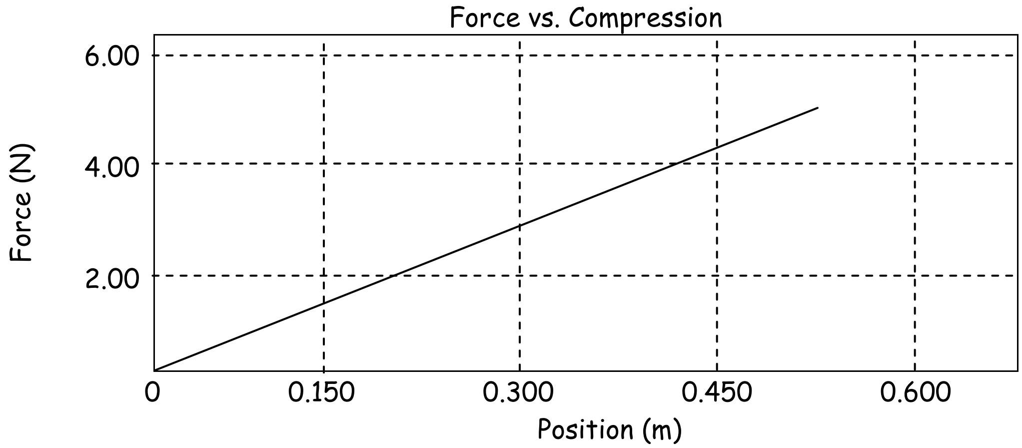
20.) A cable attached to a small tractor pulls a barge through a canal lock. The tension in the cable is 2500 N. It makes an angle of 30° with the direction in which the barge is moving. a.) What force moves the barge along the lock? b.) If the lock is 200.0 m long, how much work is done to get the barge through the lock? *2165 N 433,000 J*

21.) It takes 17,600 J of work to pull a loaded sled weighing 2200 N a distance of 22 m. To do this, a force of 1600 N is exerted on a rope that makes an angle with the horizontal. At what angle is the rope held? *60°*

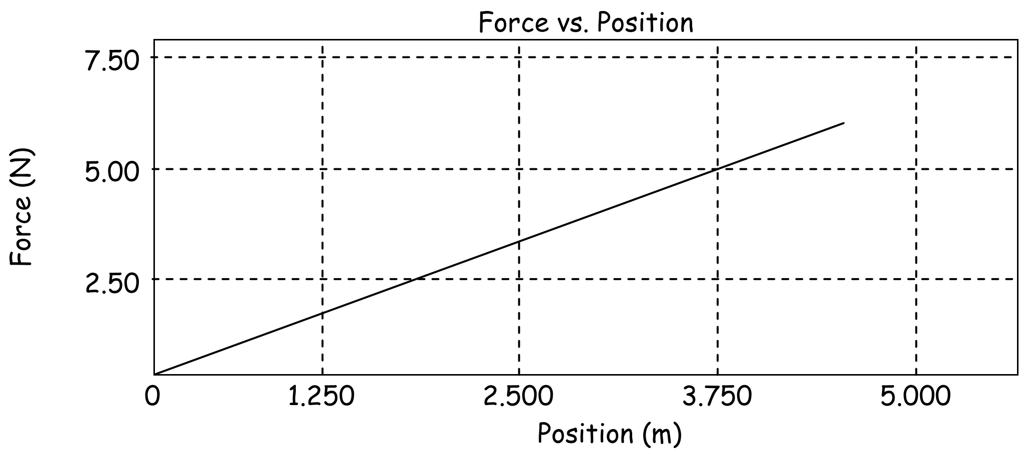
22.) A sailor pulls a boat along a dock. The rope is held at an angle of 60° with the direction in which the boat is moving and pulled with a force of 250 N. How much work is done if the sailor pulls the boat 30.0 m? *3750 J*

WORK AND VARYING FORCE: Up to this point, the forces applied were constant, that is the same amount of force was applied for the entire displacement. Sometimes, the force applied is a function of the displacement. A good example of this is when you compress or stretch a spring – the force increases with displacement. In calculus terms, the definition for work is the integral of the dot product. This means to find the area under the force-displacement curve. In the next few problems, we will look at work done on springs.

23.) Sketched below is a force vs. compression graph for a spring. How much work is done to compress the spring 0.3 meters? *0.45 J*

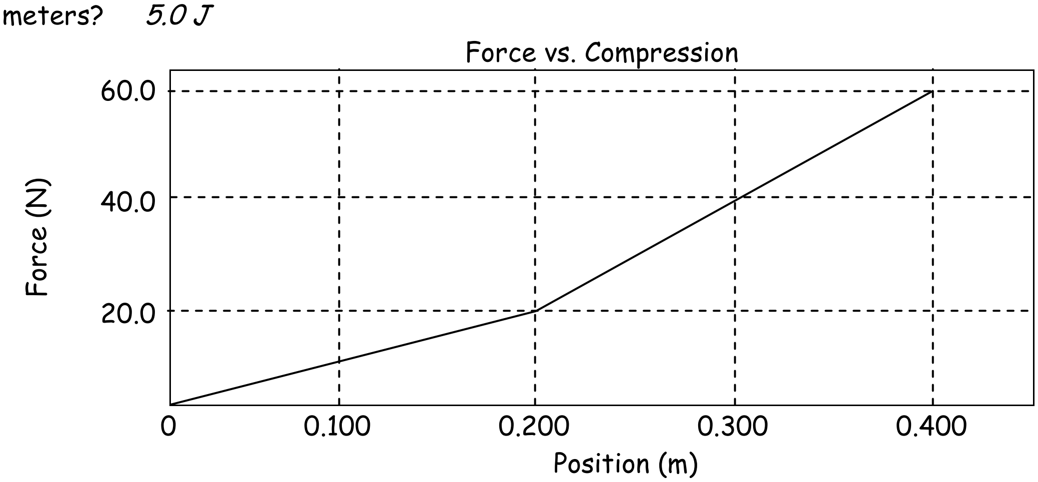


24.) A 10.0 kg mass moves against a retarding force that increases linearly by 4.00 N for every 3.00 meters the mass moves. How much work is done to move the mass 1.50 meters? *1.5 J*



25.) A linear elastic spring is compressed by 0.2 meters by a force of 20 Newtons. How much work is done to compress the spring? *about 2.0 J*

26.) The force-compression curve of a spring is shown below. How much work is done in compressing the spring 0.3 meters? *5.0 J*



POWER: is the rate of doing work: work per unit time. The SI unit of power is the watt. A watt is one joule per second. A kilowatt is 1000 watts. One horsepower = 746 watts. Power (P) = Work (W) / Δt

27.) A machine produces a force of 40.0 N through a distance of 100.0 meters in 5.00 seconds. a.) How much work is done? b.) What is the power of the machine in watts? c.) in kilowatts? *4000J 800 W 0.8 kW*

28.) A box that weighs 1000.0 N is lifted a distance of 20.0 m straight up by a rope and pulley system. The work is done in 10 seconds. What amount of power is used in a.) watts? b.) kilowatts? *2000 W 2 kW*

29.) A hiker carries a 20.0 kg knapsack up a trail. After 30.0 minutes, he is 300.0 m higher than his starting point. a.) What is the weight of the knapsack? b.) How much work is done? c.) If the hiker weighs 600.0 N, how much total work is done? d.) During the 30 minutes, what is the hiker's average power in watts? e.) kilowatts? *196 N 58,800 J 238,000 J 132 W 0.132 kW*

30.) How much work does a 400.0 watt motor do in 5.0 minutes? *120,000 J*

31.) A pump raises 30 liters of water per minute from a depth of 100.0 m. What is the wattage expended? (a liter of water has a mass of 1.0 kg) *490 W*

When a constant force acts on a body in the direction of the body's motion, the power can be expressed as the dot product of force times velocity. Power = F · v

32.) A motor operates an endless conveyor belt. The motor produces a force of 500.0 N on the belt and it moves at the rate of 6.5 m/s. What is the power of the motor in kilowatts? *3.25 kW*

REVIEW:

1.) Can you do more work per second than a horse? Some people can, but only for a short time. To find out if you can, first measure the vertical height of a staircase in meters by measuring the rise of one stair and multiplying its height by the number of stairs. Then multiply your weight in newtons by the height of the staircase in meters. This is the amount of work you must do every time you climb the staircase. Run up the stairs as fast as you can while someone times your climb. Calculate the work done per second. If it comes out higher than 746 J/s, you can work faster than a horse.

2.) Water falls at a rate of 8000 kg/s from the top of a large dam and strikes the blades of a turbine 50.0 meters below. If 80% of the falling water effectively does work on the turbine, what electric power in megawatts can the turbine develop? *3.1 MW*

3.) Using a 98 N force, a 20.0 kg mass is slid up a frictionless incline a distance of 10.0 m. a.) How much work is done on the mass? b.) How much work is done if the 20.0 kg mass is lifted straight up 5.0 m? *980 J*

4.) A 70.0 N force moves a 10.0 kg mass 25 meters up a 37° incline. a.) How much work is done on the object? b.) How much work is done if the object is lifted straight up? c.) Explain the apparent discrepancy? *1750 J 1470 J*

5.) A loaded elevator weighs 1.2×10^4 N. An electric motor hoists the elevator 9.0 m in 15 s. a.) How much work is done? b.) What is the power in watts and kilowatts? *1.08×10^5 J 7.2×10^3 W 7.2 kW*

6.) A truck's engine delivers 90,000 watts of power. The truck must overcome 4500 N of force that resists the motion of the truck. What is the truck's speed? *20 m/s*

7.) A person applies a force of 60.0 N for a distance of 20.0 m to push a desk across a floor at a constant speed. How much work is done by the person? b.) There is obviously some other force acting on the desk since the net force is zero and the desk therefore maintains constant speed. How much work is done by this other force? c.) What is the total work done on the desk? *1200 J* *-1200 J* *zero*

8.) A force of 60.0 N is needed to push a crate weighing 300 N at a constant speed across a waxed floor. How much work must be done to push the crate 15 meters? b.) The net force is zero since the crate moves with constant speed. There must be a frictional force acting between the crate and the waxed floor. How much work is done by this frictional force? c.) What is the total work done on the crate? *900 J* *-900 J* *zero*

9.) What is the weight of a 50.0 kg crate? b.) To lift the crate at constant speed, a person must apply a force equal to the weight of the crate. How much work is done by the person to lift the crate 10.0 m at constant speed? c.) Since there is no acceleration, the net force on the crate is zero. What other force is acting on the crate? d.) How much work is done on the crate by the earth's gravitational force of attraction? e.) What is the total work done on the crate? *490 N* *4900 J* F_g *-4900 J* *zero*

10.) What do you expect the crate in Problem 8 to do after the person stops pushing? b.) What do you expect the crate in Problem 9 to do if the person no longer pushes it upward? c.) Explain why your answers are the same or different. d.) Friction is called a non-conservative force and gravity is called a conservative force. Do these definitions support or contradict your answer to part c?