PH1110 **Term C00**

STUDY GUIDE 3: Work, Energy, and Momentum

Objectives

15. Define work and calculate the work done by a constant force as the body on which it acts is moved by a given amount. Be able to calculate the scalar product of two vectors.

16. Define kinetic energy.

17. State the work-energy theorem, Give examples of and solve problems for which the application of the work-energy theorem is appropriate.

18. Define power, and use the concept to solve problems involving the rate at which work is done.

19. Distinguish between conservative and non-conservative forces and give examples of each.

20. Calculate the change in potential energy of a particle in a uniform gravitational field and of a spring undergoing compression or extension.

21. Use the principle of mechanical energy conservation to solve appropriate problems.

22. Define the linear momentum of a particle and of a system of particles.

23. Define impulse of a force and relate it to the change in linear momentum that it causes.

24. Give examples of and solve problems for which conservation of linear momentum is appropriate. Distinguish between elastic and inelastic collisions.

Suggested Study Procedure for Chapter 6.

Study Secs. 6-1 through 6-5.
Answer Discussion Questions 1, 2, 11, 12, 13.
Study particularly Examples 1, 2, 4, 6, 7, 8.
Do Exercises 1, 3, 13, 15, 19, 23, 27, 30, 37.
Do Problems 47, 57, 65, 71.

A. As great as we have already found Newton's laws to be in helping us understand and predict the motion of objects, there are wondrous new and enormously powerful concepts lurking in those three disarmingly simple statements. Two such concepts that tumble mathematically right out of the 2nd law are WORK and ENERGY, the subjects of Chapts. 6 and 7.

1. A FORCE carried through a DISPLACEMENT performs WORK. But be careful here! Work is NOT force times distance; rather, it involves only the component of force parallel to the displacement. In the special case of straight-line displacement with constant force (the case we will consider most of the time!), work is equal to the product of the force component parallel to the displacement with the distance traveled.

2. Work and energy are SCALAR quantities -- they are purely numbers WITHOUT spatial direction. DO NOT attach vector directions to work or energy; that's just plain WRONG! Now it may bother you that a scalar can result from the multiplication of two vector quantities (force and displacement), but that's the way it is. The mathematical operation that accomplishes this strange feat is called the "scalar product" and is discussed in detail in Sec. 1-11. Secs. 6-1 and 6-2 provide discussion and worked examples on the subject.

B. The WORK-ENERGY THEOREM (which comes mathematically straight out of the 2nd law!) states that the TOTAL WORK done on an object is equal to the CHANGE IN KINETIC ENERGY of the object (final minus initial). What's so great about that, you may ask? Well, for one thing, a scalar equation is invariably easier to work with than a vector equation. For another, we're concerned with speeds of the object only at the beginning and at the end of the displacement, and not anywhere in between. If you know an object's speed at the beginning and end of the object's displacement, you immediately know how much total work was done on the object. If you know the total work done, you immediately know the change in kinetic energy. The power of this generalization in analyzing motion is demonstrated repeatedly from Example 6-4 on through most of the exercises and problems at the end of the chapter.

C. The one non-constant force we consider in PH 1110 is the spring force, discussed in Sec. 6-4. Study this section carefully to see how work is properly computed when the force varies linearly with displacement.

D. POWER, the RATE at which WORK is performed, is also a scalar quantity. Read about it in Sec. 6-5.

Suggested Study Procedure for Chapter 7.

Study Secs. 7-1 through 7.4.
Answer Discussion Questions 1, 3, 4.
Study Examples 1, 2, 5, 6, 7, 8, 9, 10, 12.
Do Exercises 3, 7, 13, 15, 17, 25.
Do Problems 40, 41, 53, 63, 65.

A. Believe it or not, Chapt. 7 is just one long series of applications of the Work-Energy Theorem, even though it may not look like it! As you found in Chapt. 6, the TOTAL work is just the (scalar!) SUM of the work done by each individual force. Because the work done by CONSERVATIVE FORCES (the gravitational and spring forces) depends only on the endpoints of the displacement (NOT how we got from the initial to final point!), we can pull them out of the TOTAL WORK and express them in terms of initial and final points. The way we like to express the theory of Chapt. 7 is:

$$\tfrac{1}{2}mv_i^2 + mgh_i + \tfrac{1}{2}ks_i^2 + W_{other} = \tfrac{1}{2}mv_f^2 + mgh_f + \tfrac{1}{2}ks_f^2$$

This is what Chap. 7 is all about, and Lecture #10 will be aimed at making its application crystal clear!

Suggested Study Procedure for Chapter 8.

Study Secs. 8-1 through 8-5.
Answer Discussion Questions 6, 11, 12.
Study Examples 2, 3, 4, 5, 6, 7, 8, 9, 10.
Do Exercises 1, 3, 8, 14, 23, 26, 35.
Do Problems 60, 62, 64, 65, 73, 74.

A. Two more extremely powerful concepts that tumble mathematically out of Newton's 2nd law are IMPULSE and MOMENTUM. IMPULSE is a FORCE acting through TIME -- a sort of product of force and time, with units of newton-seconds. MOMENTUM is the product of mass with velocity. According to the 2nd law, the IMPULSE received by an object equals the CHANGE OF MOMENTUM of the object.

1. Note the similarity with the form of the Work-Energy Theorem (where TOTAL WORK equals the CHANGE IN KINETIC ENERGY). Also note that, just as in the case of work-energy, we are concerned with a change from an initial to a final state, without worrying about precisely what happened in between. That's the real power of this IMPULSE-MOMENTUM stuff, just as in the case of WORK-ENERGY.

2. But PLEASE also note the PROFOUND DIFFERENCES! For example, impulse and momentum are VECTOR quantities, meaning that direction is an integral attribute of each, and problem solutions will require use of components. Nonetheless, this complication is more than offset by the power of the approach, as illustrated in Secs. 8-1 and 8-2.

B. Impulse-Momentum is especially important in considering the COLLISION of two or more objects. Here's why! Remember Newton's 3rd law? All those action-reaction pairs of forces between interacting objects are equal and opposite. Thus, if you add up all the impulses resulting from those action-reaction pairs, the sum must be ZERO! That is, the NET IMPULSE must be ZERO. Zero net impulse requires that the TOTAL MOMENTUM of the system of two or more objects NOT CHANGE during the collision. In such cases, we say that momentum is a CONSERVED QUANTITY (a constant). Secs. 8-3 through 8-5 show how this important principle of CONSERVATION OF MOMENTUM is applied to the solution of collision problems.

C. When two or more objects collide in the absence of net external force, the total momentum of the system of objects is ALWAYS AND NECESSARILY CONSERVED. The total kinetic energy of that system of objects, however, is seldom the same afterwards as it was before. In those RARE situations where kinetic energy is conserved, we call the collision "elastic." NEVER assume that a collision is elastic UNLESS you are told that it is OR you calculate that it is after you have solved the problem using momentum conservation. All other collisions where the kinetic energy changes during the collision are called "inelastic." Read all about it in Secs. 8-4 and 8-5.

HOMEWORK ASSIGNMENTS FOR STUDY GUIDE 3.

Homework Assignment #8 - due in lecture Monday, Feb 7.

Yes, we know that we have not yet touched on this material in lecture, but these are really straightforward exercises, so you should be able to dig out the necessary theory on your own!

HW 8-1: Ex. 6-2, except **change** the mass of the crate to 40.0 kg and the coefficient of friction to 0.200. Also, **draw** a free-body diagram for the crate AND **draw** a sketch of the situation, including a coordinate system, summarizing the key details at issue here**. THIS IS SOMETHING THAT YOU SHOULD CONTINUE TO DO WITH ALL PROBLEMS THROUGH TO THE END OF THE COURSE**!

HW 8-2: Ex. 6-4.

HW 8-3: Ex. 6-6.

Homework Assignment #9 - due in lecture Wednesday, Feb 9.

HW 9-1: Ex. 6-20; Also, repeat this exercise, now assuming that sand has been sprinkled on the incline so that a constant friction force is exerted on the ice block as it slides down the incline. **Determine** the coefficient of friction required so that the block will take **twice** as long to slide down the incline compared with the non-frictional case.

HW 9-2: A 10.0 kg crate is pulled up a frictional incline, starting with an initial speed of 1.50 m/s. The pulling force is 80.0 N parallel to the incline, which makes an angle of 20.0° with the horizontal. The coefficient of kinetic friction is 0.400, and the crate is pulled 5.00 m. (a) **Draw** a free-body diagram of this crate and **attach** a descriptive label to each force arrow. (b) **Calculate** the work done by each force in the free-body diagram**.** **Calculate** (c) the change in kinetic energy of the crate as is slides through this 5.00-m distance **and** (d) the speed of the crate at the 5.00 m mark.

HW 9-3: Prob. 6-61, except that the vertical height of the overpass is **changed** to 3.20 m. Also, if you now coast down from the top of the overpass to the level road 3.80 m below, **calculate** what your final speed will be on the level road, assuming no frictional loses.

Homework Assignment #10 - due in lecture Friday, Feb 11.

HW 10-1: Prob. 6-70; **Draw** free-body diagrams for both blocks and compute the work done by all of the forces present in the system. (Note that you don't need to know the actual value of the rope tension force to do this calculation! Why not?) Once you have determined the change of speed in this problem, **calculate** also the magnitude of acceleration experienced by each block over this 2.50-m distance.

HW 10-2: Similar situation to Prob. 7-46, but going directly to the part (b) conditions where h = 3.5R and R = 25.0 m. **Calculate** at each of the points B, C, and D (where D is at the bottom of the loop) the speed of the car, the radial acceleration, and the magnitude of the force with which the seat must push on a 70.0-kg passenger to keep the passenger properly in place.

HW 10-3: Similar situation to Prob. 7-40, except the incline has a coefficient of friction of 0.333 (the horizontal surface is still frictionless) and the block is released from rest at a point 3.80 m up along the incline. (a) **Calculate** the speed the block will have when it reaches the bottom of the incline and slides toward the spring; (b) **calculate** the distance the spring compresses in bringing the block to rest; and (c) **calculate** the distance the block travels back up the incline on its first rebound.

Homework Assignment #11 - due in lecture Monday, Feb 14.

HW 11-1: A 0.145-kg baseball is struck by a bat. Just before impact, the ball is traveling horizontally to the right at 40.0 m/s, and it leaves the bat, still traveling to the right but up 65.0° from the horizontal with a speed of 35.0 m/s. (a) **Calculate** the impulse received by the ball from the bat **and** the impulse received by the bat from the ball. (b) Given that the ball and bat are in contact for 1.80 ms, **find** the horizontal and vertical components of the average force on the ball.

HW 11-2: Ex. 8-28; Also, **calculate** the impulse received by each player during the collision.

HW 11-3: Prob. 8-60.

Homework Assignment #12 - due in lecture Wednesday, Feb 16.

HW 12-1: Ex. 8-24; Also, **calculate** the impulse received by each skater during the collision.

HW 12-2: A billiard ball moving at 5.00 m/s strikes a stationary ball of the same mass. After the collision, the first ball moves at 4.33 m/s and at an angle of 30.0° with respect to the original line of motion.

(a) **Calculate** the speed and direction (relative to the original line of motion of the first ball) of the second billiard ball, (b) **calculate** the impulse received by each ball, and (c) **determine** whether this is an elastic or inelastic collision.

HW 12-3: An 8.00-gram bullet is fired horizontally into a 2.50-kg block that is initially at rest at the very edge of a frictionless table top of height 0.95 m above the floor. The bullet buries itself in the block, in the process knocking the block off the table top so that it lands on the floor a horizontal distance of 1.20 m from where it was just before the bullet hit. **Determine** (a) the initial speed of the bullet, and (b) the amount of kinetic energy lost from the bullet/block system as the bullet buries itself in the block.