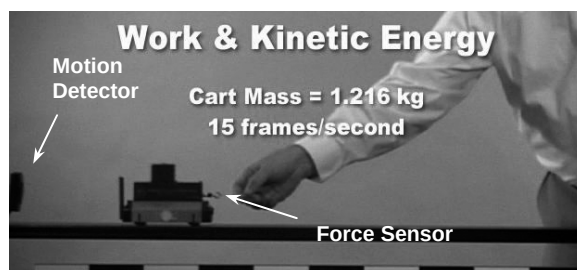


Net Work–Kinetic Energy Theorem

The *Net Work–Kinetic Energy Theorem* can be derived from Newton’s Second Law. If the velocity of an object is measured, this theorem can be used to calculate the net work on an object when the force on it is not constant. In this assignment you will view a movie of a low-friction cart with a force sensor mounted on it. The cart and force sensor are being pulled with a variable force. You can use the position and force data recorded by sensors to verify the theorem.



1. Preliminary Questions

Note: You will receive **full credit for each prediction** made in this preliminary section whether or not it matches conclusions you reach in the next section. As part of the learning process it is important to compare your predictions with your results. **Do not change your predictions!**

(a) Carefully state the *Net Work–Kinetic Energy Theorem* using both equations and words.

(b) Double click on the file <NetW_KE.mov> to open the movie in *QuickTime Player*. Play the movie or advance it frame-by-frame using the right arrow key (→) on your keyboard. If friction is present and the cart is being pulled, there are four forces on the cart. List these forces below.

Vertical Forces:

1. _____

2. _____

Horizontal Forces:

3. _____

4. _____

(c) If the frictional forces experienced by the cart are negligible, explain why the net force on the cart at each moment is the same as the pulling force measured by the force sensor at each moment.

- (d) Suppose a cart is pulled from left to right along the positive x -axis from position x_a to position x_b by unsteady horizontal forces applied to a force probe attached to the cart. Let's denote the x -component of the force as $F^{\text{pull}}(x)$ where the x indicates that the force is a function of position. What equation can be used to calculate the work, W^{pull} , done by this force?
- (e) **Observe the cart motion and plan your analysis:** Open the *Logger Pro* experiment file <NetW-KE.cmbl>. This file opens the movie <NetW_KE.mov>. The movie has been synchronized with data recorded by the motion detector and the force sensor. Since the mass of the cart and its affixed force sensor is known to be 1.216 kg, the *Logger Pro* new column feature has already been set to calculate v_x (the x -component of the cart's velocity) and K (the kinetic energy of the cart) in each frame.
1. Watch the events in slow motion by clicking on the **Start** button in the *Replay* box.
 2. Near the left end of the Toolbar switch from Page 1: "*Data*" to Page 2: "*Analysis*". Then examine the F^{pull} vs. x graph and explain how you can use this graph and the **Integral** tool in the *Logger Pro Analyze* menu to determine the *net work* done on the cart as it moves from a position x_a to a position x_b .
- (f) Still on the analysis page (denoted as "2: Analysis") of the *Logger Pro* file, indicate the range of positions for which the net work on the cart is positive. Then indicate the range of positions for which the net work on the cart is negative. Round your answers to two decimal places.
- (g) Note that the information in the *Logger Pro* data table includes calculated columns for the velocity (v_x) and kinetic energy (K), corresponding to each value of x . Explain how the value of K at each location can be calculated from the mass, m , of the cart and from the velocity of the cart corresponding to a given value of x .
- (h) What equation can be used to calculate the kinetic energy *change* ($\Delta K_{a \rightarrow b}$) as the cart moves from positions x_a to x_b ? You can denote the corresponding horizontal velocity components v_a and v_b .

2. Activity-Based Questions

Does the Work–Energy Theorem hold from one arbitrary position to another? Let's start your verification of the *Net Work–Kinetic Energy Theorem* by assuming that friction forces are negligible and see what happens. Continue to use the *Logger Pro* experiment file <NetW-KE.cml>. Start by considering what happens from $x_a = 0.199$ m to $x_b = 0.607$ m.

- (a) Find the value the cart's *kinetic energy change* in Joules for the chosen range of motion. Perform your calculations using three decimal places. **Hint:** You can use the fact that the new column feature has already been used to calculate the kinetic energy corresponding to each value of x .
- (b) Next use the *definition of work* you reported in your answer to 1(d) to find the value of the work on the cart in Joules done by the pulling force between positions x_a and x_b . Also, use the technique you described in answer 1(e). Show your equations and calculations. **Note:** Once again bring up “page 2: Analysis” and select *all the data from $x = 0.199$ m to $x = 0.607$ m*.
- (c) Compare your answers, and then calculate the percentage difference between the net work and the change in kinetic energy.
- (d) You should have found that the *Net Work–Kinetic Energy* theorem holds for our arbitrarily chosen range of motion to within about 5%, but *that the work done by the pulling force was greater than the change in kinetic energy that it caused*. **Note:** You should check your calculations if you didn't get this result.
- Explain why the presence of a small amount of friction in the cart's wheel bearings might explain this discrepancy.

3. Reflections on Your Findings

Net Work-Kinetic Energy with Friction: You should have concluded that the *Net Work-Kinetic Energy Theorem* holds reasonably well for the relatively friction-free situation of the cart on the track. If we assume some friction is present, then the net work-kinetic energy theorem should still hold! For example, let's do a thought experiment involving a special case. Suppose the cart is replaced by a block that is pulled at a constant velocity with a constant force in the presence of sliding friction.

- (a) What is the net force on the block while it is moving at a constant velocity from point a to point b? Explain how you arrived at your answer.

- (b) What is the net work done on the block while it is moving from point a to point b? Explain how you arrived at your answer.

- (c) What is the change in the kinetic energy of the block as it moves from point a to point b at a constant velocity? Explain how you arrived at your answer.

- (d) Does the *Net Work-Kinetic Energy Theorem* hold for this situation where friction is present?