7. WORK AND KINETIC ENERGY

STRUCTURED

Driving Question | Objective

How is the work done on an object by a non-zero net conservative force related to the change in that object's kinetic energy? Investigate the relationship between the change in kinetic energy of an object experiencing a non-zero net conservative force, and the work done by that net force on the object. Establish a measurement-based relationship between work and kinetic energy.

Materials and Equipment

- Data collection system
- PASCO Smart Gate photogate[1]
- PASCO Photogate Bracket[1]
- PASCO Dynamics Cart Picket Fence[2]
- Table clamp or large base
- Support rod, 45-cm
- Meter stick
- PASCO Dynamics Track[3]
- PASCO Dynamics Track Rod Clamp[4]
- PASCO Dynamics Track End Stop[5]
- PASCO Dynamics Cart[6]
- PASCO Angle Indicator[7]
- Balance, 0.1-g resolution, 2,000-g capacity (1 per class)

[1]www.pasco.com/ap21
PASCO Smart Gate

[2]www.pasco.com/ap16
PASCO Dynamics Cart Picket Fence

[3]www.pasco.com/ap08
PASCO PAStrack

[4]www.pasco.com/ap17
PASCO Dynamics Track Rod Clamp

[5]www.pasco.com/ap11
PASCO Dynamics Track End Stop

[6]www.pasco.com/ap07
PASCO PAScar

[7]www.pasco.com/ap14
PASCO Angle Indicator

Background

WORK

Work done on an object by a force is expressed as the product of the force and the magnitude of displacement of the object in the direction of that force:

$$\text{Work} = \text{Force} \times \text{Distance} \quad (1)$$

If a force is applied to an object whose resultant movement is not in the direction of the force, the work done on that object only includes that component of the force in the direction of the object's movement:

$$W = Fd\cos\theta \quad (2)$$

where d is the distance that the force F acts on the object, and θ is the angle between the applied force direction and the direction of displacement.

KINETIC ENERGY

An object's kinetic energy K is described by the equation:

$$K = \frac{1}{2}mv^2 \qquad (3)$$

where m is the mass of the object and v is the object's speed.

Although work and kinetic energy are different quantities, they are closely related to each other in a mechanical system. In this lab you will investigate the relationship between the change in kinetic energy of a cart experiencing a non-zero net force from gravity and the work done by gravity on the cart.

RELEVANT EQUATIONS

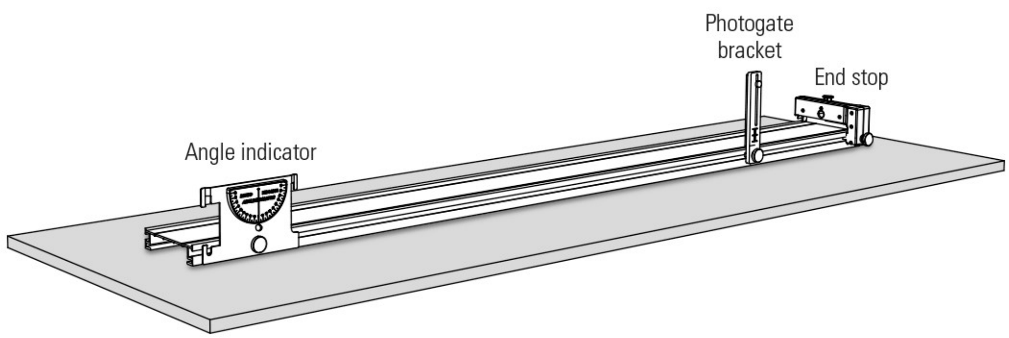
$$W = Fd\cos\theta \qquad (2)$$

$$K = \frac{1}{2}mv^2 \qquad (3)$$

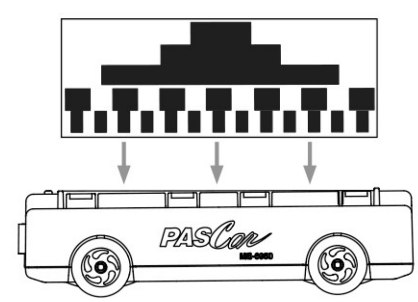
Procedure

SET UP

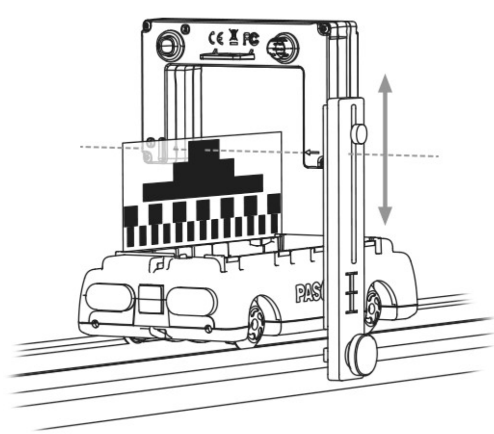
1. Attach the angle indicator, end stop, and photogate bracket to the dynamics track as in the picture below. The end stop should be at the very end of the track and the photogate bracket should be 20 cm from the end stop.



2. Insert the dynamics cart picket fence into the recessed slots on the top of the dynamics cart, oriented with the 2.5-cm solid band as the top-most pattern on the picket fence, and then place the cart on the track. The cart and picket fence will be the "object" on which work will be done in this investigation.



Insert picket fence into slot in top of dynamics cart

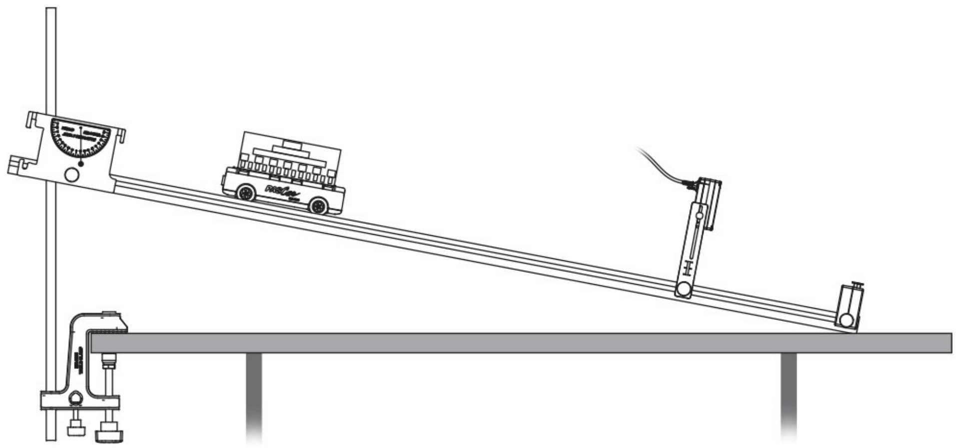


3. Attach the photogate to the photogate bracket. Adjust the height of the photogate on the bracket so the 2.5-cm band on the picket fence passes through the photogate beam as the cart rolls through the photogate.

4. Remove the cart and attach the side of the dynamics track without the end stop to the support rod using the dynamics track rod clamp. Incline the track 10°.

5. Connect the photogate to the data collection system.

6. Configure the data collection system to use photogate timing to measure the speed (or velocity) of the cart as the picket fence passes through the photogate, and then display this measurement in a digits display.

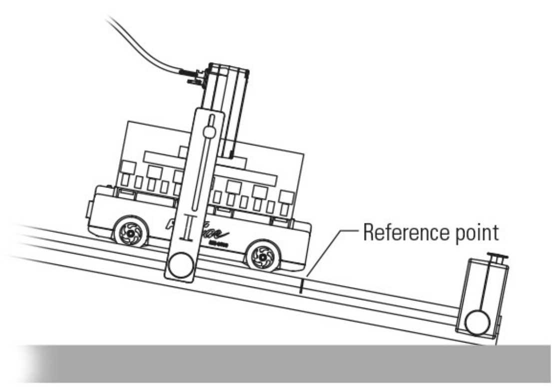


Collect Data

7. Use the balance to measure the mass of the cart and picket fence. Record this mass in the Data Analysis section below.

8. Place the cart on the track and hold it in place with the center of the picket fence aligned with the photogate as in the picture. Make note of the position of the cart's front edge; this will be the reference point from which you will make distance measurements and speed measurements in each trial.

   NOTE: It may be helpful to place a small piece of tape or make a small mark on the track noting the position of the cart's front edge (the reference point).



9. Slide the cart up the track 20 cm from the reference point and hold it in place.

10. Begin recording data on the data collection system, and then release the cart, letting it roll freely down the track
and through the photogate.

11. Catch the cart just before it hits the end stop, and then stop recording data.

12. Record the speed of the cart measured at the reference point, and the distance the cart travelled from where it was released to the reference point, into Table 1 in the Data Analysis section.

13. Repeat the same data collection steps four more times, releasing the cart from 10 cm farther up the track in each trial. Record all data into Table 1 in the Data Analysis section.

Data Analysis

Mass of cart and picket fence (kg) = ____________________

F_g (N) = ____________________

Table 1: Work and kinetic energy of a cart on an inclined track experiencing force from gravity

Trial	Distance Travelled by Cart (m)	Speed at Reference Point (m/s)	Work Done by Gravity (kg·m/s²)	Change in Kinetic Energy (J)
1				
2				
3				
4				
5				

1. Calculate the magnitude of the gravitational force acting on the cart: $\left|\vec{F}_g\right| = F_g = mg$ where m is the mass of the cart and g is earth's gravitational constant 9.8 m/s². Record your result above.

2. Use Equation 2, F_g, and the distance travelled by the cart (in Table 1) to calculate the work done on the cart by gravity in each trial. Record your results for each trial into Table 1.

   NOTE: The angle θ in Equation 2 is not equal to the angle of inclination of the track; θ is equal to the angle between $\vec{F}_g$ and the direction of displacement of the cart. For example, if the angle of inclination is 10°, θ = 90° – 10° = 80°.

3. Use Equation 3, the mass of the cart, and the speed data in Table 1 to calculate the change in kinetic energy of the cart from when it was released to when it reached the reference point in each trial. Assume the kinetic energy of the cart when it was released was zero in each trial. Record your results into Table 1.

Analysis Questions

❷ 1. How does the data for the work done on an object compare to the object's change in kinetic energy?

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❷ 2. What were some unexpected factors that may have caused error in your measured values, and how could these have been avoided?

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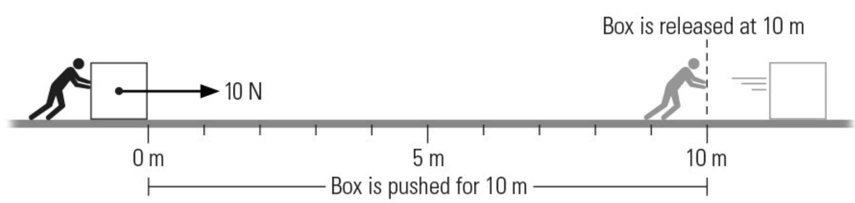
3. How do the units associated with work compare to the units associated with change in kinetic energy?

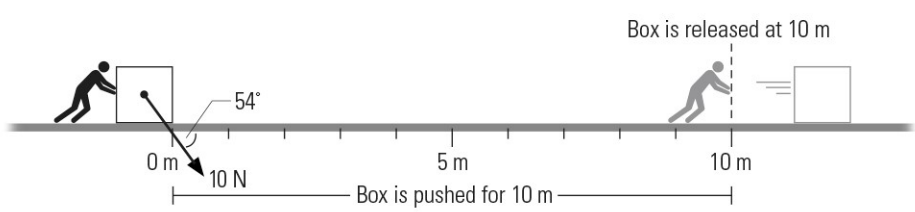
4. In one sentence, describe what you believe the mathematical relationship is between the work done by a non-zero net force on an object, and the change in that object's kinetic energy. Be specific, and use terms like "proportional to," "equal to," "inversely proportional to," and so on.

Synthesis Questions

1. A student pushes a box initially at rest, horizontally along a frictionless surface for 10.0 m and then releases the box to continue sliding. If the student pushes with a constant 15 N force, what is the box's speed when it is released?



2. If the student from the previous question hadn't pushed the box horizontally, but rather, at an angle of 54° relative to the frictionless surface, what would have been the box's speed when it was released?



❷ 3. Suppose an 18-wheel truck and trailer has a mass of 30,000 kg and is traveling with a speed of 24.5 m/s. If the driver slams on his brakes and begins to skid, what would the stopping distance be if the coefficient of kinetic friction between the truck's tires and the pavement is 0.50? Show you work.