Lab 5 - Energy and Work

Overview

One of the central concepts to physics is energy. Energy is everywhere and everything. That is a pretty bold statement, but it is true. The hard part about understanding energy is defining it. What really *is* energy? It is difficult to answer that question because there is no one kind of energy. Energy can take many forms: mechanical, electrical, chemical, nuclear, etc. Maybe a better question to ask is what does energy *do*? The answer is energy makes things happen!

OK, but how does energy make things happen? Energy does work! Or it at least has the capacity to do work. So to understand what energy is, we need to first understand what work is. Work is a lot easier to define, it's the net force on an object over the displacement an object moves.

$$W = F_{net} d \cos(\theta)$$

The significance of the $\cos(\theta)$ is that both the net force F_{net} and the displacement d are vectors, but work a scalar, so the $\cos(\theta)$ gives us the components of force and displacement that point the same direction. The direction does not matter; only the magnitude of F_{net} and d.

Now let's connect this back to energy. One specific kind of energy related to how an object moves is kinetic energy:

$$K = \frac{1}{2} m v^2$$

If an object is initially at rest and we do work on it, the object can move; i.e., it will have a velocity. So if it starts at rest (no kinetic energy), then it has a velocity after work is done (some kinetic energy), then the work done *changes* the kinetic energy of the object!

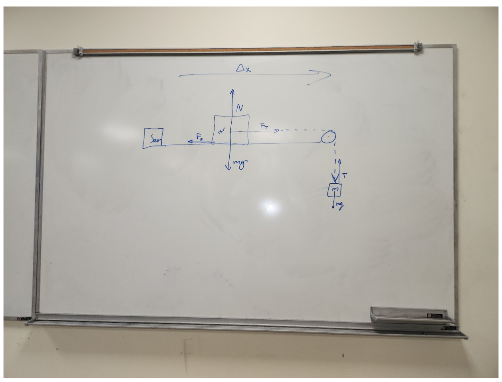
$$W = \Delta K$$

This is known as the Work-Energy Theorem. At the heart of this theorem is a fundamental principle in physics, the conservation of energy!

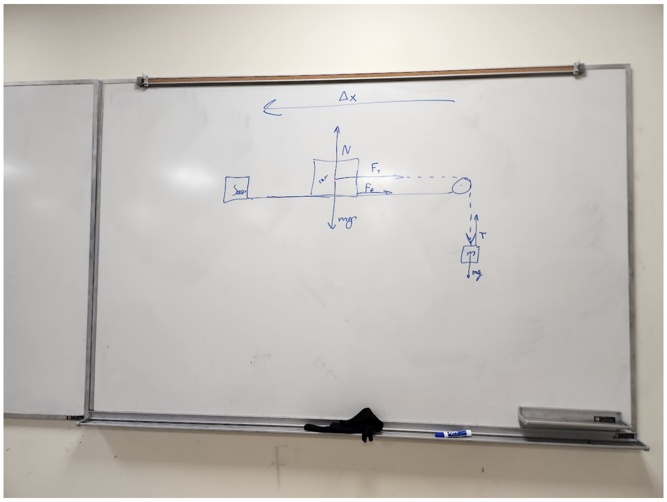
Part 1 - Positive Work

The actual experiment you will perform is almost identical to the lab on Newton's 2nd Law, but instead of measuring the forces on a PAScar, you will measure the work on the PAScar. We will use the same convention of positive direction away from motion sensor and negative direction towards motion sensor.

1. Draw a [free body diagram](#) (FBD) of the PAScar AND the hanging mass when it is moving away (positive) from the sensor. You can draw it on a whiteboard in the lab and take a picture and insert it into your report. Yes, you have drawn a FBD like this before, but what would the sign of the work be? positive or negative? Hint: think of the angle θ between the net force and displacement and use that $\cos(\theta)$ to find the sign of work. Make sure you label all the forces, including friction, AND displacement in the free body diagram.



2. What is the direction of the velocity (positive or negative) when PAScar moves away from the sensor? What is the sign of the kinetic energy when the PAscar moves away from the sensor?
   When the car moves away from the sensor the velocity is positive because the distance between the 2 increases, the kinetic energy when the car is moving away from the sensor is positive because the velocity gets squared so it will never be negative
3. Draw a [free body diagram](#) of the PAScar AND the hanging mass when it is moving towards (negative direction) the sensor. You can draw it on a whiteboard in the lab and take a picture and insert it into your report. Make sure you label all the forces, including friction, AND displacement in the free body diagram.

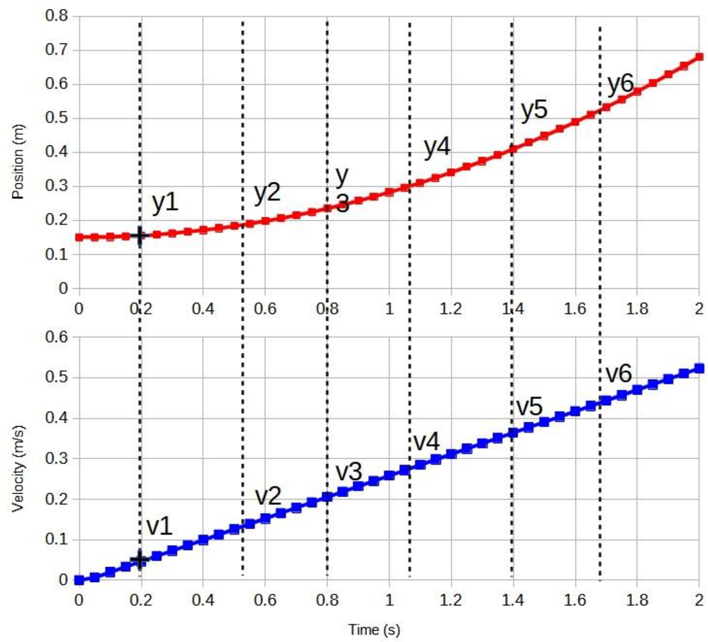


4. What is the direction of the velocity (positive or negative) when PAScar moves towards the sensor? Is the sign of the kinetic energy towards the sensor the same as when the PAScar moves away from the sensor? Explain why or why not.
   When the car moves away from the sensor the velocity is negative because the distance between the 2 decreases, the kinetic energy when the car is moving away from the sensor is positive because the velocity gets squared so it will never be negative

Now let's do the experiment. Start with a 20 gram hanging mass on the end of the string. Hold the PAScar approximately 60 cm in front of the motion sensor. Click Record in Capstone while holding the PAScar at rest. IMPORTANT: you will need to measure the at rest position and velocity. After a few seconds the PAScar. Allow the PAScar to move 3 or 4 times towards and away from the sensor.

Capstone plots both the position vs. time and the velocity vs. time of the PAScar. Note that at some intervals of time the PAScar has positive velocity (away) and at other intervals of time it has negative velocity (towards).

Activate the Multi-Coordinate Tool (the crosshair tool) from the toolbar above the position vs. time graph. The Multi-Coordinate Tool will measure both the position and velocity of PAScar at specific moments in time.



5. In the Google Sheet record the position and velocity of the PAScar as it moves *away* (positive velocity) from the sensor for about 5 or 6 positions including the at rest position. Record the value on the page tabbed 20 grams at the bottom of the Google Sheet. (use the multi-coordinate tool of Capstone!)
   In sheets
6. In the Google Sheet, make a plot of position vs. velocity. Is the plot a straight line? Would you expect it to be a straight line? Explain.

The plot is not straight, I would not expect it to be straight because the relationship is not linear.
Activate the Highlight range of active data from the toolbar for the velocity vs. time graph. Move the Highlight box over a range of data when the PAScar is moving *away* from the sensor.

7. Apply a fit to the range of highlighted data to determine the acceleration of the PAScar. Record the acceleration in the Google Sheet.

ok
Now when you plot position vs. velocity it is clear it is not a straight line. We want to show how the work done on the PAScar is related to the *change* in the kinetic energy. If we substitute the definitions of work and energy into the work-energy theorem we get:

$$F_{net} d\cos(\theta) = \frac{1}{2}Mv_f^2 - \frac{1}{2}Mv_i^2$$

If the PAScar with mass M starts at rest ($v_i = 0$), then work-energy theorem is:

$$F_{net} d\cos(\theta) = \frac{1}{2}Mv_f^2$$

So the work done on the PAScar is proportional to the *square* of the velocity; not the velocity itself.

8. Calculate the displacement of the PAScar in the Google Sheet. Subtract the position at rest from each of the other positions you measured.

ok

9. Calculate the tension in the string for each position recorded. Note: Use your FBD of the hanging mass in question 1 to figure out the formula for the tension in the string.

ok

10. Calculate the square of the velocity for each position recorded.

ok

11. Calculate the work done on the PAScar for each position recorded.

ok

12. Plot the work vs. the square velocity. Is it a straight line? What does the slope of the line relate to in the kinetic energy?

ok

13. Use LINEST() to fit the best line to work vs. square velocity for the PASCO moving away the sensor. What does the intercept represent? Explain your answer.
    The intercept represents that when there is no velocity there is no work being done.

Part 2 - Negative Work

From the FBD you drew for question 3, you can determine the sign of work is *negative*. At first it may seem strange that work can be negative, but there is an implication. If work can change the energy of an object, then the change in the energy can do *work*. The work-energy theorem is true forwards and backwards. Doing work on an object increases the object's energy, but the work done by the object *decreases* the object's energy.

Use the Multi-Coordinate Tool (the crosshair tool) to measure both the position and velocity of PAScar at specific moments in time when it is moving *towards* (negative velocity) the sensor.

14. In the Google Sheet, record the position and velocity of the PAScar as it moves *towards* the sensor for about 5 or 6 positions starting just after the PAScar hits the magnetic bumper. Record the value on the page tabbed 20 grams at the bottom of the Google Sheet.

Use the Highlight range of active data from the toolbar for the velocity vs. time graph. Move the Highlight box over a range of data when the PAScar is moving *towards* the sensor.

15. Apply a fit to the range of highlighted data to determine the acceleration of the PAScar. Record the acceleration in the Google Sheet.

16. Calculate the displacement of the PAScar in the Google Sheet. Subtract the position *just after the bounce* from each of the other positions you measured.

17. Calculate the tension in the string for each position recorded. Note: Use your FBD of the hanging mass in question 3 to figure out the formula for the tension in the string.

18. Calculate the square of the velocity for each position recorded.

19. Calculate the work done on the PAScar for each position recorded.

20. Plot the work vs. the square velocity. Is it a straight line? What does the slope of the line relate to in the kinetic energy?

Yes, it is a perfectly straight line. The slope relates work to velocity squared, the kenetic energy is the

21. Use LINEST() to fit the best line to work vs. square velocity for the PASCO moving *towards* the sensor. Does the intercept change sign when compared to question 12? Explain your answer.

No, this is because the work is not negative, v^2 cannot be negative

22. If the PAScar did work, what did it do work on? Where did the kinetic energy go? Is this consistent with conservation of energy?

The pascar did work on the rope through tension with the force of gravity, and works on the track with friction, and works on the air through friction. The kinetic energy is put into the bumper and bumper gives some back, this is consistent with conservation of energy, because all the energy goes somewhere.