Lab Handout

Lab 20. Kinetic and Potential Energy: How Can We Use the Work-Energy Theorem to Explain and Predict Behavior of a System That Consists of a Ball, a Ramp, and a Cup?

Introduction

You have learned how to use Newton's laws of motion to explain how objects move and to predict the motion of an object over time. Newton's laws of motion therefore function as a useful model that people can use to understand how the world works and to predict how different objects move after they interact with each other. Physicists, however, can use other models to explain and predict the motion of objects and to help understand natural phenomena. One such model views the motion of objects through a lens of work and energy. This model is called the *work-energy theorem.* To understand how work and energy can be used to explain and predict motion, it is important to understand the basic assumptions underlying the work-energy theorem.

The first basic assumption of the work-energy theorem is that an object can store energy as the result of its position. This stored energy is called *potential energy.* The second basic assumption of the work-energy theorem is that all objects in motion have energy because they are moving. The energy of motion is called *kinetic energy.* There are many forms of kinetic energy, including vibrational (the energy due to vibrational motion), rotational (the energy due to rotational motion), and translational (the energy due to motion from one location to another). The third assumption of the work-energy theorem is that doing work on an object results in a change in the *mechanical energy* of that object. Mechanical energy is the sum of the potential and kinetic energy of an object. A change in mechanical energy of an object can result from adding energy to an object, taking away energy from an object, or changing the type of energy an object has from one form to another. Work is done on an object when a force acts on an object over a displacement. Therefore, *work* is mathematically defined as the product of the force acting on an object times the displacement. The fourth, and final, basic assumption of the work-energy theorem is that energy cannot be created or destroyed—it just changes form as objects move or as it transfers from one object to another one.

In this investigation you will have an opportunity to explore the relationship between potential energy, kinetic energy, mechanical energy, work, and displacement in terms of the motion of objects. To explore the relationship between these various components of the work-energy theorem, you will study a simple system that consists of a ball, a ramp, and a cup. You goal is to develop a set of rules that you can use to explain and predict the motion of the ball at the bottom of the ramp and the distance the cup moves after the ball rolls down the ramp and enters the cup. To be valid or acceptable, your set of rules must be consistent with the basic assumptions underlying the work-energy theorem outlined in this section.

Your Task

Use what you know about the work-energy theorem and the importance of tracking matter and energy in a system to develop a conceptual model (i.e., a set of rules) that will allow you to explain and predict the behavior of a system that consists of a ball, a ramp, and a cup. To develop your model, you will need to design and carry out several experiments to determine how changes in several different components of the ball-ramp-cup system affect (1) the motion of the ball at the bottom of the ramp after it rolls down it and (2) the distance a cup moves when a ball is rolled down an incline and comes into contact with the cup. Once you have developed your rules, you will need to test them to determine if you can use them to make accurate predictions about the behavior of the ball-ramp-cup system.

The guiding question of this investigation is, ***How can we use the work-energy theorem to explain and predict behavior of a system that consists of a ball, a ramp, and a cup?***

Materials

You may use any of the following materials during your investigation:

- Safety glasses or goggles (required)
- Support stand
- Extension clamp
- Set of 25 mm balls (includes brass, aluminum, steel, cork, wood, and copper)
- PVC pipe
- Electronic or triple beam balance
- Plastic cup
- 2 Metersticks
- Protractor
- Stopwatch

If you have access to the following equipment, you may also consider using a video camera and a computer or tablet with video analysis software.

Safety Precautions

Follow all normal lab safety rules. In addition, take the following safety precautions:

1. Wear sanitized safety glasses or goggles during lab setup, hands-on activity, and takedown.
2. Keep fingers and toes out of the way of moving objects.
3. Wash hands with soap and water after completing the lab.

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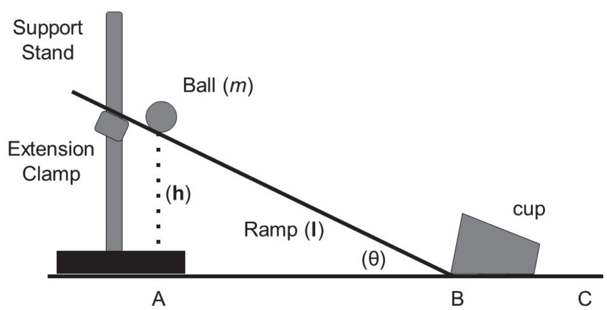
Investigation Proposal Required? ☐ Yes ☐ No

Getting Started

Your first step in this investigation is to design and carry several experiments to determine how changes in several different components of the ball-ramp-cup system affect (1) the motion of the ball at the bottom of the ramp after it rolls down it and (2) the distance a cup moves when a ball is rolled down an incline and comes into contact with the cup. Figure L20.1 shows how you can set up the ball-ramp-cup system. The components of the system that you can change include the mass of the ball (*m*), the height of the ramp (**h**), the length of the ramp (**l**), and the angle of inclination (θ). Before you design or carry out your experiments, however, you must first determine what type of data you need to collect, how you will collect it, and how you will analyze it.

FIGURE L20.1

The ball-ramp-cup system



To determine *what type of data you need to collect,* think about the following questions:

- What are the boundaries and components of the system under study?
- How will you quantify the amount of potential, kinetic, and mechanical energy in the system?
- How can you track the potential, kinetic, and mechanical energy changes within this system?
- Which factors might control rates of change in the system under study?
- What will be the independent variable and the dependent variable for each experiment?

To determine *how you will collect your data,* think about the following questions:

- What other variables will you need to control in each experiment?
- What will be the reference point for measurement?

- What measurement scale or scales should you use to collect data?
- What equipment will you need to take your various measurements?
- How will you make sure that your data are of high quality (i.e., how will you reduce error)?
- How will you keep track of and organize the data you collect?

To determine *how you will analyze your data*, think about the following questions:

- What type of calculations will you need to make?
- How could you use mathematics to describe a relationship between variables?
- What types of comparisons will be useful?
- What type of table or graph could you create to help make sense of your data?

Once you have determined how changes in the different components of the ball-ramp-cup system affect (1) the motion of the ball at the bottom of the ramp after it rolls down it and (2) the distance a cup moves when a ball is rolled down an incline and comes into contact with the cup, your group will need to develop a set of rules that you can use to explain and predict the behavior of this system. Your set of rules must be consistent with the four basic assumptions underlying the work-energy theorem outlined in the "Introduction."

The last step in this investigation will be to test your model. To accomplish this goal, you can set components of the system to values that you did not test (e.g., if you tested the height of the ramp at 0.5 m and 0.75 m, then set the height to 0.6 m) to determine if you can use your rulesto make accurate predictions, then you will be able to generate the evidence you need to convince others that your rules are a valid way to explain and predict behavior of the ball and the cup in terms of the work-energy theorem of motion.

Connections to the Nature of Scientific Knowledge and Scientific Inquiry

As you work through your investigation, you may want to consider

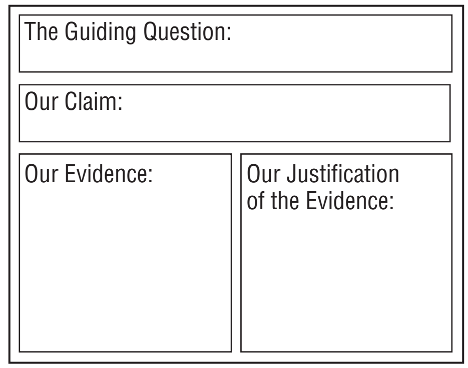
- how scientific knowledge changes over time, and
- the difference between laws and theories in science.

Initial Argument

Once your group has finished collecting and analyzing your data, your group will need to develop an initial argument. Your initial argument must include a claim, evidence to support your claim, and a *justification* of the evidence. The *claim* is your group's answer to the guiding question. The *evidence* is an analysis and interpretation of your data. Finally, the *justification* of the evidence is why your group thinks the evidence matters. The justification of the evidence is important because scientists can use different kinds of evidence to support their claims. You group will create your initial argument on a whiteboard. Your whiteboard should include all the information shown in Figure L20.2.

FIGURE L20.2

Argument presentation on a whiteboard



Argumentation Session

The argumentation session allows all of the groups to share their arguments. One or two members of each group will stay at the lab station to share that group's argument, while the other members of the group go to the other lab stations to listen to and critique the other arguments. This is similar to what scientists do when they propose, support, evaluate, and refine new ideas during a poster session at a conference. If you are presenting your group's argument, your goal is to share your ideas and answer questions. You should also keep a record of the critiques and suggestions made by your classmates so you can use this feedback to make your initial argument stronger. You can keep track of specific critiques and suggestions for improvement that your classmates mention in the space below.

Critiques about our initial argument and suggestions for improvement:

If you are critiquing your classmates' arguments, your goal is to look for mistakes in their arguments and offer suggestions for improvement so these mistakes can be fixed. You should look for ways to make your initial argument stronger by looking for things that the other groups did well. You can keep track of interesting ideas that you see and hear during the argumentation in the space below. You can also use this space to keep track of any questions that you will need to discuss with your team.

Interesting ideas from other groups or questions to take back to my group:

Once the argumentation session is complete, you will have a chance to meet with your group and revise your initial argument. Your group might need to gather more data or design a way to test one or more alternative claims as part of this process. Remember, your goal at this stage of the investigation is to develop the best argument possible.

Report

Once you have completed your research, you will need to prepare an *investigation report* that consists of three sections. Each section should provide an answer to the following questions:

1. What question were you trying to answer and why?
2. What did you do to answer your question and why?
3. What is your argument?

Your report should answer these questions in two pages or less. This report must be typed, and any diagrams, figures, or tables should be embedded into the document. Be sure to write in a persuasive style; you are trying to convince others that your claim is acceptable or valid!