Unit 3
Work and Energy
Suggested Time: 25 Hours

Work and Energy

Introduction

When two or more objects are considered at once, a system is involved. To make sense of what happens between parts of a system, the concepts of momentum and/or energy are needed. Students have seen many situations where a system of objects is involved. After the students have had a chance to look at the concepts of momentum and energy in familiar contexts, they should apply the concepts to less familiar situations. Students could begin by describing the changes they feel on various playground equipment or amusement park rides and developing an explanation for these changes using the vocabulary and concepts of energy and momentum. Eventually, their understanding of these events will involve the conservation laws, which will allow them to describe, explain, and predict the outcomes of many one-dimensional interactions.

Focus and Context

All students will be familiar with a playground environment. This context provides a wealth of examples of energy transformation and two-body interactions. Other relevant contexts, such as sport, could be used in individual schools. By reviewing their experiences and collecting data, students can begin inquiring and discussing . By examining playground events, students will discover the need to learn the concepts of momentum and energy. There is increasing social concern about playground safety. Students could be expected to pose questions and identify safety concerns by answering such questions as “How high is too high?” or “What material is appropriate?” and to develop a plan to answer their questions. Then they will be able to move from this familiar context to other situations where the concepts can be applied.

Science Curriculum Links

In intermediate science, students have explored the movement of objects in terms of balanced and unbalanced forces. They have also described quantitatively the relationships among force, area, and pressure.

In Physics 3204, students should develop a more precise understanding of momentum and energy and learn to evaluate situations using these concepts.

Curriculum Outcomes

STSE

Students will be expected to

Nature of Science and Technology

115-5 analyze why and how a particular technology was developed and improved over time

Relationships Between Science and Technology

116-4 analyze and describe examples where technologies were developed based on scientific understanding

116-6 describe and evaluate the design of technological solutions and the way they function using principles of energy and momentum

116-7 analyze natural and technological systems to interpret and explain their structure and dynamics

Social and Environmental Contexts of Science and Technology

118-2 analyze from a variety of perspectives the risks and benefits to society and the environment of applying scientific knowledge or introducing a particular technology

118-8 distinguish between questions that can be answered by science and those that cannot and between problems that can be solved by technology and those that cannot

Skills

Students will be expected to

Initiating and Planning

212-3 design an experiment identifying and controlling major variables

212-8 evaluate and select appropriate instruments for collecting evidence and appropriate processes for problem solving, inquiring, and decision making

212-14 construct and test a prototype of a device and troubleshoot problems

Performing and Recording

213-2 carry out procedures controlling the major variables and adapting or extending procedures where required

213-3 use instruments accurately for collecting data

Analysing and Interpreting

214-3 compile and display evidence and information, by hand or computer, in a variety of formats, including diagrams, flow charts, tables, graphs, and scatter plots

214-5 interpret patterns and trends in data and infer or calculate linear and non-linear relationships among variables

214-7 compare theoretical and empirical values and account for discrepancies

214-11 provide a statement that addresses the problem or answers the question investigated in light of the link between data and the conclusion

Knowledge

Students will be expected to

325-9 analyze quantitatively the relationships among force, distance, and work

325-10 analyze quantitatively the relationships among work, time, and power

326-1 analyze quantitatively the relationships among mass, height, speed, and heat energy using the law of conservation of energy

326-7 analyze common energy transformation situations using the work-energy theorem

326-5 describe quantitatively mechanical energy as the sum of kinetic and potential energies

326-8 determine the percentage efficiency of energy transformations

326-4 determine which laws of conservation of energy or momentum are best used to solve particular real-life situations involving elastic and inelastic collisions

326-6 analyze quantitatively problems related to kinematics and dynamics using the mechanical energy concept

Work and Power

Outcomes

Students will be expected to

- analyze quantitatively the relationships among force, distance, and work (325-9)
  - list the conditions under which work is done on an object when a force is applied to that object
  - define work in terms of an object's displacement and the force acting on it in the direction of the displacement
  - given two of work, displacement and force, calculate the third term
  - explain how the direction of the applied force affects the work done
  - compare the physics use of the term "work" with everyday usage
  - apply the concept of work to novel situations involving such variables as mass, force, distance and direction
- analyze quantitatively the relationships among work, time, and power (325-10)
  - define power
  - calculate one of the following when given the other two: power, work (or a means to determine the work), and time

Elaborations—Strategies for Learning and Teaching

In calculating work, only work done by an applied force will be considered. Teachers should also consider work done by an applied force at an angle to the horizontal surface using: $W = F\Delta d\cos\theta$.

If the object does not move, the force does no work on the object.

If the force is perpendicular to the direction of the object's motion, then the force is doing no work.

Also note that if an object is already moving a force must be applied to stop the motion. Negative work is done when the applied force and the displacement are in opposite directions.

The student will demonstrate an understanding that, for an object moving in a certain direction, it is the component of the applied force in that direction that determines the work done.

When an object is lifted and we only know its mass, the student should be able to determine the force (the weight) from $F_g = mg$ and then proceed to calculate work. In one step:

$$W = F_g \times d = mgd.$$

Note: Power for lifting an object at constant speed can also be expressed as $P = mgv$

since: $$P = \frac{W}{t} = \frac{mgd}{t}$$

$$\frac{d}{t} = v$$

$$\therefore P = mgv$$

Work and Power

Suggested Assessment Strategies

Journal

- Referring to the data collected, students could describe how force, distance, and work are related. They should give an analysis with an explanation of their understanding of the situation. (325-9)

Paper and Pencil

- As a written record of the dynamics cart exploration, students could submit work sheets which include neat sketches, data, and calculations for each of the three situations from their lab activity. (325-10)
- A locomotive exerts a constant forward force of 5.4×10^4 N while pulling a train at a constant speed of 25 m/s for 1.0 h. How much work does the locomotive do? What average power did the locomotive generate while pulling the train? (325-10)

Performance

- Students could compare their power output by completing Lab 9.3, *Physics: C and C,* p 380.

Resources

www.gov.nl.ca/edu/science_ref/main.htm

Physics: C and C, p 325

Physics: C and C, pp 327-328

Physics: C and C, p 325

Physics: C and C, p 325

Physics: C and C, p 331

Physics: C and C, pp 331-332

Potential and Kinetic Energy

Outcomes

Students will be expected to

- analyze quantitatively the relationships among mass, height, gravitation field strength, gravitational potential energy, and kinetic energy (326-1)
  - define gravitational potential energy in terms of its height, mass, and the force of gravity
  - relate energy transformations to work done
  - solve numerical problems related to gravitational potential energy
  - define an object's kinetic energy in terms of its mass and its speed
  - solve numerical problems related to kinetic energy

Elaborations—Strategies for Learning and Teaching

Students should demonstrate an understanding that gravitational potential energy of an object relative to a certain reference level is the same as the work required to lift the object vertically to its present position. (Conversely, gravitational potential energy can be defined as the work that the force of gravity can do on the object, if allowed to fall to the reference level).

Given, for example, a 10 kg box sitting on the floor, the student can calculate the work required to lift it 1.5 m to a tabletop and state that the gravitational potential energy of the box on the tabletop, with respect to the floor, is the same value as the work required to lift it against gravity.

Potential and Kinetic Energy

Suggested Assessment Strategies

Performance

- Students could design an experiment and using computer interface technology complete the experiment to verify the law of conservation of mechanical energy. (i.e., swinging pendulum, falling objects) (326-1)

Resources

Physics: C and C, pp 336-337

Physics: C and C, pp 333-334

Physics: C and C, pp 336-337

Physics: C and C, p 332

Physics: C and C, p 333

Hooke's Law and Simple Harmonic Motion

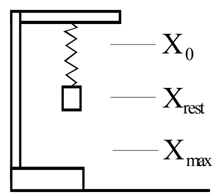
Outcomes

Students will be expected to

- analyze quantitatively the relationships among force, distance, and spring constant (326-1)
  – explain how a stretched spring can possess elastic potential energy
  – define the spring constant k
  – state Hooke's Law
  – given two of: force, distance, and k, determine the third quantity
  – write an expression for potential energy stored in a spring
  – given two of: potential energy, k, and x, determine the third quantity
- explain qualitatively the relationship between displacement, velocity, time, and acceleration for simple harmonic motion (SHM) (327-2)
- explain quantitatively the relationship between potential and kinetic energies of a mass in SHM (327-4)
  - define SHM
  - calculate speed and acceleration of a mass on a spring

Elaborations—Strategies for Learning and Teaching

Students should investigate the force/stretch relationship for springs (Hooke's Law) and related energy changes when a mass oscillates at the end of a spring. Using a spring placed horizontally and a spring scale, students could investigate how much force is required to stretch the spring to various distances. A graph of force versus distance leads to recognition of work done as the spring is stretched. The spring might be hung vertically with a mass attached which holds the spring stretched to something less than half the elastic limit of the spring.



At the rest position, X_{rest}, the change in length of the spring is equal to the height of the mass above the bottom-most point, X_{max}, if the mass had been dropped from a height where the spring is completely unstretched, X_0. ($X_{max} - X_{rest} = X_{rest} - X_0$) If the mass is released at this highest point, it will oscillate up and down for some time before coming to rest at the middle position. Students should determine velocities at various positions. This is an ideal time to use a position sensor and computer software to generate a complete set of kinematics data. This can lead students to such questions as the following:

- What effect would changing the mass have?
- How does the kinetic energy change during an oscillation?
- What happens if a spring with a different force constant is used?

Students will not be responsible for damping or pendulums. Also simple harmonic motion is to be applied to vertical situations only.

Hooke's Law and Simple Harmonic Motion

Suggested Assessment Strategies

Paper and Pencil

- Given that a 5.00 x 10^2 g mass is attached to a vertical spring of force constant 40.0 N/m, students could answer the follow questions:
  - How far below the bottom of the empty spring will the rest position of the mass be?
  - If the mass is lifted about halfway, what period of oscillation will result?
  - Determine the gravitational potential energy, the spring potential energy, and the kinetic energy at the centre of oscillation if the mass is released from the empty spring position. (327-2, 327-4)

Resources

www.cdli.ca web site (Energy Conservation Simulation)

Physics: C and C, pp 338-339

Physics: C and C, pp 180 and 339

Physics: C and C, pp 180 and 339

Physics: C and C, pp 180-181

Physics: C and C, pp 340-341

Physics: C and C, p 341

Physics: C and C, p 358

Physics: C and C, p 359

Physics: C and C, p 357

Physics: C and C, p 358

Conservation of Energy

Outcomes

Students will be expected to

- analyze common energy transformation situations using the closed system work-energy theorem (326-7)
  - state the work-energy theorem as it applies to an object experiencing a force on a horizontal frictionless surface
  - given the expression for work-energy theorem, calculate the value of any variable, given the value of the other variables, or information from which they may be found
  - describe the relationship between the concepts of work and energy
  - carry out an investigation of the work-energy theorem

Elaborations—Strategies for Learning and Teaching

After students are familiar with the basic concepts, teachers can introduce the algebraic deduction below. Work is the name given to the product of force and displacement. Since more work is done if a larger force acts, OR if the same force acts through a larger distance, the $\vec{F}\Delta\vec{d}$ product is a "cause". What is the "effect"?

For Kinematics; $\vec{v}_2^{\,2} = \vec{v}_1^{\,2} + 2\vec{a}\Delta\vec{d}$

Rearranging; $\vec{v}_2^{\,2} - \vec{v}_1^{\,2} = 2\vec{a}\Delta\vec{d}$

$$\text{But} \quad \vec{F} = m\vec{a}, \quad \therefore \quad \vec{a} = \frac{\vec{F}}{m}$$

$$\text{Therefore} \quad 2\left(\frac{\vec{F}}{m}\right)\Delta\vec{d} = \vec{v}_2^{\,2} - \vec{v}_1^{\,2}$$

$$\vec{F}\Delta\vec{d} = \Delta KE = \frac{m\vec{v}_2^{\,2}}{2} - \frac{m\vec{v}_1^{\,2}}{2}$$

$$\text{Dimensionally, work} = N\bullet m, \text{ Energy} = kg\bullet\frac{m^2}{s^2}$$

$$N\bullet m = kg\bullet\frac{m}{s^2}\bullet m = kg\bullet\frac{m^2}{s^2}$$

For convenience, both are called joules, which is the unit for all forms of energy.

The Laboratory outcomes (212-3, 212-8, 213-2, 213-3, 214-3, 214-5, 214-7 214-11) and 326-1 are addressed by completing Work Energy Theorem CORE LAB #5.

Students should also solve algebraic problems involving energy transformations.

Some examples of these types of problems include:

1. A car of mass 1000 kg accelerates from 0.0 m/s to 4.0 m/s. How much work is done by the engine?
2. If the car in problem #1 travelled 10.0 m, what was the average force exerted on the car as a result of the actions of the engine?
3. A 50.0 g arrow is pulled back a distance of 80 cm in a bow. When the string is released, it exerts an average force of 60 N on the arrow. With what speed does the arrow leave the bow?

Conservation of Energy

Suggested Assessment Strategies

Presentation

- Based on their investigations of toys and other transformation situations, students could develop a poster or other visual display that illustrates the work-energy theorem. (326-7)

Paper and Pencil

- Students could solve problems such as: A golf ball of mass 50.0 g is hit by a golf club at a speed of 35 m/s. If the effective mass of the club head is 0.32 kg and the collision is totally elastic, what velocity will the ball have just after the impact? (326-7)
- Students could solve problems such as: A 2.4 kg dynamics cart moving at 1.5 m/s undergoes an in-line elastic collision with another stationary cart of the same mass. What will the velocity of the stationary cart be after impact? (326-7)

Resources

Physics: C and C, p 334

Core Lab #5: *"Work Energy Theorem" Physics: C and C,* p 378

Physics: C and C, pp 334-335

Physics: C and C, p 334

Physics: C and C, p 378

Conservation of Energy (continued)

Outcomes

Students will be expected to

- describe quantitatively mechanical energy as the sum of kinetic and potential energies (326-5)
- analyze quantitatively the relationship between kinetic and potential energy, using the law of conservation of energy (326-1)
  - state the law of conservation of energy
  - state the law of conservation of energy as it applies to mechanical energy
  - solve problems using the law of conservation of energy, including changes in gravitational potential energy and kinetic energy
  - solve problems using the law of conservation of energy, including changes in elastic potential energy
- investigate the relationship between E_p and E_k (212-3)
- evaluate and select appropriate instruments for collecting evidence and appropriate processes for problem solving, inquiring, and decision making (212-8)
- carry out procedures controlling the major variables and adapting or extending procedures where required (213-2)
- use instruments effectively and accurately for collecting data (213-3)

Elaborations—Strategies for Learning and Teaching

The Laboratory outcomes (212-3, 212-8, 213-2, 213-3, 214-3, 214-5, 214-7, 214-11) and 326-1 are addressed by completing Conservation of Energy CORE LAB #6.

The students should be able to state that for a particular object, the sum of the E_p and E_k is a constant term. That is, ($E_p + E_k$) at one time is equal to ($E_p + E_k$) at any other time. One way to express this is:

$$E_{p_1} + E_{k_1} = E_{p_2} + E_{k_2}$$

For an object falling or rising vertically, we therefore have, at the extremes of the motion (top and bottom):

$$E_{p_{Top}} + E_{k_{Top}} = E_{p_{Bottom}} + E_{k_{Bottom}}$$

$$E_{p_{Top}} + 0 = 0 + E_{k_{Bottom}}$$

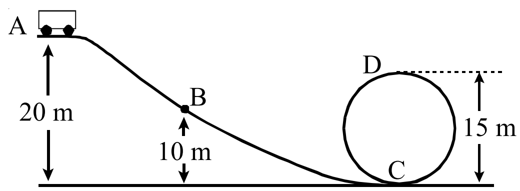
$$E_{p_{Top}} = E_{k_{Bottom}}$$

Conservation of Energy (continued)

Suggested Assessment Strategies

Paper and Pencil

- After referring to the diagram below, students could answer the following questions:
  - How much gravitational potential energy does the roller coaster car have at position A if the loaded mass is 1100 kg?
  - What is the maximum kinetic energy the car could have at B?
  - What speed would it have at B?
  - What speed would the car have at position D? (326-1)



- Kristen is playing on a swing. At her highest swing, the seat is 3.2 m above the rest position. Students could determine what speed does she have as she passes through the lowest position? (326-6)
- A pole vaulter wants to clear the bar at a height of 7.0 m above the mat. Students could determine what vertical speed must he/she have to just clear the bar? What role does the pole play in the pole vault? (326-6)
- Given that a 65 kg boy runs at a constant speed of 6.0 m/s. He jumps on a stationary 35 kg freight dolly so that his feet stay in one position and the combined mass (boy + dolly) moves off at a new speed. Assume that the dolly wheels are frictionless. Students could answer the following:
  - What final velocity will the combined mass have?
  - What impulse acted on the dolly? on the boy?
  - Was energy conserved in this interaction?
  - If the best estimate of the time of interaction is 0.20 seconds, what force acted on the dolly?
  - What acceleration did the boy experience? (326-1, 326-5, 214-7, 326-6)
- Students could determine what is meant by each of the following:

  $W = \Delta E$

  $E_k = \frac{1}{2} mv^2$

  $E_g = mgh$

  $E_e = \frac{1}{2} kx^2$ (326-6)

Resources

Physics: C and C, pp 344-345

Core Lab #6: *"Conservation of Energy" Physics: C and C,* p 378-379
OR
Computer Interface Alternative:
www.gov.nl.ca/edu/science_ref/main.htm

Physics: C and C, p 342

Physics: C and C, p 343

Physics: C and C, pp 343-347

Physics: C and C, pp 340-341

Physics: C and C, pp 378-379

Conservation of Energy (continued)

Outcomes

Students will be expected to

- compile and display evidence and information, by hand or computer, in a variety of formats, including diagrams, flow charts, tables, graphs, and scatter plots (214-3)
- interpret patterns and trends in data, and infer or calculate linear and nonlinear relationships among variables (214-5)
- provide a statement that addresses the problem or answers the question investigated in light of the link between data and the conclusion (214-11)
- determine the percent efficiency of energy transformation including the comparision of empirical and theoretical values of total energy, accounting for discrepancies (214-7, 326-8)
  - explain the role of friction in the loss of mechanical energy from a system
  - compute the percent efficiency of a system where energy is "lost" due to friction
- determine whether the law of conservation of momentum, or, the law of conservation of energy is best to analyze and solve particular real-life problems in elastic and inelastic interactions (326-4)
- analyze quantitatively problems related to kinematics and dynamics using the mechanical energy concept (326-6)

Elaborations—Strategies for Learning and Teaching

The student will express ideas such as: friction will cause agitation of the molecules of the surfaces that are in contact. This will be manifested in the production of heat and possibly, but not likely, light (sparks). Sound is almost sure to be produced because the vibration of the molecules in the materials will likely cause the neighboring air molecules to vibrate as well. All of this means that if an object is being pushed along a rough surface, it will not gain as much kinetic energy as it would on a frictionless surface.

A student might suggest the law of conservation of energy has been disproven. The response to this is that, indeed, when friction is present, **mechanical energy** is not conserved. However, total energy is conserved.

Teachers should expose students to solving problems from both a momentum and energy perspective.

Students have developed confidence in kinematics tools for solving motion problems in a straight line. In achieving this outcome, students should come to appreciate energy solutions for vertical motions.

Conservation of Energy (continued)

Suggested Assessment Strategies

Paper and Pencil

- When analyzing a problem, students could consider how they decide whether to use kinematics, momentum, or energy concepts to solve for unknowns? (326-6)
- Students could solve problems such as: An average force of 8.0 N is applied to a 1.2 kg dynamics cart that is initially at rest. If the force is maintained for a distance of 0.80 m, what velocity will the cart attain? If the force is maintained over a distance of 1.6 m, what velocity is reached? What is the ratio of the two velocities? Explain in terms of work and energy why this is so. Compared to the first trial, what could be changed to give the cart twice the velocity? (326-6)
- Students could write a scientific abstract about their experiment design, results, and interpretations. (212-8, 214-3, 214-5, 214-11)

Presentation

- In groups of three to four, students could demonstrate and discuss their experiment on the machine they chose. They must decide on their presentation format. An explanation of the data, procedure, and the efficiency of the machine should be included. (212-3, 213-2, 213-3, 214-7)
- Students could present a song, poem, speech, or short story to their classmates that involves the following terms: work, kinetic energy, gravitational potential energy, elastic potential energy, and efficiency. The presentation should show a clear understanding of the relationships between the terms momentum and energy. (326-1, 326-6)

Performance

- Students could design and conduct an experiment to demonstrate an energy transformation and account for discrepancies. For example, they could release a block at the top of a ramp, and, using available technology, determine the velocity at several points, including the bottom. They could compare theoretical kinetic energy values to the actual values and account for any differences. (326-1, 326-5, 214-7, 326-6)
- Students could conduct their lab on transformation, total energy, and conservation, and write a lab report on the experiment. They should include the data collected, analysis, information, conclusion(s), and a graph. (212-3, 212-8, 213-2, 214-3, 214-5, 214-11)

Resources

Physics: C and C, pp 377-379

Physics: C and C, p 377

Physics: C and C, pp 368-376

Conservation of Energy (continued)

Outcomes

Students will be expected to

- analyze and describe examples where energy related technologies were developed and improved over time (115-5, 116-4)
- analyze and describe examples where technological solutions were developed based on scientific understanding (116-4)
- describe and evaluate the design of technological solutions and the way they function using energy principles (116-6)
- analyze natural and technological systems to interpret and explain their structure (116-7)
- analyze the risks and benefits to society and the environment when applying scientific knowledge or introducing a particular technology (118-2)
- distinguish between problems that can be solved by the application of physics related technologies and those that cannot (118-8)
- construct and test a prototype of a device and troubleshoot problems (212-14)

Elaborations—Strategies for Learning and Teaching

The CORE STSE component of this unit incorporates a broad range of Physics 2204 outcomes. More specifically it targets (in whole or in part) 115-5, 116-4, 116-6, 116-7, 118-2, 118-8, 212-14, 326-1, 326-5, 326-6. The STSE component, *The Physics of Bungee Jumping*, can be found in Appendix A.

Note: Students are not responsible for the derivations found in this module. The intent is for students to recognize the relationships between the three types of energy involved in bungee jumping.

Conservation of Energy (continued)

Suggested Assessment Strategies

Journal

- Students could write a note explaining momentum, energy, and their transformations so a grade 8 student could understand them. (326-1)

Resources

Core STSE #3: *"The Physics of Bungee Jumping"*, Appendix A