Course

PHS-5062-2

Dynamics and Transformation of Mechanical Energy

Physics

INTRODUCTION

The course entitled *Dynamics and the Transformation of Mechanical Energy* is aimed at enabling adult learners to function effectively in situations from the *Research* and *Expertise* families which concern the application of forces to a body and the concept of work or mechanical energy.

The adult learners enrolled in this course study phenomena or technical applications related to the concepts of dynamics and the transformation of energy, and look for solutions to problems related to this area of physics. They must therefore acquire knowledge about the concepts of work and force, which do not mean the same thing in physics as they do in common usage. They deepen their knowledge of different types of forces and the principle of the conservation of energy that they studied in Secondary IV. This knowledge enables them to explain the factors that underlie certain phenomena, such as the emission of heat in a braking system or the point when a parachute reaches a constant falling speed. It can also enable them to understand the operation of technological applications such a bathroom scale or the shock absorbers of a car. In addition, since experimentation and modelling occupy a central role in the development of competencies and the construction of knowledge related to the concepts in the course, adult learners carry out several laboratory activities designed to help them autonomously exercise the particular skills related to techniques and methods.

By the end of this course, in *Research* and *Expertise* situations, adult learners will be able to:

- ✓ carry out an investigative process that includes experimentation to solve a problem related to the application of multiple forces on a body and how this affects the energy involved
- ✓ analyze a phenomenon or technological application related to the concepts of forces and mechanical energy
- ✓ use Newton’s laws to predict the effects of applying forces to a body
- ✓ verify the principle of the conservation of mechanical energy in a phenomenon or application
- ✓ follow an experimental protocol that they have prepared; one which deals with the effect of one or more forces on a body, with or without consideration of the mechanical energy involved
- ✓ write a laboratory report on the effect of one or more forces on a body, with or without consideration of the mechanical energy involved

SUBJECT-SPECIFIC COMPETENCIES

The following table lists, for each competency, the key features studied in the course. The manifestations of the key features are presented in Appendix 4.

Competency 1 Seeks answers or solutions to problems involving physics	Competency 2 Makes the most of his/her knowledge of physics	Competency 3 Communicates ideas relating to questions involving physics, using the languages associated with science and technology
▪ Defines a problem ▪ Develops a plan of action ▪ Carries out the plan of action ▪ Analyzes his/her results	▪ Identifies the principles of physics underlying a phenomenon or application ▪ Analyzes the principles of physics underlying a phenomenon or application ▪ Explains a phenomenon or an application from the standpoint of physics	▪ Interprets scientific or technological messages ▪ Produces scientific or technological messages

PROCESSES

The investigative processes enable adult learners to solve problems involving the principles of physics and to study an application or phenomenon connected with the transformation of energy or the application of forces to a body. The following are the steps in the investigative process:

- Define the problem
- Formulate a hypothesis
- Test the hypothesis
- Draw conclusions and communicate

The most appropriate investigative processes for this course are: the observation method, the experimental method and modelling. It is during the step of verifying a hypothesis that these methods become distinguishable. Section 3.5 and Appendixes 1 to 3 present these investigative processes, with their respective characteristics.

In this course, laboratory experiments require adult learners to carry out specific tasks in accordance with the following limitations and instructions.

Experimental Method	
Steps	**Tasks**
1. Plans an experiment	The adult learner: – writes up an experimental protocol for physics – selects the materials required to do an experiment – identifies the applicable safety rules, the constant parameters and the parameters to be investigated (independent variable, dependent variable)
2. Conducts the experiment	The adult learner: – follows the experimental protocol and adjusts it as required – takes measurements, keeping in mind the factor of experimental error – applies the appropriate safety rules
3. Interprets the results	In writing up a report, the adult learner: – takes significant figures into account when processing the data – analyzes the results – estimates the maximum allowable error due to the user and the environment – discusses the results – writes the conclusion, making connections with the problem in question

CROSS-CURRICULAR COMPETENCIES

The cross-curricular competencies supplement the subject-specific competencies. The development of one contributes to the development of the others. Course PHS-5062-2 allows for putting all the cross-curricular competencies into practice. Some of them, indicated in grey shading in the table below, are especially targeted in the sample learning situation presented for the requirements of the course.

Cross-Curricular Competencies			
Intellectual	**Communication-Related**	**Personal and Social**	**Methodological**
Uses information	Communicates appropriately	Achieves his/her potential	Adopts effective work methods
Solves problems		Cooperates with others	Uses information and communications technologies
Exercises critical judgment			
Uses creativity			

SUBJECT-SPECIFIC CONTENT

A) KNOWLEDGE

The compulsory concepts and techniques are presented in the tables in the following two sections.

1. Concepts

The knowledge written in italics has been acquired in the science and technology programs and must be mobilized again in this course.

The Material World	
General concept: Dynamics Dynamics studies the causes of changes in motion. Newton's laws describe the effect of forces acting on a body (friction, gravity, centripetal force). Mechanical systems, whether in equilibrium or not, are studied by drawing a free-body diagram, which is a vectorial representation of the forces acting on a system. Various methods can be used to determine the characteristics of the vectors representing the resultant and balancing forces for the system of forces in question. For a body in free fall, special attention is paid to gravitational force, which leads to the study of the concept of gravitational acceleration.	
COMPULSORY CONCEPTS	**PREVIOUSLY ACQUIRED KNOWLEDGE**
Adhesion and friction of parts	• *Describes the advantages and disadvantages of the adhesion and friction of parts in a technical object*
Constraints	• *Describes the constraints to which different technical objects are subject: tension, compression, torsion, deflection, shearing (e.g. a diving board is subject to deflection)*
Pressure	• *Defines pressure as the force exerted by particles when they collide with a constricting surface*
Relationship between mass and weight	• *Describes qualitatively the relationship between mass and weight* • *Applies the mathematical relationship between mass and weight* ($F_g = mg$)
COMPULSORY CONCEPTS	**KNOWLEDGE TO BE ACQUIRED**
Newton's laws	• Describes qualitatively the law of inertia (Newton's First Law) • Describes qualitatively the relationship between the force acting on a body, its mass and its acceleration (Newton's Second Law) • Applies the mathematical relationship between the force acting on a body, mass and acceleration *(F = ma)* • Describes qualitatively the law of action-reaction (Newton's Third Law) • Explains a phenomenon or how a technical object works, using Newton's laws
Centripetal force	• Explains qualitatively the effect of centripetal force on a body in motion
Free-body diagram	• Uses vectors to represent the forces that act on a body
Equilibrium and resultant of several forces	• Determines the magnitude and direction of the vector associated with the resultant force of a system of forces • Determines the magnitude and direction of the vector associated with the balancing force of a system of forces

Dynamics (cont.)	
COMPULSORY CONCEPTS	**KNOWLEDGE TO BE ACQUIRED**
Force of friction	• Explains the possible effects of a frictional force (slows down, stops or impedes the motion of a body) • Names the factors that can affect the force of friction in a given situation (e.g. nature of the surfaces that are in contact, shape of a body that is moving in a fluid) • Determines the value of the force of friction in a given situation (force of friction = applied force - net force)
Gravitational acceleration	• Compares the average values of gravitational acceleration on Earth and on the moon (9.8 m/s^2 on the Earth, 1.6 m/s^2 on the moon)
Gravitational force	• Associates the free fall of a body with the effect of gravitational force • Associates the gravitational force of a body with its weight • Determines the component of gravitational force parallel to the displacement of a body (e.g. inclined plane)
Hooke's law	• Describes qualitatively the relationship between the force applied to a helical spring and the variation in its length • Applies the mathematical relationship between the force applied, the spring constant and the extension of a helical spring *(F=kx)*
Effective force	• Defines effective force as the component of the applied force parallel to the direction of travel • Determines graphically the magnitude of the effective force in a given situation

General concept: Transformation of energy

The concepts previously seen in connection with the transformation of mechanical energy were examined in an environmental context. In this program, the same concepts can be applied to other contexts. The transformation of energy is mainly studied from the standpoint of kinetic and potential energy, for example by examining an application that includes a spring, a simple machine or a complex system. The concepts of work, power, energy, elasticity and heat are examined from this standpoint as well.

Note: *Hooke's law is studied only in connection with helical springs.*

COMPULSORY CONCEPTS	**PREVIOUSLY ACQUIRED KNOWLEDGE**
Forms of energy	• *Describes different forms of energy (chemical, thermal, mechanical, radiation)* • *Defines joule as the unit of measurement for energy*
Law of conservation of energy	• *Explains qualitatively the law of conservation of energy* • *Applies the law of conservation of energy in different contexts*
Energy efficiency	• *Defines the energy efficiency of a device or system as the proportion of energy consumed that is transformed into effective work (amount of useful energy / amount of energy consumed x 100)*
Relationship between power and electrical energy	• *Describes qualitatively the relationship between the power of an electrical appliance, the electrical energy it consumes and the amount of time it is in operation* • *Applies the mathematical relationship between electrical energy consumed, the power of an electrical appliance and the amount of time it is in operation ($E = P\Delta t$)*

COMPULSORY CONCEPTS	KNOWLEDGE TO BE ACQUIRED
Mechanical energy	• Explains qualitatively a transformation of mechanical energy in a given situation (e.g. a merry-go-round in motion) • Applies the mathematical relationships associated with kinetic energy, types of potential energy (gravitational, elastic), work and heat • Analyzes quantitatively a transformation of mechanical energy in a given situation
Relationship between work, force and distance travelled	• Describes qualitatively the relationship between the work done, the force applied on a body and the distance travelled by the body • Applies the mathematical relationship between work, effective force and distance travelled *(W = F⊿d)*
Relationship between energy, the spring constant and the change in length of a helical spring	• Explains qualitatively the relationship between the energy of a helical spring, its spring constant and the change in its length in a given situation (e.g. the springs in a mattress) • Applies the mathematical relationship between elastic potential energy, the spring constant and the change in length in a given situation ($E = ½ kx^2$)
Relationship between power, work and time	• Explains qualitatively the relationship between the power of a system, the work done and the time taken to do the work (e.g. a racing car) • Applies the mathematical relationship between power, work and time ($P = W/\Delta t$)

Transformation of energy (cont.)

COMPULSORY CONCEPTS	KNOWLEDGE TO BE ACQUIRED
Relationship between work and energy	• Describes qualitatively the relationship between the work done on a body and the variation in energy within that body • Applies the mathematical relationship between work and energy ($W = \Delta E$)
Relationship between potential energy, mass, gravitational acceleration and distance travelled	• Describes qualitatively the relationship between the potential energy of a body, its mass, its gravitational acceleration and the distance it travels • Applies the mathematical relationship between potential energy, mass, gravitational acceleration and the distance travelled ($Ep = mgh$)
Relationship between kinetic energy, mass and speed	• Describes qualitatively the relationship between the kinetic energy of a body, its mass and its speed • Applies the mathematical relationship between kinetic energy, mass and speed ($E_k = ½ mv^2$)

2. Techniques

The techniques presented here are grouped in two categories. Many of these techniques require the use of instruments and the handling of objects. Safety and the use of safety equipment must be a constant concern for all those using such techniques.

In the Laboratory	
TECHNIQUES	**KNOWLEDGE TO BE ACQUIRED**
Laboratory work	
• Safely using laboratory materials and equipment	• Uses laboratory materials and equipment safely (e.g. makes sure the way is clear when experimenting with masses, protects the ground when studying free fall)
• Using observational instruments	• Uses an observational instrument appropriately (e.g. force table, digital camera)
Measurement	
• Checking the reliability, accuracy and sensitivity of measuring instruments	• Takes the same measurement several times to check the reliability of the instrument used • Carries out the required operations to ensure the accuracy of a measuring instrument (e.g. calibration of a dynamometer) • Chooses a measuring instrument by taking into account the sensitivity of the instrument (e.g. uses a spark timer accurate to 1/15 of a second rather than a manual chronometer subject to the operator's reflexes; chooses a dynamometer in accordance with the forces to be measured)
• Interpreting measurement results (significant figures, measurement errors)	• Determines the margin of error attributable to a measuring instrument (e.g. the error attributable to a digital chronometer corresponds to the smallest division; the error attributable to a metric ruler corresponds to half of the smallest division on the scale) • Estimates measurement errors associated with the user and the environment • Expresses a result with a number of significant figures that takes into account the errors related to the measure (e.g. a measurement between 10.3 and 10.4 cm, taken with a ruler graduated in millimetres, should be expressed as 10.35 cm or 103.5 mm) • Expresses the value of a measurement with its absolute or relative uncertainty (e.g. $24.1 \pm 0.1\ cm^3$ or $24.1\ cm^3 \pm 0.4\%$)

B) CULTURAL REFERENCES

Cultural references make learning situations more meaningful. The following table presents some of the references related to this course. Learning situations may also draw on other cultural references.

<table>
<tr><th colspan="5">Cultural References</th></tr>
<tr><td>Technical objects, technological systems, processes and products</td><td colspan="4"><u>Dynamics and transformation of mechanical energy</u>
- Road signs
- Elevators
- Rockets
- Parachuting
- Bungee jumping
- Elements of aerodynamics (e.g. car fins, aircraft wings)
- Balances and bathroom scales
- Safety equipment for sports and work (helmets, hard hats, various protectors)
- Fitness equipment
- Propellers (e.g. boat, wind turbines, airplanes)
- Tectonic plates
- Weightlessness
- Geostationary satellites
- Civil engineering structures (e.g. bridges, towers, buildings, dams, roads)
- Automobile systems (e.g. ABS brakes, shock absorbers)
- Roller coasters and merry-go-rounds
- Pendulum clocks
- Slings
- Means of transportation (e.g. automobiles, airplanes, boats, trains)
- Turbines (e.g. electricity plants, jets)
- Simulators</td></tr>
<tr><th>Area</th><th>Scientists</th><th>Community Resources</th><th>Applications</th><th>Events</th></tr>
<tr><td>The Material World</td><td>Isaac Newton
Archimedes
Robert Hooke
James Joule
James Watt
Johannes Kepler</td><td>Association canadienne francophone pour l’avancement de la science (ACFAS)
Canadian Space Agency (CSA)
Schools and faculties of engineering
Ministère des Transports du Québec
Montréal Planetarium
Scientific and technical museums
Science clubs
Ordre des ingénieurs du Québec (OIQ)
Education kit from the Société de l’assurance automobile du Québec (available in French only): La mécanique prend la route</td><td></td><td>World fairs
Science fairs
Nobel prize in Physics
Engineering challenges</td></tr>
</table>

FAMILIES OF LEARNING SITUATIONS

The learning situations in this course, derived from the *Research* and *Expertise* families, are related to the effects of applying one or more forces to a body and to questions of mechanical energy. The paragraphs below contain examples of tasks that the adult learner may be asked to carry out.

Based on a situation involving the balance of forces and centripetal force, adult learners may be asked to explain, using a free body diagram, why a passenger feels “pushed” towards the outside when a car goes into a curve, or why the turns in a road are constructed with an incline.

A situation designed to study the transformation of elastic potential energy into kinetic or gravitational potential energy might require the adult learners to determine experimentally the force constant of a spring. They would then be able to evaluate the total quantity of energy initially held by an object in order to predict the maximum height or speed that can be attained by a projectile launched by a spring system.

Dynamics and the transformation of energy can also be studied in a learning situation involving the path of a miniature car on a track that has elevations and descents. In this situation, focusing on the concepts of friction and work might prompt the adult learners to experimentally measure the work required to move the car in a friction situation. They can then evaluate the effect of this friction on losses of energy.

In the learning situation described on the following page, the main tasks help adult learners develop the second and third competencies. This situation therefore belongs to the *Expertise* family.

BROAD AREAS OF LEARNING

Learning situations are more meaningful for adult learners when their context is connected to the broad areas of learning. The broad areas of learning most readily applicable to the learning situations for the course PHS-5062-2 are *Health and Well-Being*, *Career Planning and Entrepreneurship*, *Environmental Awareness and Consumer Rights and Responsibilities* and *Citizenship and Community Life.* The following example reflects the educational aim of the broad areas of learning *Health and Well-Being* and *Citizenship and Community Life.*

Broad Areas of Learning
Health and Well-Being
Career Planning and Entrepreneurship
Environmental Awareness and Consumer Rights and Responsibilities
Media Literacy
Citizenship and Community Life

EXAMPLE OF A LEARNING SITUATION

A ROAD BUILT TO MEASURE

In the theory section of a driving course, you have learned that a road sign placed at the entrance to a bend in a road will post the maximum speed permitted for drivers negotiating the curve. Also, you have noticed that on a road under construction near your house, there is a very tight curve and the maximum speed sign has not been put up yet. Before the Ministère des Transports installs the sign, you want to test your competencies and predict what the maximum speed should be for this bend in the road.

Your task consists in recommending a maximum speed for taking the curve, based on the principles of physics. You must first list the forces that are exerted on a vehicle when it is in a turn. Then, you will be required to determine the parameters that affect the force of friction between the tires of the vehicle and the road surface, and the relationships that connect them. After processing this information, you will be able to predict the maximum speed that will be posted. Furthermore, based on realistic friction coefficients, you will be able to determine the maximum speeds for driving in a curve when the pavement is wet and when it is dry. In addition, you will be able to evaluate how changing the incline of the road will influence the maximum allowable speed.

Expected production:

- a list and a representation, using a free body diagram, of the forces that are exerted on a vehicle in motion in a curve
- a report presenting the parameters that affect the friction between the tires and the road surface, the processing of this information and your prediction
- a comparative study of the influence of the different parameters (incline, state of the road surface, bending radius) on the maximum speed posted

END-OF-COURSE OUTCOMES

Learning situations are administered on the premise that the adult learner will become familiar with an investigative involving the experimental method, the observation method or modelling. In physics, these learning situations foster the implementation of problem-solving skills, the use of knowledge and the production of messages.

Adult learners solving a problem related to dynamics or the transformation of mechanical energy form a representation of the problem based on their reading and interpretation of scientific and technological messages. They must also develop a plan of action for one of their hypotheses, making use of their knowledge of forces, work and mechanical energy. In order to do this, the adult learners must write up an experiment protocol in which they select the required material, establish the instructions for handling the materials and determine the applicable safety rules. They must also implement a plan of action by carrying out the prescribed activities in the laboratory. During these

activities, they handle the materials correctly, apply the appropriate safety rules and take measurements, taking into account the uncertainty associated with the instruments used and the experimental conditions. In a laboratory report, they present a rigorous analysis of the results and discuss them. Lastly, they write up the conclusions of the experiment, making connections with the initial problem. Their report mentions the sources of errors and their estimated values.

Adult learners who study a phenomenon or technical application related to the forces that act on a body or to the concept of mechanical energy formulate questions on the contextual aspects and identify the physics principles involved. Using diagrams, concepts, laws, theories or models, they explain the role of forces present, the work accomplished, the transmission of power or the transformations of mechanical energy. They illustrate the application of several forces on a body by means of a free body diagram; they predict quantitatively the speed of a body in free fall in relation to its height by means of the principle of conservation of mechanical energy; they explain the relationship between the motion of a body, the work accomplished, mechanical energy and its conservation; and they explain Hooke's law by making a connection between the deformation of a spring and the spring constant associated with it. Finally, the adult learners demonstrate their understanding of the principles of physics by describing the effect of the variation of certain initial parameters, and by applying their explanations to other phenomena or applications governed by the same principles.

EVALUATION CRITERIA FOR THE COMPETENCIES TARGETED BY THE COURSE

Evaluation Criteria for Competency 1	Evaluation Criteria for Competency 2	Evaluation Criteria for Competency 3
▪ Appropriate representation of the situation ▪ Development of a suitable plan of action ▪ Appropriate implementation of the plan of action ▪ Development of relevant explanations, solutions or conclusions	▪ Formulation of appropriate questions ▪ Appropriate use of knowledge of physics ▪ Suitable production of explanations	▪ Accurate interpretation of scientific or technological messages ▪ Appropriate production or transmission of scientific or technological messages