Course

PHS-5061-2

Kinematics and Geometric Optics

Physics

INTRODUCTION

The course entitled *Kinematics and Geometric Optics* is aimed at enabling adult learners to function effectively in situations from the *Research* and *Expertise* families where they may be describing the motion of objects or representing the deviation of the trajectory of light using geometry.

The adult learners enrolled in this course study phenomena and technical applications related to kinematics, reflection and refraction of light, and look for answers to related problems. They construct knowledge about the vectorial nature of certain parameters, such as velocity, acceleration and displacement, as well as the behaviour of light reflected by a mirror or passing through a dioptometer. This knowledge leads them to induce the equations that describe uniform rectilinear motion, uniform acceleration, the trajectory of light and the characteristics of an image. They can then explain some natural phenomena, such as rainbows, mirages and falling objects, and understand the function of a technological application such as a Newtonian telescope or an accelerometer. Furthermore, since experimentation and modelling occupy a central place in the development of competencies and the construction of knowledge related to the concepts in the course, the adult learners carry out several laboratory activities that help them consolidate their learning from Secondary III and IV about 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 kinematic or geometric optics problem
- ✓ analyze a phenomenon or technological application involving the motion of an object or the deviation of light through a dioptometer or a mirror
- ✓ predict the maximum range and height of a projectile or the position and characteristics of an image formed by a mirror or a lens
- ✓ prepare an experimental protocol, according to guidelines, to answer a question related to the motion of an object or the deviation of light
- ✓ write a laboratory report, using an outline, related to kinematics or geometric optics

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 related to kinematics or geometric optics. The following are the steps in an 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 hypothesis verification 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	With guidance, 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 - collects data, keeping in mind the factor of experimental error - applies the appropriate safety rules
3. Interprets the results	In writing up a report, using an outline, the adult learner: - takes significant figures into account when processing the data - analyzes the results - identifies the sources of error - 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-5061-2 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 that will be presented in the last part 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: Kinematics Everywhere around us and inside us, things are vibrating and moving around in relation to each other. There is no universal reference system to describe motion; motion exists relative to a chosen reference system. The motion of objects generally results from a combination of various types of movement. Uniform rectilinear motion and uniformly accelerated rectilinear motion (like a body on an inclined plane or in a free fall) are studied in depth, using a range of concepts (position, displacement, distance, time, velocity, change in velocity, acceleration) that must be differentiated and compared. Data-based equations and graphs (position, velocity and acceleration as a function of time) are an essential form of representation. Equations and graphs describe the relationships among variables and highlight trends in the changes observed. Connections can be made between equations of motion and their graphical representation. In addition, if we interpret a single graph, we can deduce the other two. Changes in position, velocity and acceleration are regarded as vector quantities, and adult learners must master operations involving them. Complex motion, such as that of projectiles, is decomposed into simpler motions (vectorial components).	
COMPULSORY CONCEPTS	**PREVIOUSLY ACQUIRED KNOWLEDGE**
Uniform rectilinear motion - Relationship between speed, distance and time	• *Describes qualitatively the relationship between speed, distance and time* • *Applies the mathematical relationship between constant speed, distance and time* $(v = d/\Delta t)$
Change in velocity	• *Uses systems that allow for changes in the design of technical objects*
COMPULSORY CONCEPTS	**KNOWLEDGE TO BE ACQUIRED**
Reference systems	• Chooses a reference system suited to the situation
Uniform rectilinear motion - Relationship between the position with respect to the point of origin, velocity and time	• Provides a qualitative explanation and uses a graph to illustrate the relationship between the position of an object with respect to its point of origin (displacement), its velocity and the time during which it is in motion • Applies the mathematical relationship between position with respect to the point of origin (displacement), velocity and time $(\Delta d = v\ \Delta t)$ in a given situation
- Displacement and distance	• Distinguishes displacement from distance travelled

Kinematics (cont.)	
COMPULSORY CONCEPTS	**KNOWLEDGE TO BE ACQUIRED**
Uniformly accelerated rectilinear motion	
- Relationship between acceleration, change in velocity and time	• Provides a qualitative explanation and uses a graph to illustrate the relationship between the acceleration of a body, the change in its velocity and the time during which this change occurs • Applies the mathematical relationship between acceleration, change in velocity and change in time ($a = \Delta v / \Delta t$) in a given situation
- Relationship between acceleration, distance and time	• Provides a qualitative explanation and uses a graph to illustrate the relationship between the acceleration of a body, the distance it travelled and the time interval • Applies the mathematical relationship between acceleration, the distance travelled and time ($\Delta d = v_i \Delta t + 1/2 \ a \Delta t^2$) in a given situation
- Average velocity and instantaneous velocity	• Explains the distinction between average velocity and instantaneous velocity • Determines the instantaneous velocity of an object • Determines the average velocity of an object
- Free fall	• Provides a qualitative explanation and uses a graph to illustrate the motion of a free-falling body (position, displacement, average velocity, instantaneous velocity, acceleration) • Determines the position, displacement, average velocity, instantaneous velocity or acceleration of a free-falling body
- Motion of a body on an inclined plane	• Provides a qualitative explanation and uses a graph to illustrate the motion of a body on an inclined plane (position, displacement, average velocity, instantaneous velocity, acceleration) • Determines the position, displacement, average velocity, instantaneous velocity or acceleration of a body on an inclined plane
Motion of projectiles	• Explains the motion of a projectile (combination of uniform rectilinear motion and uniformly accelerated rectilinear motion) • Determines the position, displacement or instantaneous velocity of a projectile, or the time elapsed

General concept: Geometric optics

Concepts pertaining to the deviation of light were studied at the beginning of Secondary Cycle Two. The focus in this program is on geometric optics, which deals with phenomena related to the trajectory of light and more specifically with the ways in which light is deviated by obstacles such as water surfaces, mirrors and lenses. Geometric optics is based on the concept of light rays, a theoretical construct indicating the direction in which light travels.

Snell's laws are used to make qualitative and quantitative predictions regarding the reflection and refraction of light rays (incident beam) that strike a surface separating two different media. One of these laws can be used to calculate the refractive index of each transparent medium through which light travels.

Reflection and refraction are associated with various phenomena and are the basis for a number of common applications. Thin lenses (converging, diverging) and mirrors (plane, spherical) are used to observe microscopic or distant objects or to correct certain visual defects. The experiments they carry out will help adult learners distinguish between real and virtual images and study the relationship used to calculate and predict the position and size of an image as a function of the position and size of an object.

Note: Magnifying power will not be studied.

COMPULSORY CONCEPTS	PREVIOUSLY ACQUIRED KNOWLEDGE
Deviation of light waves	• *Describes how light rays are deviated by a plane reflective surface* • *Determines the angle of reflection of a light ray on the surface of a plane mirror* • *Describes how light rays are deviated when they pass through the surface of a translucent convex or concave surface*
Focal point of a lens	• *Determines the focal point of concave or convex lenses* • *Describes the relationship between the focal point of a lens and the degree of deviation of light rays in different situations (e.g. accommodation of the crystalline lens, choice of corrective lenses)*
Sensory receptors (eye)	• *Names the parts of the eye involved in vision (iris, cornea, crystalline lens, retina)* • *Describes the functions of the main parts of the eye*

COMPULSORY CONCEPTS	KNOWLEDGE TO BE ACQUIRED
Snell's laws (reflection) - Incident and reflected rays	• Defines a light ray as a theoretical structure indicating the direction of the propagation of light • Identifies incident rays and reflected rays in a diagram or in an actual situation • Distinguishes diffuse reflection from specular reflection in various situations
- Angle of incidence and reflection	• Measures the angles of incidence and angles of reflection in a diagram or an experiment • Explains qualitatively or quantitatively a phenomenon using the Law of Reflection (e.g. minimum height a mirror must have in order for a person to see the full length of his/her body)

Geometric optics (cont.)	
COMPULSORY CONCEPTS	**KNOWLEDGE TO BE ACQUIRED**
Snell's laws (refraction)	
- Incident and refracted rays	• Identifies incident and refracted rays in a diagram or an actual situation
- Angle of incidence and refraction	• Measures the angles of incidence and the angles of refraction in a diagram or an experiment
- Index of refraction	• Defines the index of refraction of a medium as the ratio of the speed of light in a vacuum to the speed of light in that medium ($n = c/v$) • Determines, in experiments or mathematically, the indices of refraction of various media • Explains qualitatively and quantitatively a phenomenon using the Law of Refraction ($n_1 sin\theta_1 = n_2 sin\theta_2$) (e.g. a straw in a glass of water) • Explains the phenomenon of total internal reflection (e.g. mirage, fibre optics)
Images	
- Type of image (real, virtual)	• Explains the distinction between a real image and a virtual image
- Image characteristics (magnification, position)	• Describes qualitatively the characteristics of the image formed in a given situation (mirrors and lenses) • Applies the mathematical relationships that make it possible to determine the position, orientation and height of an object or its image in the case of mirrors or lenses ($M = h_i/h_o = -d_i/d_o$; $1/d_i + 1/d_o = 1/f$)

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. handles laser beam correctly to avoid receiving the ray in the eye, takes into account the high temperature of the source object and the ray box when using lasers)
• Using observational instruments	• Uses an observational instrument appropriately (e.g. screen, semi-circular basin, recording tape, 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. uses a lens of a known focal length, verifies whether the same focal distance value can be obtained from a setup) • Chooses a measuring instrument by taking into account the sensitivity of the instrument (e.g. uses an optical bench rather than an improvised setup to measure different positions and distances; uses a spark timer accurate to 1/32 of a second rather than a manual chronometer subject to the operator's reflexes)
• Interpreting measurement results (significant figures, measurement errors)	• Determines the margin of error attributable to a measuring instrument (e.g. the error in a measurement made using a metric ruler or protractor corresponds to half of the smallest division on the scale) • Identifies 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 ± 0.1 cm^3 or 24.1 cm^3 ± 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>Kinematics</u>
- Instruments for measuring speed (e.g. radar speedometer, stroboscope, chronometer)
- Means of transportation
- Elevator
- Ballistics
- Projectiles (ballistics, ball)
- Rocket
- Computer animation

<u>Geometric optics</u>
- Mirages and optical illusions
- Rainbows
- Corrective lenses and contact lenses
- Photography
- Conjuring tricks
- Rear-view mirrors
- Observation instruments (e.g. microscope, telescope, binoculars)
- Fibre optics
- Overhead projector, cinematograph and kaleidoscope</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
Pierre Varignon
Joseph Louis Lagrange
Sofia Brahe
René Descartes
Willebrord Snell
Galileo Galilei
Louis and Auguste Lumière</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
Observatory at Mont-Mégantic
Montréal Planetarium
Scientific and technical museums
Science clubs
Ordre des ingénieurs du Québec (OIQ)
Education kits from the Société de l’assurance automobile du Québec (available in French only):
- La mécanique prend la route
- L’optique prend la route</td><td></td><td>World fairs
Science fairs</td></tr>
</table>

FAMILIES OF LEARNING SITUATIONS

The learning situations in this course, derived from the *Research* and *Expertise* families, are related to the motion of bodies and to the deviation of light rays. The paragraphs below contain examples of tasks that the adult learner can carry out in learning situations that draw on various concepts.

Based on a situation involving the motion of a projectile projected from a launching ramp, the adult learner may be asked to determine the angle of incline of the ramp and the initial speed of the projectile (for example, a bullet) that would be necessary for the projectile to reach its target.

In a learning situation involving the refraction and formation of images, the adult learner can gain an understanding of how the crystalline lens of the human eye functions or how certain vision problems can be corrected with the help of appropriate lenses. In carrying out these tasks in the laboratory, the adult learner can determine the curvature of different lenses, construct models for the principal light rays for convergent and divergent lenses, or observe the characteristics of the images formed.

In a fictitious situation related to astronomy, the adult learner can find the speed of displacement for a meteorite observed with a powerful telescope in order to determine the exact time it will hit the Earth and at what location. The learner must take into account the enlargement of the telescope and the deceleration of the meteorite after it enters the Earth's atmosphere, as well as the effect of gravitational acceleration.

In the learning situation described on the following page, the main tasks help adult learners develop the first and third competencies. This situation therefore belongs to the *Research* 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-5061-2 are *Health and Well-Being*, *Career Planning and Entrepreneurship* and *Environmental Awareness and Consumer Rights and Responsibilities.* The following example reflects the educational aim of the broad area of learning *Health and Well-Being*.

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

CHECK YOUR BLIND SPOTS

A friend who has taken a driving course confides to you how stressed he is. His instructor has explained the principle of a blind spot when changing lanes but he does not really understand it. When you get into the car he is driving, you realize that his mirrors are badly positioned. You must explain to him the principle of the blind spot, using the phenomenon of reflection. Your task consists of listing all the car's mirrors and their characteristics, and then of optimizing their positions in order to minimize the blind spots. You must demonstrate the effectiveness of the optimal positions using the concept of field of vision and a diagram of the situation, drawn to scale. Finally, you will explain to him how to estimate the time available to him to change lanes with respect to an approaching car that he can see in the field of vision of the left mirror.

You will be required to design a protocol to test the fields of vision in plane and curved mirrors. Using your friend's car, you will determine the optimal positions for the mirrors and evaluate the distance that a car coming from the left lane must cover between the time it appears in the field of vision of the left mirror and the time it arrives directly beside your car. You will then write up a laboratory report on the question. In this way, you will be prepared to draw a scale diagram of the car equipped with mirrors and in which a passenger is sitting. You will clearly determine the driver's field of vision as well as the blind spots that you can identify. You will then determine how much time is available to you according to the relative speed of the cars before the car catches up to you. Finally, you must make recommendations to your friend concerning the position of the mirrors and the estimated time available to pass a vehicle, backed up by scientific proof.

Expected outcome:

- list of mirrors present in/on the car and their characteristics
- laboratory report on the fields of vision of a car's mirrors
- diagram to scale of the situation with the position of the mirrors optimized
- calculations of distances and times available to pass a vehicle, based on the relative speed of the vehicles
- explanation of the results of optimizing the different mirrors
- recommendation as to how to estimate the time available to pass a vehicle

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 who solve a problem related to the motion of a body or the deviation of the trajectory of light form a representation of the problem based on their reading and interpretation of scientific and technological messages. They develop a plan of action for one of their hypotheses, making use of their knowledge of kinematics or optics. They are guided in writing up an experiment protocol and determining constant parameters and independent and dependent variables. They implement a plan of action by carrying out activities in the laboratory; they gather data taking into account the experimental uncertainty related to the precision of the measuring instruments used; and they apply the appropriate safety rules. Using an outline, they process data, analyze results and write up discussions about the experiment and its conclusion. If applicable, their report mentions the sources of errors that may explain the discrepancy between their results and those predicted by the theory.

Adult learners who study a phenomenon or technical application of kinematics or optics formulate questions on the contextual aspects and identify the physics principles involved. Using diagrams, concepts, laws, theories or models, they explain the role of kinematics or optics in the description of certain phenomena or in the operation of an application. In this way, they calculate the position, speed and acceleration of a body or the range and maximum height of a projectile using equations of motion. They illustrate the formation of an image with a mirror or a lens using the traces of principal light rays. They determine the position and characteristics of an image using the relationships between similar triangles. Finally, the adult learners demonstrate their understanding of physics principles 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