Projekt współfinansowany w ramach programu Unii Europejskiej Erasmus+

Physics

Topic	Free fall of bodies. Study of free fall of bodies using a lidar sensor
Duration	2 × 45 minutes
Class/Age	The cycle is primarily aimed at secondary school students studying the core physics curriculum (basic course). It can also be used to implement the core curriculum for advanced physics. - grades I–II, advanced level
Objective	• Understanding the phenomenon of free fall in Earth's gravitational field. • Developing the ability to plan and carry out physical experiments. • Analysis of measurement data using modern measuring tools (lidar sensor, computer, spreadsheet).
Description	The student: 1. Explains what free fall is and what factors it depends on. 2. Writes down the equations of uniformly accelerated motion. 3. Reads measurement data from a lidar sensor. 4. Plots graphs of the relationships $s(t)$ and $v(t)$ and determines the acceleration due to gravity g . 5. Interprets the results, compares them with the table value $g = 9{,}81\ \mathrm{m/s^2}$. 6. Identifies the causes of measurement errors. **Methods and forms of work** • Talk, guided discussion • Student experiment • Working with measurement data • Group work • Mini-presentations of results
Teaching aids	- EMPE sensor with software - desktop computer or laptop with web browser

This material is provided by the EMPE Team, responsible institution: UKEN University of Krakow

	- projector, projection screen or multimedia board - falling body: board, book or cardboard box which we weigh in subsequent measurements, gradually increasing its mass

1. Lesson plan

Stage I – Introduction (approx. 15 min)

Form: talk + guided discussion

In the core curriculum for primary schools (Chapter II, point 16), pupils describe free fall (without resistance to movement) as an example of uniformly accelerated motion under the influence of gravity, with acceleration independent of body mass.

1. **Reference to common knowledge:**
   - The teacher asks:
     - What happens when we drop a feather and a stone?
     - Why does the stone fall faster?
     - Would it be the same in a vacuum?
   - The pupils give intuitive answers.
   - The teacher guides the discussion to the conclusion that:
     - All bodies in a vacuum fall with the same acceleration.
     - In air, the differences are due to **air resistance**.
     - The phenomenon of free fall can be described as uniformly accelerated motion without initial velocity.

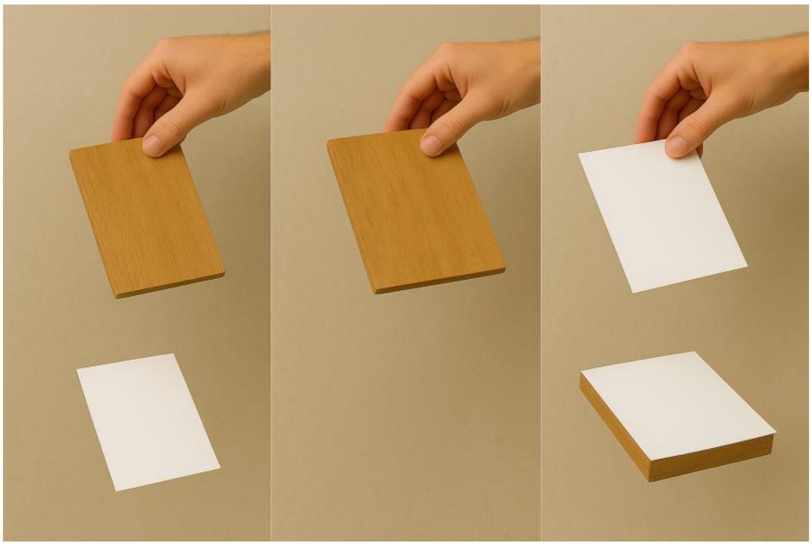
2. Reminder of the relationship:

$$s = \frac{1}{2}gt^2$$

$$v = gt$$

$$g = 9{,}81\,\mathrm{m/s^2}$$

The teacher presents a demonstration.



Drop a sheet of paper and a board of the same size from the same height.
A book can be used instead of a board. The demonstration is carried out in three stages.
1. Drop the sheet of paper and the board placed next to each other. Compare how they fall.
2. Drop the sheet of paper placed under the board.
3. We drop the sheet of paper placed on the board, showing that during free fall, the sheet of paper presses down on the board and does not detach from the falling board.

We hold a discussion. We discuss the conclusions from the experiment.

Suggested conclusions from the experiment:

1. **In the first phase** – when the sheet of paper and the board are dropped next to each other:
   - The board falls faster and the piece of paper falls slower.

    - This is because **the sheet of paper experiences greater air resistance (the resistance force is greater)** in relation to its weight.
      "Air slows down its fall."
    - Conclusion: **air resistance affects the falling speed of light and flat objects.**
2. **In the second phase** – when the sheet of paper is **under the board**:
    - The sheet of paper sticks to the board and they both fall together.
    - Air cannot get between the board and the sheet of paper, so there is no resistance to slow it down.
    - Conclusion: **if we minimise the effect of air resistance, the piece of paper falls at the same speed as the board.**
3. **In the third phase** – when the sheet of paper is lying **on the board**:
    - The piece of paper does not come off and falls together with the board.
    - This is because during the fall, the air does not separate the piece of paper from the board – the same force of gravity acts on them.
    - Conclusion: **in a vacuum (or when we remove the effect of air resistance), all bodies fall at the same rate, regardless of their mass.**

General conclusions

- Bodies falling in the air are affected by **the force of gravity** and **the force of air resistance**.
- In a vacuum (without air), all bodies fall at the same rate.
- This experiment shows that **differences in falling speed result from different values of air resistance forces, not from different masses of these bodies**.

During the discussion before and after the experiment, the teacher should encourage (but not force) pupils with autism spectrum disorder (ASD), aphasia and mild intellectual disabilities to participate actively. Conditions should be created for pupils to speak and present their ideas: give them more time to speak, and ensure that they are not interrupted by other students. This will not only allow them to be actively involved in the lesson, but also enable the teacher to ensure that the students understand the content being taught and to correct any mistakes.

Possible difficulties during work;

- autism spectrum disorder (ASD):
  - if a student has difficulty thinking in terms of cause and effect, they will be a passive participant in the discussion,
  - by making specific mental associations, they may express themselves in a way that is surprising to the teacher,
  - the student may ask additional questions,
- aphasia (A):
  - the student may have difficulty verbalising their thoughts correctly and should be helped, e.g. by suggesting appropriate words,
  - having problems drawing conclusions, his statements may deviate so significantly from what is expected that in order to properly guide both the course of the discussion and the student's train of thought, it will be necessary to calmly and tactfully, but firmly, correct his statements,
- mild intellectual disability (ID):
  - expressing movement in the form of a graph is based on thought processes, which in the case of this student are at a significantly lower level of functioning, and his statements may be completely inadequate to the topic being discussed, which will necessitate a similar approach as in the case of a student with aphasia; calm and tactful, but firm correction of his statements.
  - the student may have difficulty formulating their thoughts independently and orally and, if necessary, will need the teacher's support in the form of, for example, prompting words.

NOTE: prepare a lesson note containing both photos/drawings presenting the experiment and the conclusions drawn from it.

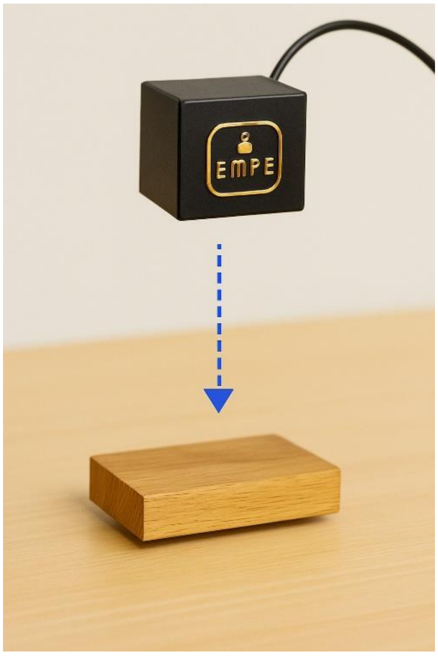
The information and concepts contained in the rest of the scenario are taught in secondary school.

3. Discussion of the purpose of the experiment:

We will analyse how a body falls in a gravitational field using the EMPE lidar distance sensor. Based on the data, we will determine the distance travelled, the speed and the acceleration due to gravity.

Stage II – Experiment (approx. 30 min)

1. **Description of the setup:**
    - The lidar sensor is positioned vertically above the falling body.
    - Data is recorded at the highest possible frequency (e.g. 10, 20 Hz).
    - We measure the fall of the object (changes in the distance of the falling object from the sensor as a function of time) from the highest possible height in the given conditions.
2. **Procedure:**
    - Students in groups of 3-4 perform 3 measurements each. We measure the fall of objects from different heights. To do this, they place the EMPE sensor at a distance of more than 30 cm above the surface of the falling object, e.g. a block. The pupils start the measurement with the highest possible frequency of stable measurements and drop the object so that it falls from the highest possible height under the given conditions. They take the measurement. They export the data to Excel.



    - They export the data from the EMPE programme, save it and analyse it in a spreadsheet.

3. **Data processing:**
    - They draw a graph of$s(t)$ and fit a parabola.
    - They draw a graph V(t) and fit a straight line.
    - They draw a graph of a(t) and discuss the results obtained.
    - They calculate the average velocity and acceleration values for several trials. They discuss the results obtained.
    - A sample data sheet with sample formulas in Ms Excel format is attached.

Stage III – Discussion of results (approx. 15 min)

- Compare the obtained values$g$ with the table value.
- Analysis of the causes of discrepancies: measurement errors, sensor delays, air resistance, imperfect deceleration of the body.
- Students formulate conclusions:
    - The motion of a freely falling body is uniformly accelerated.
    - The acceleration in this motion is independent of the mass of the body.

Stage IV – Summary (approx. 10 min)

- Short summary discussion:
    - What have we learned?
    - What are the advantages of using modern sensors in physics?
- The teacher presents the correct results and refers to the lesson objectives.