TP-2
FREE FALL (CHUTE LIBRE)

Purpose of the TP

- Study the free fall of an object not subjected to any forces (without initial velocity).
- Describe the nature of the motion of an object subjected to its weight.
- Experimentally determine the gravitational acceleration (earth's acceleration) g.
- Confirm the principle of conservation of mechanical energy.

Theoretical Part

1. Study of uniformly accelerated motion (free fall)

In the case of linear motion of an object (e.g., free fall), where the gravitational acceleration near the surface of the Earth is constant:

The average velocity of an object between the time t_0 and the time t is given by:

$\bar{v} = \frac{h - h_0}{t - t_0} = \frac{h - h_0}{t}$ with, $h_0 = h(t = 0)$ et $t_0 = 0$

The acceleration is constant, given by:

$a = \bar{a} = \frac{v - v_0}{t}$ with $v_0 = v(t = 0)$

After a certain time of acceleration:

The position and velocity of this object are expressed as:

$$h(t) = h_0 + \bar{v}t \tag{1}$$

$$v(t) = v_0 + at \tag{2}$$

And since acceleration is constant ***a=Cte***, the average velocity between the initial value v_0 and the final value v is:

$$\bar{v} = \frac{v_0 + v}{2} \tag{3}$$

Substituting equations (2) and (3) into (1), we will have:

$$h(t) = h_0 + \frac{v_0 + v}{2}t = h_0 + \frac{v_0 + (v_0 + at)}{2}t = h_0 + v_0 t + \frac{1}{2}at^2 \tag{4}$$

Substituting equation (2) into (1), we obtain:

$$h(t) = h_0 + \frac{v_0 + v}{2}t \tag{5}$$

From equation (1) : $t = \frac{v - v_0}{a}$ and replacing t in equation (5), we get:

$$h(t) = h_0 + \left(\frac{v_0 + v}{2}\right)\left(\frac{v - v_0}{a}\right) = h_0 + \frac{v^2 - v_0^2}{2a} \tag{6}$$

So : $$v^2(t) = v_0{}^2 + 2a(h(t) - h_0) \quad (7)$$

Therefore, the velocity of the object at time ***t*** is given by:

$$v(t) = \sqrt{v_0{}^2 + 2a(h(t) - h_0)} \quad (8)$$

2. Energetic study of free fall

An object in free fall at a height ***H*** has an energy called: potential energy $\boldsymbol{E_P}$ which increases with its altitude ***h***.

$$E_P \uparrow = mgh \uparrow \quad (9)$$

It also has energy during its fall called: kinetic energy $\boldsymbol{E_C}$ which increases with its speed ***v***.

$$E_C \uparrow = \frac{1}{2}mv^2 \uparrow \quad (10)$$

By definition, mechanical energy E_M is the sum of kinetic energy and potential energy. It remains **constant** over time because the only force acting on the system is gravity, which is a conservative force.

$$E_M = E_C + E_P \quad (11)$$

In the case of no air resistance, mechanical energy is conserved during the fall: $E_M(A) = E_M(B) = Cste$

$$E_M(A) = E_M(B) \Rightarrow E_P(A) + E_C(A) = E_P(B) + E_C(B) \Rightarrow \frac{1}{2}mv_A^2 + mgh_A = \frac{1}{2}mv_B^2 + mgh_B$$

$$\frac{1}{2}mv_B^2 - \frac{1}{2}mv_A^2 = mgh_A - mgh_B \Rightarrow v_B^2 - v_A^2 = 2g(h_A - h_B) \Rightarrow v_B^2 = v_A^2 + 2g(h_A - h_B)$$

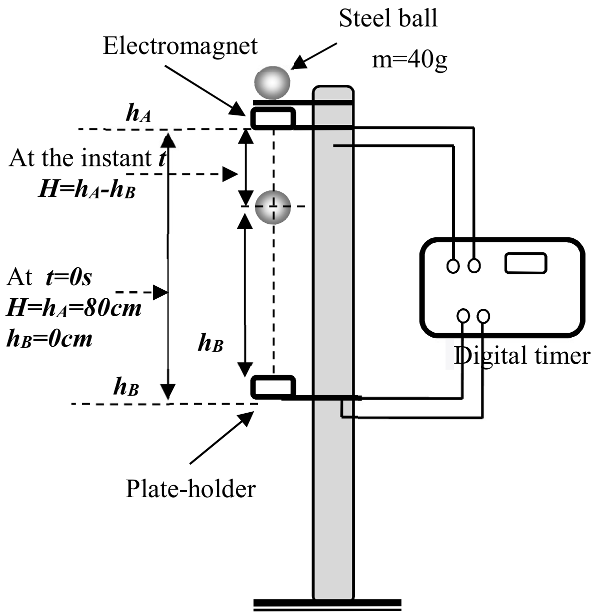
Therefore, the velocity of the object in free fall at position ***B*** is given by:

$$v_B = \sqrt{v_A^2 + 2g(h_A - h_B)} \quad (12)$$

Experiment

A steel ball with a mass of ***m=40g*** is suspended from the electromagnet at a height of $h_A = 80cm$.

- Set up the arrangement shown in the figure below.
- Secure the steel ball to the electromagnet in a way that the trajectory is vertical to the plate holder.
- Adjust the height of the fall h_B indicated in the table below by lifting the plate holder for each trial:
- Press the Start button to initiate the time measurement.
- Repeat the time measurement ***t***, 3 times for each height h_B, and record your results in the table below:



$h_B(cm)$	80	70	60	50	40	30	20	10	0
$H = h_A - h_B(cm)$	0	10	20	30	40	50	60	70	80
$t(s)$	0								
	0								
	0								
$\bar{t}(s)$	0								
$\bar{t}^2(s^2)$	0								
$g = 2H/\bar{t}^2 (m/s^2)$	9.81								
$v = \sqrt{2gH}$ (m/s)	0								
$E_P(t) = m.g.h_B$ $(joule)$									0
$E_C(t) = \frac{1}{2}mv^2$ $(joule)$	0								
$E_M(joules)$									

1. Draw on graph paper the curve $H = f(t^2)$.
2. What is the nature of the motion?
3. Deduce from the graph the experimental value of the acceleration due to gravity ***g***.
4. Compare this value with the theoretical one; provide commentary.
5. Calculate the absolute uncertainty of the acceleration due to gravity ***g***.
   We give: $\Delta t = 0.001s$ and $\Delta H = 0.1cm$ For $H = 40cm$.
6. Write the value of the acceleration of gravity in the form $g = \bar{g} \pm \Delta g \left(m/s^2\right)$.
7. Plot on the same graph paper the curves $E_C = f(t)$, $E_P = f(t)$ et $E_M = f(t)$.
8. Deduce from the graph the time of the fall t for which $E_C = E_P$.
9. What can be said about the mechanical energy E_M ?
10. Conclusion.