Projectile motion (Item No.: P2131100)

Curricular Relevance

Area of Expertise:
Physics

Education Level:
University

Topic:
Mechanics

Subtopic:
Motion in two and three Dimensions

Experiment:
Projectile motion
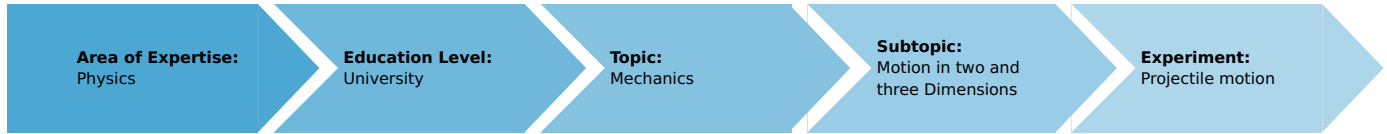
Difficulty	Preparation Time	Execution Time	Recommended Group Size
Easy	1 Hour	1 Hour	2 Students

Additional Requirements:	Experiment Variations:

Keywords:

trajectory parabola, motion involving uniform acceleration, ballistics

Overview

Short description

Principle

A steel ball is fired by a spring at different velocities and at different angles to the horizontal. The relationships between the range, the height of projection, the angle of inclination, and the firing velocity are determined.
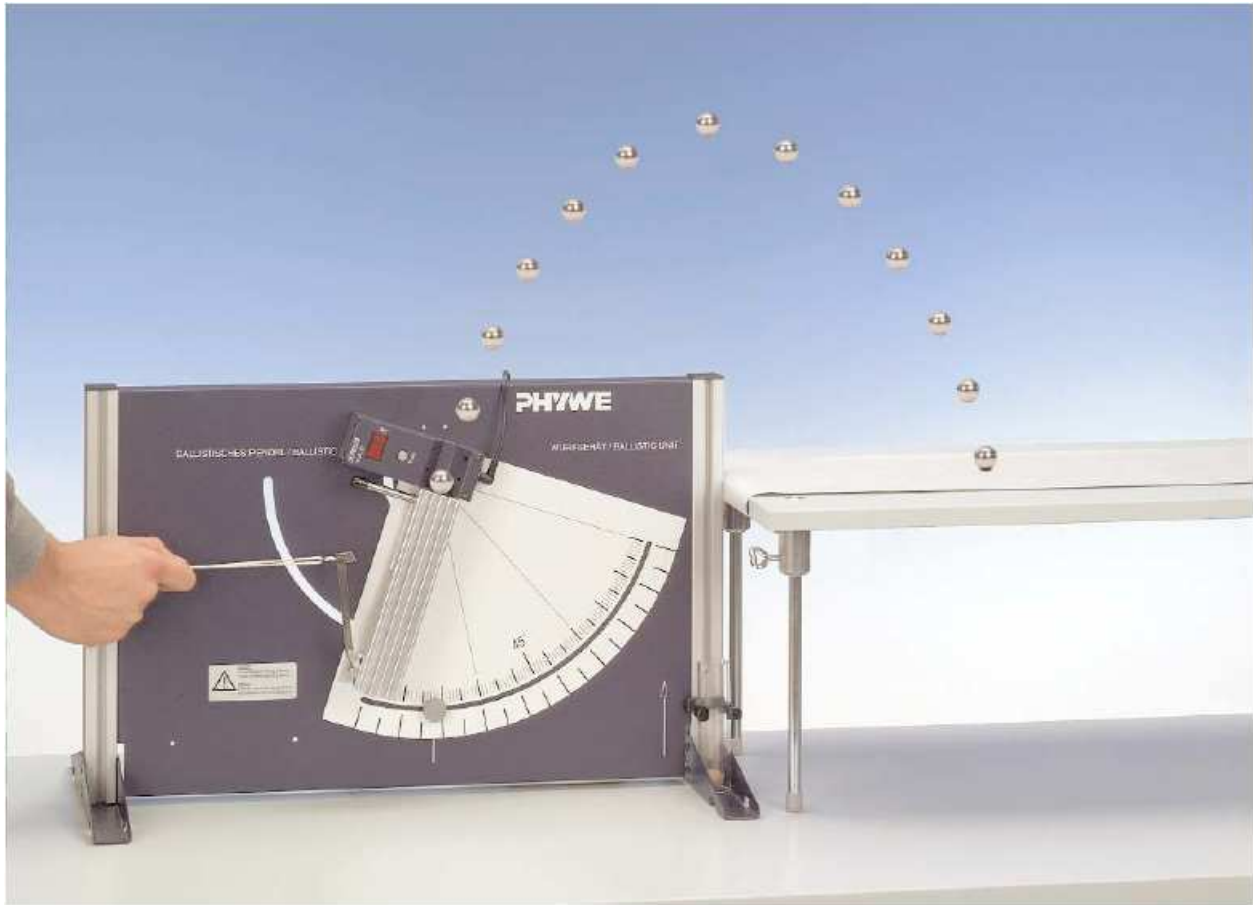
Fig. 1: Experimental set-up for measuring the maximum range of a projectile with additional equipment to measure the initial velocity.

Equipment

Position No.	Material	Order No.	Quantity
1	Ballistic Unit	11229-10	1
2	Recording paper, 1 roll,25 m	11221-01	1
3	Steel ball, d = 19 mm	02502-01	2
4	Two-tier platform support	02076-03	1
5	Scale, l = 750 mm, on rod	02200-00	1
6	Barrel base expert	02004-55	1
7	Speed measuring attachment	11229-30	1
8	Power supply 5 VDC/4 A, according EN61558-2-16	12651-99	1

Tasks

1. To determine the range as a function of the angle of inclination.
2. To determine the maximum height of projection as a function of the angle of inclination.
3. To determine the (maximum) range as a function of the initial velocity.

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Set-up and procedure

The ballistic unit is adjusted. The scale is set to read 90° and a ball is fired upwards (setting 3) and is caught in the hand. The support base adjusting screws are turned until a vertical projection is obtained.

The initial velocities of the ball corresponding to the three tension stages of the firing spring can be determined using the speed measuring attachment, or from the maximum height for a vertical projection from the expression $v_0 = \sqrt{2gh}$. The inital velocities may vary greatly from unit to unit.

The 2-tier platform support (02076-01) is used for determining the range. To mark the points of impact, the recording strip is secured to the bench with adhesive tape. It is best to measure the long ranges before the short ones (secondary impact points!) and to mark the primary impact points with a felt pen. The distance from the ballistic unit is frequently checked with the meter scale during the test. An empty box can be placed behind the bench to catch the balls.

To measure the height of projection the meter scale is clamped in the barrel base and moved parallel to the plane of projection. The empty box is again used to catch the balls. The heights of projection can be determined ballistically quite well by eye.

Theory and evaluation

If a body of mass m moves in a constant gravitational field (gravitational force $m\vec{g}$), the motion lies in a plane (see Fig. 2).
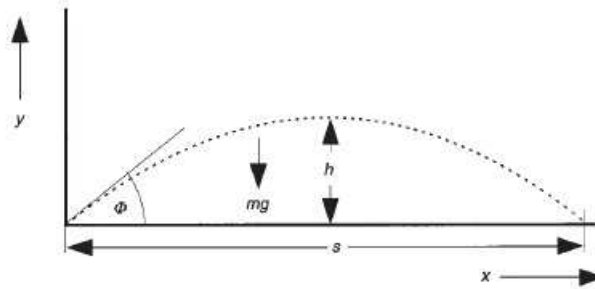
Fig. 2: Movement of a mass point under the effect of gravitational force.

If the coordinate system is laid in this plane (x, y plane, Fig. 2) and the equation of motion

$$m\frac{d^2}{dt^2}\vec{r}(t) = m\vec{g}$$

where

$$\vec{r} = (x, y); \ \vec{g} = (0, \ -g)$$

is solved, then, with the initial conditions

$$r(0) = 0 \ \text{and}$$

$$\vec{v}(0) = (v_0 \cos\phi, \ v_0 \sin\phi)$$

we obtain the coordinates as a function of time t:

$$x(t) = v_0 \cdot \cos\phi \cdot t$$

$$y(t) = v_0 \cdot \sin\phi \cdot t - \tfrac{1}{2}gt^2.$$

From this, the maximum height of projection h is obtained as a function of the angle of projection ϕ:

$$h = \frac{v_0^2}{2g}\sin^2\phi$$

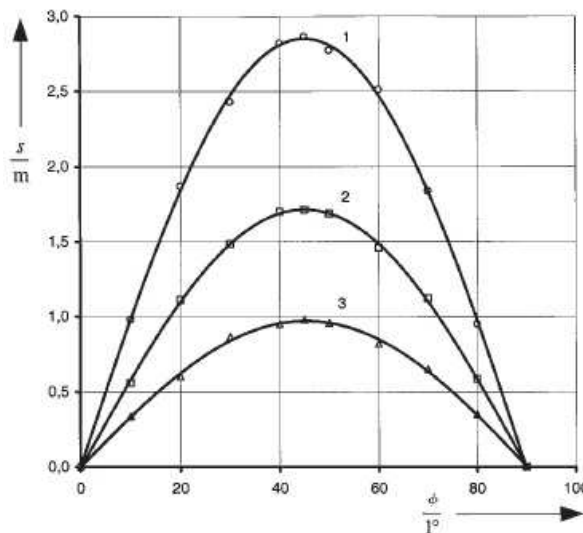and the maximum range is

$$s = \frac{v_0^2}{g}\sin(2\phi).$$

Fig. 3: Maximum range s as a function of the angle of inclination ϕ for different initial velocity v_0:

Data in Fig. 3:
curve 1: $v_0 = 5.3\,\text{m/s}$
curve 2: $v_0 = 4.1\,\text{m/s}$

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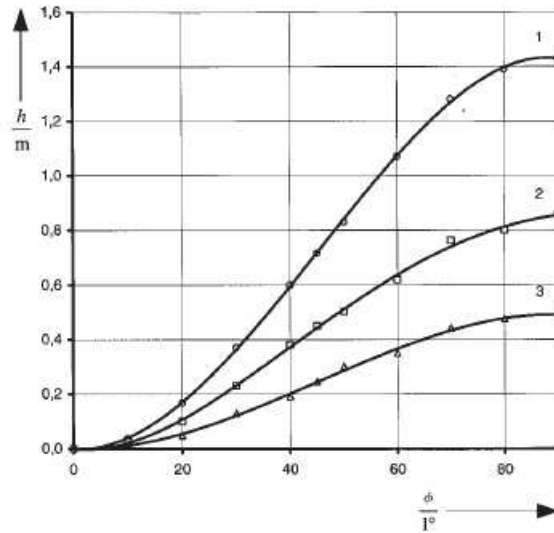
curve 3: $v_0 = 3.1\,\mathrm{m/s}$

Fig. 4: Maximum height of projection h as a function of the angle of inclination ϕ for the initial velocities as in Fig. 1.

The maximum range s is reached at an inclination angle of 45° for every initial velocity. Fig. 5 shows the range s for an angle of 45° plotted against different initial velocities v_0. By choosing a logarithmic scale, a regression line can be applied to the measured data and used to determine the maximum range for arbitrary initial velocities.
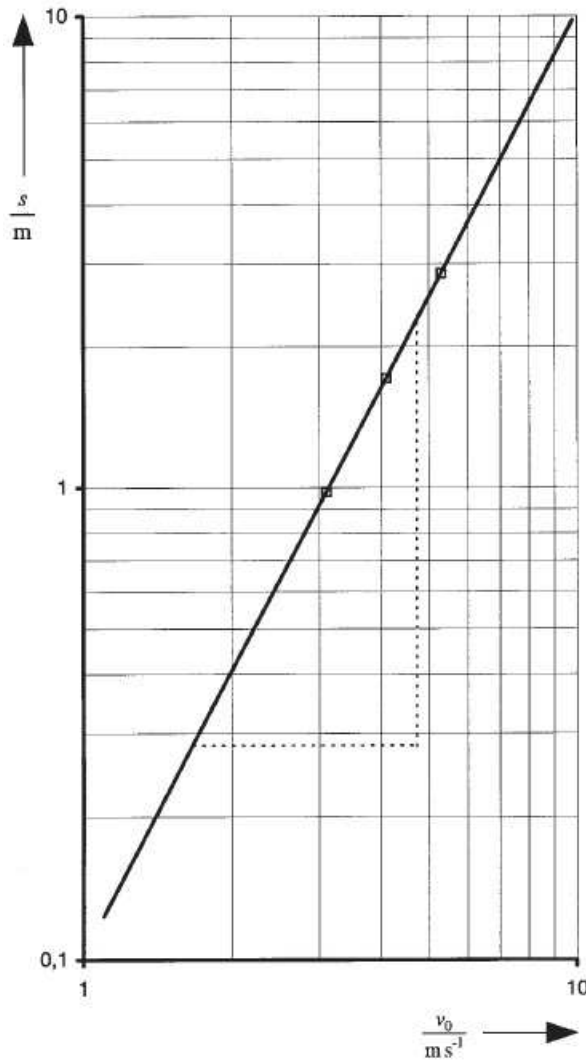
Fig. 5: Maximum range s as a function of the initial velocity v_0 with a fixed angle of inclination $\phi = 45°$.

Note

To ensure an accurate determination of the initial velocity, the time taken for the ball to cover the measuring distance must be taken into account. Depending on the angle of inclination, the ball already leaves the light barrier with a reduced velocity. If $v_{\exp}$ is the experimentally determined inital velocity we obtain as actual initial velocity

$$v_0 = \sqrt{v_{\exp}^2 + gd\sin\phi}$$

where d is the distance between the striker and the centre between the light barriers.