Frustrating golf ball

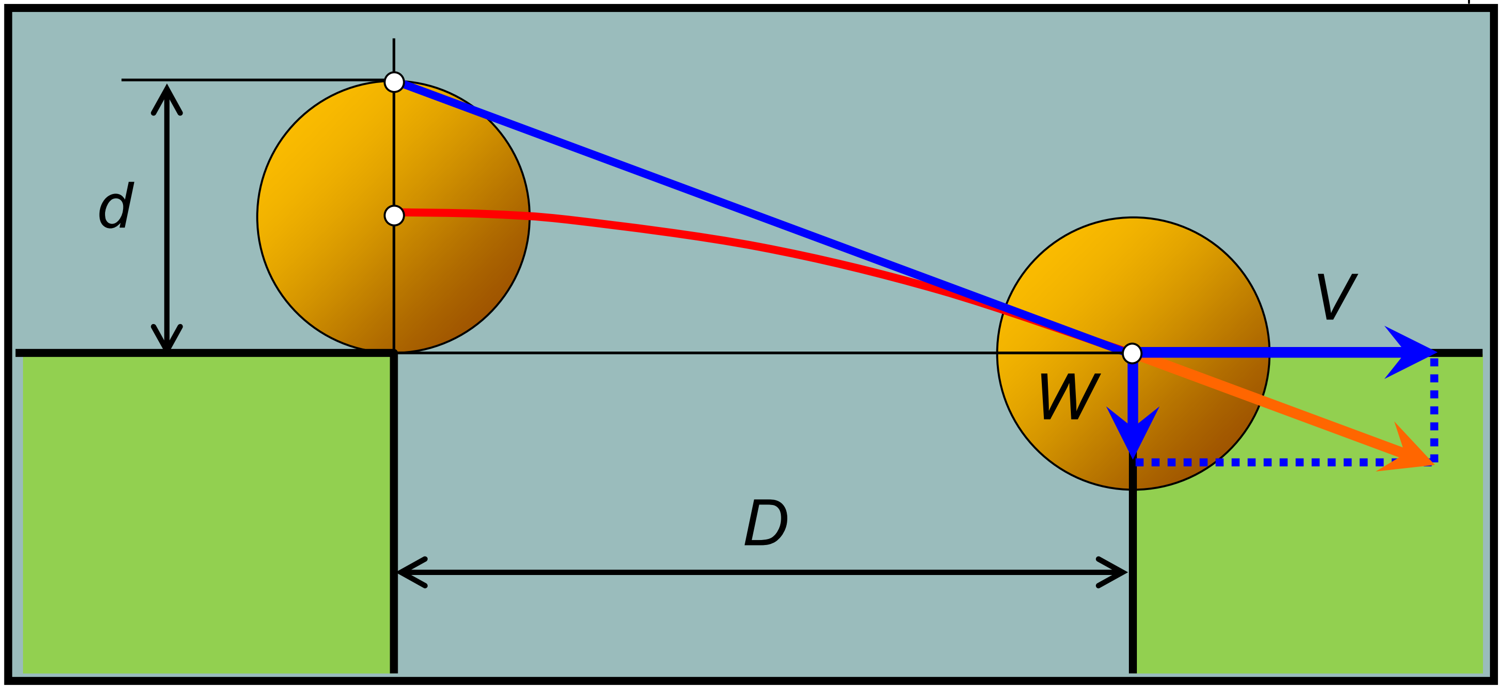
It often happens that a golf ball escapes from the hole an instant after it has been putted into it. Explain this phenomenon and investigate the conditions under which it can be observed.

Vyacheslav Matyunin, Russia

Size of the ball and the hole

Diameter of the ball = 42.7 mm
Diameter of the hole = 108 mm

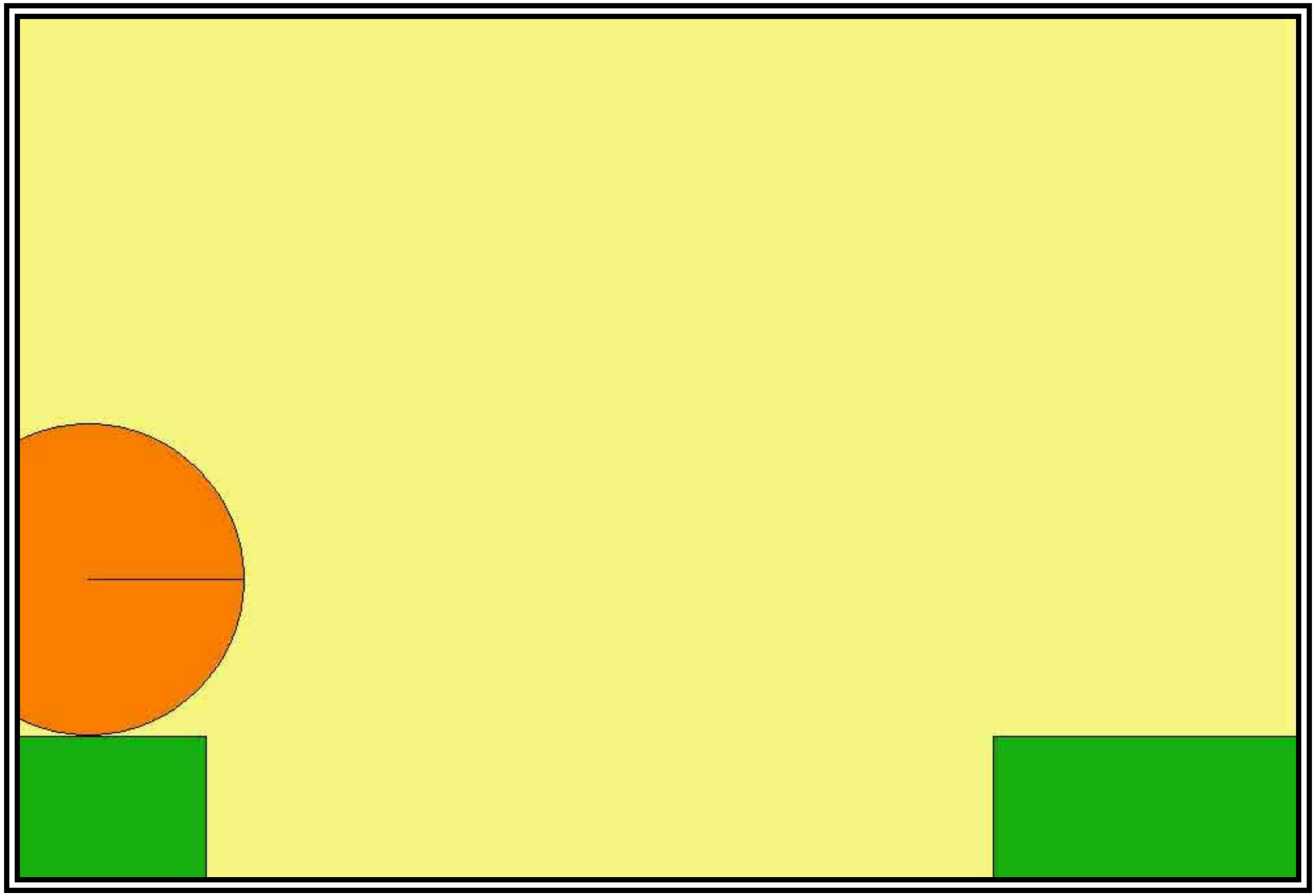
Characteristic velocity



$$W = \sqrt{2gr} = \sqrt{gd} = 65 \text{ cm/s}$$

$$\frac{V}{W} = \frac{D}{d} \rightarrow V = 164 \text{ cm/s}$$

“Interactive Physics” computer simulation of central impact



On this video:

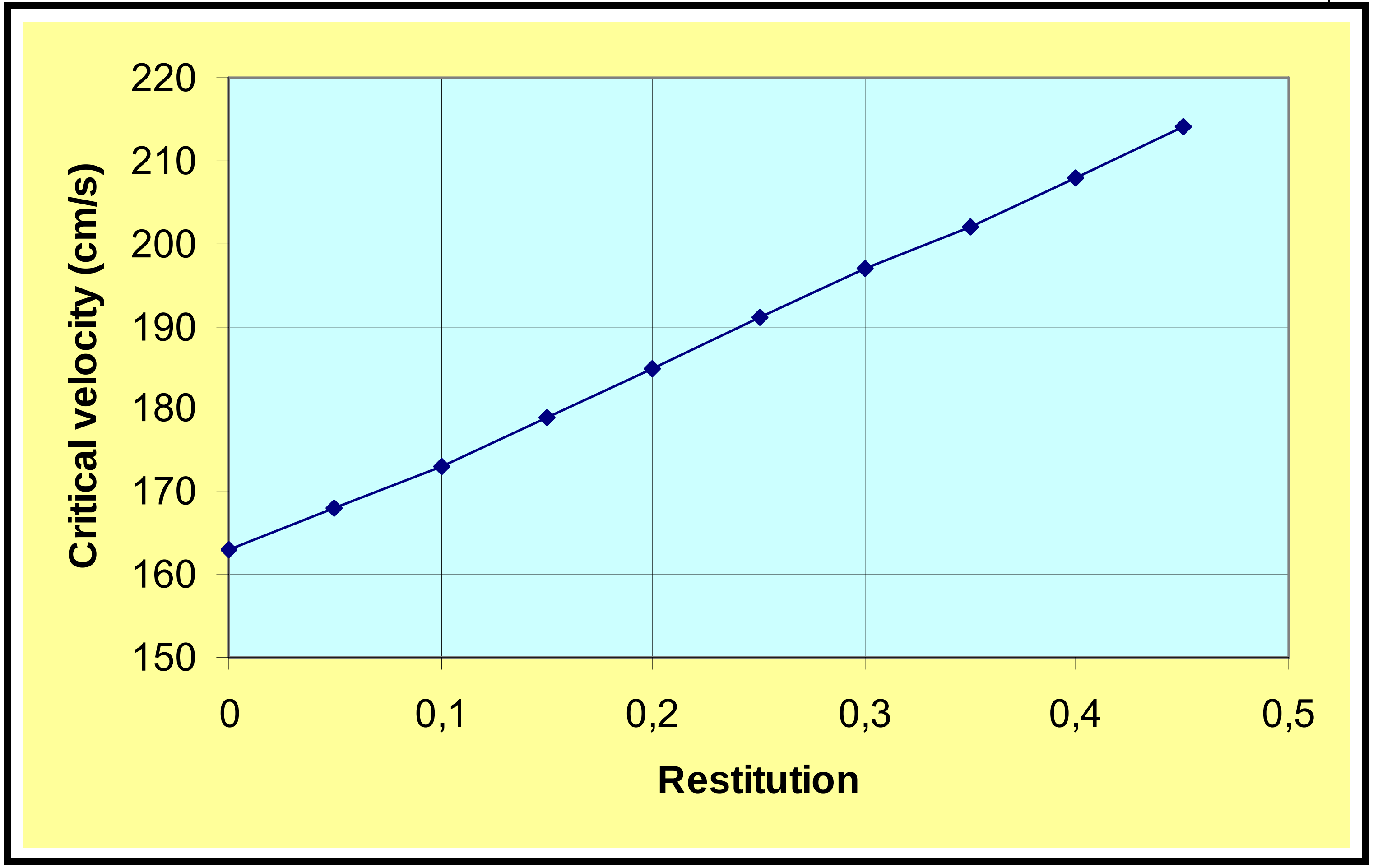
- Coefficient of restitution ε = 0.2
- Coefficient of sliding friction μ = 0.3
- Velocity of the ball *V* = 1.85 m/s

Results of the computer simulation

Critical velocity *V* (cm/s):

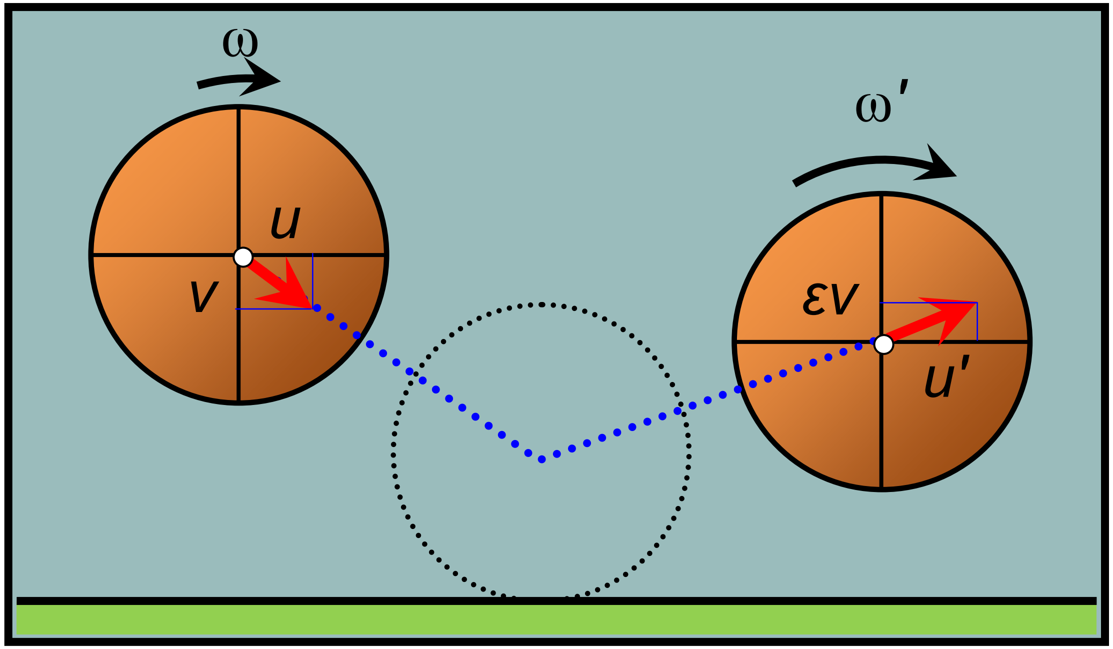
		Coefficient of restitution ε		
		0	0.1	0.2
Coefficient of slide friction μ	0	1.67	1.76	1.85
	0.1	1.65	1.75	1.85
	0.2	1.64	1.74	1.85
	0.3	1.63	1.73	1.85
	0.4	1.63	1.73	1.85

Central impact: critical velocity vs. restitution



Coefficient of slide friction μ = 0.3

Impact of the rotating ball with a wall



Regime of full connection

$$u' = \frac{5}{7}u + \frac{2}{7}\omega r$$

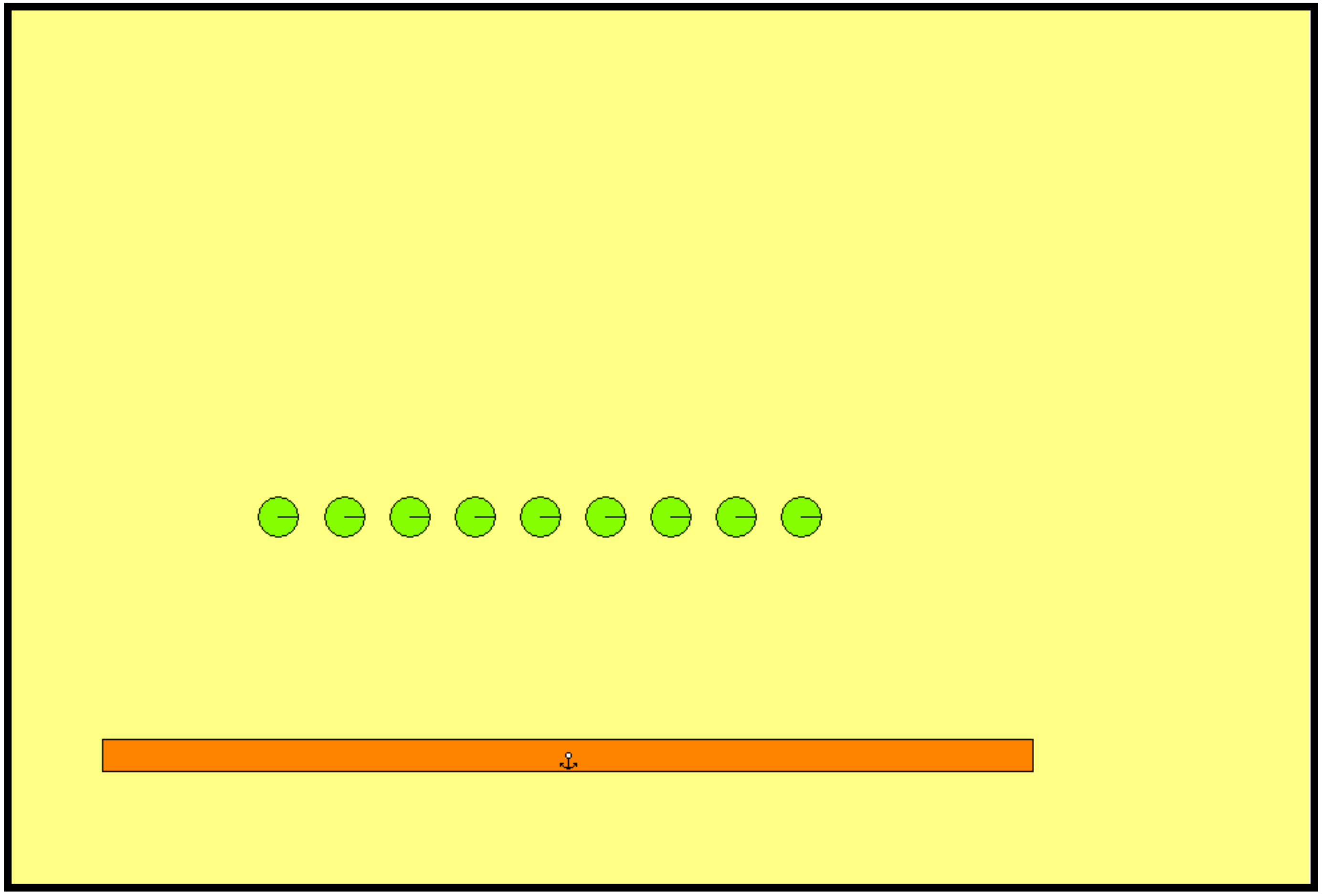
$$\omega' = \frac{2}{7}\omega + \frac{5}{7}\cdot\frac{u}{r}$$

Regime of non-full connection

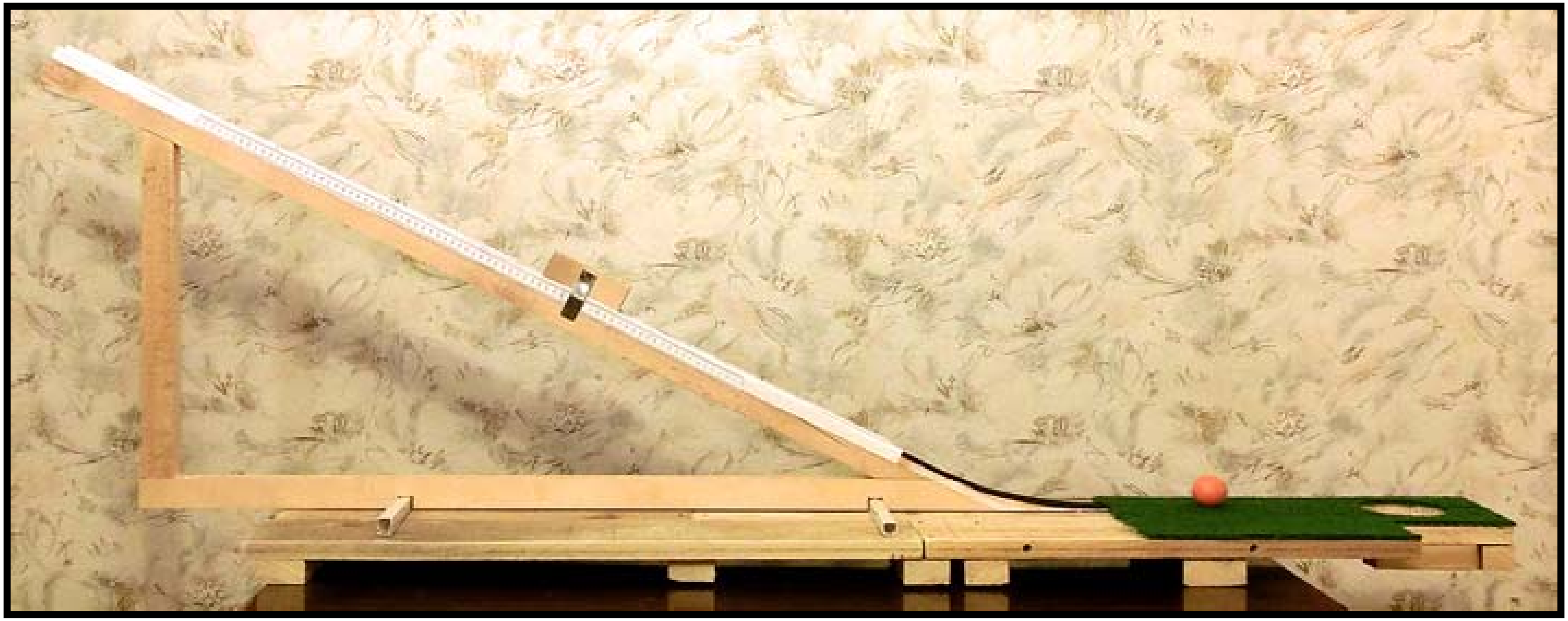
$$u' = u + \mu(1+\varepsilon)v$$

$$\omega' = \omega - \frac{5\mu(1+\varepsilon)}{2}\cdot\frac{v}{r}$$

Two regimes of impact



Experimental setup

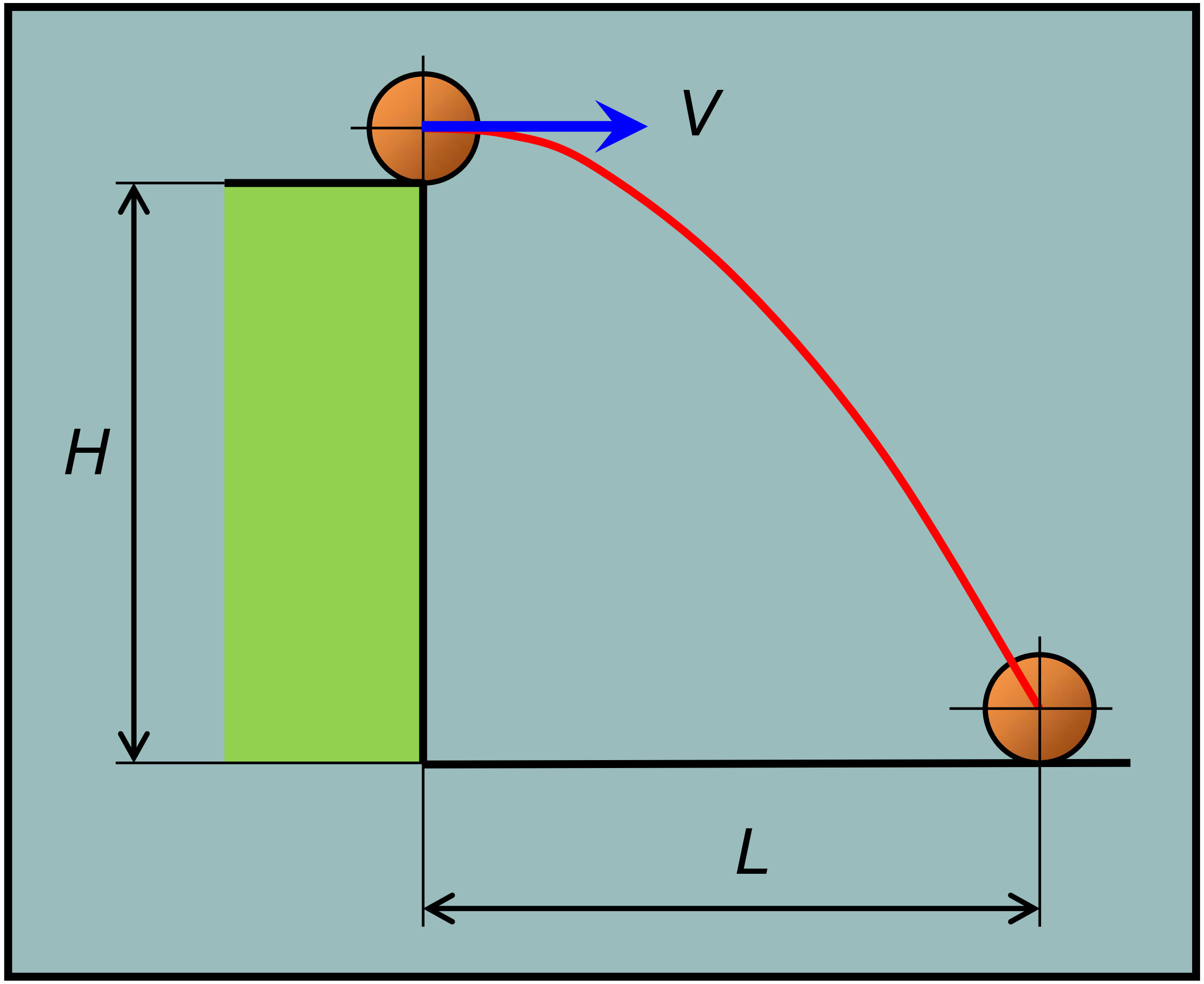


The velocity of the ball and the impact parameter defined using a slide.

The field of artificial grass, the hole and rails

Coefficient of sliding friction = 0.3
Coefficient of restitution = 0.2

Calibration of the slide



Velocity of the ball

$$V = L\sqrt{\frac{g}{2H}}$$

under the condition

$$V \geq \sqrt{gr} =$$
$$= 31 \text{ cm/s}$$

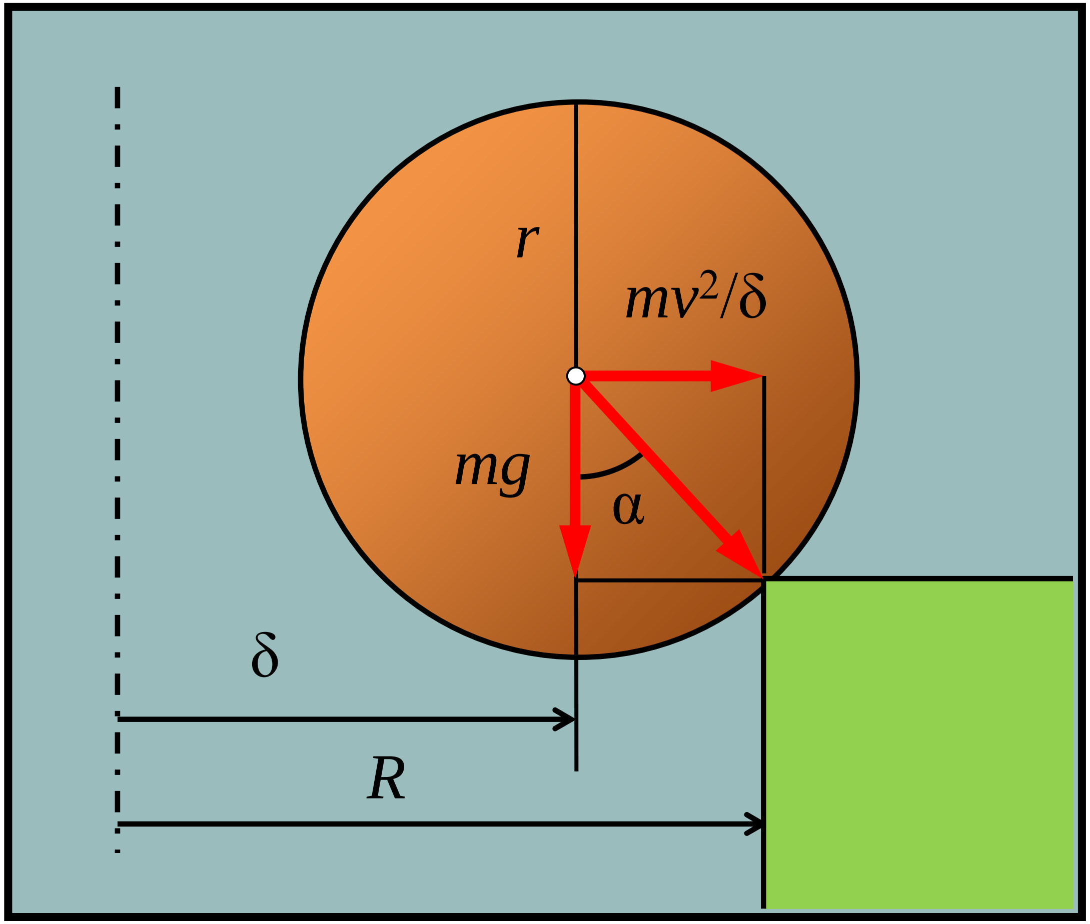
Centre impact (480 fps)

This regime was studied in “Interactive physics”

Off-centre impact (480 fps)

For this regime a simple model could be created

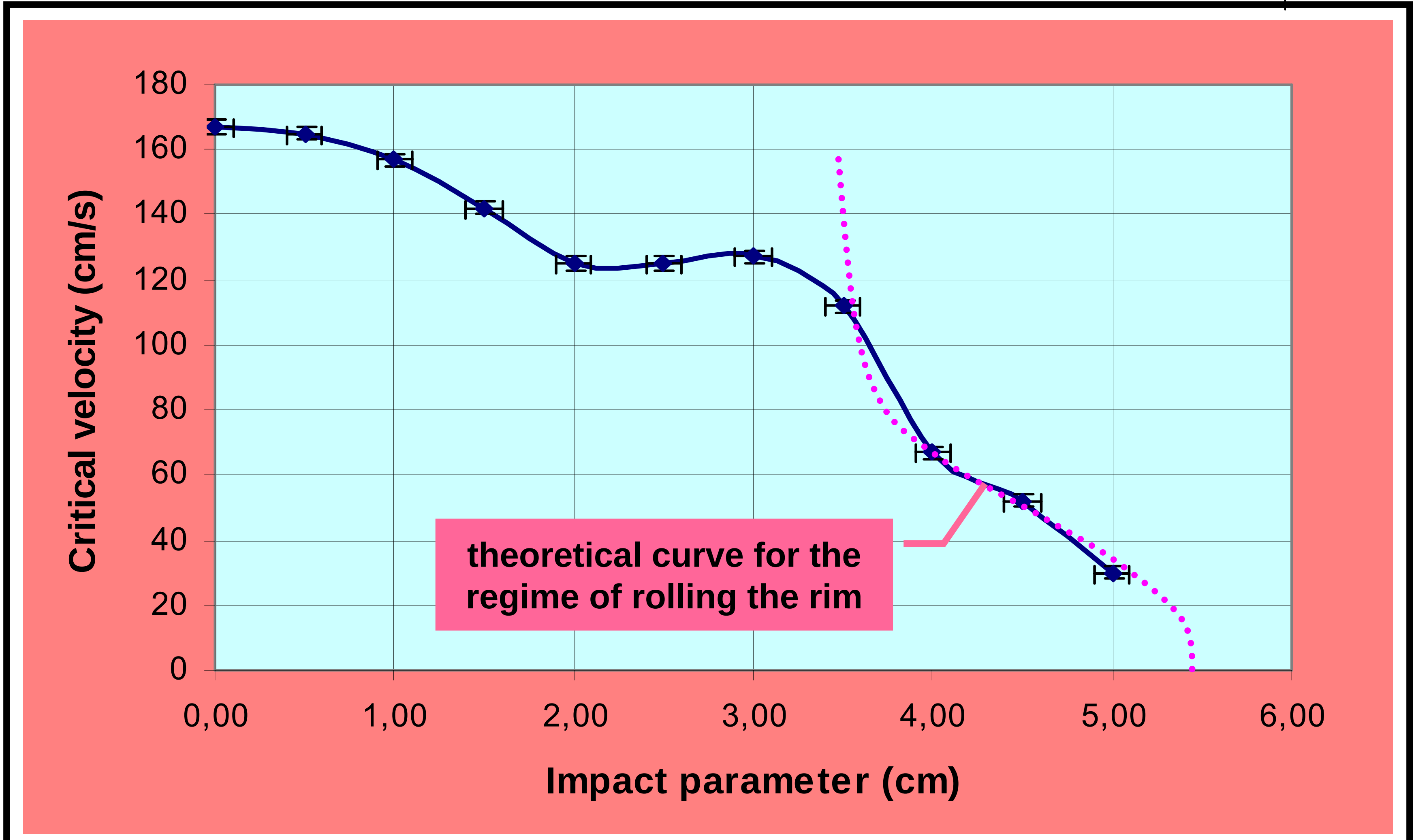
The ball rolls on the rim



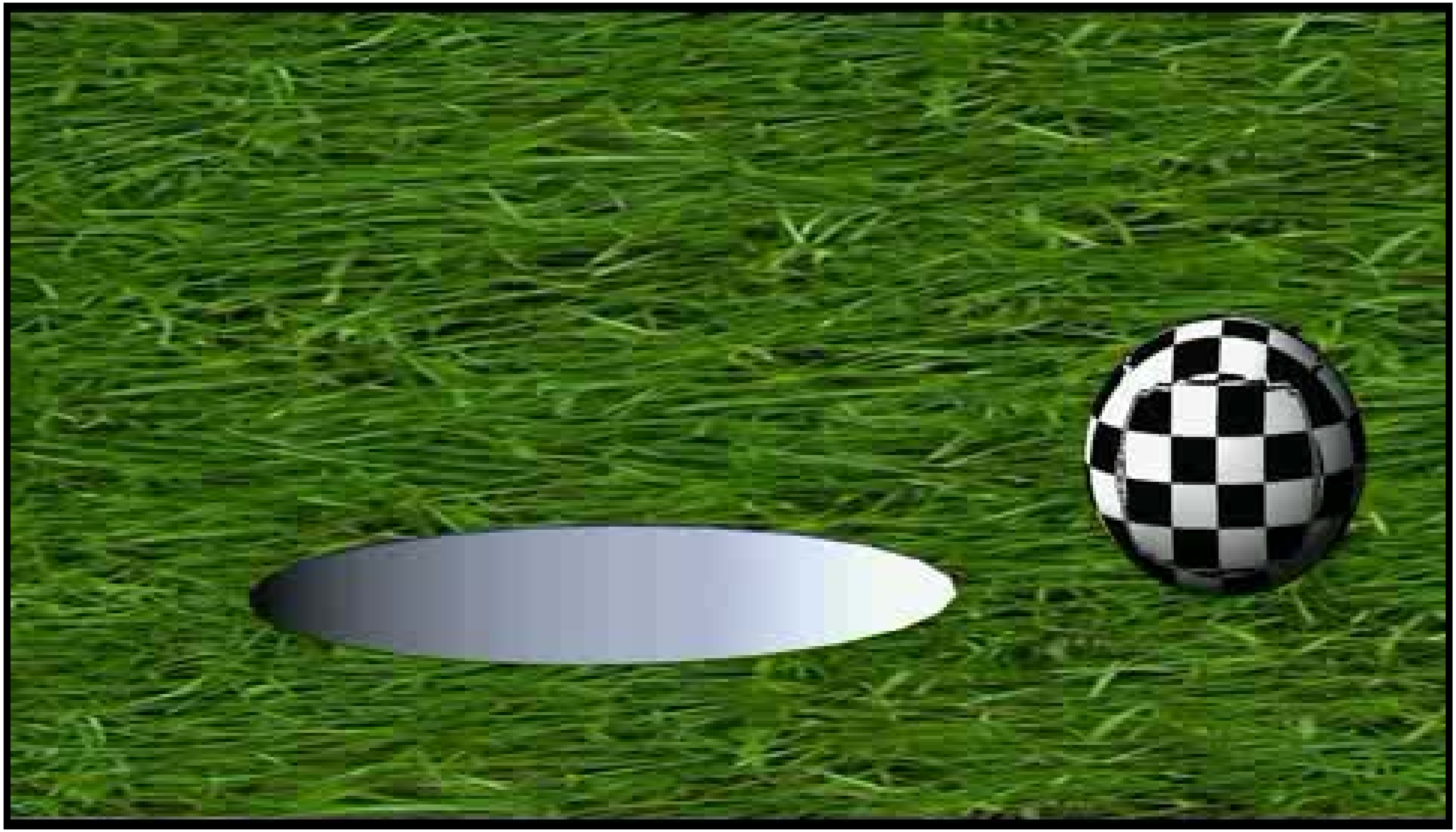
$$\frac{v^2}{\delta} = g \cdot \mathrm{tg}\,\alpha$$

$$v^2 = \frac{g\delta}{\sqrt{\left(\frac{r}{R-\delta}\right)^2 - 1}}$$

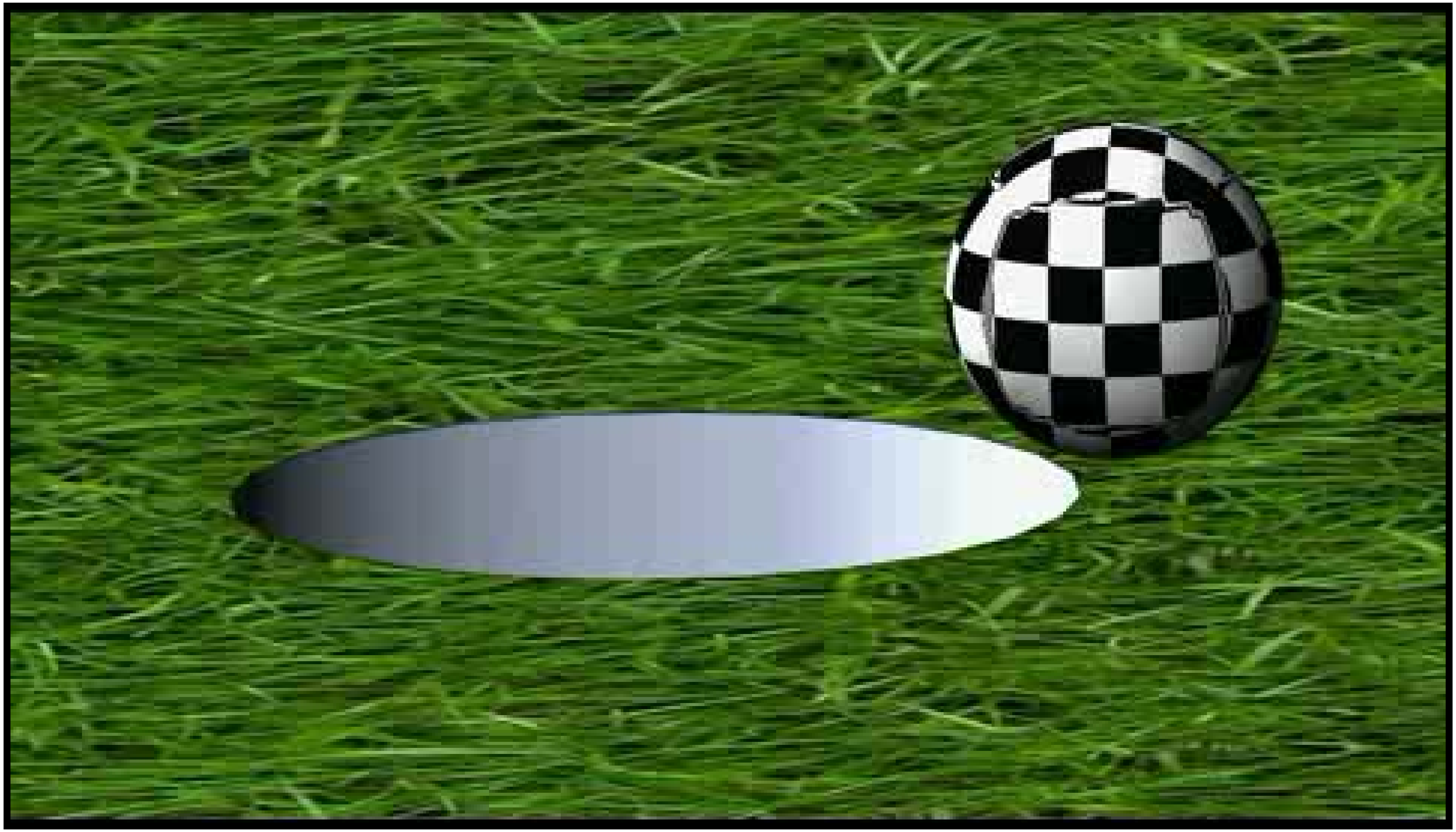
Experimental boundary of the capture region



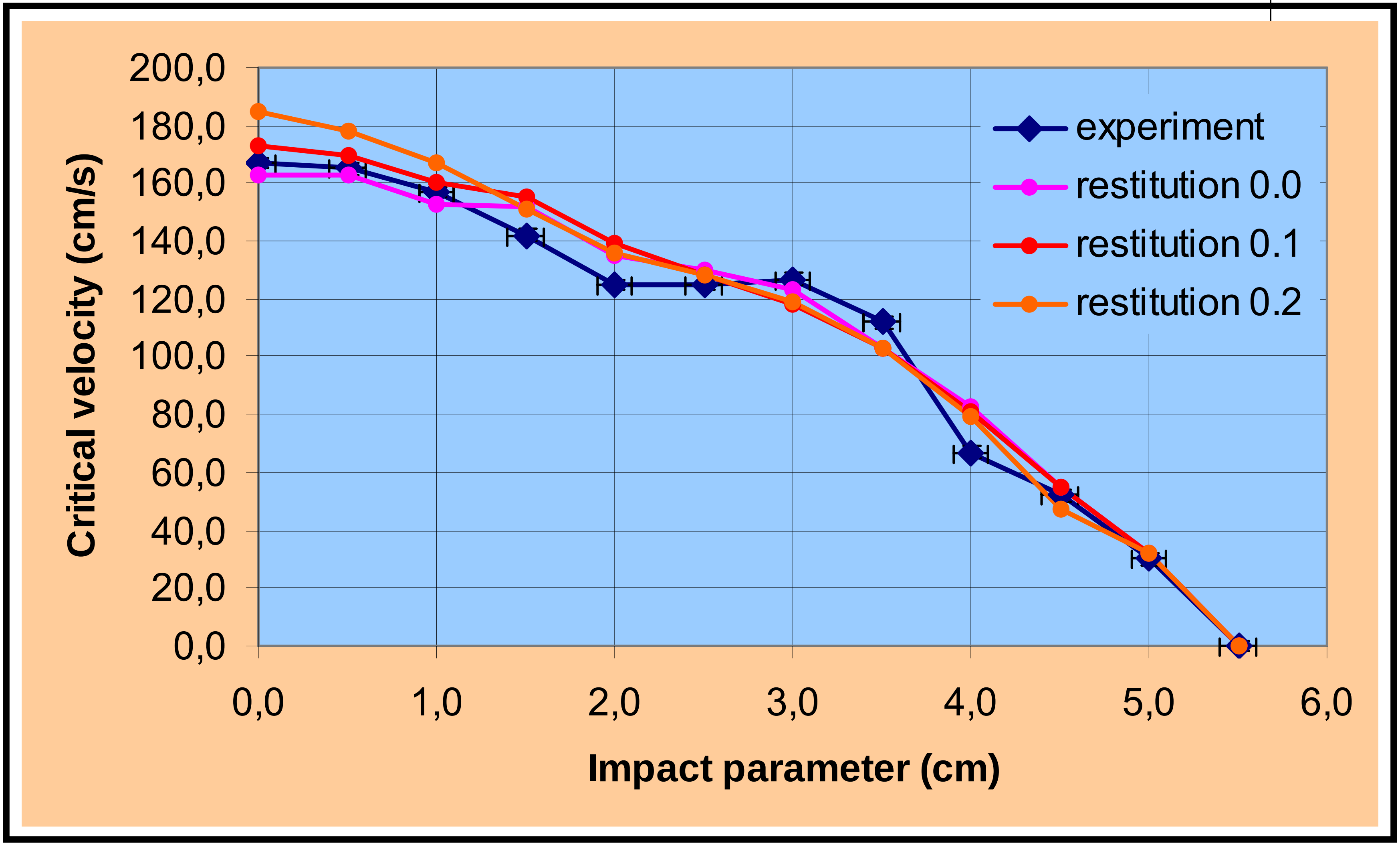
Centre impact (Solid Works)



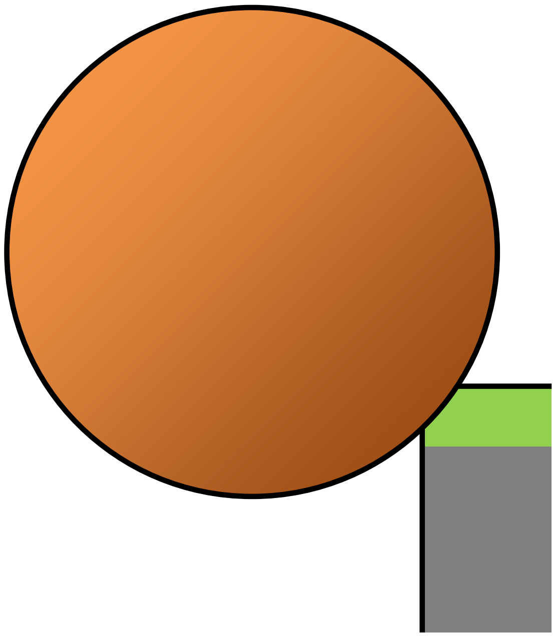
Off-centre impact (Solid Works)

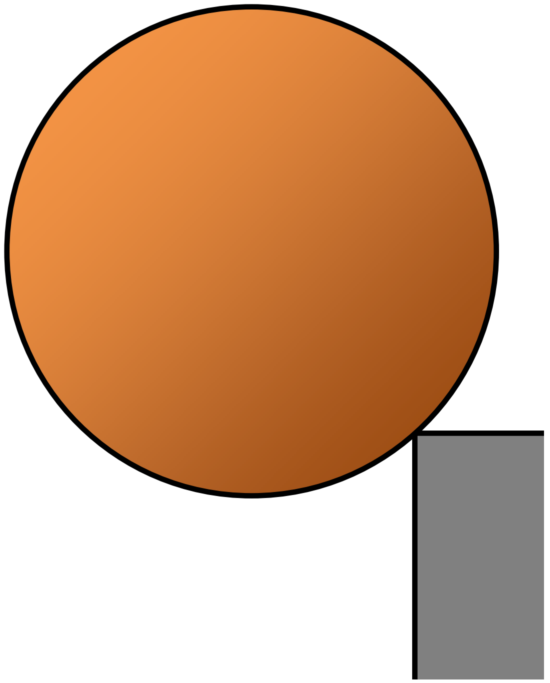


Results of “Solid Works” computer simulation



Real experiment and computer simulation





Real experiment:
the edge is **soft**

Computer simulation:
the edge is **rigid**

Summary

- Characteristic velocity
- 2-D simulation in “Interactive Physics”
- Experimental setup
- Boundary of the capture region
- Regimes of an impact
- Model for the rolling regime
- 3-D simulation in “Solid Works”

Bibliography

- Holmes B. W. (1991) “Putting: how a golf ball and hole interact”. *American Journal of Physics*, **59**, 129–136
- Penner A. R. (2002) “The physics of putting”. *Canadian Journal of Physics*, **80**, 1–14