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IYPT
International Young Physicists' Tournament

14. Ball on Membrane

When dropping a metal ball on a rubber membrane stretched over a plastic cup, a sound can be heard. Explain the origin of this sound and explore how its characteristics depend on relevant parameters.

14. Gulička na membráne

Keď pustíte kovovú guličku na gumenú membránu natiahnutú na plastový pohár, môžete počuť špecifický zvuk. Vysvetlite pôvod tohto zvuku a preskúmajte, ako zvuk závisí od relevantných parametrov.

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dropping

metal ball

rubber membrane

stretched

over a plastic cup

sound

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explain

origin of sound

explore

how its characteristics

depend

on relevant parameters

14. Ball on Membrane

How does it work?

- ball bouncing
- rubber membrane vibrates
- forced vibration
- compresion of air column in cup
- membrane and cup as acoustic resonators

14. Ball on Membrane

Basic physics

Bouncing ball (hard surface)

- free fall from initial height
- boncing from hard surface
- coefficient of restitution, *e*
- t_i time between impacts
- impact time neglected

$$mgh_0 = \frac{1}{2}mv^2$$

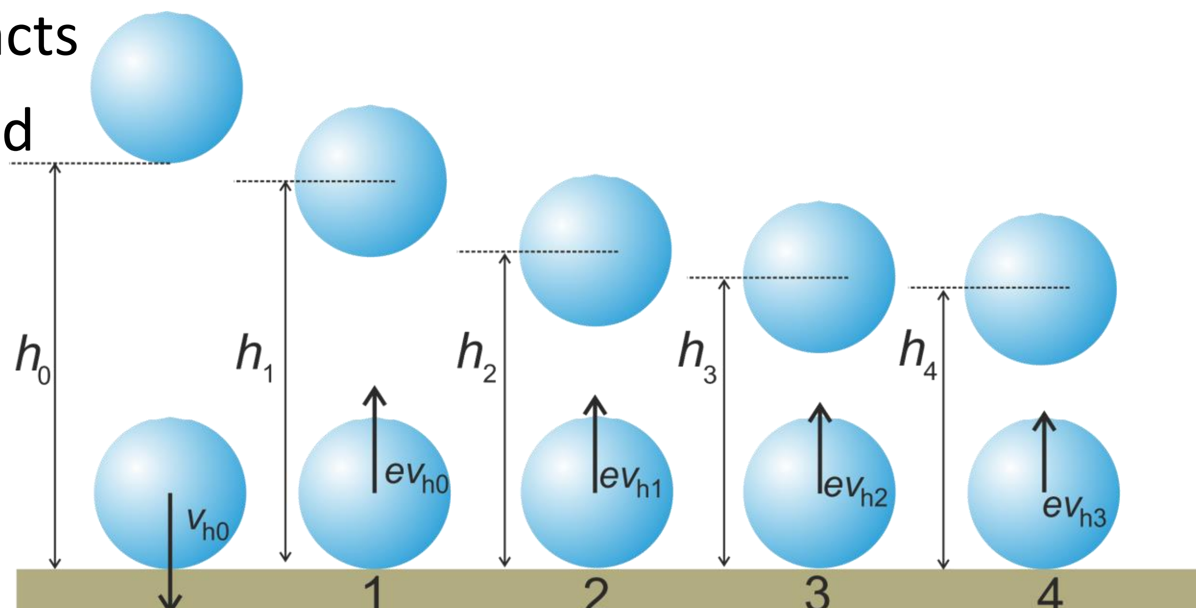
$$v_{h0} = \sqrt{2gh_0}$$

$$t_{h0} = \sqrt{\frac{2h_0}{g}}$$

$$e = -\frac{\boldsymbol{v}_i}{\boldsymbol{v}_{hi-1}}$$

$$v_i = ev_{hi-1}$$

$$t_i = \frac{2ev_{hi-1}}{g}$$



14. Ball on Membrane

Basic physics

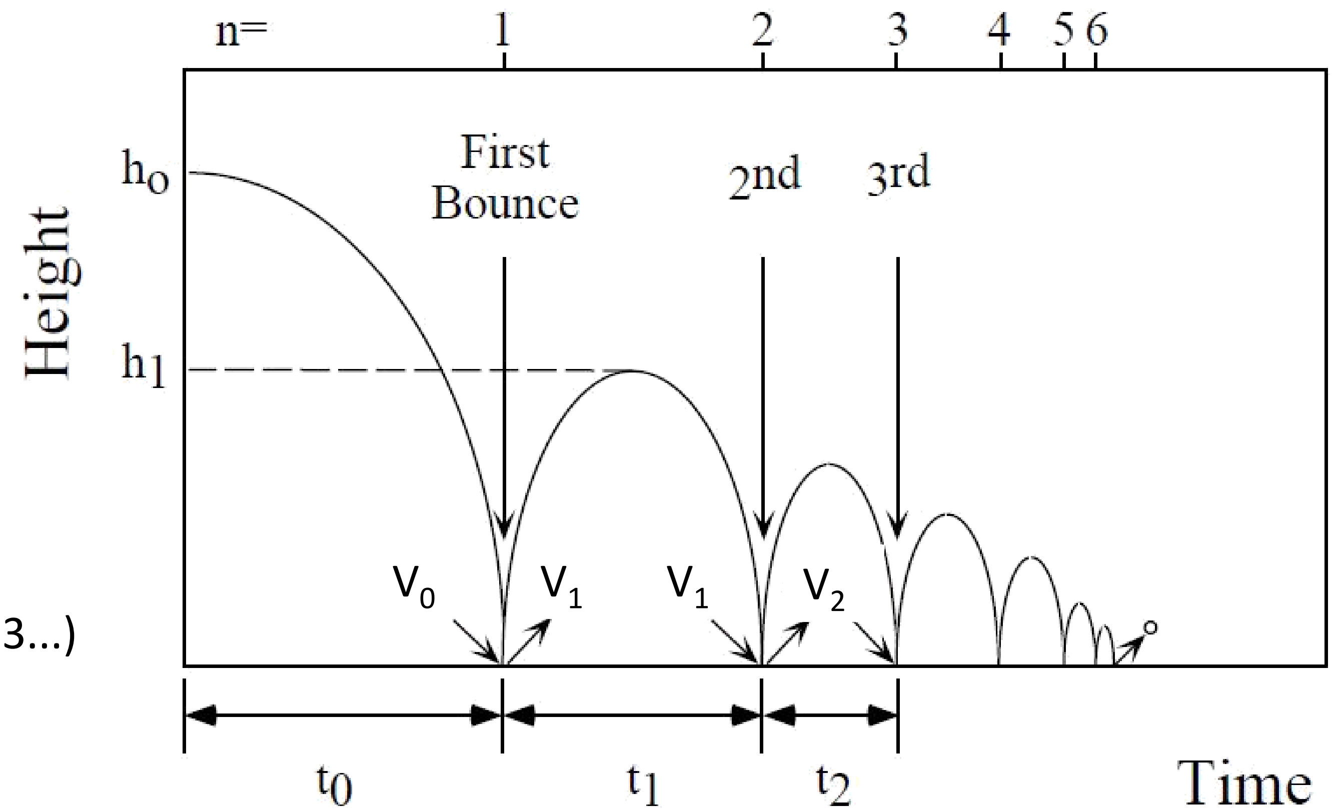
Bouncing ball

$$e < 1$$

$$v_n = \frac{1}{2} g t_n$$

$$v_n = e v_{n-1} = e^n v_0$$

$$t_n = e^n \left(\frac{2v_0}{g}\right) \text{ (n=1,2,3...)}$$



e = constant

motion will cancel after infinite number of bounces

Falcon, E., Laroche, C., Fauve, S. *et al.* Behavior of one inelastic ball bouncing repeatedly off the ground. *Eur. Phys. J. B* **3,** 45–57 (1998). https://doi.org/10.1007/s100510050283

14. Ball on Membrane

Basic physics

Bouncing ball and vibrating surface

- velocity of the ball before u_n^- and after u_n^+ collision
- velocity of the plate v_n at time t_n

$$u_n^+ - v_n = -e(u_n^- - v_n)$$

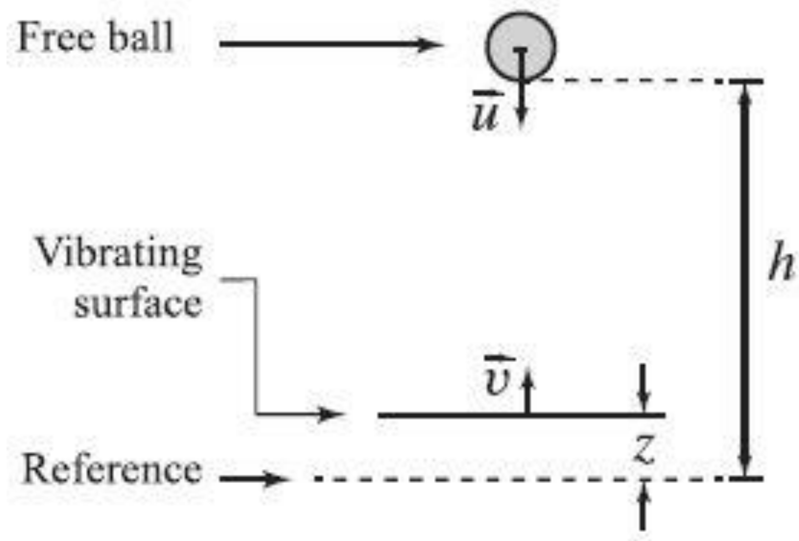
$$h(t) = h_n + u_n^+(t - t_n) - \frac{g}{2}(t - t_n)^2$$

- time of the next collision t_{n+1} when

$$h_{n+1} = z_{n+1} \equiv z(t_{n+1})$$

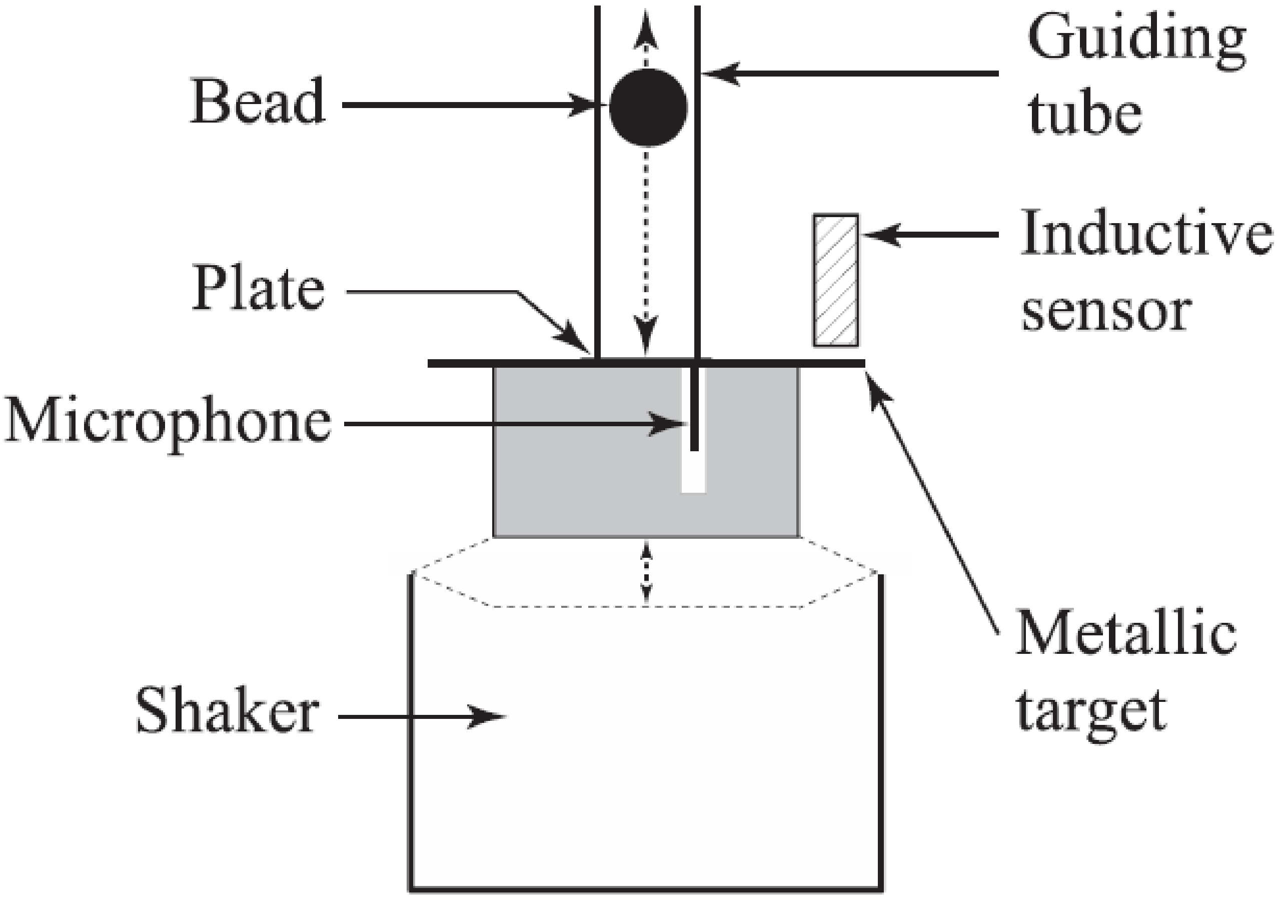
velocity of the ball before collision:

$$u_{n+1}^- = u_n^+ - g(t_{n+1} - t_n)$$



Chastaing, Jean-Yonnel & Bertin, E. & Geminard, Jean-Christophe. (2015). Dynamics of a bouncing ball. American Journal of Physics. 83. 518-524. https://doi.org/10.1119/1.4906418.

14. Ball on Membrane



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14. Ball on Membrane

„Relevant“ parameters for sound characteristic

membrane

- tension
- size of the surface
- stickness
- material

metal ball

- radius
- mass

cup

- volume

14. Ball on Membrane

Possible approaches to the task

1. Visualization of membrane movement
   (e.g.by high speed camera, strobe)
2. Observe the rubber membrane, standing waves, Chladni figures.
   (forced oscillation by loudspeaker)
3. Bouncing ball in different part of membrane.
   (due to standing waves)
4. Recording of sound and sound analysis.
   (e.g. by Audio Spectrum Analyzer Soft.)
5. Sound characteristics
   (basic and higher frequencies)
6. Plastic cup as an acoustic resonator
   (make a hole - open end)