24th International Young Physicists' Tournament

Team of Belarus

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Ministry of Education Republic of Belarus

Kayson Belarus

Reporter:
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№10

Formulation of the problem: FARADAY HEAPING

When a container filled with small spheres (e.g. mustard seeds) is vibrated vertically with a frequency between 1 – 10 Hz, so called Faraday heaping occurs. Explore this phenomenon.

Demonstration

Steps of solution the problem:

I. Explanation of the phenomenon

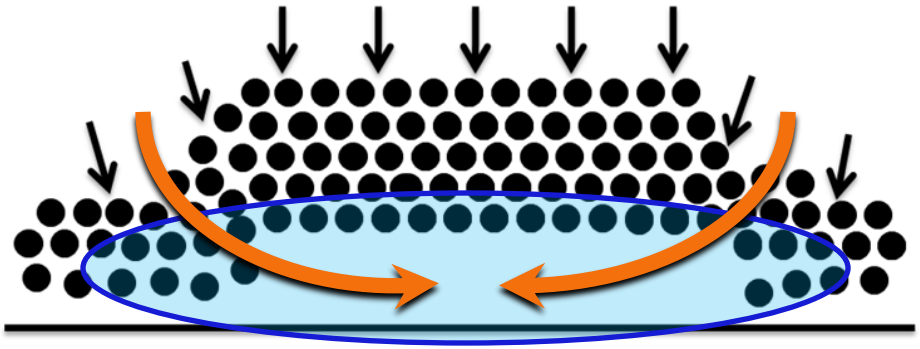
II. Experimental investigation

III. Theoretical model

I. Explanation of the phenomenon

One cycle of heap forming

1



$\vec{a};$

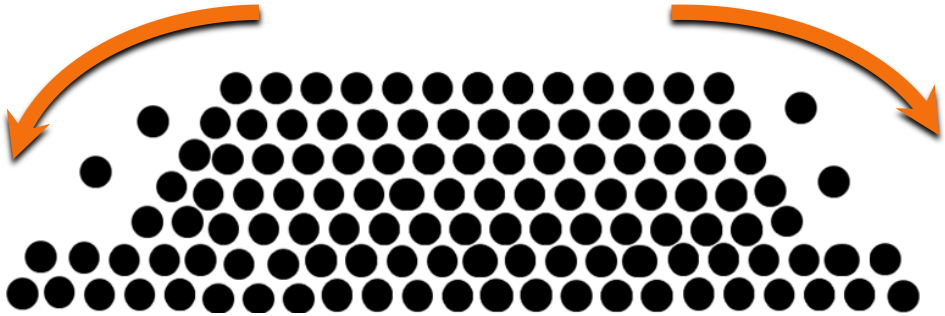
$a > g$

Reasons of particle horizontal motion

Air flows

Static pressure differences

2



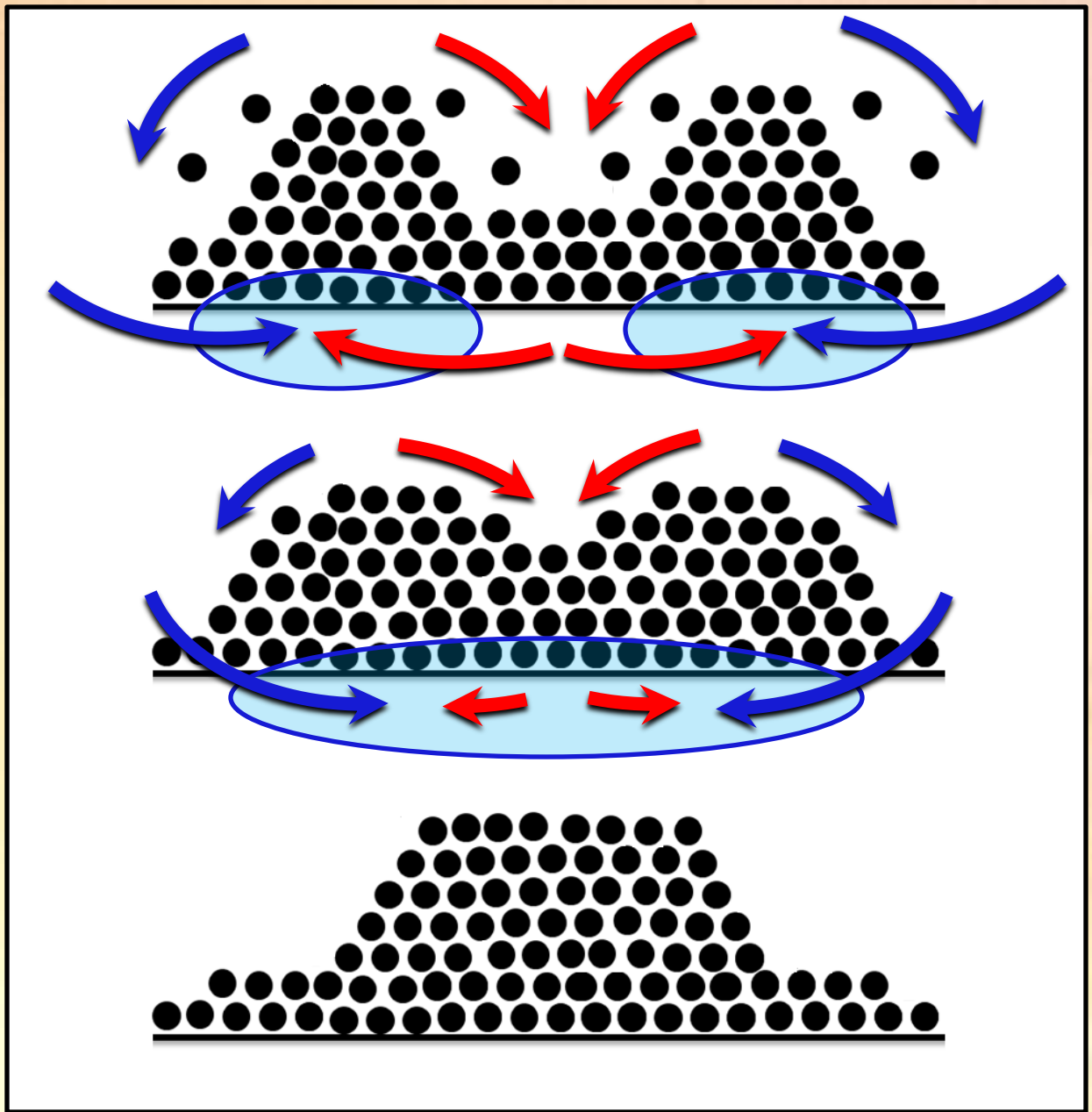
$\vec{a}$

Heaps merging

1

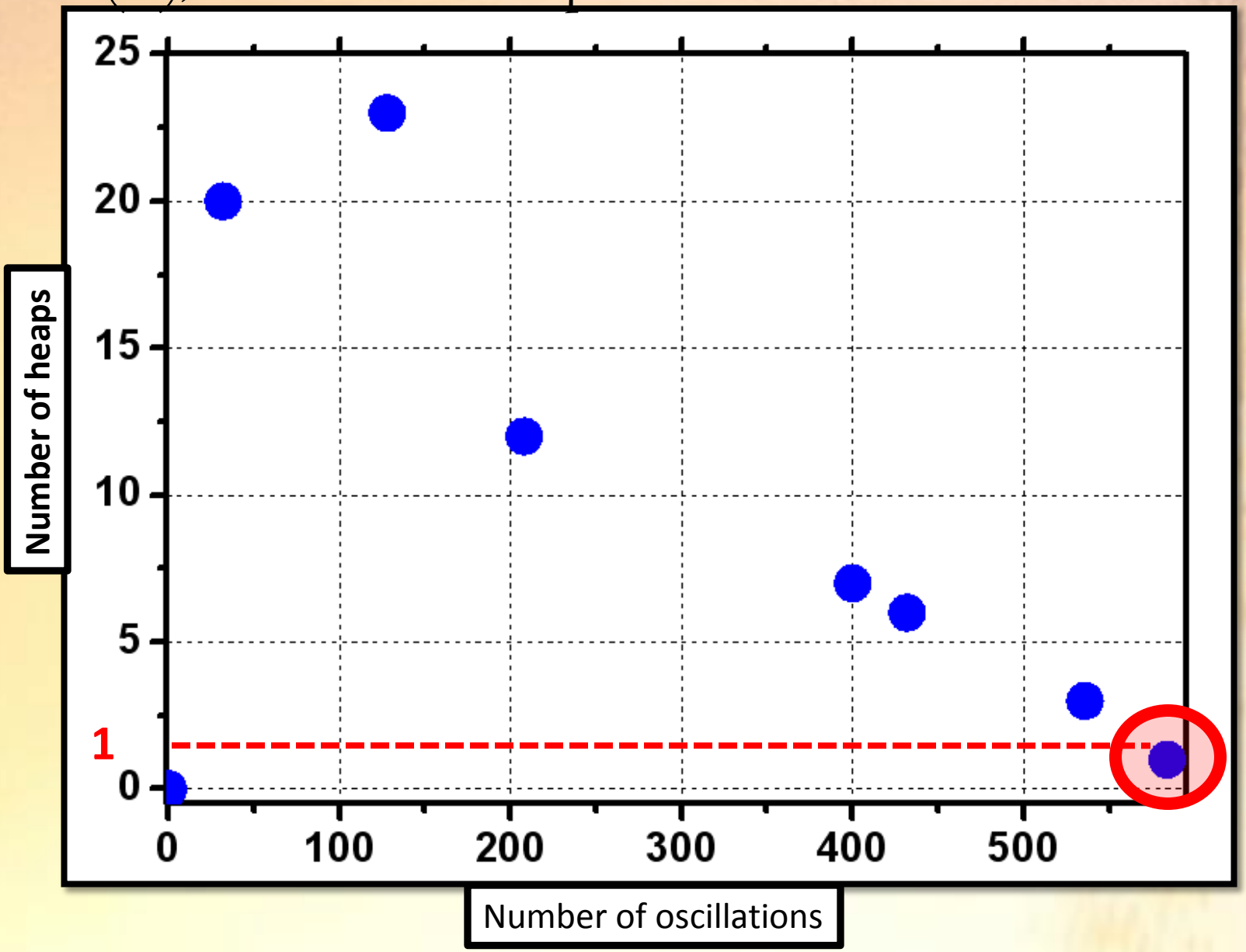
2

3

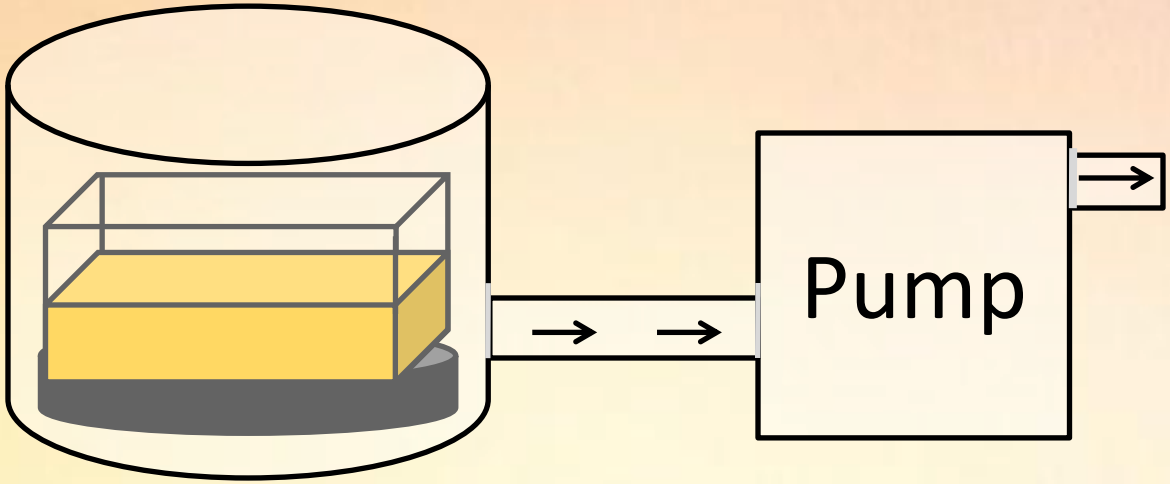


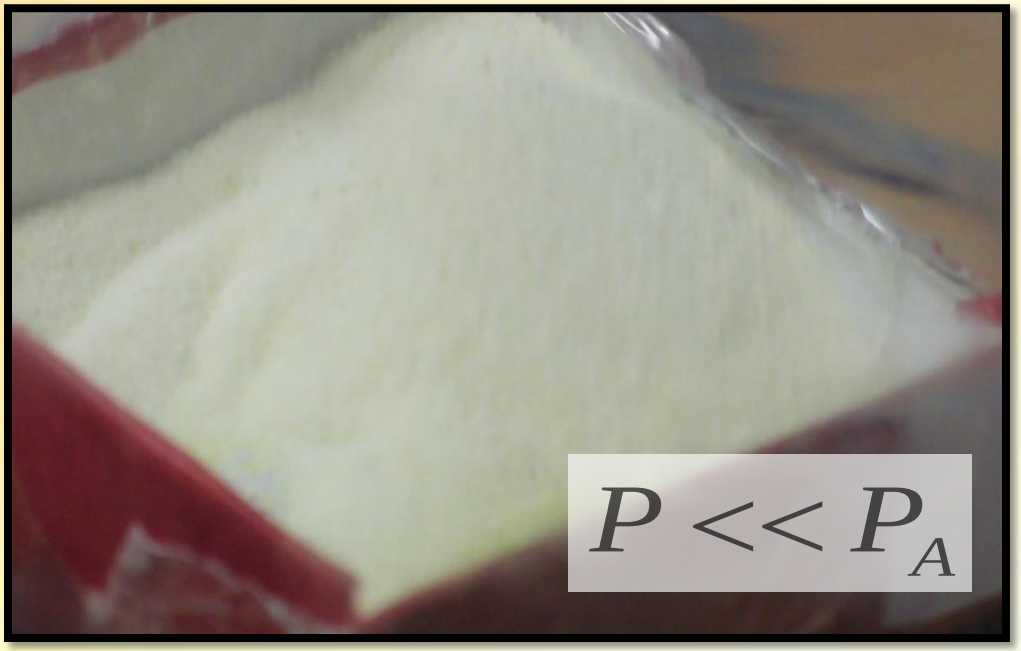
Evolution of Faraday Heaping

N(n), number of heaps Vs number of oscillations



Air influence





Conclusions of the first part

1. Air flows and static pressure differences are main reasons for heap forming

2. Particles circulation is observed in stationary heaps

3. After some time initial small heaps tend to merge into one big heap

4. Air is the key factor for heap forming

II. Experimental investigation

EXPERIMENTAL SETUP

Vessel

Subwoofer

Amplifier

Parameters of setup:

Input signal: **sine**

$$\nu \in (1;50)Hz$$

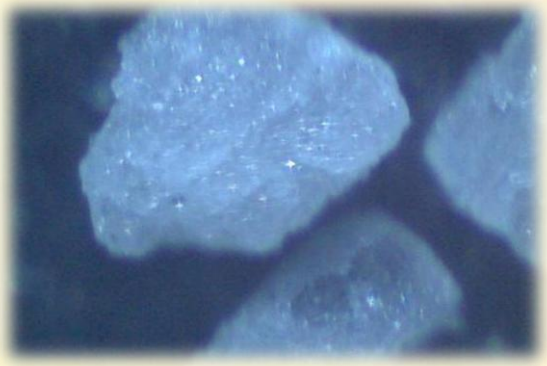
$$A_{\max} = 7mm$$

Particles used

Particle parameters

1. Shape
2. Dimension
3. Density
4. Elastic properties
5. Friction

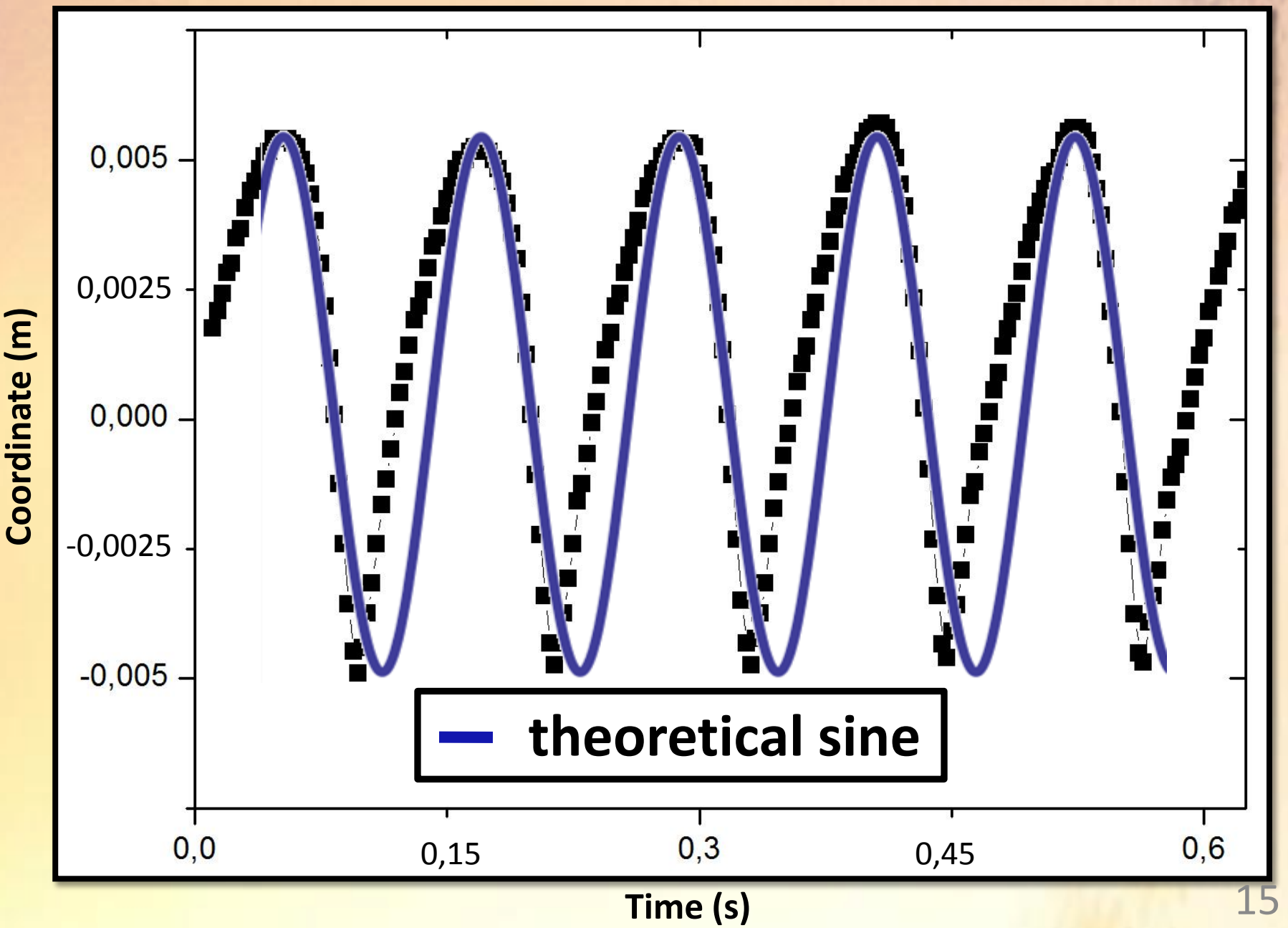
Sand
D≈0.2 mm



Semolina
D≈0.6 mm

Millet
D≈2.0 mm

Motion law of the vessel **ν=8 Hz**



Harmonic oscillations

(1) $x = A\sin(\omega t)$

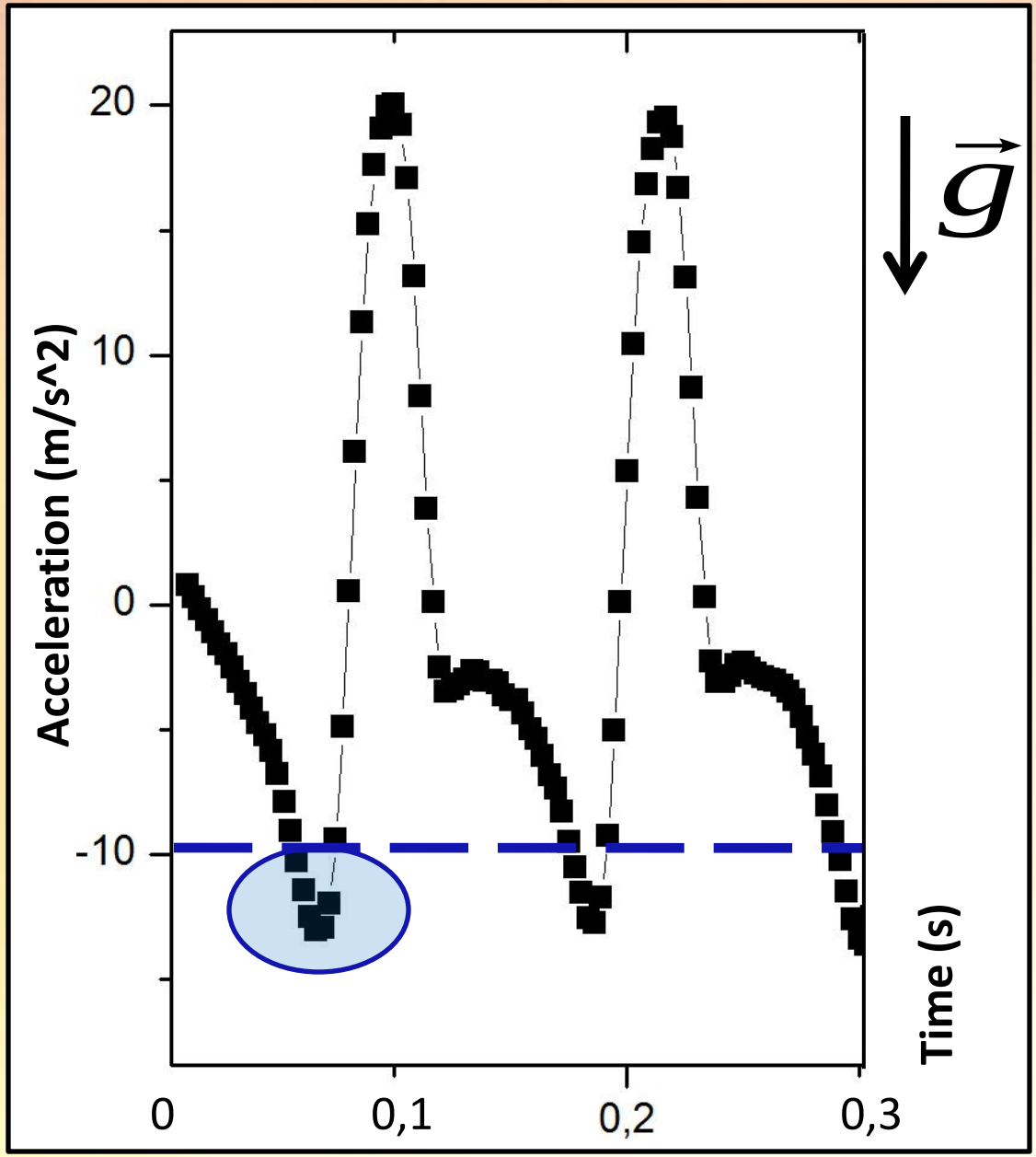
(2) $x'' = -A\omega^2 \sin(\omega t)$

(3) $\boxed{A\omega^2 > g}$ **- condition of particles separation**

(4) $\boxed{A \leq 7mm}$ **- limitation of experimental setup**

(5) $\boxed{\nu \geq 6Hz}$ **- theoretical frequency for observing phenomenon with amplitude of 7 mm**

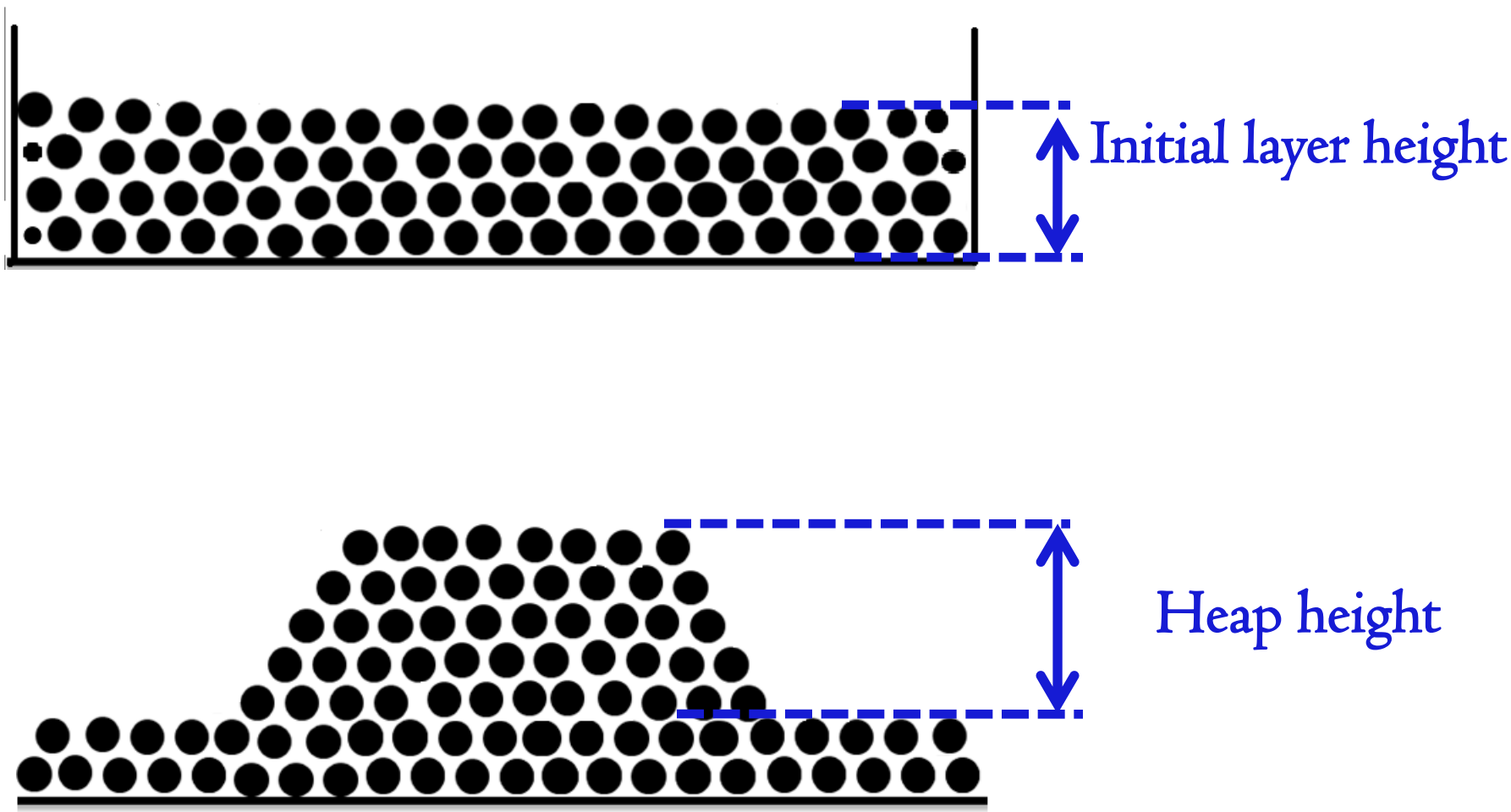
The acceleration of vessel Vs time



Time of separation

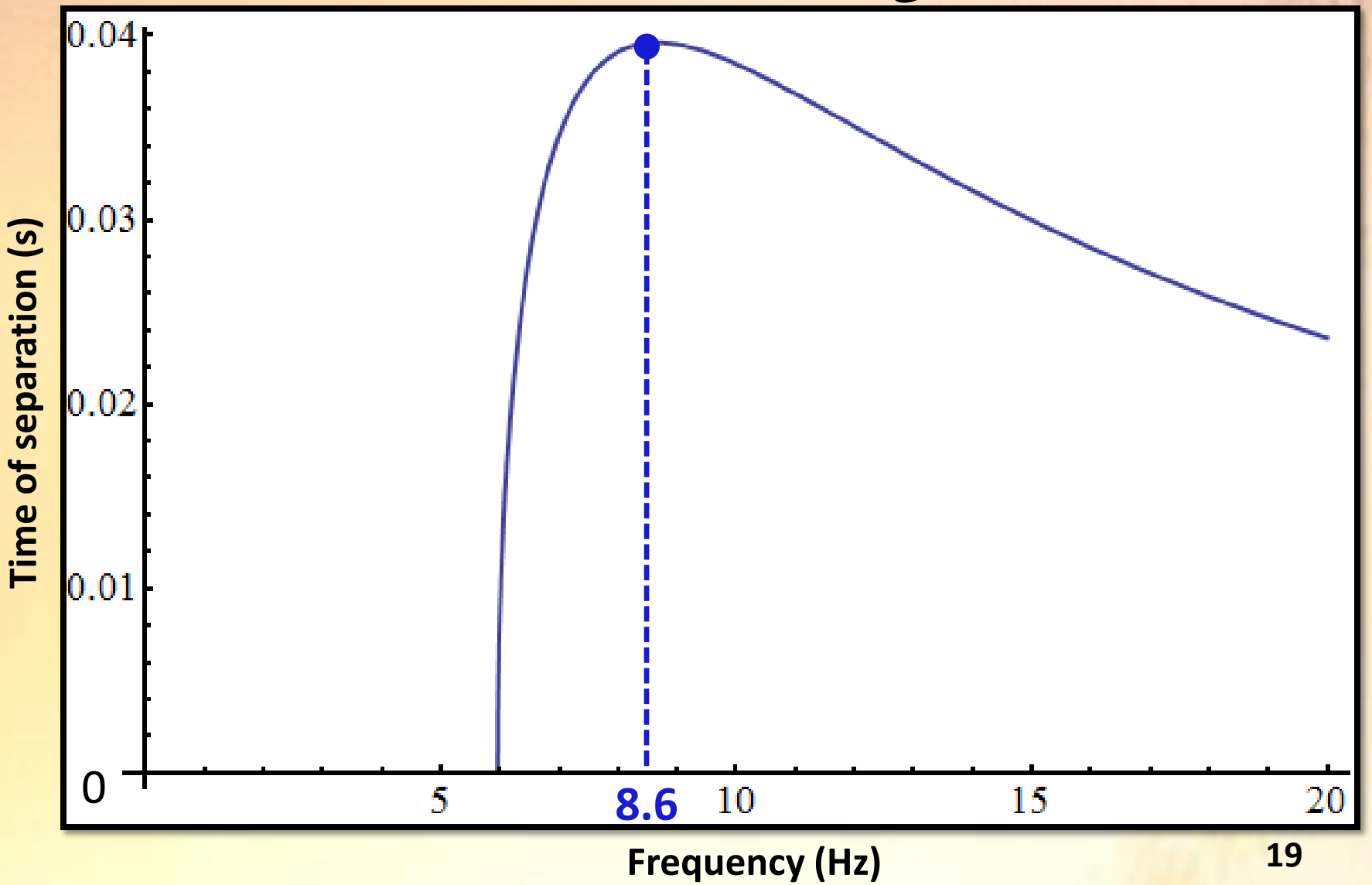
$$t_{sep} \approx 10^{-3}\ s \quad \textbf{(6)}$$

H(h) height of heap Vs initial layer height

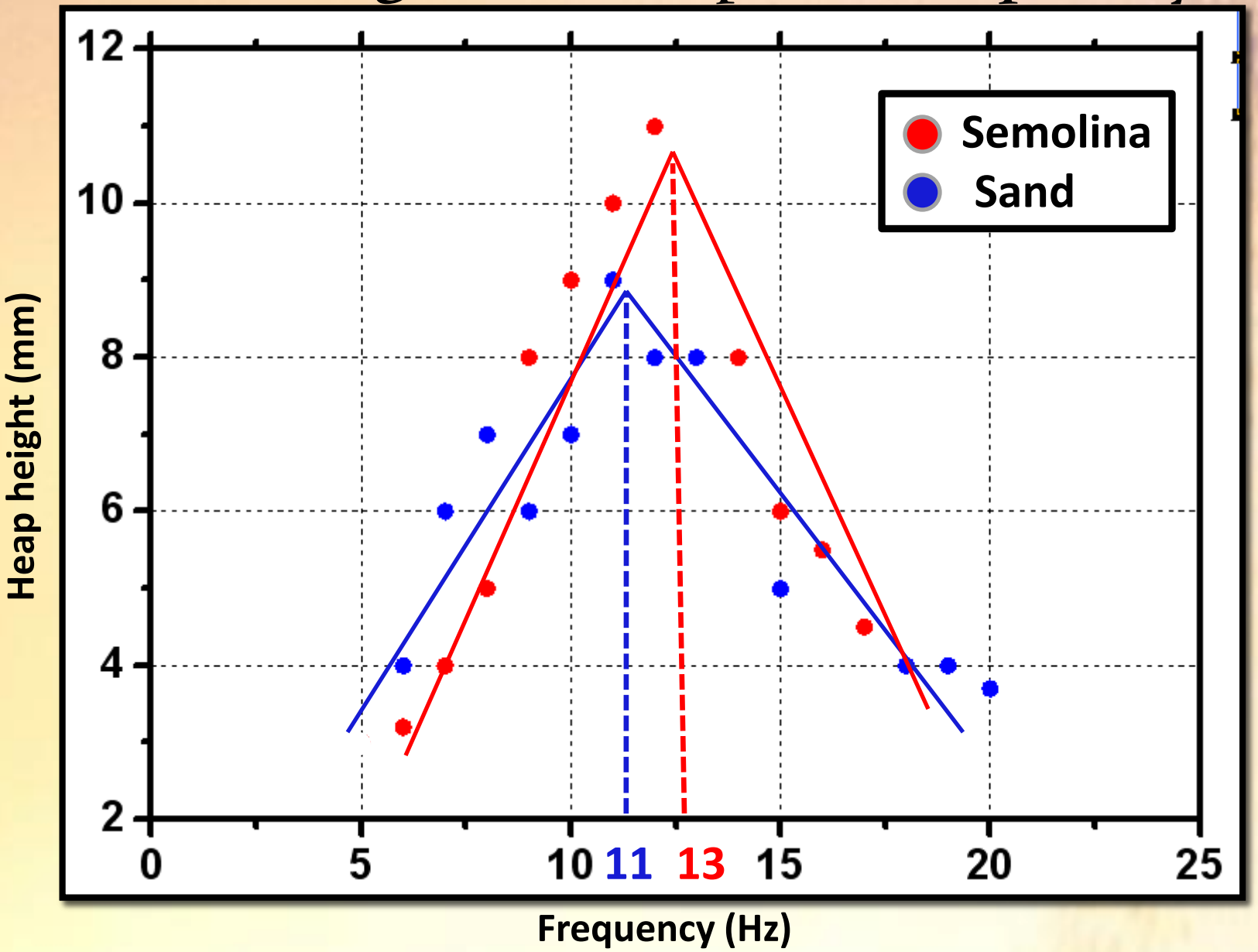


Initial layer height (mm)

$t(\nu)$, time of separation Vs frequency for ideal sine signal



$h(\nu)$, height of heap Vs frequency



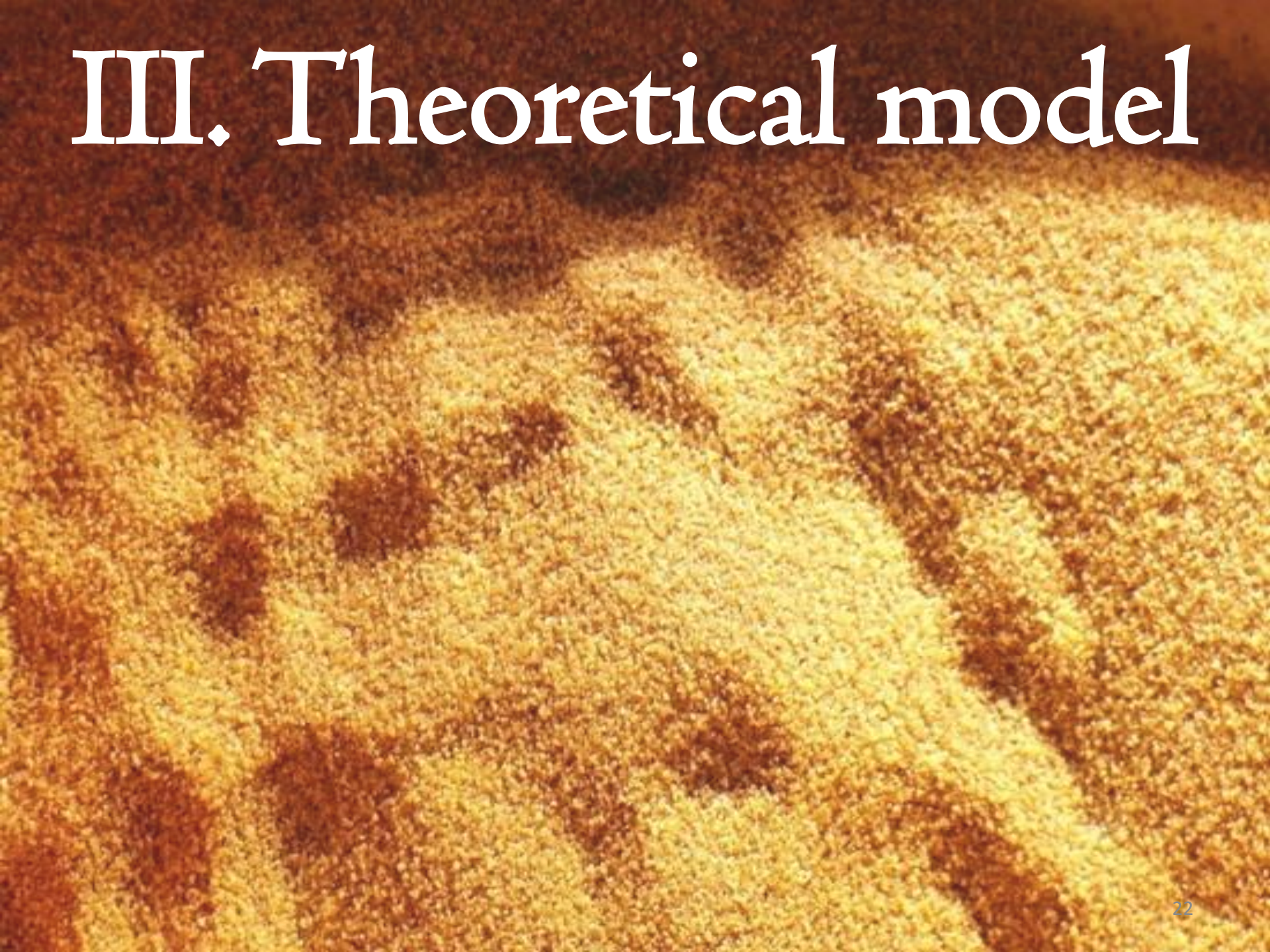
Conclusions for the second part

1. Critical parameter for heap formation is time of separation

2. The certain optimal frequency exists for highest heaps formation

3. With increasing the initial height of layer maximum heap height tends to some constant value.

III. Theoretical model



Model assumptions

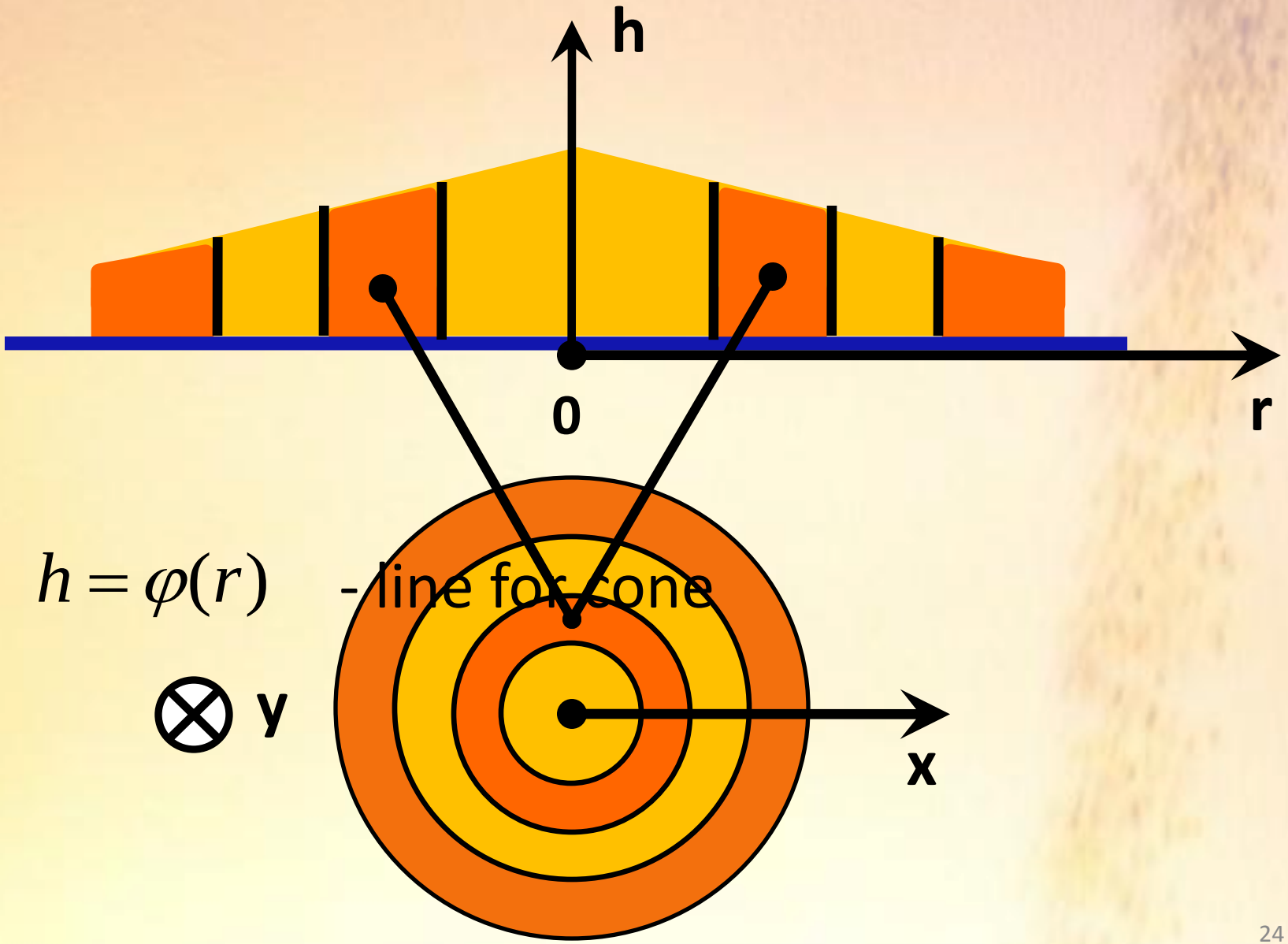
1. All sand movement is caused by unequal distribution of static air pressure.

2. The effect of directed air flows dragging particles is negligible.

3. Heap incline is limited by a certain critical angle attributed to particle type, rolling down intensity per unit area is constant.

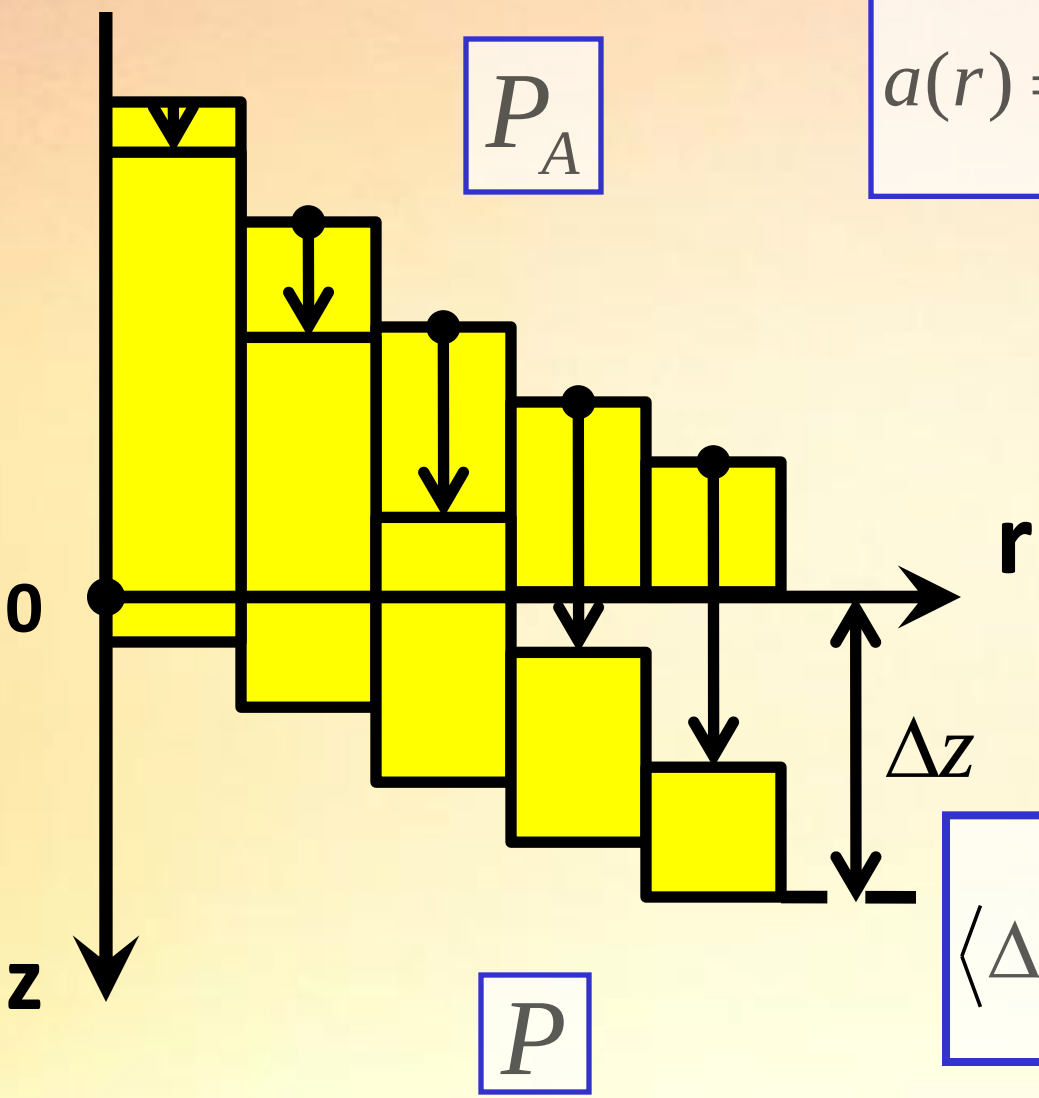
Structure of shear profile

Initial shape of shear profile



(7) $h = \varphi(r)$ - line for cone

Vertical displacement of elements



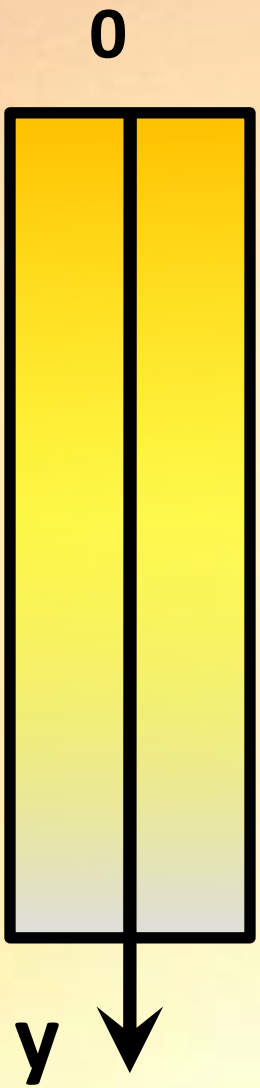
$$a(r) = \frac{(P_A - P)}{h(r)\rho} \approx 10^4\ m/s^2 \quad \textbf{(8)}$$

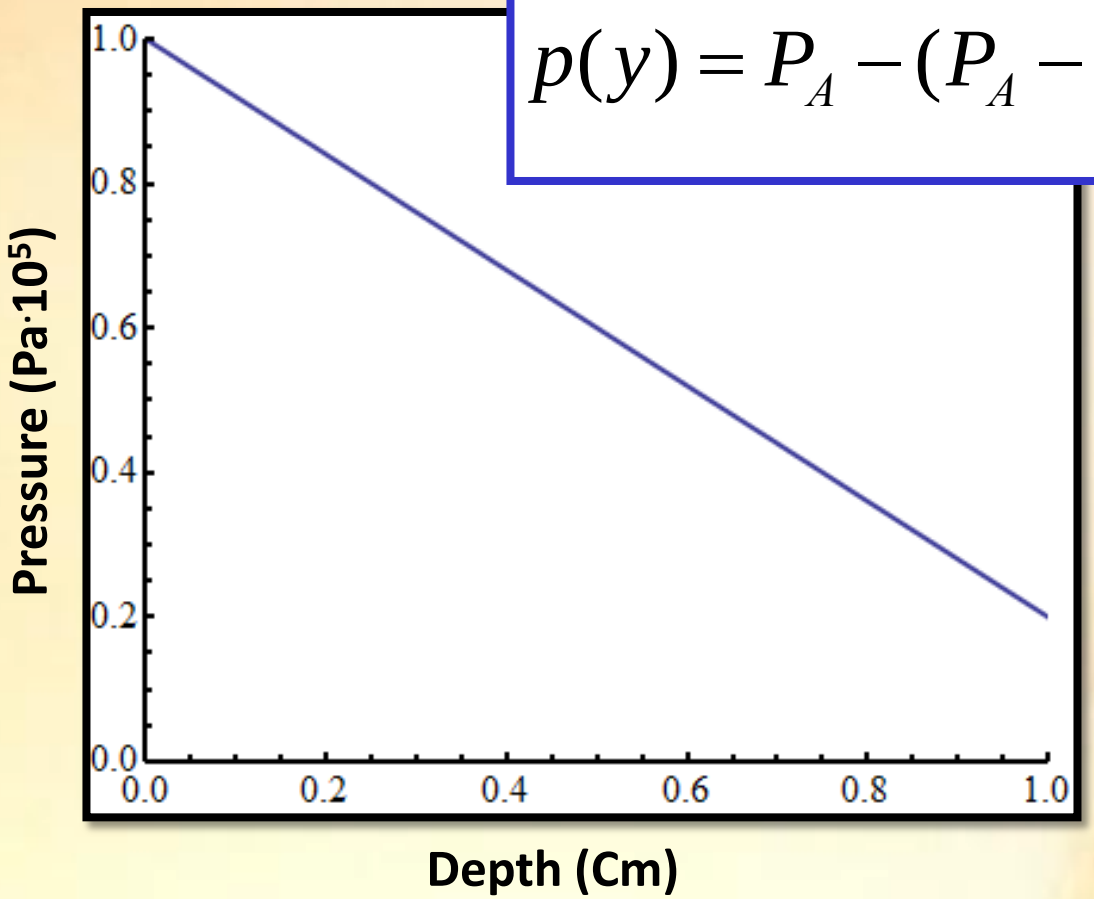
Vertical acceleration of each element

Average vertical displacement

$$\langle \Delta z_r \rangle = \frac{a t_{sep}^{\ 2}}{2} \approx 10^{-2}\ m \quad \textbf{(9)}$$

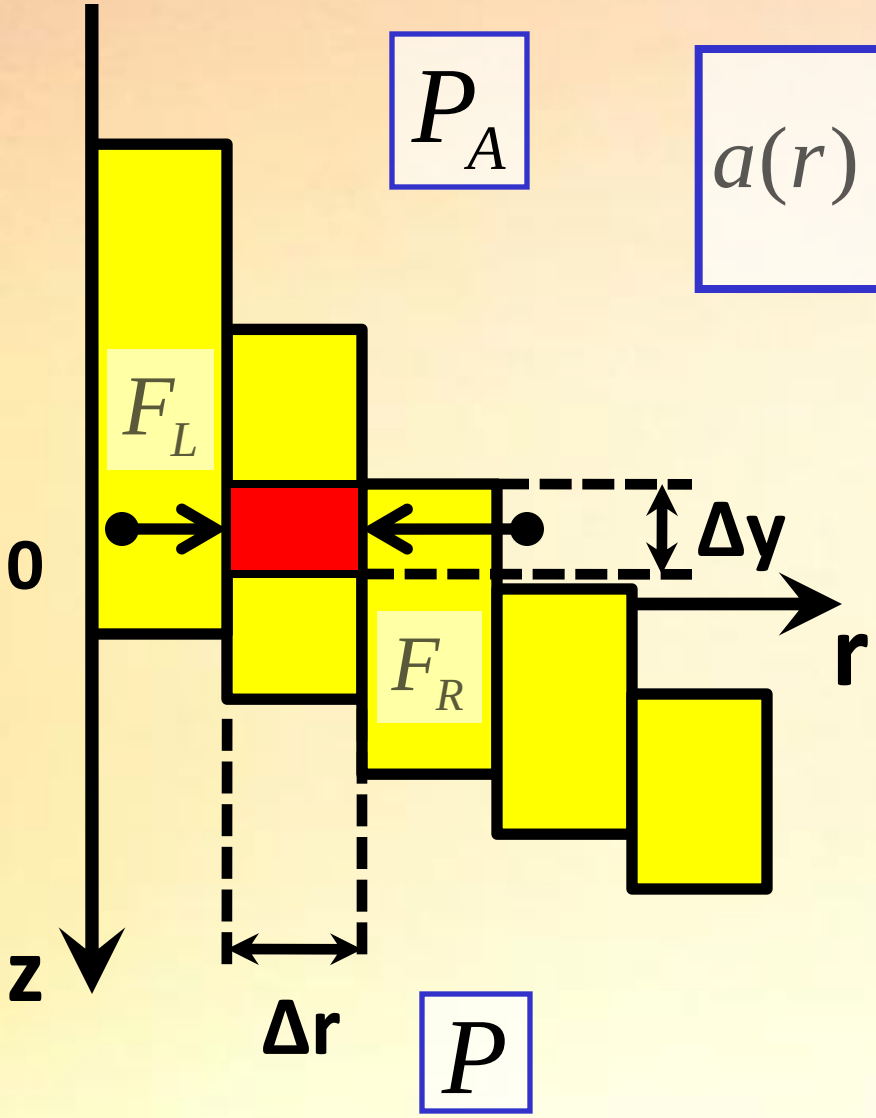
Pressure distribution in particles layer





$$p(y) = P_A - (P_A - P)\frac{y}{h(r)} \quad (10)$$

Motion of elements

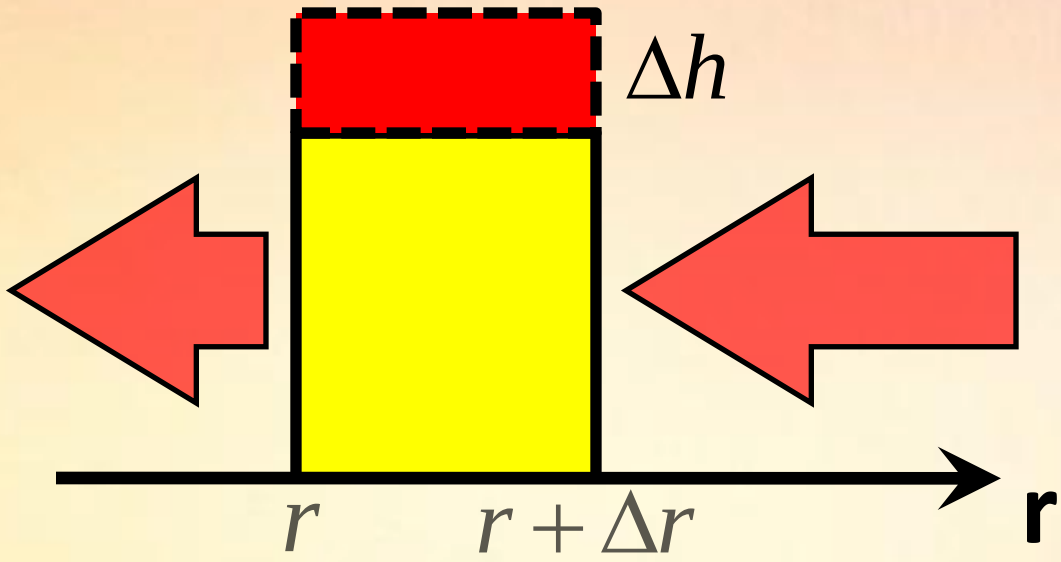


$$a(r) = \frac{F_R - F_L}{m} \sim \frac{\Delta P}{\rho}(\Delta z)'_r \quad \textbf{(11)}$$

$$a(r) \sim \frac{\Delta P^2}{\rho^2} t^2 \quad \textbf{(12)}$$

$$v(r) \sim \frac{\Delta P^2}{\rho^2} t^3 \quad \textbf{(13)}$$

Growing of cylinder

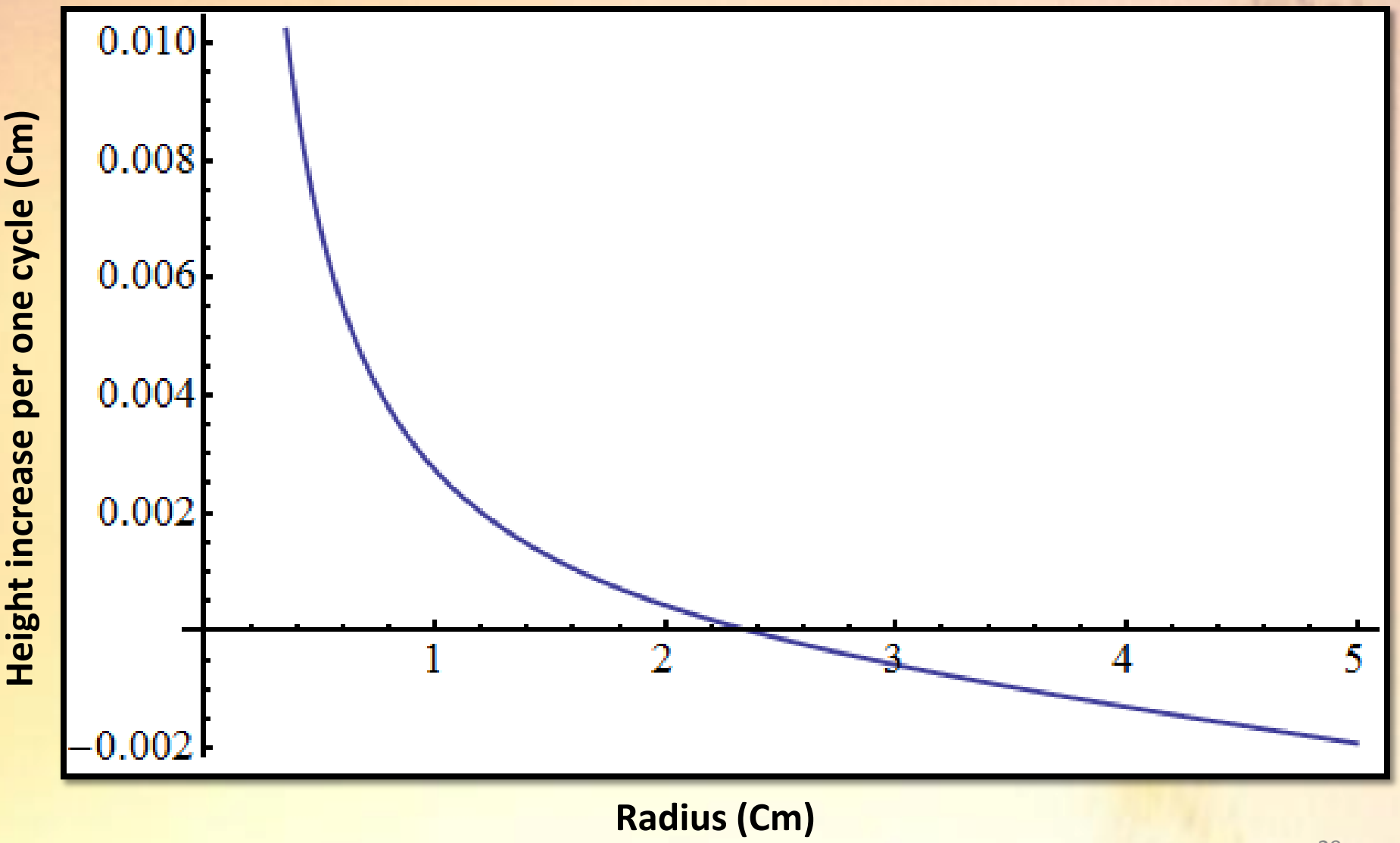


(15) $$\Delta h_{cycle}(r) = \frac{\Delta P^2}{\rho^2} t_{sep}{}^4 f(r)$$

ρ **-substance density**

t_{sep} **- separation time**

Heap increase per one cycle Vs radius



Model calculation

Iteration number: 0

Key conclusions

1. Low pressure zone forms if the acceleration of the vessel more than **g.**

2. Horizontal particle motion occur by air flows and static air pressure differences.

3. After some time initial small heaps tend to merge into one big heap

4. Separation time and number of layers ($\frac{H}{d}$) are main parameters of heaps formation.

Key conclusions

5. Frequency and amplitude determine separation time. In experiments with amplitude equals 7 mm and range of frequencies between 6 and 20 Hz **Faraday Heaping** is observed.

6. Heap growing could described by static pressure differences.

7. Horizontal displacement of particles is caused by unequal shift of layers under pressure difference.

References

- H. J. van Gerner, M. van der Hoef, D. van der Meer, and K. van der Weele. Interplay of air and sand: Faraday heaping unravelled. Phys. Rev. E 76, 051305 (2007), http://doc.utwente.nl/58270/1/interplay_of_air_and_sand.pdf

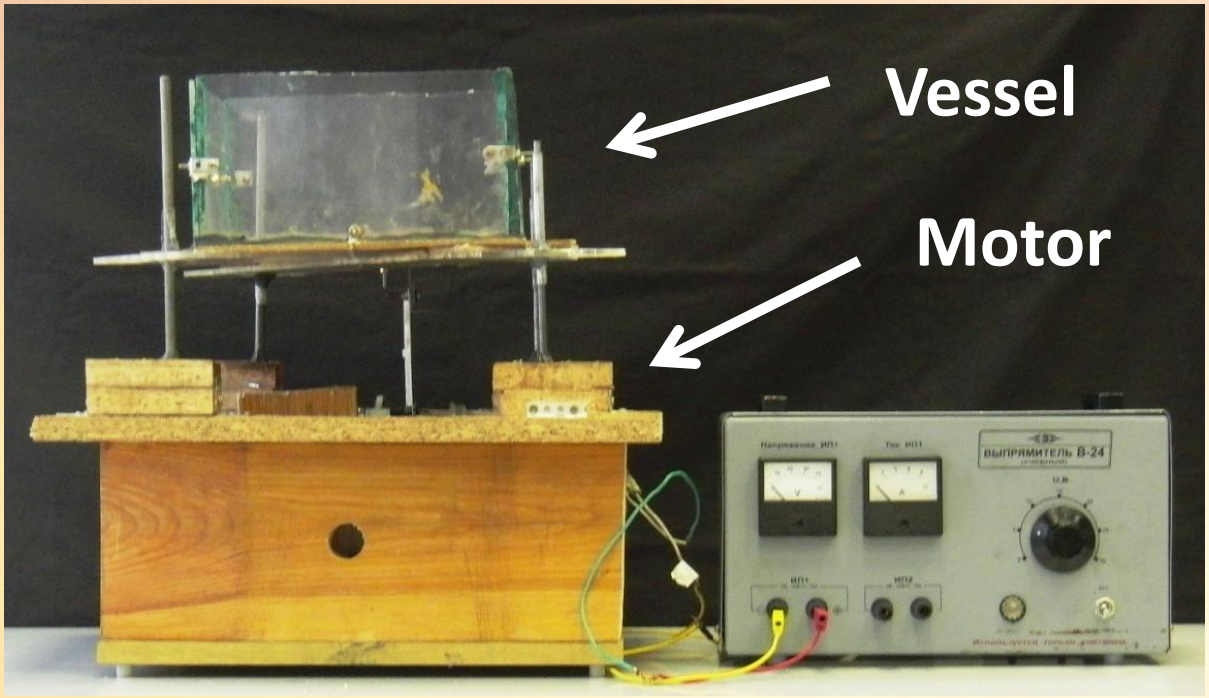
- H. J. van Gerner, G. A. Caballero Robledo, D. van der Meer, K. van der Weele, and M. A. van der Hoef. Coarsening of Faraday Heaps: Experiment, Simulation, and Theory. Phys. Rev. Lett. 103, 028001 (2009), http://doc.utwente.nl/67345/1/coarsening.pdf

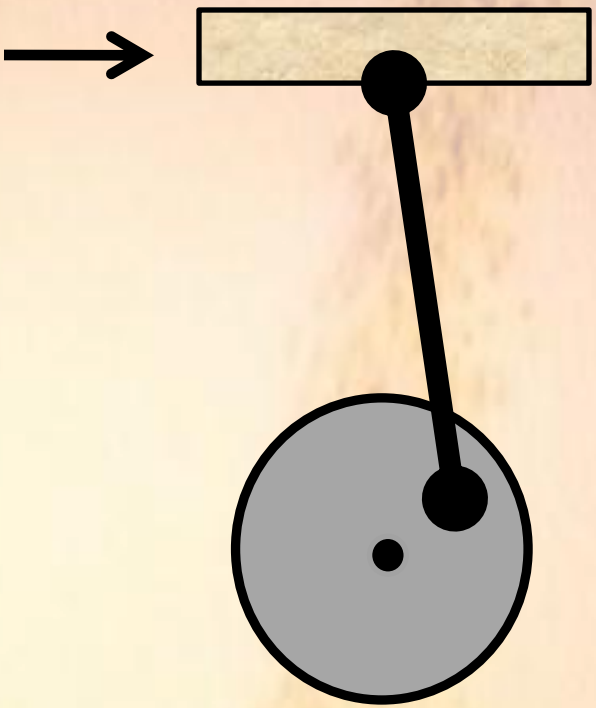
- D.V. Sivukhin «General Course of physics. Mechanics».

Thank you for your attention!

Additional slides

II-nd EXPERIMENTAL SETUP





EMF source

Parameters of setup:

$$\nu \in (;)Hz$$

$$A = mm$$

Demonstration