Explanation

- We considered the granular mixture as a system of two different fluids
- We demonstrate that this approach is adequate
- The denser component sinks to the bottom, in analogy with real fluids
- Larger particle behaviour:
  - If the larger particles have lower density, they will emerge
  - If they are denser, they will sink

Experiment

1. Intruder ball

- Measured quantity: time of emerging/sinking of the intruder
- Parameters:
    - Frequency
    - Amplitude
    - Ratio of intruder and surrounding balls densities
    - Volume of intruder

Used intruders

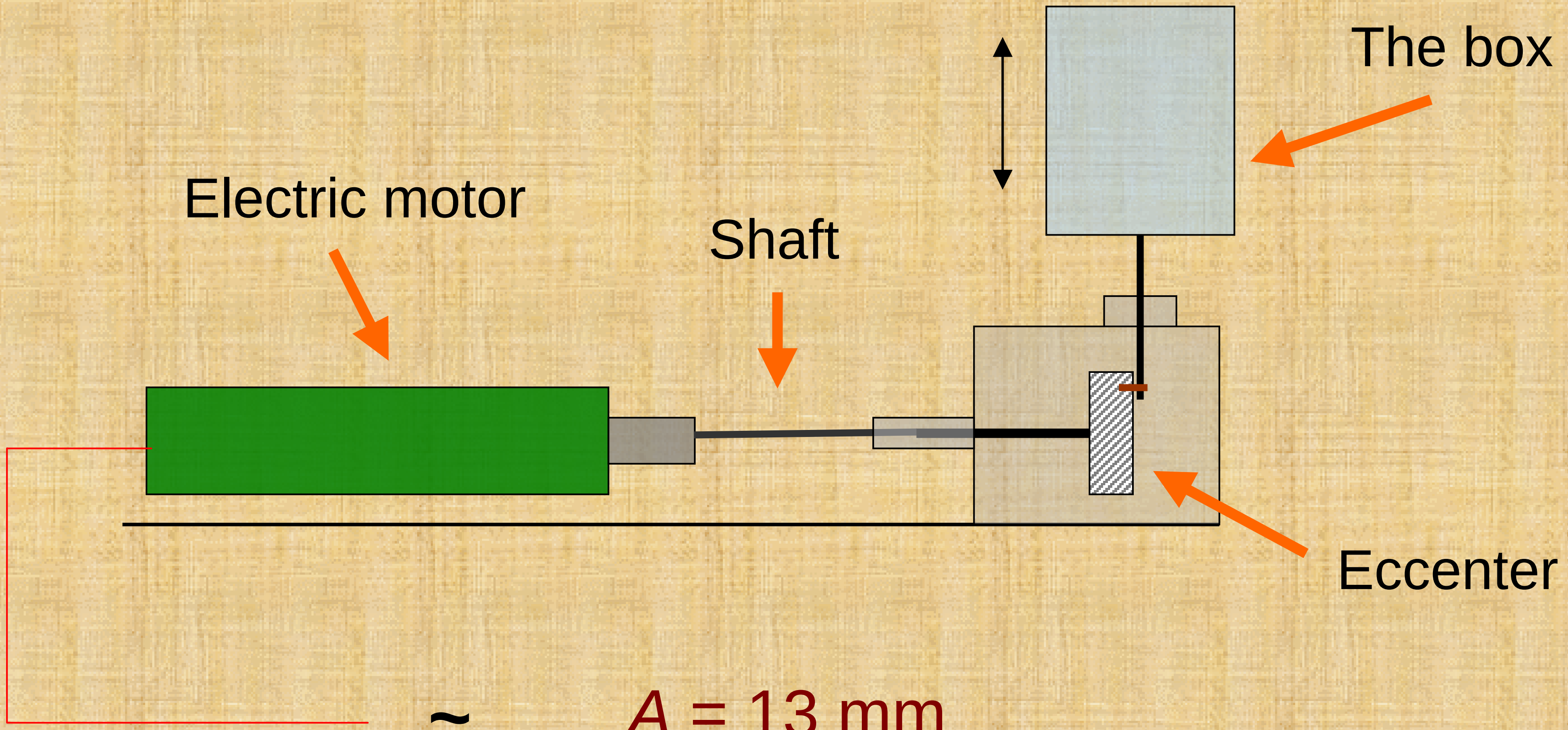
material	mass [g]	density[kg/m3	diameter [cm]	volume [cm3]
lead	86,3	10550	25	8,2
wood 1	3,62	864,2	20	4,2
wood 2	0,42	464	12	0,905
plastic	0,26	969,8	8	0,268
styropor 1	1,34	21,7	49	61,6
styropor 2	0,32	31	27	10,3
glass 1	14,07	2523,7	22	5,6
glass 2	5,1	2378	16	2,14

2. Binary mixtures

- Main goal – obtain transition from brazil nut effect to reverse effect
- Parameters:
  - Frequency
  - Volume ratios of the constituents
  - Density ratios of the constituents
  - Shape of constituents

Apparatus

1. Higher amplitude apparatus



A = 13 mm

Measurements

1. Intruder ball

- Conditions for the occurence of brazil nut effect in our conditions:
    - Frequency above 8.4 Hz
    - Ratio of intruder and surroundig balls densities under ~0.6 at 8.4 Hz
- The emerging balls were:

Styrofoam 2

Intruder balls - summary

material	density ratio to surrounding balls	behaviour
lead	13,19	sinks
wood 1	1,08	sinks
wood 2	0,58	floats
plastic	1,21	sinks
styropor 1	0,027	floats
styropor 2	0,039	floats
glass 1	3,15	sinks
glass 2	2,97	sinks

2. Binary mixtures

- Several mixtures involved

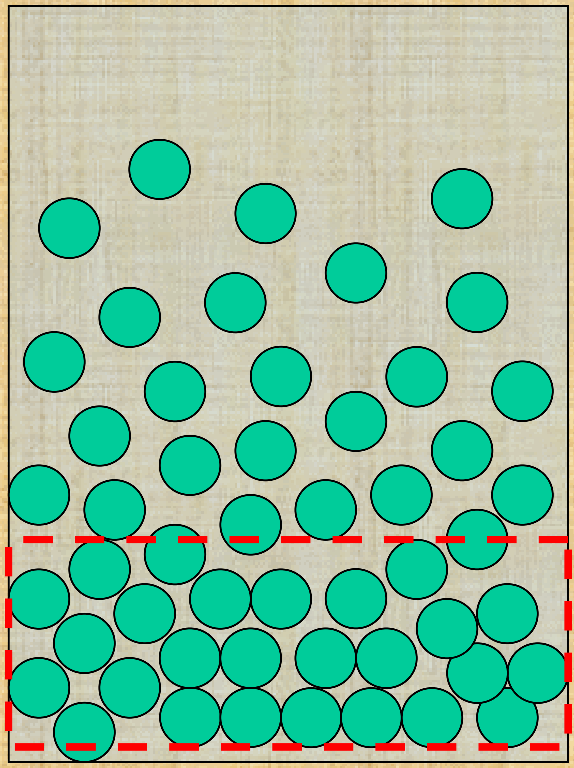
- The reverse effect occurs for heavier constituents of mixture

Theoretical approach

- Several explaining models have been proposed for the brazil nut effect:
    - Fluid model (*D. C. Hong, et al., Phys. Rev. Lett.* ***86****, 2001*)
    - Percolation (*T. Rosato et al., Phys. Rev. Lett.* 58)
    - Gravity – entropy competition (*H. Walliser, Phys. Rev. Lett. 89, 2002*)
    - Air – driven segregation
- We will discuss the fluid model in detail because of its simplicity and experimental proof

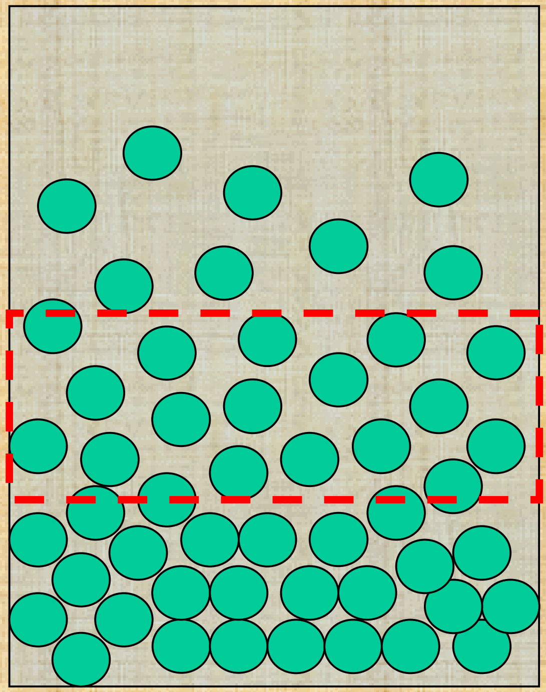
The fluid model

- Main assumptions:
    - The granular system may be regarded as a dense gas with three phases:



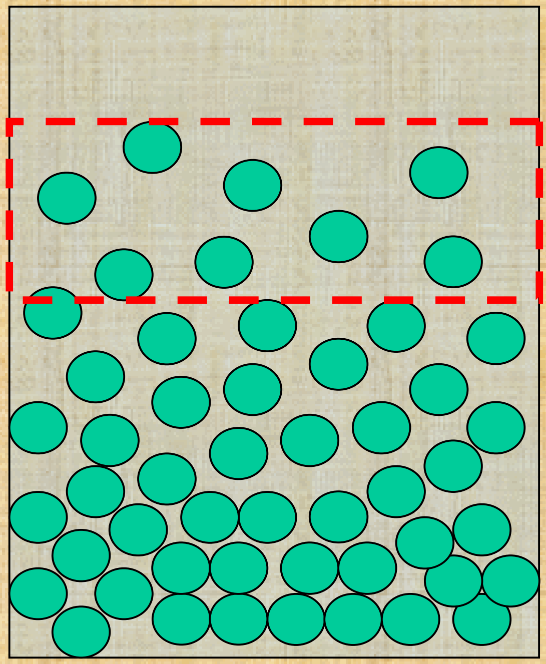
1. Solid phase

The balls are so near that they can’t interchange postitions but just oscillate on the same place – analogous to solids



2. Liquid phase

The balls interchange places, but do not move vigorously – analogous to liquids



3. Gaseous phase

The balls move fast and collide at random – analogous to gases

- As such, the ˝granular gas˝ can be described by a Fermi – Dirac distribution function:

$$\phi(z) = \frac{1}{1 + e^{\frac{mgd}{T}(z-\eta)}}$$

$\phi(z)$ **- Probability of finding a ball at height *z***

d **- ball diameter**

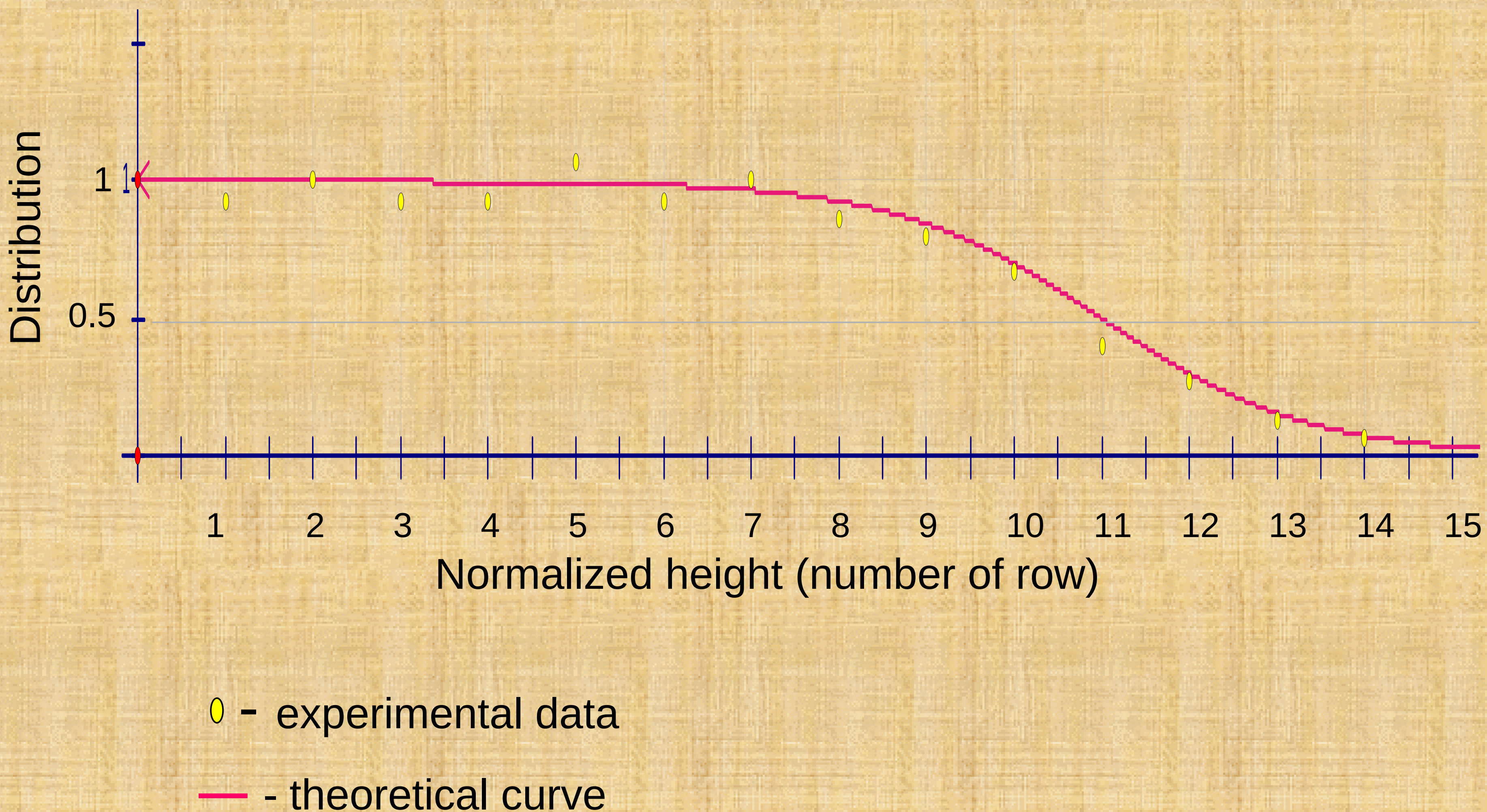
m **- ball mass**

z **- normalized height**

T **- equivalent temperature (function of frequency)**

η **- number of layers at 0 deg. Eq.**

- This distribution is experimentally substantiated:



- The granular gas density can be defined as

$$\rho_g = \rho_i \psi$$

ρ_g – gas density

ρ_i – density of one ball

ψ – packing density, defined as $\psi = \frac{\sum_{i=1}^{N} V_i}{L}$

L – the volume taken up by the balls

- In analogy to a fluid we define the buoyancy force:

$$F_u = V \rho_g \psi g$$

V – volume of intruder

Condition for brazil nut effect

- For intruder balls:

$$\frac{\rho_{\text{int}}}{\rho_i} \geq \overline{\psi}$$

ρ_{int} – intruder density

ρ_i – surrounding ball density

ψ – mean packing density

- For binary mixtures:

$$\frac{\rho_1}{\rho_2} \geq \frac{\overline{\psi}_1}{\overline{\psi}_2}$$

ρ_i – densities of mixture constituents

ψ_i – mean packing densities of constituents