

### Related topics

Kinetic gas theory, pressure, equation of state, temperature, gas constant.

### Principle and task

Glass or steel balls are accelerated by means of a vibrating plate, and thereby attain different velocities (temperature model). The particle density of the balls is measured as a function of the height and the vibrational frequency of the plate.

### Equipment

Kinetic gas theory apparatus	09060.00	1
Power supply var. 15 VAC/12 VDC/5 A	13530.93	1
Light barrier with Counter	11207.08	1
Power supply 5 V DC/0.3 A	11076.93	1
Digital stroboscope	21809.93	1
Stopwatch, digital, 1/100 sec.	03071.01	1
Glass beads, d 2 mm, 10000 pcs	09060.01	1
Steel balls, d 2 mm, 1000 pcs	09060.02	1
Tripod base -PASS-	02002.55	2
Support rod -PASS-, square, l 400 mm	02026.55	1
Right angle clamp -PASS-	02040.55	1
Connecting cord, 750 mm, red	07362.01	1
Connecting cord, 750 mm, blue	07362.04	1

### Problems

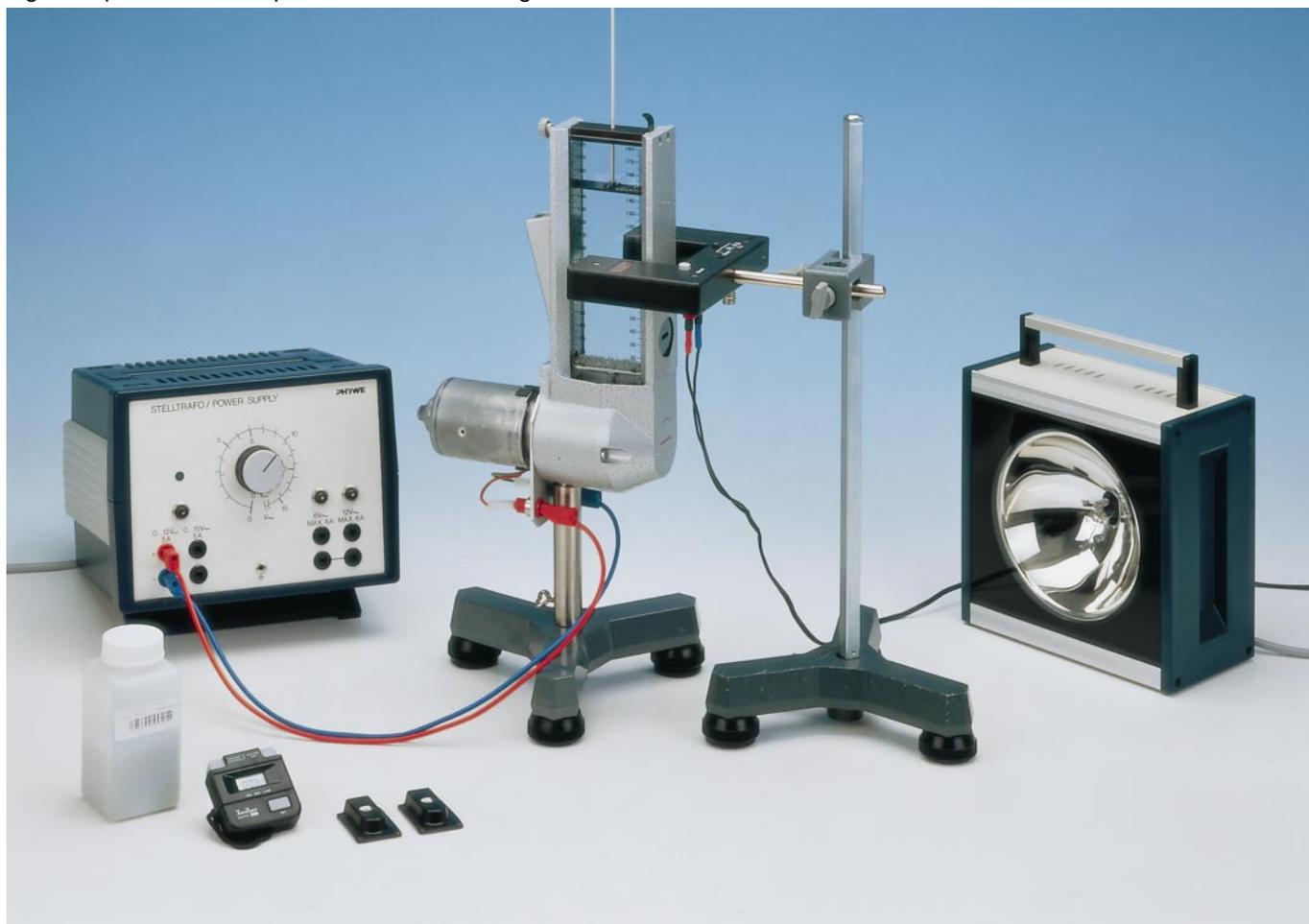
Measurement of the particle density as a function of:

1. the height, at fixed frequency
2. the vibrational frequency of the exciting plate, at fixed height.

### Set-up and procedure

The experimental set up is as shown in Fig. 1. The kinetic theory apparatus is filled with about 400 steel balls. (Approximately one layer of balls) The plunger is set to maximum volume. The speed of rotation – and hence the vibrational frequency – is adjusted by means of the power supply and measured with the stroboscope (stationary image of the vibrating plate). The maximum speed of rotation of  $3000 \text{ min}^{-1}$  should not be exceeded. Using the forked light barrier with counter, the number of balls which pass the beam of light in the prescribed time is counted (an area of approx.  $0.4 \text{ mm}^2$  is used). Immediately above the vibration plate the probability of several balls passing through is very high. It is therefore recommended that the measurements are started at a height of only about 3 cm above the vibration plate.

Fig. 1: Experimental set-up for the barometric height formula.



**Theory and evaluation**

If one imagines a vertical cylinder with its base as unit area cut out of the atmosphere, the pressure at the base of the cylinder is equal to the weight of the column of air.

At a point  $h + dh$  above the base of the cylinder the pressure is lower than for  $h$  by an amount equal to the weight of the column of air of height  $dh$ :

$$dp = -g\rho dh \tag{1}$$

where:  $g = 9.81 \text{ m/s}^2$  is the acceleration due to gravity  
 $\rho$  = the density of air.

Introducing the volume  $V$  of the gas, we obtain:

$$\rho = \frac{M}{V}$$

where  $M$  is the mass of the gas and, using the equation of state:

$$p \cdot V = n \cdot R \cdot T = n \cdot L \cdot k \cdot T \tag{2}$$

the following is thus obtained from (1):

$$dp = -p \cdot \frac{mg}{kt} dh \tag{3}$$

where:  $n$  = the number of mols  
 $T$  = the temperature expressed in  $K$   
 $R = 8.31 \text{ JK}^{-1} \text{ mol}^{-1}$ , the universal gas constant  
 $L = 6.02 \cdot 10^{-23} \text{ mol}^{-1}$ , the Loschmidt number  
 $k = 1.38 \cdot 10^{-23} \text{ JK}^{-1}$ , the Boltzmann constant  
 $m$  = the mass of a molecule.

If equation (3) is solved for  $p$  for

$$p = p_0 \text{ where } h = 0$$

then we obtain:

$$p = p_0 e^{-\frac{mgh}{kT}} \tag{4}$$

(see Fig. 2)

Since

$$\frac{p}{p_0} = \frac{\rho}{\rho_0}$$

then, also:

$$\rho = \rho_0 e^{-\frac{mgh}{kT}} \tag{5}$$

(see Fig. 3)

**Note**

Additional qualitative experiments as thermal movement, evaporation and distillation may be performed with the kinetic gas theory apparatus. For quantitative experiments see LEP 3.2.03.

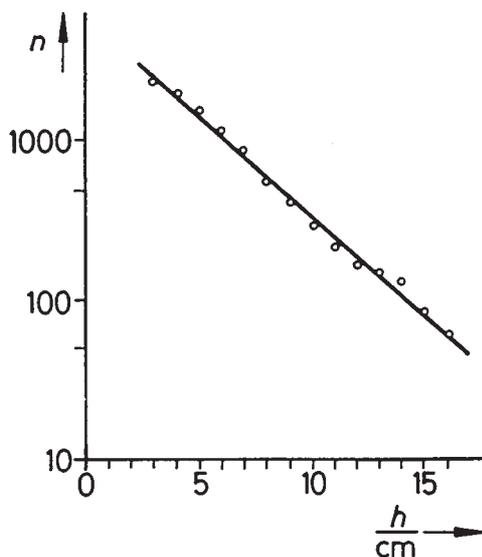


Fig.2 : Number of steel balls ( $m = 0.034 \text{ g}$ ), as a function of the height  $h$ , which pass through the volume element  $\Delta V$  in 30 seconds (vibrational frequency 50 Hz).

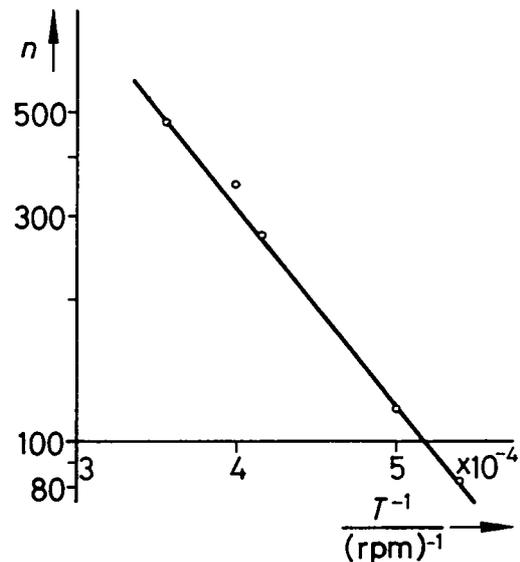


Fig.3 : Number of steel balls, as a function of the vibrational frequency, which pass through the volume element  $\Delta V$  within 30 seconds (height  $h = 8 \text{ cm}$ ).